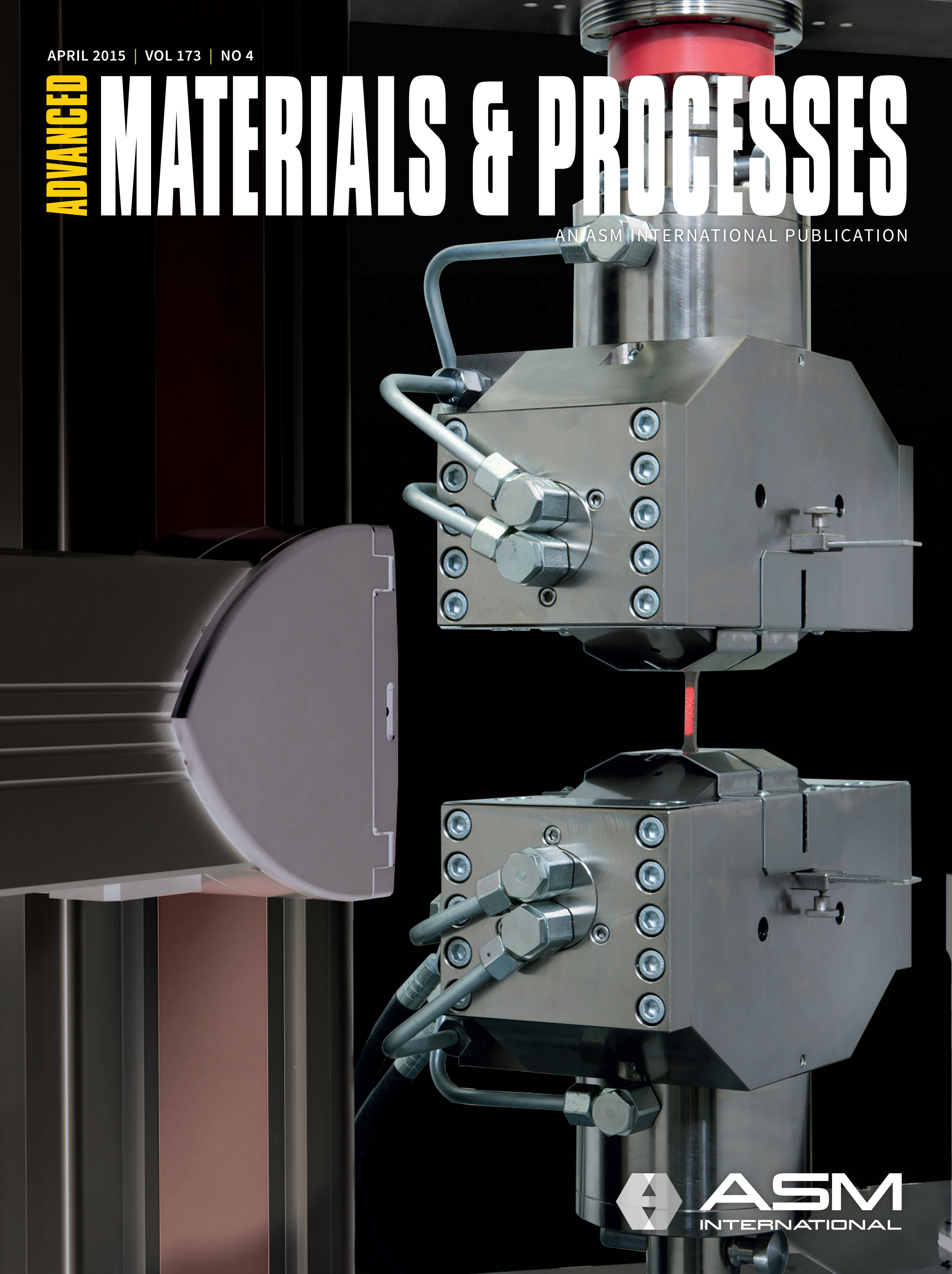
APRIL 2015 | VOL 173 | NO 4

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION



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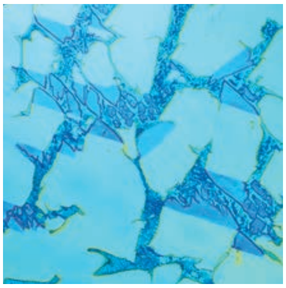
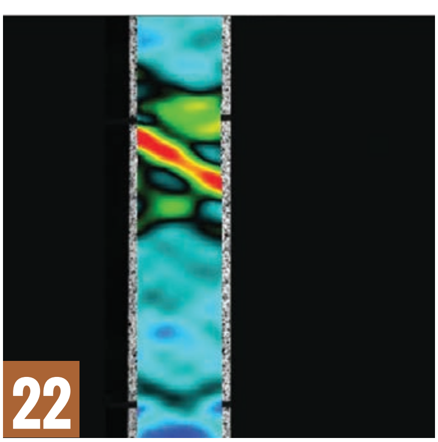
MATERIALS CHARACTERIZATION
POWDER METAL TESTING

ASM INTERNATIONAL



On The Cover:

Hydraulic grips may be applied to clamp component test specimens that are mere inches in length. Courtesy of Zwick/Roell, Ulm, Germany. zwick.com.



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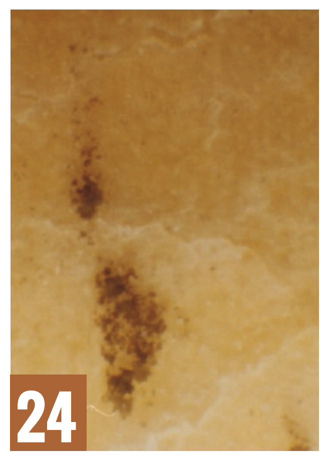

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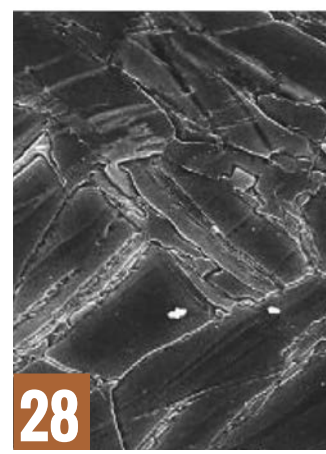

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COACH TRESSEL SHARES WORDS OF WISDOM

A few weeks ago, I had the pleasure of attending my first meeting of the Association of Women in the Metal Industries (AWMI). I heard about this group through the ASM Cleveland Chapter, and ASM President Sunniva Collins highly recommended that I attend this event—starring none other than football coaching phenom Jim Tressel. The meeting was held at Youngstown State University (YSU), where Tressel now serves as the university's president after coaching the Ohio State Buckeyes from 2001-2010. Little did I know, I was in for an evening of surprises and inspiration.

I had never visited YSU before and didn't know how beautiful the campus was. The students were very welcoming too, taking me directly to the building I needed on a rainy evening. The next surprise was the dynamic and diverse AWMI crowd: I was expecting only women. In fact, about 80% of the attendees were men, although AWMI's board members are all women. Tressel's speech, which was basically a pep talk about life itself, followed a delicious dinner. I was a bit skeptical at first, fearing a string of sports analogies. However, what he delivered was both simple and profound.

He began with one of his favorite quotes, which he also has inscribed on a coffee mug: "Great ideas are welcomed. Execution is worshipped." Whether in sports, work, or any other aspect of life, coming up with good ideas is easy. It's getting the real work done—the heavy lifting—that is the hard part. Tressel posed four questions he thinks people should ask themselves at every stage of life, touching on themes of connectedness, autonomy, physical health, and perspective.

He first tackled connectedness. Do you feel connected to the people around you, including your friends, family, significant other, and colleagues? If so, count your blessings. If not, it might be time to think about making changes, either on a personal level or finding a work situation that is a better fit. His second question involved autonomy. As a worker, do you feel you have control over how you get your work done, in the manner that suits you? If you are a manager, do you provide autonomy to others? Tressel pointed out that this is one of the biggest factors in work satisfaction and whether or not people stay in their current jobs.

Next up: Physical health. How do you feel about how you feel? Are you getting enough sleep, nutritious food, and exercise? Tressel points out that during one tough football season, he started a mandatory closing time for the coaching office. People were forced to go home, get some rest, and return to work refreshed. In a fairly short time, he saw noticeable improvements in both morale and game stats.

His final question involved perspective. Do you feel like you have the big picture in perspective, that you have your priorities in the right order? This may be the hardest question of all, but Tressel says it deserves attention and some introspection. He concluded his speech, and the evening, with the following poem by Edward Everett Hale:

I am only one,
But still I am one.
I cannot do everything,
But still I can do something;
And because I cannot do everything
I will not refuse to do the something that I can do.

F. Richards

frances.richards@asminternational.org

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Course	Date	Location
Practical Fracture Mechanics	5/4-5	IMR Testing Labs, Lansing, NY
Metallurgy of Steel for the Non-Metallurgist	5/4-6	ASM World Headquarters
Vacuum Heat Treating	5/5-6	ASM World Headquarters
Practical Fractography	5/6-7	IMR Testing Labs, Lansing, NY
Advanced Metallographic Techniques	5/11-14	ASM World Headquarters
Corrosion	5/11-14	Provaglio D'Iseo, Brescia, Italy
Metallurgy of Welding and Joining	5/11-14	ASM World Headquarters
Design for Additive Manufacturing – Materials, Processes, and Geometries	5/12-13	America Makes, Youngstown, OH
Practical Induction Heat Treating	5/18-20	ASM World Headquarters
Stainless Steels	6/1-4	ASM World Headquarters
Metallographic Techniques (Lab Session)	6/2-3	ASM World Headquarters
Advanced High Strength Steels	6/8-9	ASM World Headquarters
Refractory Technology	6/9-11	ASM World Headquarters
Metallurgy for the Non-Metallurgist Blended	6/15-16	ASM World Headquarters
Introduction to Heat Treating	6/15-17	ASM World Headquarters
Advanced Heat Treating	6/18-19	ASM World Headquarters

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MARKET SPOTLIGHT

SMART MATERIALS MARKET TO REACH $42.2 BILLION IN 2019

A new report from BCC Research, Wellesley, Mass., says that the global market for smart materials was valued at $23.6 billion in 2013 and nearly $26 billion in 2014. The market is anticipated to reach more than $42.2 billion in 2019 at a compound annual growth rate (CAGR) of 10.2% between 2014 and 2019, according to analysts. Motors and actuators make up the largest application segment, with sales of almost $16.8 billion (70.8% of the market) in 2013, increasing to $30.2 billion (nearly 71.6% of the market) by 2019.

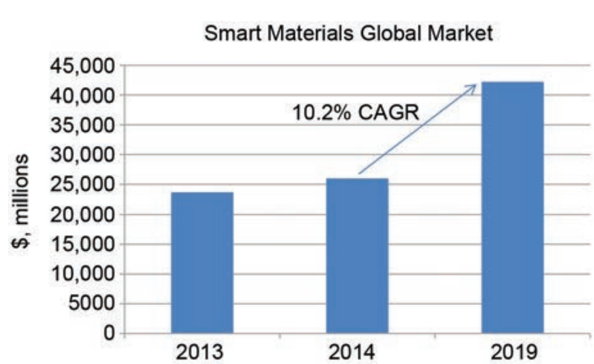
Smart materials are defined as those that dynamically respond to electrical, thermal, chemical, magnetic, or other environmental stimuli. These materials are incorporated in a growing range of products, enabling devices to alter their characteristics or otherwise respond to external stimuli.

The Asia-Pacific region accounted for the largest production of smart materials in 2013, followed by the U.S. and Europe. However, European production is projected to grow somewhat more slowly than the global average, i.e., at a CAGR of 9.9%, say analysts. The U.S. share of global smart materials production is projected to increase from 28.2% in 2013 to 29% in 2019.

Phase-change materials (PCMs) may have an important role to play in energy storage, particularly for heat produced by parabolic trough solar collectors. Various smart materials such as piezoelectrics and electrostrictive polymers can be used to harvest energy from the vibrations produced by ordinary activities such as walking. Another example are shape memory alloy actuators used to open and close greenhouse windows.

"Monitoring the structural integrity of bridges, dams, offshore oil-drilling towers, and other structures is attracting attention as well," says analyst Andrew McWilliams. "Embedding sensors made from smart materials within structures to monitor stress and damage can reduce maintenance costs and increase lifespan. These are already used in more than 40 bridges worldwide."

Smart Materials and Their Applications: Technologies and Global Markets analyzes the principal end-user segment for each type of material and includes commercial, industrial, medical, research, and military sectors. The report also includes estimates of the current and projected worldwide market for each material and application through 2019. *For more information, visit bccresearch.com.*



Source: BCC Research (AVM023E), January 2015

FEEDBACK

READER BEGS TO DIFFER

I just received the latest issues of *AM&P* with your historical articles ("Metallurgy Lane," Jan. and Feb.). I beg to object on the point made on duplex stainless steel. The first vessel was produced by Avesta in 1932, in 435S. For further information, refer to Acom No. 3-92 or some of the lectures given by Charles or Nilsson in the duplex conferences. Although a specialty, duplex was used in the paper industry during the early 1930s and much work was done in Sweden, France, and Finland. Due to steelmaking problems, it was regarded as a special and difficult grade until the use of low carbon combined with a nitrogen addition was understood. Some people still regard this as a difficult grade. Mats Liljas presented a good summary of duplex steel history at the 6th European Stainless Steel Conference in 2008.

Kåre Johansson, Norway

[I did not realize the extent of the work on these steels in Europe and I found little on them being used in the U.S. When I learned that they make up only 1% of total stainless steel production, I thought I would mention them but not go into detail. The precipitation hardened stainless steels are far more popular in the U.S. I will try to write more on the duplex steels at the next opportunity.

—Charles R. Simcoe]

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS

PAINT CHANGES COLOR WITH A CHARGE

LitCoat, Las Vegas, could revolutionize the painting industry with its new paramagnetic electroluminescent paint, which changes color when in contact with an electric charge. The new color, called electroluminescence, also gives off its own light. The basecoat material, ELfarbe, is an environmentally friendly nanocomposite polymer binder system. It is used in all painting layers and goes from the dielectric layer all the way to the electroluminescent layer. For the dielectric layer, ELfarbe is combined with barium titanate powder, whereas in the conductive layer it is combined with graphene oxide or antimony-doped tin oxide. In the electroluminescent layer, ELfarbe is combined with phosphoric pigment representing the color of a user's choice. *litcoat.com, elfarbe.com.*

PRINTING MUSICAL INSTRUMENTS IN 3D

Before completing his medical degree from the University of Connecticut School of Medicine, real-life renaissance man, Robert Howe, earned dual undergraduate degrees in chemistry and music through a joint program between Case Western Reserve University and the Cleveland Institute of Music.

Sina Shahbazmohamadi, who received his Ph.D. from UConn in 2013, worked with Howe and Bass to develop a new method for using micro-computed tomography to examine antique wind instruments and then create new parts using 3D printing technology. Courtesy of Sean Flynn/UConn Photo.

Recently Howe has accelerated his interest in studying music more formally as Ph.D. candidate in UConn's School of Fine Arts. Along with his doctoral advisor, Richard Bass, Howe has orchestrated a collaborative effort between musicians and engineers, using technology typically exclusive to medical science—micro-computed tomography—to explore the makeup of 18th- and 19th-century musical instruments.

Using the technology in this way for the first time provides researchers with precise measurements to within thousandths of a millimeter for parts of antique instruments such as the saxophone and recorder. Their findings have resulted in the unprecedented replication of instrument parts—using 3D printing—that could allow instruments hundreds of years old to be played once again while providing security authentication for rare instruments held by collectors and museums. *uconn.edu.*

THE HISTORY OF PLASTIC MONEY

The Reserve Bank of Australia (RBA) and CSIRO's 20-year bank project resulted in the polymer banknote—the first ever of its kind, and the most secure form of currency in the world. The project commenced in 1968 and continued until 1988 with the release of the A$10 bicentennial commemorative banknote.

Australia's transition from the pound to the dollar was a momentous occasion. With cutting edge security features such as watermarks and metal thread, things couldn't have been better for the note-issuer, the RBA. But the new notes were not infallible, and it didn't take long for counterfeiters to strike.

By the end of the year, a team of amateurs from suburban Melbourne, armed with simple office equipment and a desire to make some money, produced a batch of fake notes that netted them almost A$800,000 (worth A$9.6 million in 2013) worth of forgeries. Despite their initial success, authorities soon picked up on their activities and the forgers went to jail in 1967.

The first polymer banknotes. One side symbolized European settlement and the other, the original discovery and settlement of Australia 40–60,000 years earlier. Courtesy of RBA/Wikimedia Commons.

After some preliminary planning, the bank project began. Originally, seven top Australian scientists were enlisted to help the RBA develop a more secure banknote. As well as being difficult to forge, the new notes were also more durable than the traditional "rag notes," more environmentally friendly, and less likely to carry dirt and disease. These technical improvements were made within the first 10 years of the bank project, but behind-the-scenes delays prevented the issue of these revolutionary notes until the bicentennial year 1988. In a defiant gesture to the original counterfeiters, the first note issued was a A$10. *www.csiro.au.*

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

METALS | POLYMERS | CERAMICS

A GEnx-1B engine suspended from a Dreamliner jet. A version of this engine will also power the next Air Force One. Courtesy of GE Aviation.

SUPER CERAMIC MATERIAL SHOWS PROMISE FOR AIRCRAFT

General Electric developed a jet engine for Boeing's Dreamliner to test engine parts made of a new ceramic super-material. The material could help pave the way to more fuel efficient airplanes. The temperatures inside jet engines are so extreme that even parts from high-end titanium alloys require an intricate cooling system to work well. But the new material, called ceramic matrix composite (CMC), requires 20% less cooling air, which allows engineers to extract more power from the extra heat. "When you drop the need for cooling components, your engine will become aerodynamically more efficient and also more fuel efficient," says Jonathan Blank, who leads CMC and advanced polymer matrix composite research at GE Aviation.

The GEnx jet engine with ceramic parts is being tested at GE's hard-core testing facility in Peebles, Ohio. The parts include inner and outer combustor liners, high-pressure turbine stage one shrouds, and stage two nozzles. CMC stage one nozzles for the high-pressure turbine will be tested on the second build of the demo engine. CMC has one-third the weight of metal, and is made from a combination of silicon carbide ceramic fibers and ceramic resin that is sealed together and further enhanced with proprietary coatings. *geaviation.com.*

NEW POLYMER COULD PREVENT BLEEDING DEATHS

Administered by a simple shot, a new polymer called PolySTAT finds any unseen or internal injuries and starts working immediately to strengthen blood clots. The material could become a first line of defense in battlefield injuries, rural car accidents, and search and rescue missions. In an initial study with rats, 100% of animals injected with the material survived a typically lethal injury to the femoral artery, while only 20% treated with a natural protein that helps blood clot survived.

"Most patients who die from bleeding die quickly," says Nathan White, assistant professor of emergency medicine at University of Washington. "This is something you could potentially put in a syringe inside a backpack and give right away to reduce blood loss and keep people alive long enough to make it to medical care."

To develop the macromaterial, researchers were inspired by factor XIII, a natural protein found in the body that

BRIEFS

Red Brick Brewing Co., Atlanta, is now offering its beer in aluminum cans made from **Novelis'** (Warren, Ohio) evercan—said to be the world's first certified high-recycled content aluminum can sheet. Recycling aluminum requires 95% less energy and produces 95% fewer greenhouse gas emissions than primary manufacturing. *novelis.com, redbrickbrewing.com.*

Red Brick Brewing introduces Laughing Skull Amber Ale in evercan aluminum cans.

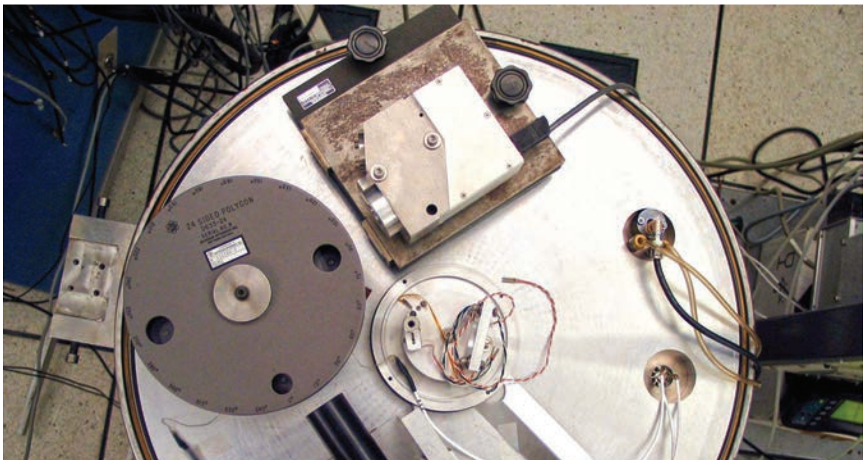
Alcoa, Pittsburgh, signed a definitive agreement to acquire **RTI International Metals Inc.,** a global supplier of titanium and specialty metal products and services for the commercial aerospace, defense, energy, and medical device markets. Alcoa will purchase RTI in a stock-for-stock transaction with an enterprise value of $1.5 billion. RTI will expand Alcoa's range of titanium offerings and add advanced technologies and materials. *alcoa.com, rtiintl.com.*

3D rendering shows fibrin forming a blood clot, with PolySTAT (in blue) binding strands together. Courtesy of William Walker/U. Washington.

helps strengthen blood clots. Normally after an injury, platelets in the blood begin to congregate at the wound and form an initial barrier. Then a network of specialized fibers—called fibrin—start weaving themselves throughout the clot to reinforce it. Both PolySTAT and factor XIII strengthen clots by binding fibrin strands together and adding cross-links that reinforce the latticework of the natural bandage. *For more information: Nathan White, whiten4@uw.edu, www.washington.edu.*

A new process for producing titanium is significantly less expensive and less energy-intensive than conventional methods. Being developed by **SRI International,** Calif., the process takes fewer steps, uses less energy, and produces titanium powder, rather than ingots. The powder can be pressed and fused into near-net shape, reducing the amount of final machining required. *sri.com.*

TESTING | CHARACTERIZATION



A laser from the NIST-designed autocollimator (square device at top) is beamed at the mirrored polygon in the gray circle at left, and its reflection allows the angle of the polygon's faces to be precisely determined while the polygon rotates. The black device at the bottom takes measurements that minimize wobbling by the polygon while spinning. Courtesy of Hudson/NIST.

BRIEFS

Granta Design, UK, released new software and services that support rigorous and auditable composite qualification processes. New data were added to the existing **GRANTA MI: Composites** software package, developed with input from leading aerospace companies. The software enables management of complex data associated with composite materials, including layup, cure cycles, directional properties, and the history and properties of constituent parts. *grantadesign.com.*

NEW TECHNIQUE REDUCES UNCERTAINTY IN X-RAY MEASUREMENTS

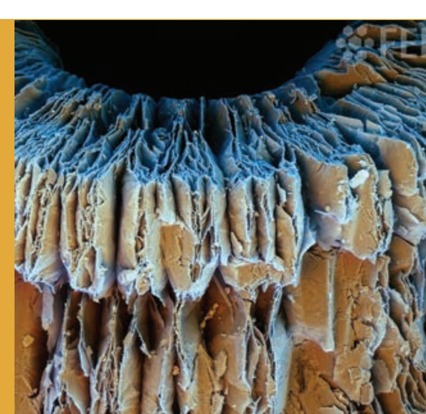
Scientists at the National Institute of Standards and Technology (NIST), Gaithersburg, Md., developed a new method to reduce uncertainty in x-ray wavelength measurement that could provide much anticipated improvements. Accurate measurement of x-ray wavelengths depends on the ability to measure angles very precisely and with very little margin for error. The new approach is reportedly the first major advance since the 1970s in reducing certain sources of error common in x-ray angle measurement.

X-ray wavelengths are measured by passing a beam through special crystals and carefully measuring the angle that exiting rays make with the original beam. The crystal is typically mounted on a rotating device that spins the crystal to two different positions where a spectral line is observed. The angle between the two is measured, which determines the line's position more precisely than a single measurement would and also cancels out some potential errors. However, one limit is the accuracy of the digital encoder, which translates the crystal's rotation to an angle measurement.

Larry Hudson and his team found a way to dramatically reduce the error in that measurement. Their new approach uses laser beams bouncing off a mirrored polygon that is rotated on the same shaft that would carry the crystal. The approach allows the team to use additional mathematical shortcuts to their advantage. With new NIST sensing instrumentation and analysis, x-ray angles can now be measured routinely with an uncertainty of 0.06 arcsec—an accuracy more than three times better than an uncalibrated encoder.

Hudson describes this reduction as significant enough to set world records in x-ray wavelength measurement. "If a giant windshield wiper stretched from Washington to New York City (364 km) and were to sweep out the angle of one of these errors, its tip would move less than the width of a DVD," he says. Calibrating measurement devices to greater precision will

Francisco Rangel won **FEI Co.'s** (Hillsboro, Ore.) 2014 Image Contest grand prize for "Expanded Vermiculite," a hydrated magnesium-aluminum-iron silicate. Rangel, who works at the **National Institute of Technology-INT/MCTI Characterization Center for Nanotechnology Materials and Catalysis,** won airline tickets to London or Washington, a hotel stay, travel stipend, and two tickets to the IMAX movie, *Mysteries of the Unseen World. fei.com/image-contest.*



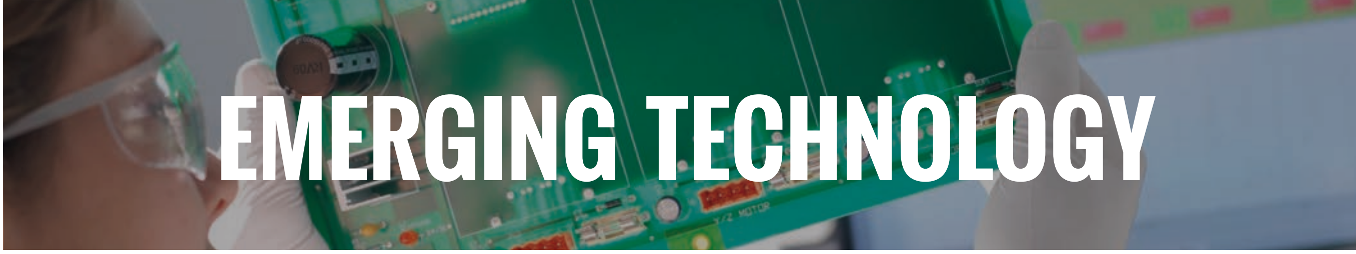
provide better understanding of a host of newly designed materials, which often have complicated crystal structures that give rise to unusual effects such as high-temperature superconductivity. *nist.gov.*

RESEARCH EXPLORES MYSTERY BEHIND WRINKLED SURFACES

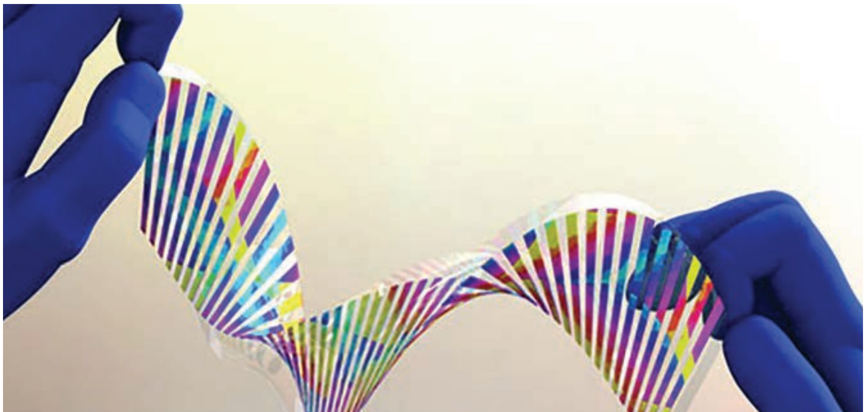
The reason why layered materials sometimes form one kind of wrinkly pattern or another has now been explained at a fundamental level by researchers at Massachusetts Institute of Technology, Cambridge. The underlying process is the same in all cases: Layers of material with slightly different properties tend to form patterned surfaces when they shrink or stretch in ways that affect the layers differently. For the first time, the new analysis creates a unified model that shows exactly how the properties of the individual layers, and how they are bonded to each other, determines the exact form of the resulting texture.

MIT associate professor of mechanical engineering Xuanhe Zhao and postdoctoral researcher Qiming Wang report that the patterning process they describe applies to everything from the folds on the surface of the brain to wrinkles on an aging face, and from the buckling of tree bark to the ridged skin of a pumpkin. By understanding the factors that produce these patterns, researchers say it should become easier to design synthetic materials with exactly the kinds of surfaces needed for specific applications, such as better traction or water-shedding properties. They also expect that this model will not only be helpful for understanding growth and aging patterns in biological organisms, but could also help in the design of materials for disease treatment, cell cultures, control of biofouling, controllable properties of water shedding, and flexible electronic materials. *For more information: Xuanhe Zhao, 617.324.6367, zhaox@mit.edu, zhaox.org.*

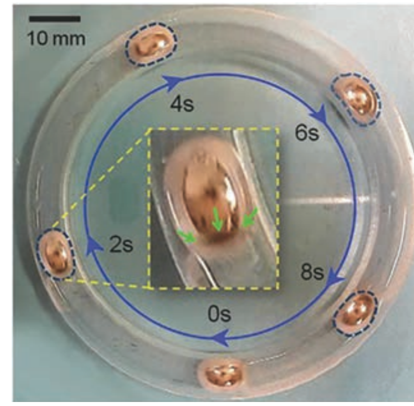
MIT researchers explore why layered materials form one kind of wrinkly pattern or another. Courtesy of Jose-Luis Olivares/MIT.



EMERGING TECHNOLOGY



Artificial "skin" changes color as a small amount of force is applied. Courtesy of The Optical Society.



Research from Tsinghua University could pave the way to deliver materials through pipes or even blood vessels using liquid metal drops.

MATERIAL CHANGES COLOR ON DEMAND

Scientists at the University of California, Berkeley, created an incredibly thin material that can change color on demand by applying a small amount of force. The novel material offers possibilities for a new class of display technologies, color-shifting camouflage, and sensors that can detect otherwise imperceptible defects in buildings, bridges, and aircraft. "This is the first time anybody has made a flexible chameleon-like skin that can change color simply by flexing it," says researcher Connie Chang-Hasnain. By carefully etching tiny features—smaller than a wavelength of light—onto an extremely thin silicon film, the team was able to select the range of colors the material would reflect, depending on how it was flexed and bent. *berkeley.edu.*

SHAPE-SHIFTING METAL MIMICS TERMINATOR ROBOT

Researchers at Tsinghua University, China, report they have discovered a way to mimic the shape-shifting robot in the *Terminator* movies, at least in a small way. The team was working with gallium. After adding a small amount of indium and tin, a tiny piece of aluminum was fixed to a single drop of the alloy (to serve as fuel) and was dropped into a container of either sodium hydroxide or salt water. The drop propelled itself around the container for about an hour. In subsequent tests, the container was shaped with channels and the drop followed a predetermined path. Further, if the drop encountered a part of the channel that was slimmer than it was, it could still squeeze through.

Closer analysis reveals that when the drop is placed in the solution, a charge imbalance occurs between the drop's front and back, causing a pressure differential. As aluminum reacts with salt water, tiny bubbles are formed and serve to push the drop forward. The experiments build on prior work, which show that an electric charge can cause a drop to both expand and change shape with some liquid metals. This could result in drops that not only move themselves through liquids, but change shape according to predetermined needs. *www.tsinghua.edu.cn.*

BRIEFS

N1 Technologies Inc., Daytona Beach, Fla., filed a patent for a nano-engineered super glass called TungstenGlass. It features high impact and torsion resistance and enhanced electrical properties, and will initially target applications in cell phones and other mobile devices. The material is a borosilicate-based glass infused with tungsten and carbon nanotubes. *tungstenglass.com.*

Two new projects underway at the **Stanford Institute for Materials and Energy Sciences** (SIMES), Calif., could enable future electronic and photonic applications. SIMES is a joint institute of **Stanford University** and **DOE's SLAC National Accelerator Laboratory.** Both projects will explore an emerging field called *valleytronics,* in which electrons move through the lattice of a 2D semiconductor as a wave with two energy valleys whose characteristics can be used to encode information. *simes.slac.stanford.edu.*

PROCESS TECHNOLOGY

From left, LLNL researchers Ibo Matthews, Wayne King, and Gabe Guss examine a 3D-printed part. Courtesy of Julie Russell/LLNL.

From left, Mayank Bulsara, Merton Flemings, FASM and ASM Life Member, and Xiaoman Duan. Courtesy of Denis Paiste/MPC.

AMERICA MAKES FUNDS ALGORITHM RESEARCH

General Electric (GE) and Lawrence Livermore National Laboratory (LLNL), Calif., received $540,000 to develop open-source algorithms to improve additive manufacturing (AM) of metal parts. The award is from America Makes, the National Additive Manufacturing Innovation Institute in Youngstown, Ohio. The project intends to develop software algorithms that allow selective laser melting (SLM) to produce high quality parts. Currently, there is no common approach to SLM to reduce problems with this method such as surface roughness, residual stress, porosity, and micro-cracking—issues that may cause part failures.

In order to print a 3D part using SLM, users must enter data into the printer via a stereolithography file. However, errors can appear during file translation, requiring users to fill in missing information as well as specify the type of powder material used. To complicate matters, traditional printer designs treat every powder layer the same, without giving consideration to thermal properties. In an ideal system, different layers would demand different laser scanning speeds and powers because the powder environment changes as the build proceeds. The new software will be able to control the scan laser's parameters as well as powder characteristics and the part shape being printed. GE and LLNL will develop the algorithms during the next 18 months, which will then be publicly available. *llnl.gov.*

MATERIALS PROCESSING CENTER CELEBRATES 35 YEARS

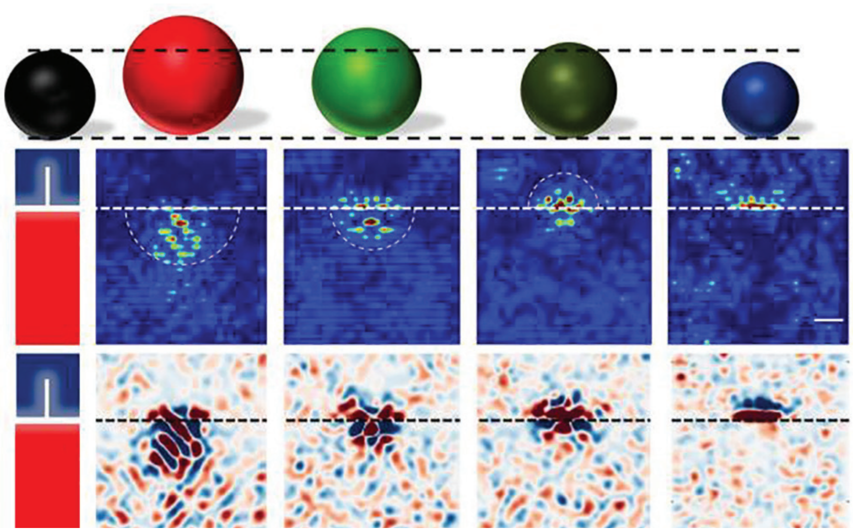
On February 1, the Materials Processing Center (MPC) at Massachusetts Institute of Technology, Cambridge, marked 35 years of service to both faculty and the materials research community. Current MPC research topics build on the center's original foundation of metallurgy, polymers, composites, and ceramics. As a center within MIT's School of Engineering, MPC serves roughly 60 researchers, assists in drafting proposals and administering grants, and provides industrial outreach. Merton Flemings, FASM, founding director of MPC, recalls that the center arose in 1980 in response to a need to make American industry more competitive and bring the focus back to civilian industry as the Cold War was winding down. NASA was an important early MPC funder, focusing on space materials. Today, MPC researchers are working on projects to design and implement energy storage systems that go beyond the capabilities of lithium-ion batteries, develop materials that will enable quantum computing, and lay the groundwork for integrated microphotonic systems. *mit.edu.*

American Welding Society

BRIEF

The **American Welding Society,** Miami, revamped their website to deliver full content and functionality across all devices. The new site allows visitors the ability to customize their experience, whether they are a student looking for welding classes, a professional searching for conferences and certifications, or a job seeker looking for new opportunities. *aws.org*.

ENERGY TRENDS



Simulations show the effects of dislocations in cerium dioxide on the redistribution of differently sized dopant atoms, replacing a cerium atom in the crystal lattice. Results reveal different amounts of segregation around the dislocation caused by the differently sized elements. The sizes of the other atoms are compared to a cesium atom (left, in black). The white dashed line shows the plane of the dislocation caused by strain. Courtesy of the researchers.

SURPRISING PROPERTY FOUND IN OXIDES

Dislocations in oxides such as cerium dioxide, a solid electrolyte for fuel cells, have a property that is the opposite of what researchers expected, according to new analysis at Massachusetts Institute of Technology, Cambridge. Researchers thought that a certain kind of strain—specifically, strain caused by dislocations in the material's atomic lattice—would speed the transport of oxygen ions through the material, potentially leading to much faster diffusion than necessary in high-performance solid oxide fuel cells, water-splitting, or oxygen-separation membranes. But the new atomic-level simulation of oxide ion transport reveals that while these dislocations do greatly accelerate atom transport in metals, they can have the opposite effect in this metal-oxide material, and possibly in others.

Instead of easing ion mobility, it turns out that dislocations in cerium dioxide cause a kind of "traffic jam" for the flowing ions, slowing them to a crawl, says graduate student Lixin Sun. The surprising result suggests that a different approach is needed to try to speed up the movement of these ions. *For more information: Lixin Sun, 617.253.1749, lixinsun@mit.edu, www.web.mit.edu.*

POLYMER BLEND ENABLES MORE EFFICIENT SOLAR POWER

A University of Cincinnati, Ohio, research partnership is reporting advances on how to one day make solar cells stronger, lighter, more flexible, and less expensive when compared with the current silicon or germanium technology on the market.

Yan Jin, a UC doctoral student in the materials science and engineering program, describes how a blend of conjugated polymers resulted in structural and electronic changes that increased efficiency three-fold, by incorporating pristine graphene into the active layer of the carbon-based materials. The technique results in better charge transport, short-circuit current, and a more than 200% improvement in device efficiency. "We investigated the morphological changes underlying this effect by using small-angle neutron scattering (SANS) studies of the deuterated-P3HT/F8BT with and without graphene," says Jin.

The partnership with Oak Ridge National Laboratory and the DOE is exploring how to improve the performance of carbon-based synthetic polymers, with the ultimate goal of making them commercially competitive. *uc.edu.*

BRIEFS

The **Energy Department** announces up to $35 million in available funding to advance fuel cell and hydrogen technologies, and enable early adoption of fuel cell applications, such as light duty fuel cell electric vehicles. This funding opportunity aims to boost U.S. innovation in these technologies by supporting both research and development efforts and initial deployments. *tinyurl.com/lferfqw.*

Helsinki Region Transport and **VTT Technical Research Centre of Finland Ltd.** will launch an extensive joint pilot program to introduce highly efficient lightweight electric buses with technology to charge their batteries during operation. The buses use quickly rechargeable batteries and feature aluminum frames. Other benefits include zero emissions and quiet operation, say researchers. *vttresearch.com.*

SURFACE ENGINEERING

Mihri and Cengiz Ozkan, both professors in the Bourns College of Engineering.

CAGE-LIKE GLASS COATING IMPROVES BATTERIES

One major problem in lithium-sulfur batteries is reaction products, called lithium polysulfides, that dissolve in the battery's electrolyte and travel to the opposite electrode permanently; decreasing the battery's capacity over its lifetime. Researchers in the Bourns College of Engineering at the University of California, Riverside, investigated a strategy to prevent this polysulfide shuttling phenomenon by creating nanosized sulfur particles, and coating them in silica (SiO_2), otherwise known as glass.

Research groups have been working on designing a cathode material in which silica cages "trap" polysulfides having a very thin shell of silica, and the particles' polysulfide products now face a trapping barrier—a glass cage. The team used an organic precursor to construct the trapping barrier. "Our biggest challenge was to optimize the process to deposit SiO_2—not too thick, not too thin, about the thickness of a virus," says Mihri Ozkan.

"We decided to incorporate mildly reduced graphene oxide (mrGO), a close relative of graphene, as a conductive additive in cathode material design, to provide mechanical stability to the glass caged structures," says Ozkan. The new generation cathode provided an even more dramatic improvement than the first design, because both a polysulfide-trapping barrier and a flexible graphene oxide blanket that harnesses the sulfur and silica together during cycling were engineered. *For more information: Mihri Ozkan, 951.827.2900, mihri@ece.ucr.edu, www.engr.ucr.edu.*

NANOPARTICLE PAINT MAKES TOUGH SELF-CLEANING SURFACES

A new paint to create robust self-cleaning surfaces was developed by a team led by University College London, UK, researchers. The coating can be applied to clothes, paper, glass, and steel and when combined with adhesives, maintains its self-cleaning properties after being wiped, scratched with a knife, and scuffed with sandpaper.

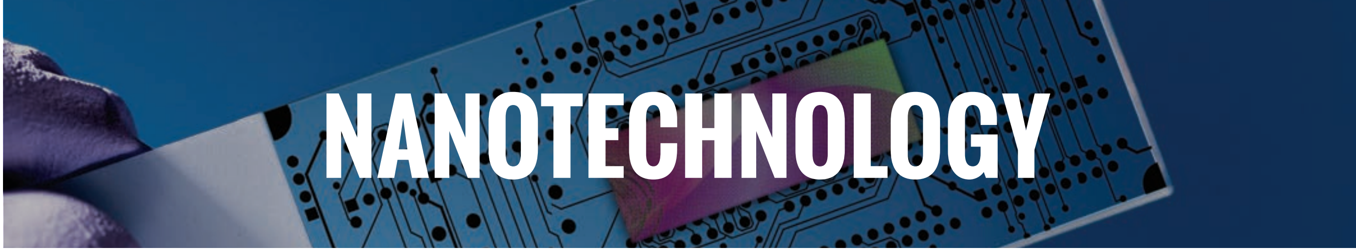
"Being waterproof allows materials to self-clean as water forms marble-shaped droplets that roll over the surface, acting like miniature vacuum cleaners picking up dirt, viruses, and bacteria along the way. For this to happen, the surface must be rough and waxy, so we set out to create these conditions on hard and soft surfaces by designing our own paint and combining it with different adhesives to help the surfaces withstand damage," says chemist Yao Lu.

Different coating methods were used to create the water repellent surfaces, depending on the material. An artist's spray-gun was used to coat glass and steel, dip-coating was used on cotton wool, and a syringe was used to apply the paint onto paper. All materials became waterproof and self-cleaning as water droplets of different sizes were seen bouncing instead of wetting the surface, removing the dirt applied by the researchers. This was maintained after damage was inflicted on the surfaces.

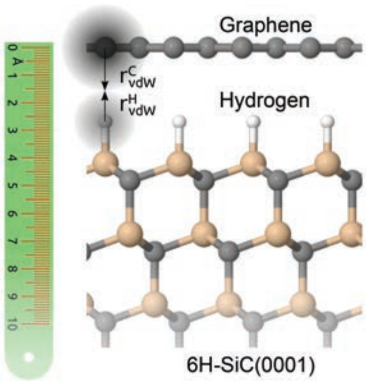
"Our paint works extremely well for a variety of surfaces in tough conditions which were designed to simulate the wear and tear of materials in the real-world. For example, car paint frequently gets scuffed and scratched and we wanted to make sure our paint would survive that," says Lu. *www.ucl.ac.uk.*

BRIEF

A one-step coating that blocks protein growth and kills surface-bound bacteria on silicone may significantly reduce infections from medical devices such as catheters, according to a study at **A*STAR Institute of Bioengineering and Nanotechnology,** Singapore. Yi Yan Yang and his international colleagues accomplished this with a synthetic technique that combines biomimetic surface adhesion and antimicrobial capabilities into a brush-like polymer film. *www.ibn.a-star.edu.sg*.



NANOTECHNOLOGY



Graphene on a silicon carbide substrate whose surface was treated with hydrogen in order to electrically decouple the graphene. The distance between the two layers, minus the respective van der Waals radii, gives an approximate value for the interaction strength. Courtesy of Sforzini et al., *Physical Review Letters*/The American Physical Society.

NEW FORMULA FOR IDENTIFYING SUITABLE GRAPHENE SUBSTRATE

Physicists from Forschungszentrum Jülich, Germany, developed criteria with which scientists can seek suitable substrate materials for graphene in a targeted way. Interactions with the substrate material often remove the amazing properties that characterize this special form of carbon. Together with partners at other institutions, scientists demonstrated that the influence exerted by the substrate on the electronic properties of graphene can be estimated by means of a simple structural parameter.

Harder than diamond, tougher than steel, and many times more conductive than silicon—these and further extraordinary properties are the reason why graphene is intensively studied worldwide. The material is only one atomic layer thick. Its use, however, is so far mostly limited to laboratory experiments. One of the major tasks on the way to practical applications is the search for suitable substrate materials without which the extremely thin material is of little use.

"We simply wanted to find an accessible parameter which can be used to compare different substrates directly," reports François Bocquet. "The decisive criterion turned out to be the atomic distance between the graphene layer and the underlying substrate," he explains. *For more information: François Bocquet, +49 2461 61-3987, f.bocquet@fz-juelich.de, www.fz-juelich.de.*

BRINGING CLEAN ENERGY A STEP CLOSER

Researchers at Case Western Reserve University, Cleveland, have shown that an inexpensive metal-free catalyst performs as well as costly metal catalysts at speeding the oxygen reduction reaction in an acidic fuel cell for the first time. The carbon-based catalyst also corrodes less than metal-based materials and has proved more durable. The findings are major steps toward making low-cost catalysts commercially available, which could, in turn, reduce the cost to generate clean energy from PEM fuel cells—the most common cell being tested and used in cars and stationary power plants.

The key to the new catalyst is its rationally designed porous structure, says Liming Dai, the Kent Hale Smith Professor of macromolecular science and engineering at Case. Researchers mixed sheets of nitrogen-doped graphene, a single-atom thick, with carbon nanotubes and carbon black particles in a solution, then freeze-dried them into composite sheets and hardened them. Graphene provides enormous surface area to speed chemical reactions, nanotubes enhance conductivity, and carbon black separates the graphene sheets for free flow of the electrolyte and oxygen, which greatly increased performance and efficiency. Researchers found that those advantages were lost when they allowed composite sheets to arrange themselves in tight stacks with little room between layers. *For more information: Liming Dai, 216.368.4176, liming.dai@case.edu, www.case.edu.*

Structure enables a carbon-based catalyst to perform comparably with metal catalysts in an acidic fuel cell. Carbon black agglomerates maintain a clear distance between graphene sheets imbedded with carbon nanotubes, allowing oxygen and electrolyte to flow through and speeding the oxygen-reduction reaction (a). Without the agglomerates, the sheets stack closely, stalling the reaction (b).

BRIEF

The president's budget for fiscal year 2016 provides $1.5 billion for the **National Nanotechnology Initiative** (NNI), a continued Federal investment in support of the president's priorities and innovation strategy. Cumulatively totaling more than $22 billion since the inception of the NNI in 2001, this funding reflects nanotechnology's potential to significantly improve our fundamental understanding and control of matter at the nanoscale and to translate that knowledge into solutions for critical national needs. *nano.gov/2016BudgetSuplempplement.*

TECHNICAL SPOTLIGHT

SOLVING TESTING CHALLENGES IN POWDER METALLURGY

Powder metallurgy is a process that produces metal alloys in powder form, consolidates them into shapes, and then sinters them to achieve final geometry and properties. Sintering involves producing a hard solid metal or ceramic piece from a starting powder. A variety of metal alloys can be used, including precious metals. Historically, iron was extracted by hand from metal sponge and ground into a powder for final melting or sintering.

Using solid state sintering, metal powder is placed into a mold or die. Once compacted into the mold, the powder is heated to a high temperature. Under heat, bonding takes place between the porous aggregate particles and once cooled, the powder bonds to form a solid piece.

Powder processes can generate a wider range of products than what is possible through direct alloying of fused materials. Alloying requires complete melting of the base materials and consideration of solid-liquid phases in order to achieve the desired combination of metals. For this reason, powder metallurgy processes offer advantages over casting, extrusion, and forging.

Advanced technologies expand on this basic idea using additive manufacturing, in which parts are built to near-net or net shape. Metal powders may be sintered in layers, sprayed in specific patterns, or melted by electron beams to form parts. Nearly every alloy can be formed into parts via powder metallurgy, while some alloys can *only* be made by powder metallurgy. Powders can also be rolled to form sheets, a method commonly used to produce sheet metal for electrical and electronic components.

POWDER METAL TESTING

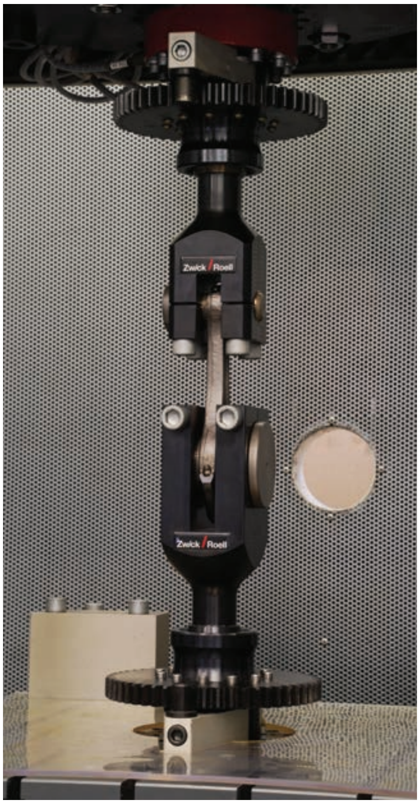
Maintaining powder metal quality during fabrication begins with tests on the powders themselves. They are checked for correct chemistry, particle size distribution, and physical and mechanical properties. Components manufactured by powder metal processes are typically tested for hardness, impact resistance, tensile strength, and density.

Castings and forgings are predominantly used in the automobile industry and for aircraft manufacture, as well as power station construction. Casting technology is used to create complex parts cost-effectively, with light metal castings frequently applied to reduce weight, especially in engine manufacturing.

Where castings and forgings are concerned, everything depends on reliable fatigue strength data. This requires that specimens, and even entire components such as connecting rods, undergo intensive testing under cyclic loads. For example, some resonance testing machines simulate operating conditions with components characterized under cyclic loads to 1000 kN at frequencies to 300 Hz. As an example of this type of equipment, Zwick/Roell, Germany, offers a range of resonance testing machines that provide an alternative to servohydraulic platforms.

The company's Vibrophores support fatigue testing of materials and components under force control or strain control modes, while the resonance drive within these systems consumes very little energy and enables testing at high frequencies, which may be applied to reduce test time and increase throughput.

Test method	Properties measured
Metallography	Microstructure, particle size and distribution, composite reinforcements
Scanning electron microscope (SEM)	Combined imaging and elemental analysis
Chemistry	Fillers, binders, contaminants
Rockwell, Brinell, Vickers	Hardness
Charpy	Impact strength
Stress rupture	Time to failure under a specified overload
Inductively coupled plasma/mass spectrometry (ICP/MS)	Trace elements identification and amounts
X-ray fluorescence	Coating thickness
Image analysis	Particle size and shape



Zwick Vibrophore systems apply the resonance principle to enable fatigue testing of metal specimens. Testing at high frequencies may be done rapidly, enabling greater overall test throughput.

TENSILE TESTING

Products made using casting processes require very little additional processing before completion. For tensile testing, this means that either entire specimens must be removed from specific locations, or that whole components must be used to determine tensile strength. Testing complete component requires high test loads and component-specific gripping arrangements and fixturing, while component geometries often result in specimens with small final dimensions. For these small and round specimens, special specimen grips that are easy to handle allow the use of automatic extensometers on certain testing equipment. In addition, complete components are addressed by a comprehensive group of accessories for gripping and fixturing.

Testing of metal components requires specialized fixturing and gripping t echniques.

A metal component mounted and gripped for fatigue testing in a Vibrophore system.

HARDNESS, COATING, AND DENSITY TESTING

Hardness value is an important characteristic in the manufacture of cast components. The high-load Brinell method is often used on components—where large indentations enable a stable average value to obtain metallographic constituents. The hardness of these metallographic constituents and individual phases may be determined on specimens via microhardness testing in accordance with ASTM B933. As an example of this type of equipment, Zwick's Brinell hardness testing machines with automatic indentation measurement to 29,000 N are complemented by a comprehensive micro Vickers instrument range, including fully automatic systems.

Powder materials are also used for coatings to protect substrates from corrosion, wear, high temperatures, erosion, or abrasion. Coatings are tested for thickness, adherence, composition, porosity, hardness, and impact strength.

Hydraulic grips are able to clamp very small test specimens.

For powder metallurgy materials containing less than 2% porosity, density measurement may be used to determine if the part has been densified, either overall or in a critical region, to the degree required by the application. Density alone cannot be used for evaluating the degree of densification because chemical composition and heat treatment affect the pore-free density.

For cemented carbides, a density measurement is normally used to determine if there is any significant deviation in composition of the carbide grade. If the measured density is beyond specified limits, the overall composition is considered to be outside of the limits as well. However, a measured density within the specified limits does not ensure correct composition; compensation between two or more constituents could result in the expected density with the wrong composition. Density alone cannot be used for evaluating a cemented carbide grade.

SUMMARY

Powder metallurgy offers distinct advantages for the production of certain alloys. The degree to which contents of the alloy may be prescribed represents tremendous potential and supports alloy use in new applications. However, robust testing of powder metallurgy alloys is required to assess their potential and quality. Fatigue testing via the resonance principle enables metallurgists to achieve greater throughput in testing programs, while novel hardness testing platforms support analysis of individual phases in porous powder metallurgy specimens. **~AM&P**

For more information: Boris Plach is product manager, testing machines, Zwick/Roell, August-Nagel-Str. 11, D-89079 Ulm, Germany, +49.7305.100, info@zwick.de, www.zwick.com.

NON-CONTACTING EXTENSOMETRY EXCELS IN STRAIN MEASUREMENT

Stress and strain are the two fundamental components of a materials test. When a material is put under a compressive or tensile load, *stress* is the load relative to the cross-sectional area of the material, while *strain* refers to how much it elongates. Both stress and strain data provide important material characteristics such as stiffness, yield stress or yield point, ultimate tensile strength, and total elongation. Many industries require use of calibrated and verified equipment to measure a material's stress and strain—usually with a universal testing machine, load cell, and an integrated extensometer or strain measurement device.

Various extensometers are commercially available for a wide range of materials and provide accurate strain data for specific applications. Often this strain data must be of the highest accuracy and repeatability, as many critical material characteristics depend on accurate, early-in-test strain data. The resulting characteristics can be used as quality control benchmarks, and/or material selection criteria in research and development with great impact on the final components.

TESTING STANDARDS

Most industries, such as polymer, steel, and carbon fiber composite manufacturing, have regulated procedures for testing raw materials before they can be sold. These processes are most commonly governed by organizations such as the International Organization for Standardization (ISO), Geneva, and ASTM International, West Conshohocken, Pa. Other standards organizations exist globally and typically make small adaptations to the most common ISO and ASTM standards.

Testing standards vary in stringency, some requiring very low accuracy instrumentation and some requiring high accuracy, high-resolution instrumentation to characterize materials. The stringency usually correlates with the material's end use. Composites, metals, and polymer manufacturing tend to have the strictest extensometry requirements within the materials testing sector due to the material's stiffness and use in critical applications.

EXTENSOMETERS: BASICS AND BENEFITS

Extensometry can be broken down into two fundamental categories: contacting and non-contacting. As their names suggest, *contacting extensometers* require contact with the materials testing specimen, whereas *non-contacting extensometers* use technologies like video or lasers to measure elongation. Non-contacting extensometry offers a wide range of benefits in materials tests. Depending on the specific application, non-contacting extensometry may be the only option for strain measurement.

Non-contacting: The most obvious feature of non-contacting extensometry is that it does not come in contact with the specimen during tests. This is important for delicate materials, such as biomedical tissues, paper, and even some polymers. For some fragile materials, contacting extensometry can affect important strain-based calculations like modulus or yield. Heavy contacting devices can damage fragile specimens causing them to bend and deform during the test, and/or can dig into the material's surface with sharp edges, causing weakening at contact points and thus premature failure.

High accuracy: Both BS EN ISO 6892-2:2011 and BS EN ISO 527-1:2012—the two most common global tensile testing standards—require very accurate extensometry (ISO 9513:1999 Class 1). Non-contacting extensometer technology uses a combination of lighting, fans, and high-resolution digital cameras to achieve the accuracy needed for these

Fig. 1 — Polarized LED lighting on the Instron AVE2 increases extensometer accuracy by removing ambient light effects.

Fig. 2 — Film testing conducted on the Instron AVE2.

applications, and can also perform advanced applications such as strain control and dynamic testing.

Flexibility of applications: One of the most beneficial features of non-contacting extensometry is its ability to be used for almost any application. This flexibility allows adaptation to various tests with minimal changes to base equipment. Equally, non-contacting extensometers work well in quality control environments where repeatability and robustness are key.

Various lenses: Most video and laser extensometers have interchangeable lenses. The different lenses dictate the field of view of the strain measurement—how much of the test space can be seen by the camera. Smaller field-of-view lenses are typically used when very high-accuracy measurements are required, such as in metals and composites tests, whereas larger field-of-view lenses are used for high-elongation tests, such as films and elastomers.

Ease of use: Many commercially available non-contacting extensometers require minimal operator intervention during the test, as they are usually integrated into the test method automatically. Operators only need to mark materials with dots, lines, speckle, or other surface patterns to be picked up by the camera.

Temperature chamber use: Because non-contacting extensometers do not contact specimens, they are suitable for both high and low temperature testing. They can be attached to chambers that are fitted with windows, with minimal compromise to strain signal accuracy.

Robustness: There are no moving parts on most non-contacting extensometers, so there is little wear and tear on the device itself. Robust devices need less servicing over their lifetime and can last for many years before being repaired or replaced, maximizing the uptime of testing operations.

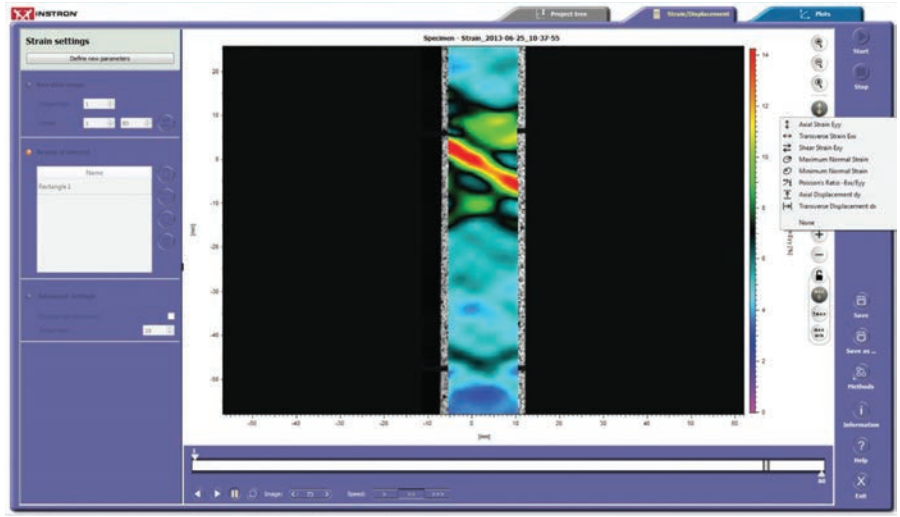


Fig. 3 — Digital image correlation analysis shows localized strain on a metal tensile specimen.

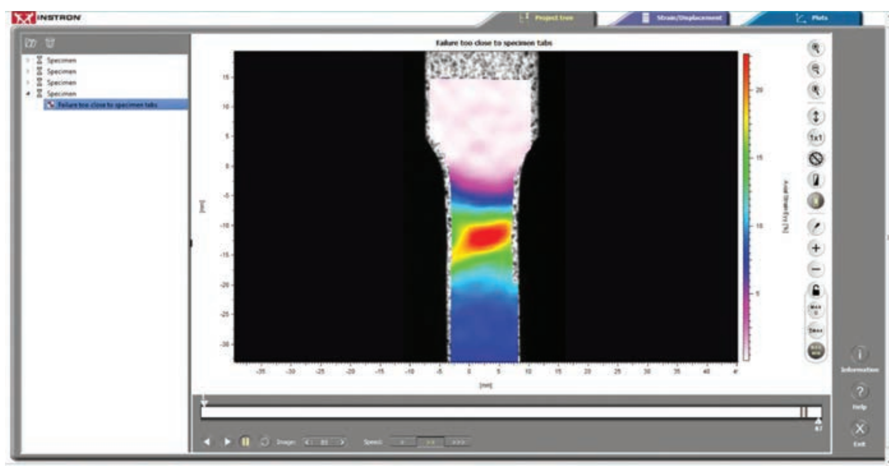


Fig. 4 — Digital image correlation analysis shows localized strain on a plastic tensile specimen.

LOOKING FORWARD

Non-contacting strain devices are not limited to simple elongation and deformation measurements. Recently, video extensometers have been used to collect images for digital image correlation (DIC). DIC is an optical technique that has been used within research environments for more than 30 years and allows strain to be measured over the entire surface of a specimen or component. Sequential images are taken during a test and DIC software analyzes these post-test to extrapolate displacement data by tracking changes to a pattern either applied to the specimen or occurring naturally in the material. This allows a strain map, similar to an FEA-analysis or thermal image, to be shown for the entire surface with single camera systems working in 2D and two camera, or stereo, systems allowing measurements in 3D.

As DIC provides operators with strain data across the full field of the specimen surface, as opposed to only elongation between two points from a traditional extensometer, it can also provide more information such as discontinuous yielding, shear strain, localized necking, and can locate strain hot spots. This allows FEA models to be validated with real products and weaknesses in design and common failure points to be discovered. DIC also enables strains to be found that an extensometer would not be able to discover, and is a valuable teaching tool as well.

Although DIC has been a popular standalone research technique for years, it was only recently that its capabilities have been integrated with commercially available video extensometers with a simplified user interface, making this powerful analytical tool available for any capable materials testing operator. **~AM&P**

For more information: Elena Mangano is market development specialist, Instron, 825 University Ave., Norwood, MA 02062, 800.877.6674, elena_mangano@instron.com.

SOLVING PROBLEMS IN HUMAN/LEGAL DOMAINS USING FAILURE ANALYSIS METHODS

Difficulty in clearly and quantitatively answering questions concerning a component or product failure can lead to courtroom debates, arguments, and battles.

Priyadarshan Manohar, Robert Morris University, Moon Township, Pa.*

When a product or system failure occurs, it can have unfortunate consequences, such as lost productivity and negative effects on customer loyalty, not to mention serious injury or loss of life. Therefore, the total cost of failure depends on the specific nature of all damage incurred. In cases where there is disagreement over who is to blame, the dispute might go to a court of law where several important aspects of the failure analysis (FA) are tested, discussed, and judged. Aspects to consider include:

- Did the investigative FA methodology follow accepted scientific procedures, such as those established by national and international agencies, and relevant industry codes, standards, and specifications?
- Was the evidence protected via chain of command documentation?
- Were appropriate protocols established and agreed upon by all parties involved regarding evidence collection and testing?
- Was the sequence and chronology of failure events established?
- Were all parties involved in the design, manufacturing, assembly, commissioning/construction, use, and maintenance of the product/system identified?
- Were the reason(s) for failure determined with reasonable scientific certainty?

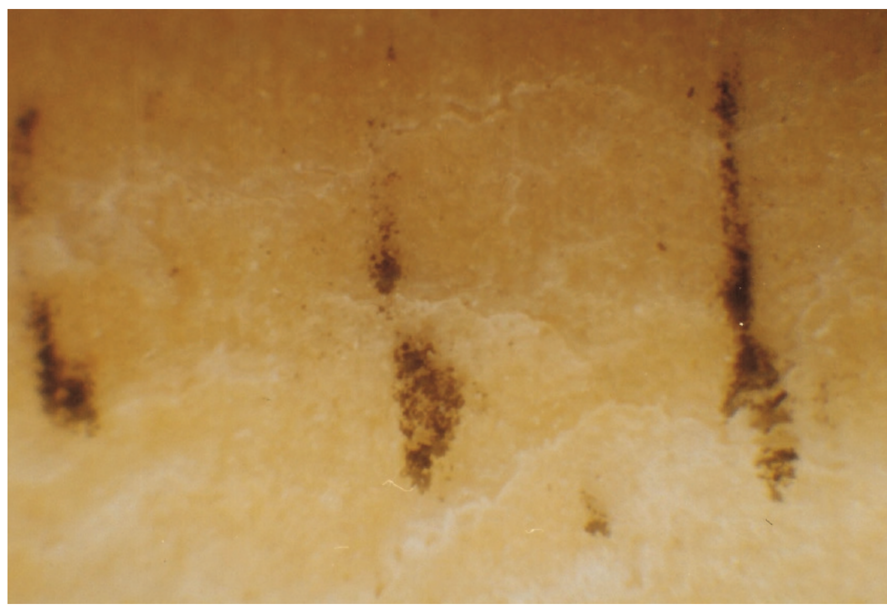


Fig. 1 — Surface of a freshly baked bread roll shows black deposits at regular intervals. FTIR spectroscopic analysis determined that burnt deposits are associated with corn meal used as a release agent during the baking process.

- What amount of damages should be awarded to victims?
- Is the responsibility of the failure shared, determined, and agreed upon?

These issues can be contentious, leading to keen legal debate and arguments to determine product liability. Arguments are based on failure analysis reports and expert testimonies, which must withstand both direct and cross examination. This can be a daunting situation for FA professionals, who might not be familiar with legal jargon and procedures. Further, although the questions raised above are important, they do not necessarily have straightforward answers. The case studies examined here identify and describe technical procedures to assist with explaining complex situations and thereby assist in solving failure analysis problems. These examples show that the kinetics of metallurgical reactions, phenomena, and phase transformations including corrosion, fatigue, creep, grain growth, and heat treatment—coupled with fractographic analyses and mathematical modeling—can be adapted to find answers to important questions in the legal/human domains.

*Member of ASM International

PRODUCT CONTAMINATION

A manufacturer of industrial-scale bakery equipment was advised of a problem where bread rolls produced in its equipment were contaminated by black marks on the bread's surface (Fig. 1). Relevant questions in this case include: Is contamination on bread rolls related to the machine, operator, work environment, or processing variables? Is it a health hazard? The chemical analysis of the contaminant was determined using Fourier transform infrared (FTIR) spectroscopic analysis.

FTIR reveals that the black marks are associated with burning/overheating of corn meal used as a release agent in the baking process. Further investigation determined that the conveyor belt mesh cleaning system was not effective in removing excessive corn meal that stuck to the mesh, which eventually burned and stuck to the dough surface and created the black marks. Thus it is clear that the black marks were not due to defects in the manufacturing process, nor a faulty design, but were caused by inadequate maintenance of cleaning equipment during continuous operation.

PREMATURE HEATING ELEMENT FAILURE

Heating elements failed in a furnace that had a specified maximum operating temperature of 1200°F, which translated to a heating element temperature of 1825°F. The user claimed the elements failed even though the maximum temperature of the furnace was never set higher than 1200°F. Relevant questions regarding this failure include: Is the heating element material at fault? Is it the heat treater's error? Is it due to a faulty temperature sensor/controller? Is it due to operator error of inadvertently setting the furnace temperature too high? How high did the temperature go before the element failed? The answers to these questions were determined using optical metallography as shown in Fig. 2.

The heating element material was a Ni-Cr-Fe base electrical-resistor material containing 0.014% Ti, 0.043% Nb, 0.029% C, and 0.006% N. Microalloy precipitates coarsen or melt[2-6] at high temperatures and therefore do not prevent grain growth, which sometimes leads to abnormal growth. The temperature of the elements must have exceeded 1900°F for niobium nitride/carbonitride precipitates in this material to go into solution. The normal heating element operating temperature was 1825°F maximum, meaning the heating element probably failed due to abnormal operating conditions of excessive furnace temperature, either due to a faulty temperature setting or faulty temperature sensor/controller.

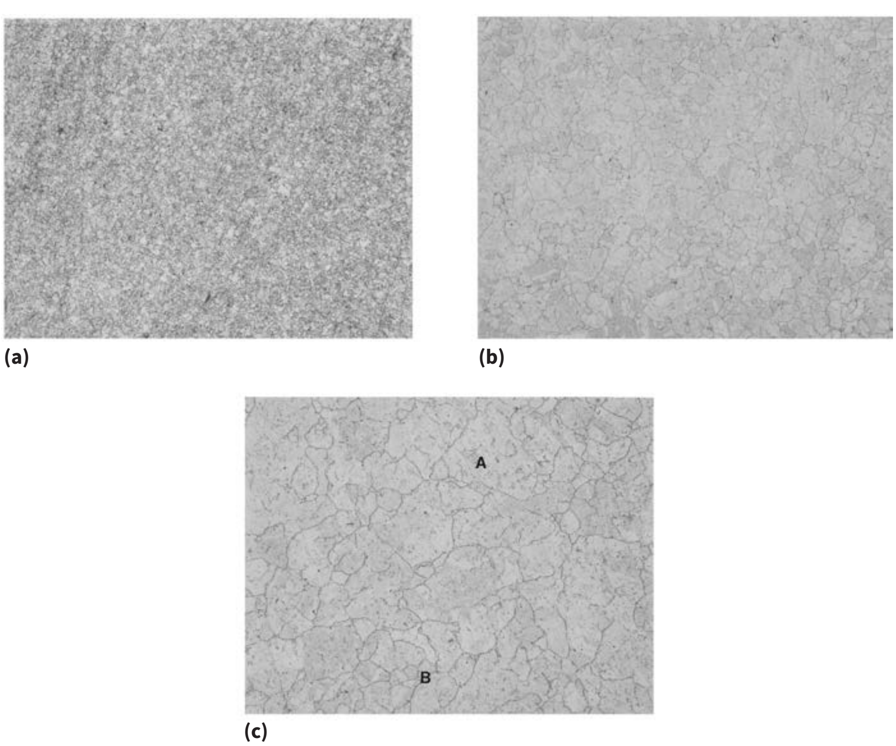


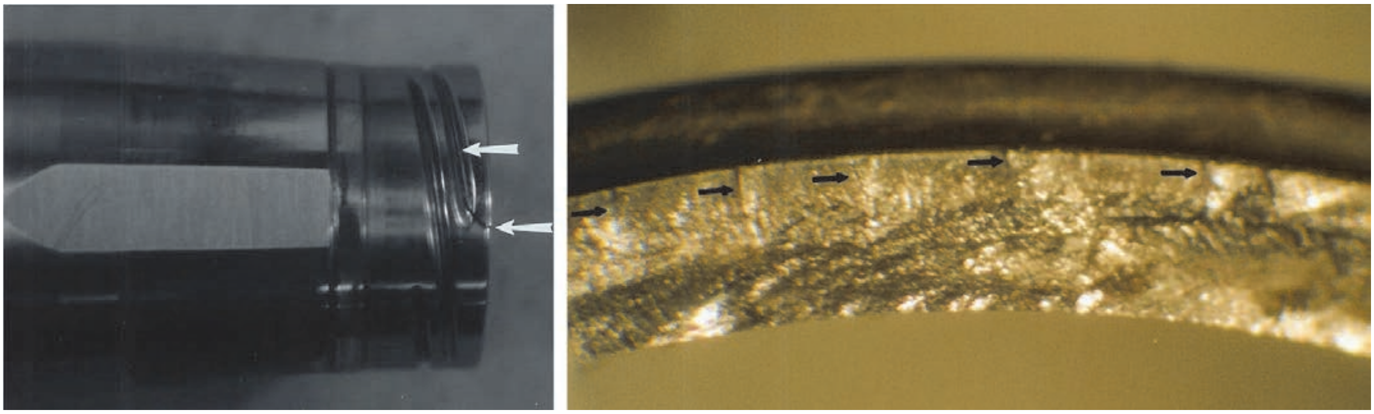
Fig. 2 — (a) Microstructure of original heating element showing fine-grained austenite, mag: 100×; (b) microstructure of used heating element showing coarse-grained austenite, mag: 100x; and (c) example of a mixed microstructure and abnormal grain growth in the failed heating element (A = coarse grains, B = fine grains; mag: 200×). Etchant was modified Marble's reagent[1].

INJECTION NOZZLE FATIGUE FAILURE

Metal quality is an important factor in machine component failure, such as the injection molding machine at the center of this case. Visual and stereomicroscopic examination of crack interfaces of the component revealed that cracking occurred due to metal fatigue initiated at multiple locations on the fillet radii of two threads on the outside surface (Fig. 3). Fracture surfaces did not reveal any corrosion products, abnormal contact patterns, or temper colors, suggesting that component operating conditions during service were not aggressive.

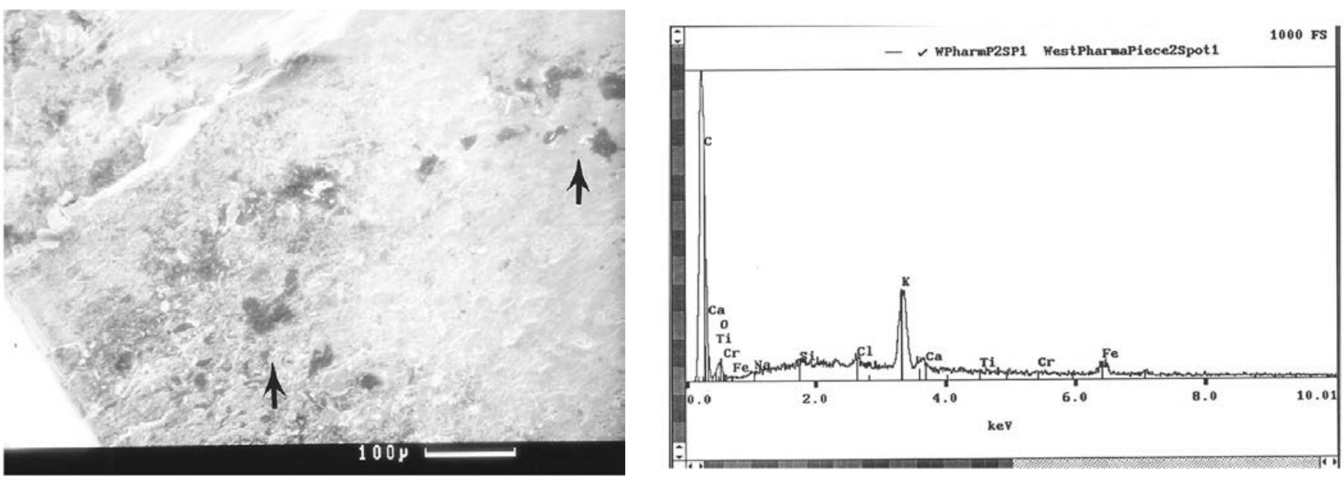
Metallurgical examination indicated that the material's heat treatment, microstructure, hardness, and bulk chemical composition met relevant standards and drawing specifications. However, a large cluster of coarse nonmetallic inclusions was observed at one location in the microstructure (Fig. 4). Scattered, large inclusions were also observed in other locations. Electron microscopy of the fracture surface reveals a large number of secondary-phase particles and inclusions clustered around crack initiation regions. Most of these particles contained Cr, C, S, and Si, suggesting that chromium carbide precipitated on preexisting silicate and sulfide inclusions.

One of the particles had a glassy appearance and contained significant amounts of C, K, and Ca. This particle is most likely from the ironmaking operation in the blast furnace. Sources for K are iron ore and coke ash, while Ca comes from the basic flux, such as lime (CaO) used for desulfurizing iron. Large clustered inclusions in a material significantly decrease its fatigue resistance and toughness by serving as crack initiation



(a) (b)

Fig. 3 — (a) Cracked injection-molding machine component, and (b) stereomicrograph of the crack interface revealing a multiple origin fatigue failure suggested by ratchet marks (black arrows).



(a) (b)

Fig. 4 — (a) SEM image at failure initiation zone with a ratchet showing clusters of inclusions and precipitates (arrows), mag: 160×, and (b) energy dispersive spectroscopy (EDS) spectrum of an inclusion indicates peaks for C, K, Ca, Cl, and Cr. This particle has probably come from the ironmaking operation in the blast furnace where sources for K are iron ore and coke ash while Ca is from the basic flux, such as lime (CaO), used for desulfurization of iron ore.

sites. Therefore, it was concluded that fatigue cracking of the component was facilitated by inadequate steel quality, i.e., lack of cleanliness.

SHEAR OVERLOAD FAILURE OF GAS PIPELINE BRACKET

A leaking underground gas pipeline resulted in a house explosion, causing grievous personal injury. The excavated pipeline revealed that two pieces separated, causing a massive gas leak. Extensive failure investigations boiled down to one question: Did the failure occur over a period of time or was it due to a single catastrophic event? Analysis of the fracture surfaces of the brackets holding the pipes together provide the answer. Figure 5 shows the fractography of one of the brackets, clearly indicating a sudden shear overload failure. It was eventually concluded that the pipeline pieces separated from each other due a landslide event in the valley not far from the location where the pipeline was buried, and the failure was mainly caused by the natural disaster rather than human error. ~AM&P

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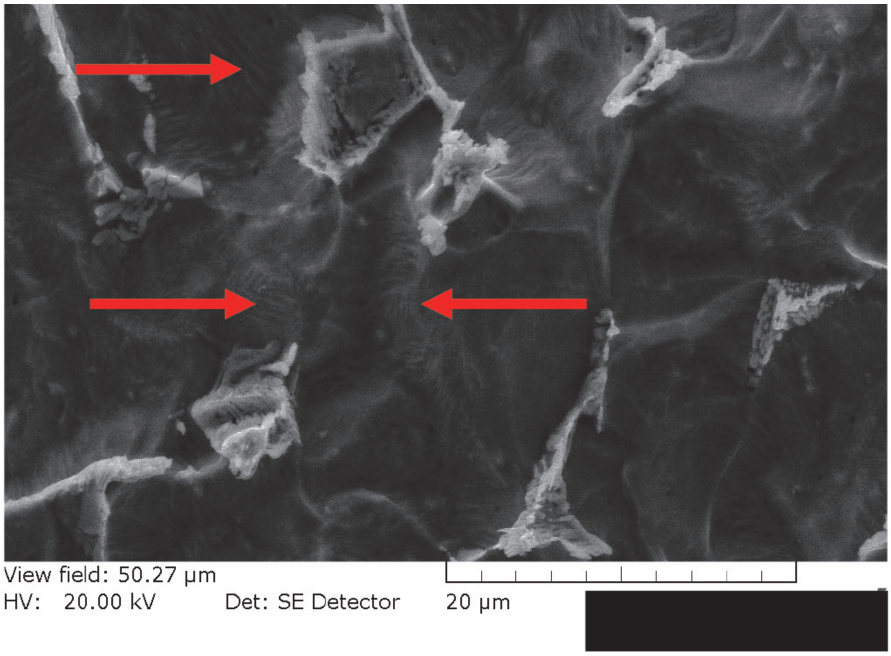

Fig. 5 — SEM fracture surface of bracket showing a mixed fracture mode of shear dimples and transgranular cleavage. Deformation lines (river pattern) on the cleavage surface of crystals are marked by red arrows. Mag: 6000×.

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OVERVIEW OF STATIC RECRYSTALLIZATION IN MAGNESIUM ALLOYS

This article presents a broad overview of key annealing processes such as recovery, recrystallization, and grain growth in magnesium and its alloys.

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Jayant Jain
Indian Institute of Technology Delhi, New Delhi

Magnesium and its alloys are receiving a lot of attention in today's structural and automotive industries due their lightweight nature, thus improving fuel economy and minimizing exhaust emissions[1]. However, wider usage is restricted by limited formability at room temperature due to their hcp structure[2]. Grain refinement and texture modification are considered to be effective ways of improving magnesium's poor formability performance at room temperature[3]. Controlling grain structure and crystallographic texture can be achieved by thermally actuated processes such as recrystallization, which can soften and restore the ductility and formability of deformed material.

The majority of research work to date focuses on dynamic recrystallization in wrought magnesium alloys[4-7], with comparatively little work on static recrystallization[8,9,10]. This is mainly due to the limited deformation capabilities of magnesium alloys at low temperature. However, based on recent efforts to improve ductility with alloying additions[11,12] and strain path changes[10,13], it is timely to review the experimental work on static recrystallization in these alloys. Note that no attempt is made to compile the status of modeling and simulation studies on recrystallization. This article explores the role of recovery in recrystallization behavior, evolution of recrystallization microstructure and texture, current understanding of grain coarsening in magnesium alloys, and concludes with a perspective on future research.

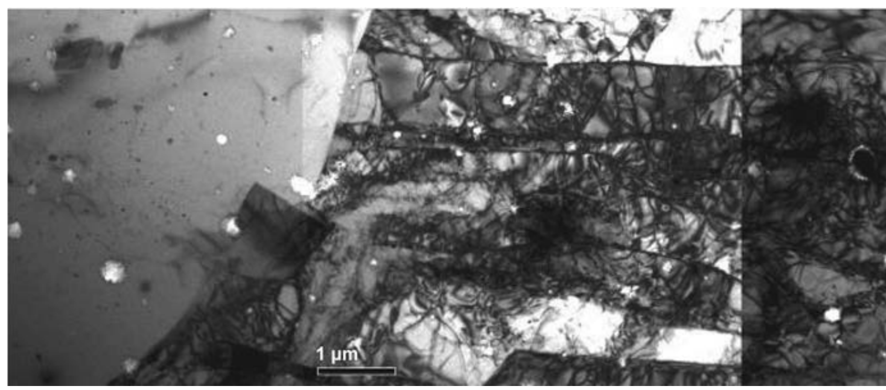


Fig. 1 — TEM image illustrating the formation of sub-grain structures in AZ31 magnesium alloy when deformed to a strain of ~0.1 followed by annealing at 250°C for 1800 s[10].

RECOVERY

It is generally observed that magnesium and its alloys exhibit incomplete recrystallization[9,10,14]. In most cases, this is due to the occurrence of intense recovery prior to recrystallization[9,10]. The recovery process reduces the system's available stored energy, thus keeping some grains from recrystallizing. The extent of recovery depends on stacking fault energy (SFE). Magnesium features a stacking fault energy of 125 mJ/m2, very close to metals like Al (166 mJ/m2) and Ni (90 mJ/m2), therefore favoring an occurrence of intense recovery[3]. The work of Okrutny[15] and subsequently Liang[10] clearly demonstrates the formation of subgrain structures in AZ31 magnesium alloys (TEM image, Fig. 1).

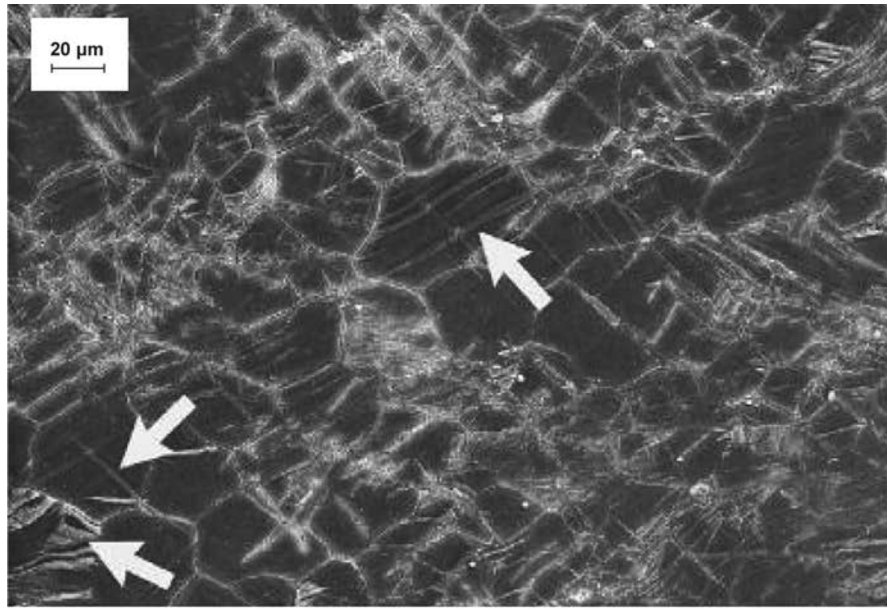
The addition of alloying elements changes the SFE. For example, adding Li and Gd to magnesium alters the SFE, which eventually affects the recovery kinetics[12,16]. The concept of static recovery is not as thoroughly studied in magnesium alloys compared to other light metals like aluminum. For example, in aluminum alloys the interaction of precipitates with dislocations inhibits the recovery process[17]. However, no such information exists with regard to magnesium alloys. More work is required to explore the recovery process as well as factors that may affect the kinetics, leading to better understanding of the recrystallization phenomenon.

STATIC RECRYSTALLIZATION

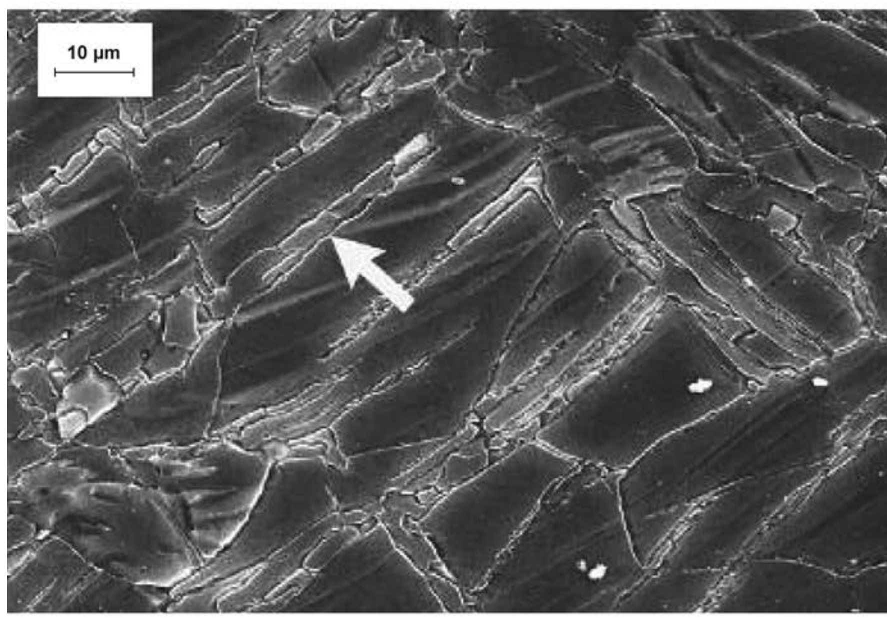
Recrystallization is a thermally activated process during which new strain-free grains replace the existing deformed microstructure by the formation and migration of high angle grain boundaries (HAGBs)[17,18]. As previously stated, magnesium suffers from incomplete recrystallization as well as retention of deformation texture (basal texture). The latter is detrimental to sheet formability, thus restricting broad applicability of magnesium alloys[19]. Several factors contribute to the retention of deformation texture in annealed material. These include limited nucleation sites that allow nucleation of off-basal orientations, absence of recrystallization within significant portions of the material, and grain boundary bulging.

Plastic deformation of magnesium takes place by the activation of many slip and twin systems. Among different slip systems, basal slip is considered to be the easiest mode with CRSS ~0.5 MPa[20]. Slip on non-basal slip systems such as prismatic <a>, pyramidal <a>, and pyramidal <c+a> are also observed[2]. However, the CRSS required to initiate slip on these systems is very high (e.g., CRSS of prism ~44 MPa; pyramidal <c+a> ~40 MPa[20]). Besides slip, the following twin modes are frequently observed in magnesium: *Extension twinning,* activates when <c> axis is under tension; *contraction twinning,* activates when <c> axis is under compression; and *double twinning,* formed by contraction twinning followed by extension twinning within the contraction twin[21]. The extension twinning reorients the grain by approximately 86°, while contraction twinning and double twins make a 56° and 36° angle with the matrix, respectively.

Many scholars[9,10,14,21] emphasize the significance of deformation twinning in the recrystallization of magnesium alloys. The work of Levinson et al.[14] illustrates the role of extension twinning. They deformed AZ31 alloy samples (compressive strain = 0.05) in the orientation that favors extension twinning and then subsequently annealed (T = 275°C). Results suggest that only 33% of the material was recrystallized even after prolonged annealing. The mechanism of recrystallization was reported to be strain induced boundary migration (SIBM) or grain boundary bulging. Nonetheless, this suggests that extension twinning plays a small role in nucleation of strain-free grains and subsequently retards the recrystallization rate. In another study[9], it is reported that extension twinning has very mobile twin boundaries; thus they opt for thickening rather than creating the further strain localization necessary for recrystallization.



(a)



(b)

Fig. 2 — Microstructures of AZ31 magnesium alloy rolled at 100°C and then annealed at 280°C for 10 s demonstrating (a) the presence of contraction twins and (b) nucleation at contraction twins[9].

Alternatively, contraction and double twins are very thin (Fig. 2a)[21]. These are mostly formed at the later stage of deformation (i.e., $\varepsilon > 5\%$) and often act as a potent site for recrystallization nucleation (Fig. 2b). Formation of new recrystallized grains at contraction twins also appears in Fig. 2b. In some instances, it is attributed to the transformation of <a> type of glissile dislocations into sessile dislocations due to twinning[22]. This leads to accumulation of dislocations within the twinned regions and thus increases the stored energy required to drive the recrystallization. Moreover, the volume of material associated with contraction/double twinning is favorably oriented for basal slip[23]. This results in localization of slip within the twinned regions and, as a result, high stored energy. It could also lead to eventual formation of shear bands[21].

Orientation of grains nucleating at contraction and double twins are different than the initial texture of the material[14]. This affects the overall recrystallized texture, but only for the initial annealing stage. On further annealing, this effect diminishes and finally arrives at incomplete recrystallization. One hypothesis is the occurrence of immense recovery prior to recrystallization, which absorbs most of the stored energy of the deformed sample. Also, the nuclei originating from the twins grows very slowly, thereby failing to consume the entire specimen. As a consequence, nucleation starts occurring at the grain boundaries that have an attribute of retaining the initial texture of the material. Nevertheless, it appears that in order to have an observable effect on recrystallization texture of magnesium, the number of contraction/double twins per unit area of the deformed sample must be increased and with less number of grain boundaries. One way to accomplish this is to increase the initial grain size of the material, because more twins are formed in large-grained structures and will also simultaneously decrease the grain boundary area[14]. The other possibility is to probe the significance of second phase particles on contraction twin nucleation and growth. Recent work[24,25,26] on precipitate-containing magnesium alloys suggests that precipitates are capable of increasing the number and density of extension twins, but restricting their growth.

In many alloy systems, large particles or dispersoids were used to successfully modify grain structure by affecting the recrystallization process and recrystallization texture via particle simulated nucleation (PSN)[27]. The size, spacing, and amount of particles are key parameters that can affect the recrystallization process[28]. Very few attempts have been made to study the significance of the effect of dispersoids and these variables on the recrystallization of magnesium alloys. The effect of large Mn-rich dispersoid particles (size > 1 μm) on recrystallization of Mg-Mn alloy was studied by Robson and colleagues[27]. Their results suggest that the matrix surrounding the particles undergoes a rotation, which is consistent with that observed in other alloy systems where PSN occurs. The new recrystallized grains were formed in the deformed zone around the hard particle. The orientation of those grains was significantly different from the parent orientation of the grain. However, the overall density of such grains was so small that their effect on global texture was minimal.

One key issue highlighted above is the incomplete recrystallization in magnesium alloys. This is often attributed to insufficient stored energy. However, with recent alloying efforts (e.g., Y, Gd, Li, etc.)[16,12,29] and strain path changes (e.g., cross rolling, multidirectional forging)[10,13], it is possible to store higher energies at low temperatures. For example, AZ31 magnesium alloy accommodated an equivalent strain up to 0.77 by cross rolling[10]. The greater the amount of stored energy, the faster the recrystallization kinetics. The same work also shows that at higher strains other potent sites for nucleation such as twin-twin interactions, as well as twin grain boundary interactions, increase substantially[10]. Grains originating from these sites also exhibit widely different orientations, providing an opportunity to alter recrystallization texture.

GRAIN GROWTH IN MG ALLOYS

Generally, recrystallized grains in magnesium undergo abnormal grain coarsening[30,31]. Under certain circumstances, some grains grow excessively compared to others and can increase in size to a few centimeters. This phenomenon is referred to as abnormal grain growth, secondary recrystallization, or discontinuous grain coarsening[17,18]. Abnormal grain growth occurs either when normal grain growth is obstructed or some grains have specific favorable features for growing faster than their neighbors. Many factors can cause abnormal grain growth, such as presence of second-phase particles, texture, and surface effects[17,18].

Magnesium exhibits abnormal grain growth behavior when subjected to severe annealing conditions, i.e., at high temperatures and for prolonged heating periods[30,31]. According to Perez et al.[31], grains with $\{11\bar{2}0\}$ orientation, i.e., $\{11\bar{2}0\}$ plane of grains parallel to the sheet plane surrounded by grains with basal texture, give rise to a boundary of high misorientation and mobility. This allows specific grains to grow faster than others. The reason is that in a strongly textured material, the HAGBs exist between prismatic and basal planes having higher energy and mobility as compared to other grain boundaries, thus helping the former to grow faster. In some cases, even under moderate annealing conditions, magnesium reveals secondary recrystallization in specific areas, for example, the outer surface of an extruded sheet[30].

When an extruded AZ31 magnesium alloy is subjected to annealing at 450°C for three hours, the outer surface witnesses abnormal grain growth (Fig. 3). A texture gradient occurs along the thickness of the sheet. In comparison to inner layers, the outer surface experiences a large amount of shear, thus more stored energy is available to initiate abnormal grain growth. In another study, grain growth kinetics were investigated on an AZ31 magnesium alloy in the 350° to 450° C temperature range[32] and no evidence of abnormal grain growth was found. This implies that there must be some critical temperature above which abnormal grain growth occurs in magnesium. It should be noted that compared to other light metals such as Al, very limited information is available on the role of solute elements and precipitate particles on abnormal grain growth in magnesium alloys.

SUMMARY

The recovery process has a strong influence on the recrystallization phenomenon. However, current understanding of recovery in magnesium and its alloys is very limited. This incomplete understanding suggests that recovery

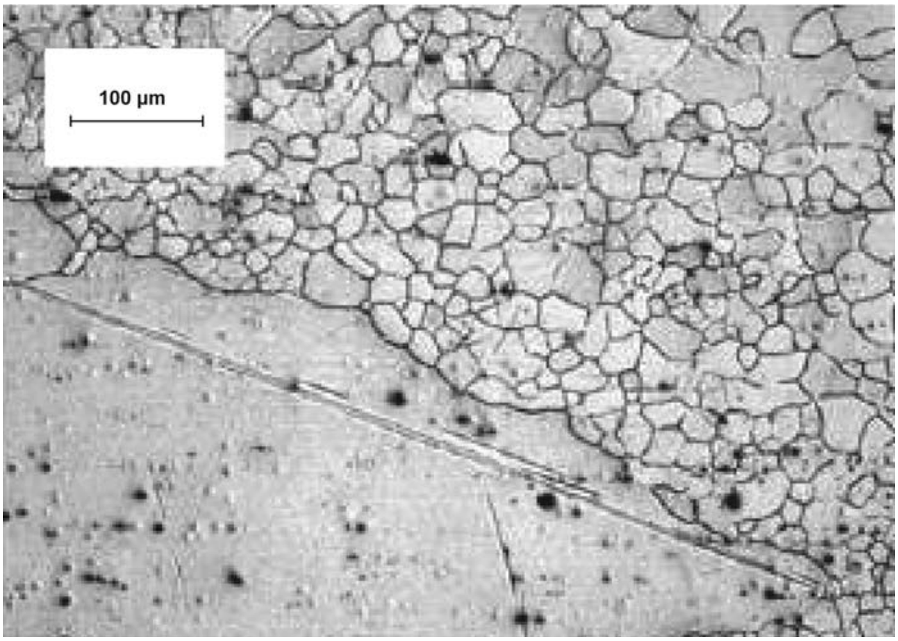


Fig. 3 — The microstructure of the outer surface of an extruded AZ31 magnesium alloy showing the occurrence of abnormal grain growth when annealed to 450°C for three hours[30].

takes place quite rapidly and is often responsible for incomplete recrystallization. The kinetics can be slowed by adding specific alloying elements that can lower the SFE. A greater understanding of the role of solute elements and second phase particles on the recovery kinetics of magnesium alloys is needed.

Preferred sites for recrystallization in magnesium are the grain boundaries, contraction/double twins, twin-twin intersections, and twin-grain boundary interactions. Among these, the latter three provide an opportunity to weaken the detrimental basal texture. A careful increase in the density of such sites would not only address the problem of incomplete recrystallization, but also help in weakening the basal texture in magnesium alloys. This can be achieved by adding the solute elements and precipitates, and changing the strain path. More detailed research is required so these factors can be systematically probed to obtain the desired microstructure. The potential of PSN in magnesium alloys has not been explored to a fuller extent. Additional work is required to investigate the effect of dispersoids' size, spacing, and volume fraction on the recrystallization process.

Magnesium also suffers from secondary recrystallization. Better control of microstructure and therefore mechanical properties will be key in deciding the future of magnesium and its alloys. The effect of solute elements and second phase particles on grain growth needs to be investigated in detail.

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EXHIBITION

SMST provides attendees a unique perspective on shape memory manufacturing and applications. Exhibitors display their latest offerings within this highly specialized field, network with their target audience, elevate their brand exposure, and build customer loyalty.

Exhibitor setup
Monday, May 18
12:00–5:00 p.m.

Welcome reception/exhibits
Monday, May 18
5:00–8:00 p.m.

Exhibitor and poster reception
Tuesday, May 19
4:30–7:00 p.m.

Exhibitor teardown
Tuesday, May 19
7:00–11:00 p.m.

*Times are tentative and subject to change.

PLENARY SESSION

History of Our Industry

Keith Melton, consultant, and Tom Duerig, NDC, Fremont, Calif.

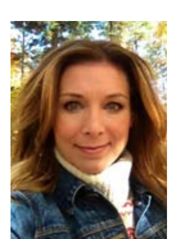
Two technical and commercial frontiersmen of shape memory and superelasticity reunite to give a somewhat personal overview of the history of the industry and its evolution. Overall changes in the industry will be tracked using personal anecdotes. The presentation also highlights a number of problematic gaps in understanding these alloys, emphasizing that this exciting new field is still in need of fundamental research.

Corrosion and Biological Response
Christine Trepanier, NDC, Fremont, Calif.

Corrosion of implantable medical devices can have damaging effects on device performance and may result in the release of corrosion products with harmful biological consequences. Research reveals the importance of the passivation process to improve the corrosion resistance and biocompatibility of Nitinol devices. These processes dissolve the nickel-rich phase formed from thermally oxidized Nitinol and promote formation of a uniform and protective titanium oxide layer that provides good corrosion

Melton

Duerig



Trepanier

Schuessler

Jahad

resistance. This presentation will review studies that characterize the surface properties of Nitinol and the impact on the material's corrosion behavior.

Engineering Nitinol Thin Films for Medical Devices—A Process Review

Andreas Schuessler,
Admedes Schuessler GmbH, Germany

Nitinol sputter deposition technology was recently proposed as an innovative manufacturing process resulting in superior fatigue performance and consistent material characteristics up to 85 μm thickness. Developing new and cost effective micro components and devices from sputter deposition, however, requires dedicated and advanced design rules. A number of advanced engineering processes for using Nitinol sputter technology for micro actuators and medical devices will be reviewed. The session will also highlight a number of enhanced micro joining and femto-laser technologies for various types of system building concepts and product applications.

Additive Manufacturing of Nitinol Fixation Hardware for Reconstructing Mandibular Segmental Defects

Ahmadreza Jahad,
The University of Toledo, Ohio

The goal of this project is to advance the scientific knowledge of Nitinol by investigating production of 3D shapes using selective laser sintering. The group has full access to a range of facilities at the Nitinol Commercialization Accelerator for conducting research. Results of this investigation are expected to create a paradigm shift in Nitinol research. Functional devices with shape memory and superelastic properties with versatile geometries are fundamental to open innovation frontiers in disciplines such as medical devices and aerospace actuators. Mohammad Elahinia will present with Jahad.

EDUCATION COURSE

Nitinol workshop
Monday, May 18
9:00 a.m.–4:30 p.m.

Organized by Alan R. Pelton, this optional all-day education course on Nitinol technology will provide attendees with a fundamental understanding of shape memory and superelasticity. Course topics include:

- How Nitinol works: Basic thermal and mechanical properties
- How to make Nitinol: Processing to optimize in vivo performance of medical devices
- How to design with Nitinol: Strategies on design of medical devices
- How Nitinol performs: Insight into fatigue and corrosion properties

This course is an excellent opportunity to strengthen understanding of shape memory and superelastic materials in advance of the technical sessions.

METALLURGY LANE

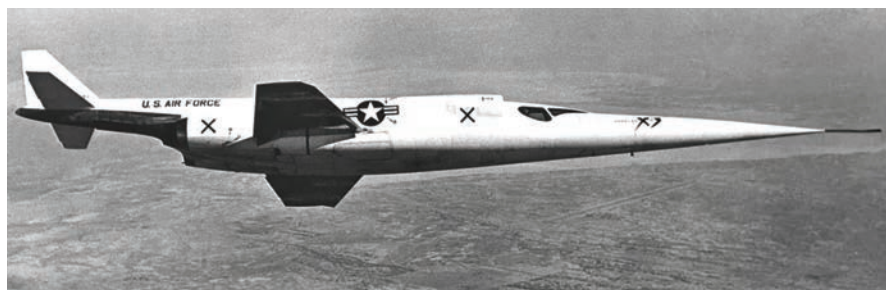
Metallurgy Lane, authored by ASM life member Charles R. Simcoe, is a yearlong series dedicated to the early history of the U.S. metals and materials industries along with key milestones and developments.

TITANIUM: A METAL FOR THE AEROSPACE AGE – PART II

THE TITANIUM INDUSTRY WAS LAUNCHED IN THE 1950S AND REQUIRED THE EFFORTS OF NUMEROUS METALLURGICAL ENGINEERS AND RESEARCH LABORATORIES, NEARLY A DOZEN CORPORATIONS, AND TITANIUM METAL PRODUCERS, ALONG WITH HUNDREDS OF MILLIONS OF DOLLARS.

In 1950, a joint venture was formed between Allegheny Ludlum Steel Co. and National Lead Co. to produce sponge, melt and cast the resulting metal into ingots, and supply metal products. This entity was called Titanium Metals Corp. of America (TMCA). A second arrangement was made between the Remington Arms Division of DuPont and the Crucible Steel Co., called Rem-Cru Titanium Inc. The following year, a third combination was formed between P.R. Mallory Co. and Sharon Steel Co., called Mallory-Sharon Titanium Corp. This company did not produce its own sponge, but purchased it from DuPont instead.

Research activities accelerated in 1950 and 1951. The Army Ordnance Corps at Watertown Arsenal began a large in-house research initiative under Leonard D. Jaffe, as well as a major program of contract research with outside firms. Scientists at Wright-Patterson Air Force Base, Dayton, Ohio, began extensive in-house and contract programs at the same time. As the phase diagram and alloy development studies funded by various government agencies were getting underway in 1950 and 1951, a commercial research project on alloy development was started at Battelle, supported by Rem-Cru. This research, conducted by Robert Jaffee and his staff of engineers, would have profound implications on the future of titanium alloys. They investigated alloys of titanium and aluminum with the addition of a third element. Many compositions for a broad range of alloys were examined and numerous patent applications were filed. The most promising contained titanium with aluminum and vanadium. An alloy in this group would eventually become the most important for aerospace applications.



The Douglas X-3 Stiletto was a 1950s experimental jet aircraft manufactured by Douglas Aircraft Co., and the first design to use titanium in major airframe components.

TITANIUM SPONGE PRODUCTION

Production of titanium sponge and titanium metal products was slow in getting started. In 1951, the Material Advisory Board (MAB) of the National Research Council, National Academy of Sciences, forecasted the need for 30,000 tons of metal products; the total shipment was only 75 tons with 500 tons of sponge produced. This was barely enough metal for research contracts and provided some leftovers to the aircraft industry for evaluation. At the same time, Col. John Dick of the Air Force was urging aircraft manufacturing companies to use titanium as a replacement for steel. Col. Benjamin Mesick of the Army Ordnance Corp. placed an order for $1 million worth of the metal to help the industry get underway.

The problem was not a lack of orders, but difficulties encountered in melting sponge and fabricating products with this new and unfamiliar material. It was widely believed that titanium could be melted, rolled, and shaped on the same equipment used for stainless steel. To some extent this was true, but the titanium was much more difficult to handle.

INCREASING DEMAND

Demand for titanium metal products increased in 1953 under encouragement from the Air Force. Aircraft companies were beginning to use titanium in new fighter and bomber aircraft and Pratt & Whitney was designing it into their latest engines. Producers, however, were on a difficult learning curve and could not keep up with demand. Total production of titanium metal products was only 1100 tons. A voice of caution came from the Office of Defense Mobilization (ODM), which argued that the forecast would require 50% of the total Air Force budget. Titanium promoters fought this, however, and the ODM set new goals at 37,500 tons of titanium sponge per year.

TECHNICAL CHALLENGES

A much more serious technical problem occurred in early 1954 while attention was focused on future needs and supply issues. The Pratt & Whitney Engine Division and The Douglas Aircraft Co. received shipments of metal that was brittle. Sheet metal tore and engine parts cracked under very low stresses. The problem was quickly traced to high hydrogen contents. A massive effort was immediately launched to determine the hydrogen source, safe level for specification, new methods for hydrogen analysis, embrittlement mechanisms, and how to salvage all the metal on hand. Vacuum annealing was quickly identified as a process for removing hydrogen from the contaminated metal and the initial panic gradually subsided. The hydrogen problem, however, did not disappear. New tolerance levels were established that required additional vacuum melting and processing for titanium.

The producers were making progress on improvements in the manufacture and quality of their product, but stronger alloys were still required. One aircraft company complained that they would not design titanium into new planes unless stronger alloys were available. Much of the titanium used previously had been lower strength, commercially pure (CP) titanium. Fortunately for the industry, an alloy was under development that would solve the strength problem.

RESEARCH PROGRESS AND PROBLEMS

The Armour Research Foundation (ARF) under the direction of Max Hansen, a world expert in phase diagrams, had been working on a Watertown Arsenal contract for alloy development. Hal Kessler and his group were studying various alloy systems, including those containing aluminum and vanadium. One of their most promising alloys contained 6% aluminum and 4% vanadium, Ti-6Al-4V. Sample ingots were supplied to the arsenal for heat treatment, mechanical property, and ballistic studies. The Air Force initiated a contract at ARF to study the high temperature

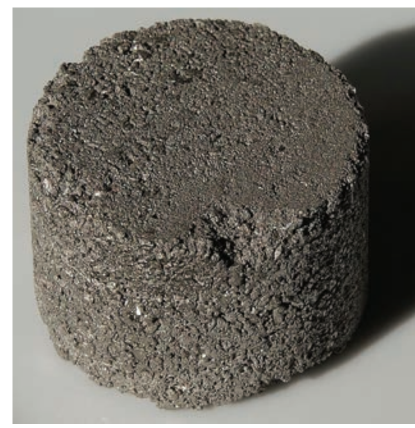
The Binga Bank and Arcade Building next to it, Chicago, were purchased by the Armour Research Foundation and IIT in 1952. Courtesy of IIT Archives Acc. No. 1998.199/Box YY-1/Buildings.

properties of interest to jet engine applications. Later, ARF supplied 100-lb ingots of Ti-6Al-4V to the engine builders for evaluation. The success of this effort soon brought the alloy to the attention of the entire titanium world. Titanium producers immediately began producing the alloy, and before long it was designed into jet engines.

Because the ARF work was done under a Watertown Arsenal contract, the patent belonged to the Arsenal. The Arsenal, however, delayed its patent application because it decided to keep the ballistic information secret. In agreement with Watertown Arsenal, ARF applied for a broad patent on Ti-Al-V alloys, including the 6Al-4V composition. On the basis of a government-sponsored project resulting in the ARF patent application, one defense contractor ceased paying royalties to Rem-Cru. This precipitated a lawsuit pitting Rem-Cru against the government and several users and producers. The suit was eventually withdrawn, leaving the invention of Ti-6Al-4V unsettled. To complicate matters further, a patent was granted to Watertown Arsenal on heat treating Ti-6Al-4V alloy. Now the Arsenal, ARF, and Rem-Cru could all claim inventing the alloy. The final word seems to be contained in a letter from Charles F. Hickey, Chief, Technology Management Branch of Watertown Arsenal to Harold Kessler stating that he (Kessler) was indeed the inventor of the most important titanium alloy.

Problems with titanium processing, including hydrogen embrittlement,

Harold Kessler, supervisor of alloy development at Armour Research Foundation, and his team developed the Ti-6Al-4V alloy under a contract with Watertown Arsenal, pictured here.



Titanium cylinder, 3 x 4 cm, 120 grams. Courtesy of Jurii, Wikimedia Commons.

limited its production in 1954 to 1300 tons, hardly more than in 1953. Sponge production, however, more than doubled to 5400 tons. Metal shipped in 1955 increased to 1900 tons and sponge to 7400 tons. The main use was in jet engines and the biggest customer was Pratt & Whitney. Sponge production moved ahead much faster than metal production. In addition, in a case of one hand not knowing what the other was doing, the government contracted with the Japanese to exchange surplus grains and other foods for titanium sponge. This Japanese sponge, which started as a trickle in 1953, reached 600 tons in 1955 and 3600 tons in 1957. The competition forced the price of sponge from $5 a pound to $2.25.

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

ASMNEWS

Chief Scientist for Mars Curiosity Rover to Speak at AeroMat/ITSC/IMS

John Grotzinger, chief scientist and head of strategic science planning for NASA's $2.5 billion Curiosity rover mission to Mars, will serve as the plenary speaker for ASM's triple tradeshow event, taking place May 11-14 in Long Beach, Calif. These three co-located shows include AeroMat, International Thermal Spray Conference (ITSC), and Microstructural Characterization of Aerospace Materials & Coatings (IMS).

Grotzinger

Selfie of NASA's Curiosity Mars rover shows the vehicle at the "Mojave" site, where its drill collected the mission's second taste of Mount Sharp.

A veteran geologist with more than 30 years of exploration experience with Earth and Mars, Grotzinger now heads the most visible mission in the history of robotic space exploration in its search for evidence of past life. He received NASA's prestigious Outstanding Public Leadership Medal for the unprecedented success of the mission, and *Popular Mechanics* included him on its list of "10 Innovators Who Changed the World." Grotzinger will discuss strategic planning, motivating and leading teams working under intense pressure, and the need to take on a "grand challenge" while sharing amazing stories, video, and photos about space and unexplored Mars territories. For more information, visit tinyurl.com/oy7b7hj.

Queen Mary Networking Event Sets Sail May 12

All aboard the Queen Mary for an exciting networking event during ASM's triple tradeshow event, taking place May 11-14 in Long Beach, Calif. This historic ship, named after King George's wife Mary, was once hailed as the grandest ocean liner in the world and carried Hollywood celebrities like Bob Hope and Clark Gable. She was outfitted to become a troopship during WWII due to her legendary speed (nicknamed the "Grey Ghost") and retired in California in 1967 as a floating attraction. Attendees of the co-located AeroMat, ITSC, and Microstructural Characterization of Aerospace Materials & Coatings shows will be able to enjoy her rich history during an old Hollywood glamour event with special surprises and entertainment. Space is limited so be sure to secure your spot today! For more information, visit asminternational.org/events.

In This Issue

ASM INTERNATIONAL

Submit news of ASM and its members, chapters, and affiliate societies to Frances Richards, editor, ASM News | ASM International
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HIGHLIGHTS CHAPTER NEWS

2015 IMC Continues with Fewer Classes and Larger Prize Money

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

The five classes include:

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

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

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

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

ASM INTERNATIONAL | Orange Coast Chapter

Orange Coast Highlights
Jet Propulsion Lab

The March meeting of the Orange Coast Chapter featured speaker Peter Dillon, a technologist from Jet Propulsion Lab, as the evening's speaker. Left to right, Chris Do, Martha Mecartney, Peter Dillon, James Earthman, Chris Hoo, and Khinlay Maung.

IN MEMORIAM

Robert F. Kane, FASM, Life Member, was born March 27, 1936 and died March 5, 2015. He graduated from Euclid High School in 1953 and from Case Institute of Technology with a Bachelor of Science degree in metallurgical engineering in 1957. He subsequently graduated from Case with a Masters of Science degree in metallurgy. Kane began his career working for the Thompson Products Co. in Euclid, Ohio, as a process engineer. Thompson Products was later merged into the Thompson Ramo Wooldridge Corp. and renamed as TRW Inc. In 1972, he transferred to the TRW Co. in Houston. He was elected chairman of the ASM Houston Chapter in 1985, the same year TRW Mission Manufacturing was sold to Sandvik Inc. and renamed Sandvik Mission. He often said that he worked for the same company for 43 years, and that each of his 5-year service pins had a different company name engraved on it. He retired from Sandvik in 2001.

ASM MATERIALS EDUCATION FOUNDATION

FROM THE FOUNDATION


Campana

Activities and Initiatives Update

Nichol Campana, Director of Development and Operations

The Foundation continues its trajectory of accomplishing milestones. With the assistance of our thoughtful and generous donors, we achieved our fundraising goal, conducted our first annual corporate sponsorship campaign, and established a new scholarship in memory of David J. Chellman, a longstanding Senior Technical Fellow with Lockheed Martin Corp.

In an effort to assist our Materials Camp organizers and fundraisers, we hosted the first of what we anticipate will be many webinars, which was aptly titled *Fundraising 101*. We shared our experience with best practices along with a new toolkit, which is intended to support the tireless efforts of our volunteers and ASM members to secure funding for their respective camps.

The Foundation also procured WestEd to conduct a Teachers Materials Camp program evaluation, our first since 2005. The evaluation aims to attend to issues of diversity, equity, and inclusion. Further, recommendations will be provided for future teacher camp activity and internal evaluations. The addition of a current program evaluation will be instrumental in securing future and potential grants.

We are pleased to announce a new Teachers Camp location in Vitoria, Brazil, scheduled for January 2016, and a new *Materials Choice Award*. ASM student board members Anthony Lombardi, Myrissa Maxfield, and Virginia Judge established the award, which is intended to familiarize middle and high school students with the materials profession and show the importance of materials in “cool” products or applications.

Lastly, our Board of Trustees voted to reinstate the Technical & Community College Scholarship program. Five scholarships of $1000 each will be awarded annually to students attending a technical or community college and pursuing an engineering technologist degree. We thank the Alternate Education Pathways Committee, especially Raymond Decker, for their efforts in launching the ASM Materials Education Foundation Technology Work Force Initiative.

ASM INTERNATIONAL

THE POWER OF ONE | MEMBERSHIP DRIVE

ASM Membership Drive Update


Pittman

Rachel Pittman, Senior Manager, Membership & Volunteerism

The 2014-2015 Membership Drive concluded last month, and we reached many prospective members and brought in an exciting group of new members to expand our materials community. A big thank you goes out to the members, volunteers, committees, and chapters who spent their time and energy to raise awareness about ASM, the value of membership, and our many educational offerings. We hope you are enjoying your cash rewards!

A special congratulations to the following Power of One participants who were selected to win a grand prize:

$3500 General Member Prize—Jayne Spanos, ASM and IMS member, Buffalo Chapter

$1000 National Committee Prize—Emerging Professionals Committee

We would also like to give special recognition to the five chapters that brought in the most new members: Cleveland, Chicago Region, Northwestern PA, Pune, and Warren.

Though the Membership Drive is over, you can still do your part to grow ASM International, the world’s largest association of metal-centric materials engineers and scientists. Simply go to the ASM website, and under the membership tab you will see a page that says “Refer a Member.” There you will find a membership application, a value of membership statement, and a marketing tips sheet. Then, apply this information the next time you meet a budding student, colleague, or meeting attendee to encourage them to join ASM—and don’t forget to give them your name to put on their application! We want to continue to recognize your great efforts. Thank you once again and we sincerely hope you continue to embrace the Power of One!

Perspectives from an Emerging Failure Analyst

Andrew DeVillier, Exponent: Failure Analysis Associates

DeVillier

Imagine that someone hands you a broken part and asks, "How did it break?" Many young engineers may immediately want to perform a detailed analysis to find out exactly how that part broke. Let's suppose that the part failed in bending overload. The bending load must then be the cause of failure, right? While technically true as the immediate cause, it doesn't answer the broader question, "What was the root cause?" Failure analysis isn't just an individual action, but a process. It doesn't just involve the events immediately preceding the failure, but everything that led up to the failure, including information such as people, processes, documents, and maybe even the weather and the environment. The root cause may not even appear to be directly related to the failure at first. So why was our part overloaded in bending? Was it made from the right material, with the right heat treatment, and properly processed? Were there any defects during manufacturing? Was it designed to handle load, and was that design sufficient? Was too much load applied?

All of these questions help establish the root cause of the failure. Maybe no one knew what the load limits were. Or maybe the part wasn't designed to handle load in the first place, but loading the part proved convenient for another task! It's easy to get caught up in tools like electron microscopy, mechanical testing, and metallography when performing failure analysis, but at the end of the day, the most important tool of all is the one between our ears. Without it, we lack the ability to ask questions, interpret data and results, and make connections between all of the information we've collected and the events that occurred. And that's what failure analysis is really about.

For the new failure analyst, ASM offers several useful reference books including *How to Organize and Run a Failure Investigation* (D.P. Dennies); *Understanding How Components Fail* (D.J. Wulpi); and *ASM Handbook Volume 11: Failure Analysis and Prevention*.

Canada Council

Canada Council Award Nominations Due April 30

ASM's Canada Council is seeking nominations for its 2015 awards program. These prestigious awards include:

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

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

John Convey Innovation Awards—In 1977, the Canada Council created a new award to recognize contributions of sustaining member companies for further development of the materials engineering industry in Canada. The award considers a new product and/or service directed at the Canadian or international marketplace. Two awards are presented each year, one to a company with more than $5 million in sales. *Recent recipients include Dr. Kartik Shanker, principal engineer at StandardAero Ltd., and Mr. Fred Doern, chair, Red River College, both of Winnipeg, Manitoba.*

Nomination forms and complete rules can be found at asminternational.org/membership/awards/nominate.

For more information, contact Christine Hoover at 800.336.5152 ext. 5509 or christine.hoover@asminternational.org

Deadline Extended to April 30 for 2015 Distinguished Life Membership and Medal for the Advancement of Research Awards

Distinguished Life Membership was established in 1954 and is conferred on leaders who have devoted their time, knowledge, and abilities to the advancement of the materials industries. The award is among the most prestigious of the Society. It is expected that all nominees will be truly outstanding. The **Medal for the Advancement of Research** was established in 1943 to honor an executive in an organization that produces, fabricates, or uses metals and other materials. The recipient, over a period of years, shall have consistently sponsored research and development and helped substantially to advance the art and science of materials science and engineering. ASM Membership is not mandatory for either of these awards.

For more information, visit asminternational.org/membership/awards or contact Christine Hoover at 800.336.5152 ext. 5509 or christine.hoover@asminternational.org.

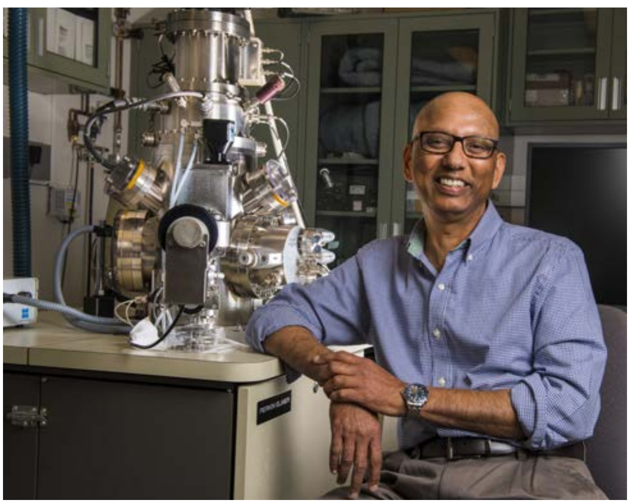
William Marino of the Inductotherm Group accepts the 2014 Distinguished Life Member Award on behalf of Henry M. Rowan.

Aziz Asphahani, FASM, of QuesTek LLC, received the 2014 Medal for the Advancement of Research Award.

HIGHLIGHTS MEMBERS IN THE NEWS

Prasad Wins Asian American Engineer of the Year Award

Somuri Prasad, FASM, of Sandia National Laboratories, Albuquerque, N.M., received the Asian American Engineer of the Year Award (AAEOY) during the 2015 AAEOY Awards Gala held in Los Angeles in February. Prasad was recognized for his pioneering contributions to the science and applications of tribology, and mentorship of graduate students, postdoctoral associates, and early career staff. Launched in 2002 by the Chinese Institute of Engineers-USA, the AAEOY Award honors outstanding Asian-American professionals in science and engineering for their leadership, technical achievement, and remarkable public service. Prasad is also an active member of ASM's *AM&P* Editorial Committee.



Prasad

Rosei Honored by American Vacuum Society

Federico Rosei of INRS's Énergie Matériaux Télécommunications Research Centre was honored by the American Vacuum Society (AVS, Science and Technology of Materials, Interfaces, and Processing) in recognition of his mentorship of young researchers. It is the first time a scientist working in Canada has received the AVS Excellence in Leadership Award. He launched a number of training and mentoring initiatives, including the UNESCO Chair on Materials and Technologies for Energy Conversion, Saving and Storage. Rosei holds the chair, which is a source of training for young scientists from developing countries. Over 100 young researchers from 30 countries around the world have benefitted from his knowledge and supervision.

Rosei

Turchi Installed as 2015 TMS President

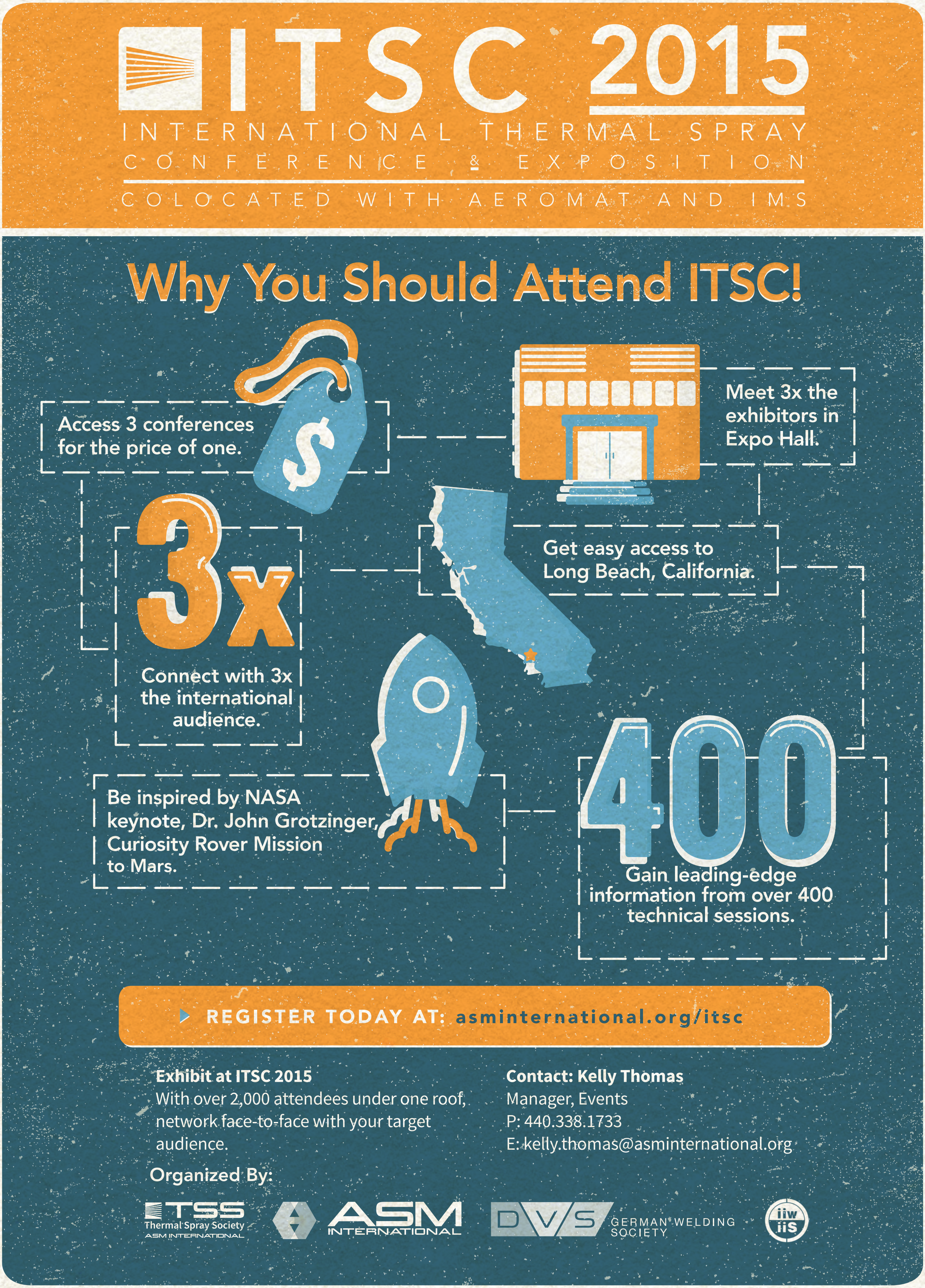
Turchi

The Minerals, Metals & Materials Society (TMS), Warrendale, Pa., installed **Patrice E.A. Turchi** as its 2015 President at the TMS 2015 Annual Meeting & Exhibition held in Orlando, Fla., in March. Turchi is advanced metallurgical science and engineering group leader, Materials Science Division, at Lawrence Livermore National Laboratory, Calif. Turchi has been an active member of TMS for more than 25 years, and has served on the TMS Board of Directors as chair of the Electronic, Magnetic & Photonic Materials Division (now the Functional Materials Division). Turchi is also co-founder of the International Alloy Conference, chair of ASM's Alloy Phase Diagram Committee, and a member of the Alloy Phase Diagram International Commission.

Madison Receives Black Engineer of the Year Award

Jon Madison of Sandia National Laboratories was recently named winner of a Black Engineer of the Year Award (BEYA) for Most Promising Scientist. BEYA is a program of the national Career Communications Group, an advocate for corporate diversity, and is part of its STEM achievement program. The awards annually recognize the nation's best and brightest engineers, scientists, and technology experts. Madison received his award at the 29th BEYA conference held in February in Washington. After completing his master's and Ph.D. in materials science and engineering at the University of Michigan, his work now centers on destructive and nondestructive techniques to understand microstructures in 3D.

Madison



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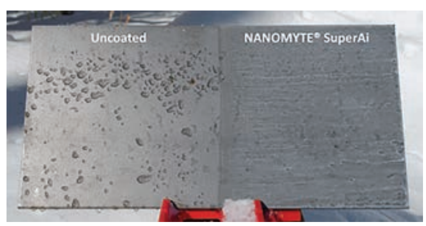
PRODUCTS & LITERATURE

Tinius Olsen, Horsham, Pa., offers its all-new SL series **materials testing machines and software,** which feature a dual-pressure hydraulic loading system and rugged four-column construction for exceptional load frame rigidity. With the advanced digital control, load accuracy is dramatically enhanced and should be better than 0.1% of the displayed reading within the operating range of 0.2% to 100% of the frame capacity. System accuracy is governed by ASTM and ISO standards. SL machines can be controlled via a range of user interface options, including Bluetooth wireless, tethered interface, or a virtual interface on a PC. *tiniusolsen.com.*

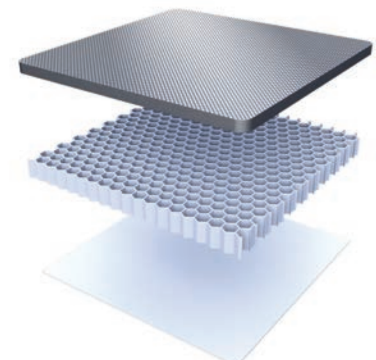
Instron, Norwood, Mass., launched a **new website,** which features simplified navigation, an improved literature library, a new press room, and GeoLocation, which intelligently tailors the website experience to each customer across the globe. The new design is also fully responsive, so visitors can enjoy the same ease of use whether they are on a desktop, tablet, or other mobile device. *instron.com/en-us.*

Hitachi High-Tech Science Corp., Tokyo, released the FT150 series of **x-ray coating thickness gauges** for measuring plating thickness and composition at micro spots of less than 100 μm in diameter. The improved x-ray detection mechanism achieves a measurement speed twice that of the conventional instrument (FT9500X) to measure the thickness of Au/Pd/Ni/Cu multi-layer plating used in printed circuit boards or connectors. The newly developed polycapillary (an optical element that works like a convex lens to focus x-rays onto a micro spot and is composed of several thousands of glass capillary tubes) allows measurement of electrode plating thickness on extremely small passive components. *hitachi-hitec-science.com/en.*



NEI Corp., Somerset, N.J., introduces Nanomyte SuperAi—an **anti-icing, nanocomposite coating,** which provides a hard, dense, and smooth finish. It can be applied by dip, spray, or brush to a variety of substrates, including plastics, metals, glass, and ceramics. The coating cures at room temperature through exposure to ambient conditions for 6 to 8 hours. Accelerated curing is achieved in 1 hour or less at temperatures in the range of 100°-150°C. *neicorporation.com.*

A **free whitepaper** detailing how new ICP-OES spectrometer technologies are substantially cutting operating costs in environmental, industrial, and academic laboratories is available for download from Spectro Analytical Instruments, Kleve, Germany. *How New Spectrometer Technologies Substantially Cut Operating Costs* explores how engineering innovations have addressed design issues to enable significant savings while improving performance. According to the paper, these innovations cut operating costs by enabling easier, less expensive installation, operation, and maintenance, while improving ICP-OES performance and usability. *icp-oes.spectro.com/blue.*



Morgan Advanced Materials, UK, developed a new capability of **brazing carbon fiber materials** directly to a titanium honeycomb. The technique brings together the best qualities of both components, ensuring the final material is strong, lightweight, and impact- and heat-resistant. Adding the titanium honeycomb to the carbon fiber allows easy joining of the titanium to other structures through traditional techniques. The material is suitable for aerospace applications, especially on lifting surfaces such as wings or flaps, where strength, low weight, and a thin cross-section are important, and the rear sections of engines, where combined high strength and thermal transfer is critical. *morganadvancedmaterials.com.*

Hiden Analytical Ltd., UK, extended their latest **series of SIMS systems** to offer a choice of equipment specification levels to suit a broad range of budget requirements. All systems are UHV compatible and feature a dual-mode Maxim mass spectrometer operating in both the secondary ion mode and the secondary neutral mode for data quantification. The entry level system is supplied with the IG-20 fine-focus (50 μm) oxygen/argon ion gun, multiple sample holder, and primary ion beam monitor. *hidenanalytical.com.*

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STRESS RELIEF

The first method to capture an individual's hair style (left) in a manner suitable for miniaturization and physical reproduction while still preserving the essential visual look of the style (right).

3D-PRINTED PRINCESS HAIR

Researchers at Disney Research Zurich and the University of Zaragoza, Germany, developed a method that can incorporate an individual's hairstyle as well as facial features into miniature figurines. They were inspired by artistic sculptures, such as Michelangelo's David, which reproduce the essence of a hairstyle, but in the solid form of a helmet. In the case of 3D-printed figurines, researchers sought to retain the appearance of directional wisps and the overall flow of hair, as well as color. Beginning with several color images captured of the subject's head, the system first computes a coarse geometry for the surface of the hair. Color information from the images is then added, matching shades as closely as possible. In the next step, color stylization, the level of detail is reduced enough to enable the representation to be miniaturized and reproduced, while preserving the hairstyle's defining features. Finally, geometric details are added in a way that is consistent with the color stylization. *disneyresearch.com/project/stylized-hair-capture.*

WORLD'S LARGEST FLAG MADE OF PENCILS

The General Directorate of Civil Defense achieved a new Guinness World Record by forming the world's largest flag made of pencils. The UAE flag was displayed in the courtyard of the Emirates Palace in Abu Dhabi to celebrate the 43rd UAE National Day.

The previous record was shattered by the construction of a national flag that stretched over 1000 m^2 with one million pencils, using 250,000 for each color. The department received the record holder certificate for the World's Largest National Flag Made of Pencils from Guinness World Records. *guinnessworldrecords.com.*

Abu Dhabi Civil Defense sets a new record with this unusual flag made of colored pencils. Courtesy of Business Wire.

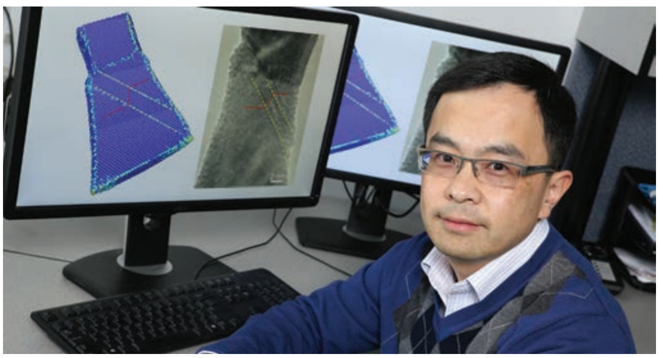
As the first humanoid robot to pay for a seat on a commercial flight, Athena traveled in style, dressed in a white t-shirt and red shoes. Courtesy of MPI for Intelligent Systems, Tübingen.

ROBOT FLIES THE FRIENDLY SKIES

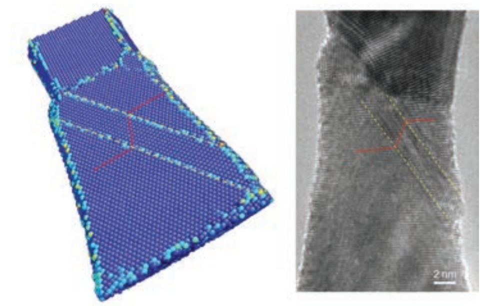
The first robot passenger traveled from Los Angeles to Frankfurt late last year. Despite causing quite a stir when boarding the plane, Athena, dressed in a t-shirt and red shoes, received no special treatment—like most of us, she flew economy class. During the nine-hour flight, the robotic creation was accompanied by scientists from the Max Planck Institute for Intelligent Systems, Germany. Athena made the flight to acquire many new skills: standing, balancing, walking, and various other activities she can use to assist people in daily life. The humanoid robot, measuring 1.88 m in height and weighing only 48 kg, stands on two legs and has feet. She is part of a project aimed at developing truly autonomous robots. *www.is.mpg.de/en.*

SUCCESS ANALYSIS

SPECIMEN: TUNGSTEN NANOCRYSTALS



Ting Zhu of Georgia Tech, worked with colleagues at the University of Pittsburgh and Drexel University to develop a better understanding of a key deformation mechanism in nanoscale tungsten. Courtesy of Candler Hobbs.



The computer model (left) and experimental image (right) reveal atomic-level deformation twinning in a tungsten nanowire under axial compression. The lattice of the deformation-induced twin band (between yellow lines) is a mirror image of that of the parent crystal. Courtesy of Ting Zhu.

VITAL STATISTICS

Researchers at the University of Pittsburgh, Drexel University, and the Georgia Institute of Technology designed a new way to study atomic-scale deformation mechanisms, revealing an interesting phenomenon in tungsten. The group is reportedly the first to observe atomic-level deformation twinning in bcc tungsten nanocrystals. Twinning has been observed in large-scale bcc metals and alloys during deformation. However, whether twinning occurs in bcc nanomaterials was unknown until now.

SUCCESS FACTORS

Observation of atomic-scale twinning was made inside a transmission electron microscope (TEM). This kind of study was previously impossible because TEM imaging requires samples less than 100 nm in size and it is difficult to make bcc samples that small. Graduate student Jiangwei Wang and Professor Scott Mao, both at the University of Pittsburgh, designed a novel way of making bcc tungsten nanowires. Under a TEM, two small pieces of individual nanoscale tungsten crystals were welded together, creating a wire about 20 nm in diameter. This wire was durable enough to stretch and compress while the twinning phenomenon was observed in real-time using a high-resolution TEM.

Next, Christopher Weinberger, an assistant professor at Drexel University, developed computer models that show the mechanical behavior of the tungsten nanostructure at the atomic level. Along with Weinberger's modeling, Ting Zhu, an associate professor at Georgia Tech, conducted advanced computer simulations, using molecular dynamics to study deformation processes in 3D. Zhu's simulation reveals that tungsten's strength behavior is not without problems. "If you reduce the size to the nanometer scale, strength can be increased by several orders or magnitude," says Zhu. "But there is a dramatic decrease in the ductility. We want to increase strength without compromising ductility, so we need to understand the controlling deformation mechanisms."

ABOUT THE INNOVATORS

Scott Mao is a professor in the Swanson School of Engineering at the University of Pittsburgh and Jiangwei Wang is a graduate student. Christopher Weinberger is an assistant professor in Drexel's College of Engineering and Ting Zhu is an associate professor in the Woodruff School of Mechanical Engineering at Georgia Tech.

WHAT'S NEXT

Results should lead to further investigation of deformation mechanisms in nanoscale metals and alloys, ultimately enabling the design of nanostructured materials to fully realize their latent mechanical strength, say researchers.

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