MARCH 2015 | VOL 173 | NO 3

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

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MIXED MATERIALS

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33 *HTPro* NEWSLETTER INCLUDED IN THIS ISSUE

ASM INTERNATIONAL

Precision

Atmosphere

ATLAS®
Ipsen's single-chain ATLAS® is a batch-type, integral-quench furnace. This in-out-style furnace has a load size of 36" x 48" x 38" (W x L x H) and is precisely configured for maximum compatibility with the same push-pull chain loader as the industry standard, allowing it to integrate into existing lines for any brand of atmosphere furnace with ease.*

With one of the largest atmosphere furnace installation bases in the U.S. – several thousand since being founded in 1948 – Ipsen believes a key part of innovating is listening to customers' specific needs and challenges and then providing ideal solutions that meet those needs.

This allows us to tailor our products and services so we can provide our customers with optimum equipment they can trust and rely on for full-scale solutions and precision heat-treating.

ATLAS At-A-Glance:

- Ability to integrate into existing atmosphere furnace lines (any brand)*
- Intelligent controls with predictive process capabilities – Carb-o-Prof®
- Compact footprint
- Ease of maintenance, thanks to a plug-type heat fan assembly, shelf-mounted quench oil heaters and oil circulation pump, safety catwalks and more
- Efficient combustion system, which provides energy and cost savings
- Variable speed quench agitation, allowing users to achieve and maintain better quenching control and uniformity

To find out more about ATLAS, visit www.IpsenUSA.com/ATLAS

Retrofits and Upgrades

Enhancing your furnace's performance and efficiency has never been easier. Ipsen's experienced Retrofit Specialists will work with you to determine your exact needs and quickly deliver the necessary solutions so your older equipment will once again run like new. Our extensive upgrades, retrofits and rebuild packages allow you to reach and maintain proper control and functionality of your equipment, which is paramount to achieving success in thermal processing.

* Compatible with most single-chain, in-out-style atmosphere furnace lines

Versatility

Vacuum

TITAN At-A-Glance:

- Horizontal and vertical models with up to 10,000 lbs. (4,5000 kg) capacity
- Globally certified vessel
- Ability to operate in most languages and meet global industry standards
- Variety of standard processes, including tempering, annealing, hardening, brazing and more
- Quick delivery, installation and startup
- Rent or lease options that allow customers to meet ever-changing production demands
- Easy-to-use, intelligent controls
- Capable of meeting Nadcap and AMS 2750E requirements

TITAN®
Ipsen delivers proven vacuum technology that allows you to achieve maximum flexibility in the form of the TITAN® vacuum furnace – where legacy meets innovation. Endurance testing combined with ongoing user feedback allows the TITAN to remain agile while setting a standard for excellence.

When developing the TITAN, our engineers created a unique, innovative flow-production process that integrates premium components, all developed with the customer in mind. Ipsen's TITAN furnace offers a wide range of sizes, versatility of processes, speed and uniformity, all while maintaining cost-effective pricing, delivery and operation.

The TITAN is a globally certified vessel that fits neatly into a standard truck or shipping container, delivers within weeks, supports 20+ languages and is available with either graphite or all-metal hot zones.

To find out more about TITAN, visit www.IpsenUSA.com/TITAN

Service and Support

Count on Ipsen's responsive Aftermarket Support Team to help keep your equipment running at peak performance and minimize costly downtime. Our global service and support networks offer parts and service for atmosphere and vacuum furnaces, extensive training, preventative maintenance and more.

Find out more about what Ipsen can do for you at www.IpsenUSA.com/Aftermarket-Support.

www.IpsenUSA.com

Ipsen

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MIXED MATERIALS DRIVE LIGHTWEIGHT VEHICLE DESIGN

David Wagner, Matthew Zaluzec, Jeff Conklin, and Tim Skszek

An ambitious automotive concept incorporates mixed materials in all major vehicle systems to achieve an overall weight reduction of 23%.

On The Cover:

A new multi-material lightweight vehicle design demonstrates the potential for lightweighting of a five-passenger sedan while maintaining critical vehicle performance and occupant safety metrics. Courtesy of Ford Motor Co., Detroit. ford.com.

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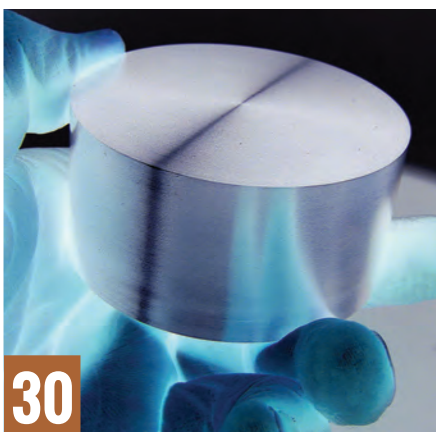
TECHNICAL SPOTLIGHT: TITANIUM POWDER

Eric Bono

Additive manufacturing makes titanium use more feasible.



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METALLURGY LANE TITANIUM: PART 1

Charles R. Simcoe

The only process available for producing titanium was patented by William J. Kroll in 1940, marking the dawn of a new metals industry.

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ASM NEWS

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

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FEATURES

24 MATERIALS RESEARCH FOR ADVANCED POWER ENGINEERING IN EUROPE

John Shingledecker, Amit Shyam, and Bernd Kuhn

From September 15-17, 2014, more than 160 delegates—including researchers from 19 European countries, the U.S., Japan, and India—met in Belgium for the 10th Liège Conference on Materials for Advanced Power Engineering.

33 *HTPro*

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

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JUST SAYING

Do you enjoy sitting around a table with friends or colleagues trying to solve the world's problems? I find it to be one of life's greatest pleasures. Case in point: Just yesterday, a group of us from the ASM Cleveland Chapter enjoyed lunch before helping judge the Northeastern Regional Science Fair at Cleveland State University. The Cleveland Chapter awards $1000 worth of prizes to the best materials-related projects. Our lunch discussion revolved around how to get kids more interested in STEM fields, and how to get younger workers in general more involved in manufacturing.

We had fairly diverse opinions at our table. Some of us had volunteered at different educational programs such as science camps and career days. These folks find it inspiring to work with the kids who seem genuinely interested in science as a potential career. Others had worked with younger people in industrial settings and decried the lack of ambition among this set. Some gave examples of 20-somethings who just couldn't show up to work on time or pass a drug test, or quit after only a few weeks. These weren't minimum wage jobs either. Many positions had starting wages of $20 to $40 per hour. With hundreds of thousands of well-paying manufacturing jobs unfilled and an aging workforce, it's hard to know where the "disconnect" is.

> **"You can lead a horse to water, but you can't make it drink."**
>
> **–English proverb**

Our group had no shortage of theories. Is it the parents' fault for not instilling a love of math and science in the early years? Too many video games and princess toys rather than LEGOs? Perhaps it's the fault of middle school teachers for not making math and science more exciting? In high school, we thought maybe it was the guidance counselors not pushing enough people into vocational training rather than four-year degrees? We talked about some other countries as well, notably Germany and its apprenticeship programs. Not every kid is "college material," but that doesn't mean the less academic types can't earn a good living as an auto mechanic, welder, CNC machine operator, or other such job.

It seems these days that STEM education is all over the news. However, not everyone has the ability or interest to excel in math and science. Schools, teachers, and parents can do everything in their power to promote these fields, and some kids may bite—likely the same kids who would have had a natural inclination toward these fields in the first place. But what about the kids we know who "hate math" or simply aren't good at it, despite the best efforts of the adults around them? I think these kids should also be told there is a place for them in society. Growing up, I remember junior high and high school career days where we were taught that all work has value to society. This seemed like a comforting message at the time and I believe it's worth repeating. If you have thoughts on these matters, we'd like to hear them.

F. Richards

frances.richards@asminternational.org

MARKET SPOTLIGHT

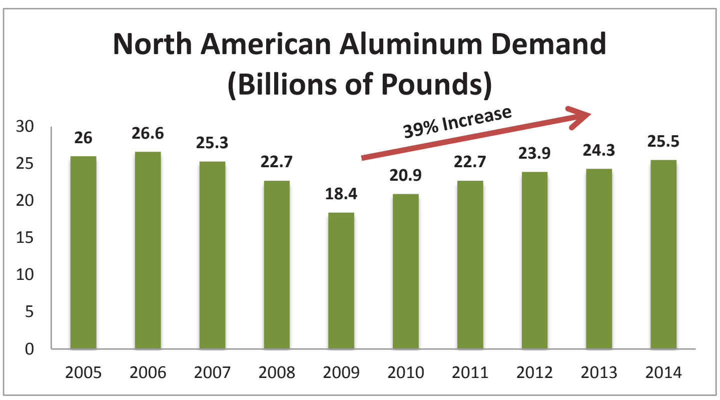
NORTH AMERICAN ALUMINUM INDUSTRY SHOWS SUSTAINED GROWTH

According to preliminary data released in the Aluminum Association's monthly *Situation Report,* the aluminum industry in the U.S. and Canada experienced year-over-year demand growth of 5% through the end of 2014. The estimated 25.5 billion lb of aluminum shipped by North American producers and fabricators last year is the largest shipment total for the industry since 2006, say analysts. Key findings include:

- Apparent aluminum consumption (demand minus exports) in domestic markets totaled 22 billion lb through the end of 2014, a 7.3% increase over 2013.
- Total mill product shipments grew 4.5% in 2014, led by growth in extrusion, foil, and sheet and plate markets.
- New orders of aluminum mill products rose 3.9% in 2014 and were up 3% in January year-over-year.
- Secondary recovery—or recycling—of aluminum is up 4.1% year-to-date through November 2014 (U.S. only).
- Primary aluminum production declined 7.1% in 2014 and was down 4% year-over-year in January.
- Imports of aluminum (excluding U.S./Canada cross-border trade) rose 20.2% in 2014 to 5.5 billion lb, while exports declined 6.8% to 7.4 billion lb.

"Growth in North American demand for aluminum in 2014 is even more impressive given the harsh winter weather the region experienced at the start of the year, and the significant impact it had on operations," says Ryan Olsen, vice president of business information and statistics for the Aluminum Association. "Demand grew just eight-tenths of one percent year-over-year during the first four months of 2014, compared to a year-over-year increase of 7.1% over the final eight months."

According to the latest data, aluminum demand has grown by 38.3% since the depths of the Great Recession in 2009 and continues to expand. Over the past two years, Aluminum Association member companies have announced domestic plant expansions and planned investments totaling more than $2.3 billion. Investments are intended to meet anticipated demand growth for aluminum in the automotive sector as manufacturers strive to make lighter and more fuel-efficient vehicles. The investments announced to date could increase industry auto sheet capacity by more than two billion pounds over the next decade. *For more information, visit aluminum.org/statistics.*



Courtesy of the Aluminum Association.

FEEDBACK

THE JOY OF STAINLESS

I thoroughly enjoyed the recent article on stainless steels ("Metallurgy Lane," January). I am a metallurgist by training and have been asked to prepare a presentation on stainless steels for UTC Aerospace Systems' personnel. I am also interested in any other information, articles, or presentations that the author might be willing to share on the subject.

Robert Bianco, FASM

[*AM&P* supplied an advance copy of "Stainless Steel: Part II" from the February issue for use in Dr. Bianco's presentation.—Eds.]

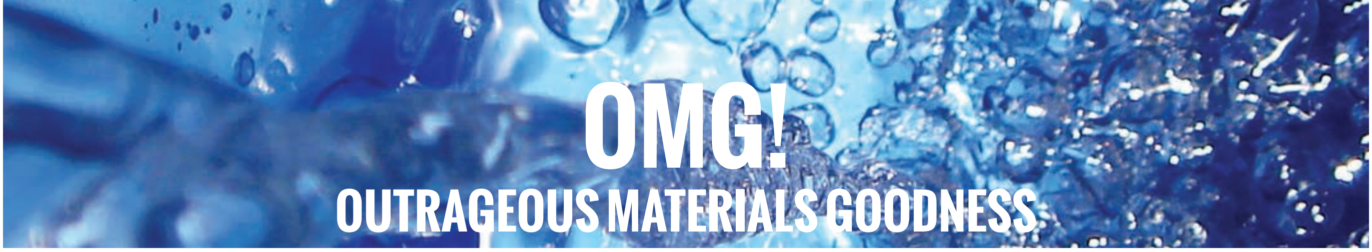
ALUMINUM ALLOYS

I immensely enjoy the "Metallurgy Lane" articles in *AM&P.* I am a student of the history of aluminum, and I live in one of the most important areas for the production of early aluminum products, Manitowoc, Wis. I just wanted to point out what I believe to be an oversight in Part III of the aluminum series, published in Nov/Dec 2014. In this article, the 2000 series is identified as aluminum-magnesium alloys. However, I believe these are conventionally referred to as aluminum-copper alloys.

David Weiss

[Weiss is correct in that the 2000 series is reserved for the Al-Cu alloys, but 2024 must include Mg. I should have said Al-Cu-Mg alloys.—Charles R. Simcoe]

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



OMG!
OUTRAGEOUS MATERIALS GOODNESS

Just a few grains of a newly synthesized material could allow people to stay underwater without scuba tanks.

NEW MATERIAL LETS YOU BREATHE UNDERWATER

Scientists at the University of Southern Denmark created a crystalline material that can pull all the oxygen out of a room and release it when and where it's needed. What some have dubbed the *Aquaman crystal* offers promise for those tethered to bulky equipment. The material uses cobalt bound in an organic molecule. "Cobalt gives the new material precisely the molecular and electronic structure that enables it to absorb oxygen from its surroundings," says professor Christine McKenzie. The material, like a sponge, can absorb oxygen and release it many times over. Once absorbed, the oxygen can be released with a small amount of heat or by exposure to low oxygen pressure, like a vacuum. Researchers are also investigating whether the oxygen release could be triggered by light. *For more information: Christine McKenzie, mckenzie@sdu.dk, www.sdu.dk/en.*

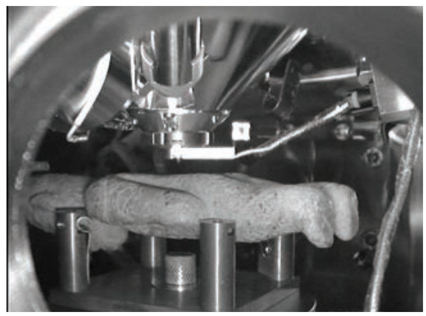
RESTORING RARE DINOSAUR FOSSILS WITH CT SCANNING

A rare dinosaur fossil was restored by an international team of scientists, led by the University of Bristol, UK, using high-resolution x-ray computed tomography (CT scanning) and digital visualization techniques. The team studied the skull of *Erlikosaurus andrewsi,* a 3-4 m (10-13 ft) large herbivorous dinosaur called a therizinosaur, which lived more than 90 million years ago in what is now Mongolia. Using a digital model of the fossil, the skull of *Erlikosaurus* was virtually disassembled into individual elements. Any breaks or cracks in the bones were digitally filled, while missing elements were duplicated and deformation was removed using retrodeformation techniques to digitally reverse the deformation steps. Finally, the reconstructed elements were reassembled. *For more information: Stephan Lautenschlager, glzsl@bristol.ac.uk, www.bris.ac.uk.*

SPECIALIZED SEM HELPS ANALYZE ANCIENT ARTIFACTS

Geologist Timothy Rose of the Smithsonian Institution's Analytical Laboratories, Washington, used his lab's high-tech nanoscale scanning electron microscope (nanoSEM) to analyze hundreds of artifacts from the ancient Olmec, Maya, Teotihuacan, and Mezcala civilizations dating from 1500 B.C. to 600 A.D. "With our modern imaging and analytical tools we can look at objects at very high magnification, which can reveal new details about how, and sometimes when, objects were created," says Rose. "Being able to work in the low-vacuum mode

Reconstruction of the Cretaceous therizinosaur *Erlikosaurus andrewsi* shows original fossil (back), reconstructed digital skull model (middle), and life-reconstruction (front). Courtesy of Stephan Lautenschlager.



A 17-cm carved stone figurine shown inside the SEM chamber ready for nondestructive imaging and analysis. Courtesy of T. Rose/Smithsonian.

allows us to put samples into the microscope au naturel without coating them with an electrically conductive material such as carbon, which would be almost impossible to remove from a specimen." The nanoSEM functions reliably over a range of pressures. *For more information: Timothy Rose, roset@si.edu, mnh.si.edu/rc/lab.*

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.

Header image: Courtesy of Marlon Felippe.

METALS | POLYMERS | CERAMICS

Samples of some colors produced in electrochromic polymers. The materials can be used for applications such as sunglasses and window tinting that can be turned on and off through the application of an electrical potential. Courtesy of Rob Felt.

ELECTROCHROMIC POLYMERS CREATE A RAINBOW OF COLOR

Researchers created a broad color palette of electrochromic polymers, materials that can be used for sunglasses, window tinting, and other applications that rely on electrical current to produce color changes. Supported by BASF, Germany, the research was conducted in the laboratory of John Reynolds, a professor at the Georgia Institute of Technology, Atlanta. "We've demonstrated the ability to create virtually any color we want by mixing different electrochromic polymers, just like mixing paint," says Reynolds. "Using a simple coating method or even inkjet printing, we can create films that change color with the application of a voltage."

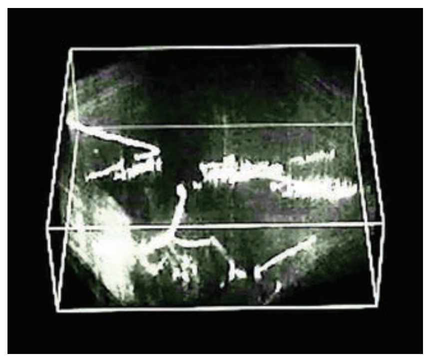
The electrochromic materials rely on a reduction-oxidation reaction triggered by the application of an electrical potential provided by a simple coin battery—a positive one volt causes the glasses to be clear, while a minus one volt switches to the color. "Essentially, we are just charging and discharging the device, which is what causes the color change," Reynolds explains. *For more information: John Reynolds, reynolds@chemistry.gatech.edu, www.gatech.edu.*

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, RESEARCHERS FIGURED OUT EXACTLY WHICH CHARACTERISTICS OF A METAL STRUCTURE TEND TO FOSTER EMBRITTLEMENT IN OIL WELL TUBES LINED WITH METAL IN THE PRESENCE OF HYDROGEN. THEY ALSO DETERMINED THAT SIMPLE CHANGES IN PROCESSING CAN MODIFY THE STRUCTURE IN A WAY THAT MAY GREATLY REDUCE THE CHANCES OF DAMAGE, EXTENDING THE SAFE OPERATING LIFETIME. *web.mit.edu*.

UNCOVERING OXYGEN'S EFFECT ON TITANIUM

University of California, Berkeley, scientists found the mechanism by which titanium becomes brittle with just a few extra atoms of oxygen. This discovery has the potential to open the door to more practical, cost-effective use of titanium in a broader range of applications.

Andrew Minor, associate professor of materials science and engineering, led a research team focused on solving the long-standing metallurgical mystery of how oxygen causes such a profound change in the characteristics of metals. Researchers subjected various grades of titanium samples to nanocompression



A cross-section of grade 3 titanium (containing 0.3% oxygen) placed under stress and deformed. Defects are evident. Oxygen impurities force the defects to spread onto different planes of the material. Courtesy of Qian Yu.

BRIEFS

Blueshift International Materials Inc., San Antonio, introduced a commercially available polyimide aerogel, which combines the physical and toughness properties of plastic films with the insulation properties of aerogels to create a strong yet lightweight, thin, clean, and flexible insulator. The product's 100% polyimide polymer construction eliminates dusting as well as dangerous handling protocols. *blueshift-materials.com.*

tests and examined the results using advanced TEM techniques and quantum mechanical predictions of defect structures. They found that the interactions between oxygen and the crystalline defects, known as dislocations, that are characteristic of titanium were key to how the material hardened.

Oxygen atoms act like bumps in the road for the corkscrew-shaped dislocations found in titanium. "The mechanical shuffling that occurs as dislocations pop up and over those atomic bumps creates a domino effect of more dislocations," says Minor. With increased oxygen, titanium becomes more difficult to bend and therefore more susceptible to cracking. *For more information: Andrew Minor, 510.495.2749, aminor@berkeley.edu, www.berkeley.edu.*

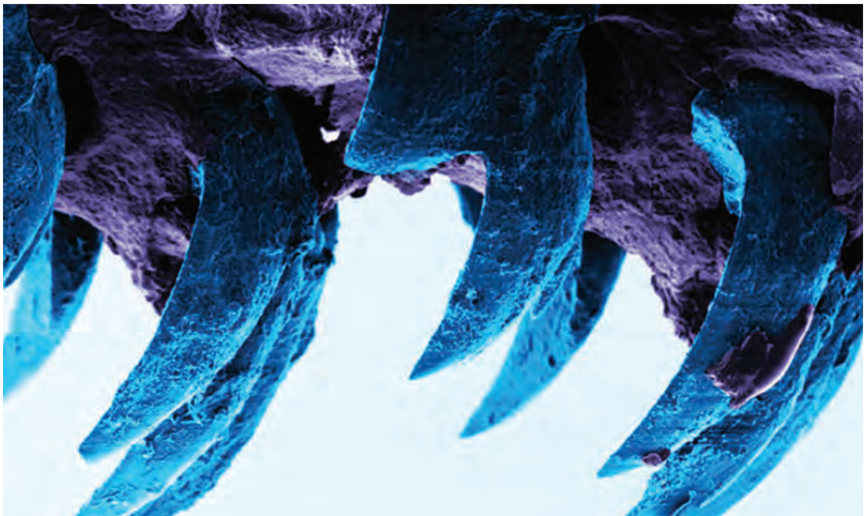
RECIPE FOR LIGHTER, STRONGER STEEL

A recipe for lighter, stronger steel adds nickel to an alloy of iron, carbon, aluminum, and manganese. Courtesy of Imaginechina/Corbis.

Scientists at Pohang University of Science and Technology, South Korea, are improving lightweight steel by altering how metal compounds are arrayed in an alloy. The microstructure of their material is even stronger and more pliable than titanium alloys.

One possible structure in steel is B2—a hard, brittle cube formation. Iron and aluminum tend to form B2 structures in steel alloys, but scientists usually try to prevent this by adjusting the temperature or adding other elements. Researchers made a steel that takes advantage of both B2's hardness and austenite's ductility. By adding nickel and temperature-treating an alloy of iron, aluminum, manganese, and carbon, they induced smatterings of B2 to form evenly throughout the steel. The resulting material, in which the hard B2 lattices reinforce the supple austenite matrix, has impressive tensile strength. *www.postech.ac.kr*.

TESTING | CHARACTERIZATION



SEM image of limpet teeth. Courtesy of University of Portsmouth.

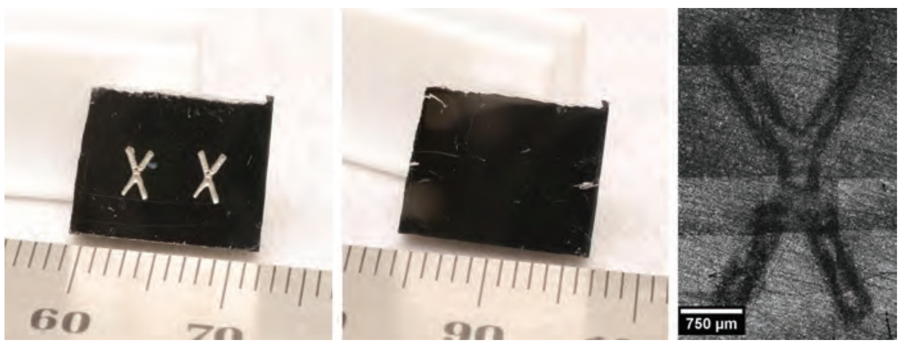
LIMPET TEETH OUTSHINE SPIDER SILK

A new study finds that limpet teeth may be the strongest natural material ever discovered. Researchers from the University of Portsmouth, UK, found that limpets—small aquatic snail-like creatures with conical shells—have teeth with biological structures so strong they could be copied to make future automotive and aerospace parts. The study examined the small-scale mechanical behavior of limpet teeth using atomic force microscopy. Professor Asa Barber led the study. His team found that the teeth contain a hard mineral known as *goethite,* which forms in the limpet as it grows, and also discovered that limpet teeth are the same strength regardless of size.

"Until now we thought that spider silk was the strongest biological material, but now we have discovered that limpet teeth exhibit a strength that is potentially higher," says Barber. "This means that the fibrous structures found in limpet teeth could be mimicked and used in high-performance engineering applications such as Formula 1 racing cars, the hulls of boats, and aircraft structures." *www.port.ac.uk.*

USING EBSD TO DETECT LOST SERIAL NUMBERS

Researchers at the National Institute of Standards and Technology (NIST), Gaithersburg, Md., demonstrated a technique for mapping deformation in metals that can recover destroyed serial numbers on metal objects such as firearms. Analysts typically try to restore the numbers with acid or electrolytic etching or polishing, because deformed areas behave differently from undamaged material. But these methods don't always work.



In an experiment to recover destroyed serial numbers, NIST researchers hand-stamped X imprints into stainless steel (left) to simulate a firearm serial number. Then they polished away the imprints (middle, mm scale bar). The imprints were recovered (right) by combining pattern quality maps, calculated by software, which reveal crystal damage and deformation in the steel. Courtesy of White/NIST.

Winners of the 2013 Zwick Science Award.

BRIEFS

Testing equipment manufacturer **Zwick/Roell,** Germany, will hold its 6th annual **Zwick Academia Day** on June 2 at **ETH** in Zurich. The event will include workshops and lectures from leading materials experts. Winners of the annual Zwick Science Award and Paul Roell Medal also will be announced. More than 100 papers from 15 countries entered the competition. *zwick.com.*

As an alternative, NIST researchers used electron backscatter diffraction (EBSD) to read, in the crystal structure pattern, imprints on steel that had been removed by polishing. The more perfect the crystal structure, the stronger and clearer the pattern. Software can then calculate the pattern quality to reveal crystal damage; areas with more damage produce lower quality patterns.

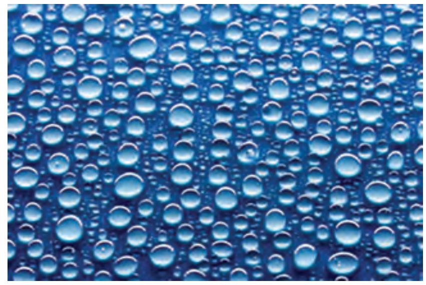
Ordinary SEM imaging methods reveal very faint outlines of the X stamps in the metal grains, whereas pattern quality mapping shows the outlines more clearly. The latter technique is significantly more sensitive to small amounts of crystal lattice damage. While the method is still experimental, it holds a lot of promise, say researchers. *nist.gov.*

CHARACTERIZING SUPERHYDROPHOBICITY

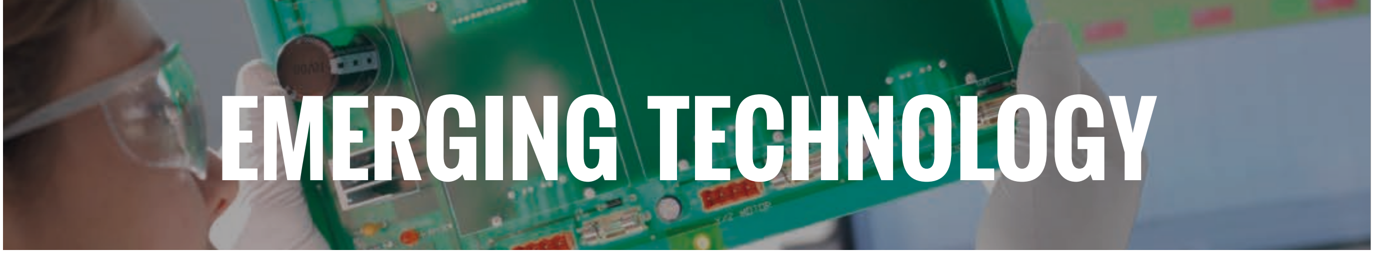
Scientists recently discovered that inherently water repellent surfaces can be made superhydrophobic by patterning them with micro or nanoscale structures. On such surfaces, water droplets can be either suspended across neighboring protrusions or impaled between them. The transition between these two states as well as the effect of microstructures on vapor condensation have been investigated, but few computational studies have explored how droplets initially form by condensation from vapor.

Now, Weiqing Ren of the A*STAR Institute of High Performance Computing, Singapore, and Yunzhi Li of the National University of Singapore have systematically analyzed how micropillars on a hydrophobic surface affect the condensation of water vapor. They used a powerful computational technique known as the string method, which Ren developed in a previous study.

Ren and Li used this technique to investigate the effect of parameters such as the height and spacing of micropillars and the supersaturation and intrinsic wettability of the surface on the condensation process. They discovered that both the pathway and configuration of the initial nucleus from which droplets form—the *critical nucleus*—depend on the geometry of the surface patterns. In particular, they found that for tall, closely spaced pillars on a surface with low supersaturation and low wettability, the critical nucleus prefers the suspended state, whereas for the opposite case it prefers the impaled state. By generating a phase diagram, critical values of the geometrical parameters at which the configuration of the critical nucleus changes from the suspended state to the impaled state can be determined. *www.ihpc.a-star.edu.sg.*



Superhydrophobic surfaces hold promise for industrial applications as well as self-cleaning, defrosting, and anti-icing surfaces. Courtesy of Yurok Aleksandrovich/iStock/Thinkstock.



EMERGING TECHNOLOGY

An MRSEC team from Harvard examined the formation of biofilms in *B. subtilis,* a type of rod-shaped bacteria often found in soil, which can cause agricultural damage and corrosion. Courtesy of Hera Vlamakis, Harvard University Medical School.

NSF AWARDS $56 MILLION FOR MATERIALS RESEARCH

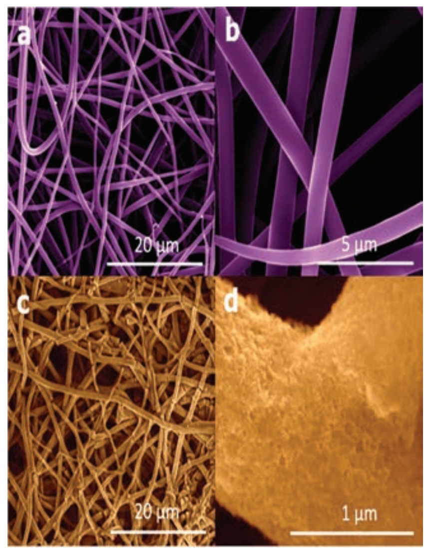
In February, the National Science Foundation (NSF) announced awards worth $56 million in funding for 12 Materials Research Science and Engineering Centers (MRSECs). NSF's newest MRSEC at Columbia University will have two interdisciplinary research groups (IRGs) attempting to build higher dimensional materials from lower dimensional structures with unprecedented control. One of the groups will study how 2D materials interact to create novel geometries and structures for potential use in electronic devices. The other group will work on establishing a new type of periodic table by using molecular clusters to assemble materials with exceptional electronic and magnetic properties. Columbia will lead the MRSEC and partner with City College of New York, Harvard University, Barnard College, the University of the Virgin Islands, Brookhaven National Laboratory, IBM, and DuPont. The partners will work together to develop educational outreach activities for nearby K-12 schools.

The other 11 awards, made to existing MRSECs, also represent cutting-edge materials science and engineering, and in most cases, the centers will take on new materials research and focus on education. Awardees include Brandeis University, University of Chicago, University of Colorado at Boulder, Harvard University, University of Minnesota, Massachusetts Institute of Technology, University of Nebraska, New York University, The Ohio State University, Penn State University, and Princeton University. *mrsec.org.*

SILICON NANOFIBERS BOOST BATTERY PERFORMANCE

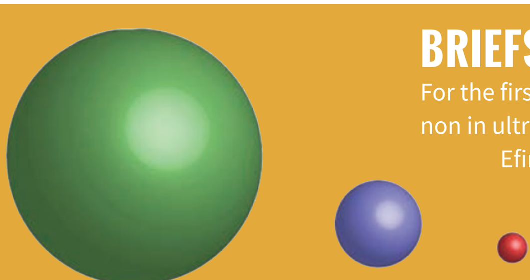
Researchers at the University of California, Riverside's Bourns College of Engineering developed a novel paper-like material for lithium-ion batteries that could boost performance several times over. The material, composed of spongey silicon nanofibers more than 100 times thinner than human hair, could be used in batteries for electric vehicles and personal electronics. Nanofibers were produced using electrospinning, where up to 40,000 V is applied between a rotating drum and nozzle that emits a solution composed mainly of tetraethyl orthosilicate.

The nanofibers are then exposed to magnesium vapor to produce the spongelike silicon fiber structure. This technology also solves a problem that has plagued freestanding, or binderless, electrodes for years—scalability. Freestanding materials grown using chemical vapor deposition, such as carbon nanotubes or silicon nanowires, can only be produced in very small quantities (micrograms). However, the team was able to manufacture several grams of silicon nanofibers at a time, even at the lab scale. *For more information: Mihri Ozkan, 951.827.2900, mihri@ece.ucr.edu, www.ece.ucr.edu.*



Scanning electron microscope images of (a) SiO_2 nanofibers after drying, (b) SiO_2 nanofibers under high magnification, (c) silicon nanofibers after etching, and (d) silicon nanofibers under high magnification. Courtesy of UC Riverside.

BRIEFS



For the first time, **University of Chicago** scientists experimentally observed a phenomenon in ultracold, three-atom molecules predicted by Russian theoretical physicist Vitaly Efimov in 1970. In this quantum state, called geometric scaling, the triatomic molecules fit inside one another like an infinitely large set of Russian nesting dolls. The illustration shows the sizes of the triatomic, lithium-cesium molecules at a fraction of a degree above absolute zero. *uchicago.edu.* Courtesy of Shih-Kuang Tung/Cheng Chin.

PROCESS TECHNOLOGY

A new two-step process makes recycling rare-earth metals easier and more cost effective. Here, magnesium is melted with magnet scrap in an induction furnace. Courtesy of DOE's Ames Laboratory.

NEW RECOVERY PROCESS IMPROVES RARE EARTH RECYCLING

Scientists at the DOE's Critical Materials Institute (CMI), Ames, Iowa, developed a two-step recovery process that makes recycling rare-earth metals easier and more cost effective. Building upon previous research work done at the Ames Laboratory, CMI scientist Ryan Ott and his team developed a two-stage liquid metal extraction process that uses differences between the solubility properties of various elements to separate out rare-earth metals.

"Magnesium has good solubility with rare earths, particularly with neodymium, and poor solubility with the other components of magnets, like iron and boron," says Ott.

In the new method, scrap metals are melted with magnesium—lighter atomic weight rare earths like neodymium bind with the magnesium and leave the iron scrap and other materials behind. The rare earths are then recovered from the magnesium through vacuum distillation. In the second step, another material is used to bind with and extract the heavier atomic weight rare earths, like dysprosium. *For more information: Craig Forney, 515.294.9513, ceforney@iastate.edu.*

Orbital ATK is starting production of advanced composite primary structures for the 787 Dreamliner. Courtesy of Boeing.

ADVANCED COMPOSITES SUPPORT DREAMLINER

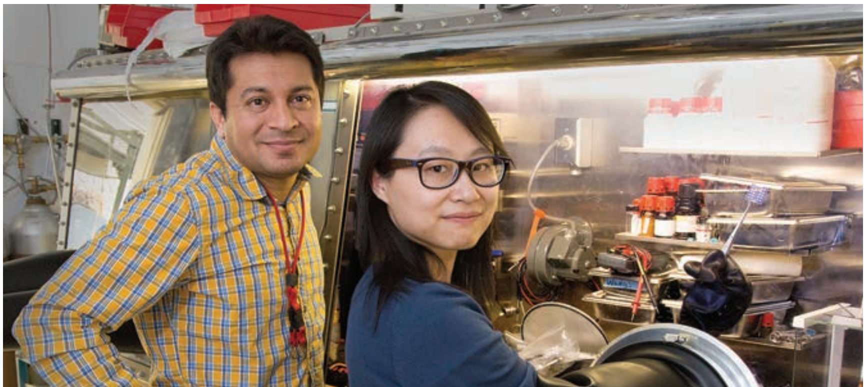
Orbital ATK Inc., Dulles, Va., is now manufacturing advanced composite primary structures for The Boeing Co.'s 787 Dreamliner in the Orbital ATK Freeport Composites Center in Clearfield, Utah. The company is starting production of composite frames for the Boeing 787-9 center and aft fuselages, and will support identical structures on the 787-10 variant currently in development. Orbital will begin shipping components in the first half of 2015 and will reach full production rates in 2018. *orbitalatk.com.*

AK STEEL, WEST CHESTER, OHIO, WILL BUILD A 120,000-SQ-FT, $36 MILLION RESEARCH AND INNOVATION CENTER IN MIDDLETOWN, OHIO. THE NEW FACILITY WILL HOUSE PILOT LINES THAT SIMULATE THE COMPANY'S STEEL MANUFACTURING OPERATIONS FOR USE IN RESEARCH, PROBLEM SOLVING, AND NEW PRODUCT DEVELOPMENT. *aksteel.com.*

BRIEFS

Lockheed Martin, Bethesda, Md., won three 2015 Manufacturing Leadership Awards for achievements in engineering and production technology from **Frost & Sullivan.** Lockheed Martin's Applied Additive Tooling Technologies Project led to more than 5000 additively manufactured tools and shop aids on the F-35 program as a lower cost, lightweight alternative to metallic and hand-laid fiberglass tooling traditionally used in aircraft production. *lockheedmartin.com.*

ENERGY TRENDS



Scientists Aditya Mohite, left, and Wanyi Nie are perfecting a crystal production technique to improve perovskite crystal production for solar cells at Los Alamos National Laboratory.

PEROVSKITE SOLAR CELLS CLOSER TO REALITY

Researchers at DOE's Los Alamos National Laboratory, N.M., fabricated planar solar cells from perovskite materials with large crystalline grains that had efficiencies approaching 18%, among the highest reported in the field of perovskite-based light-to-energy conversion devices. The cells demonstrate little cell-to-cell variability, resulting in devices showing a hysteresis-free photovoltaic response, which had been a fundamental bottleneck for stable operation of perovskite devices. "Characterization and modeling attribute the improved performance to reduced bulk defects and improved charge-carrier mobility in large-grain perovskite materials," says Aditya Mohite, lead scientist, "and we've demonstrated that the crystalline quality is on par with that observed for high-quality semiconductors like silicon and gallium arsenides." *For more information: Aditya Mohite, amohite@lanl.gov, www.lanl.gov.*

BUILDING BETTER CAR BATTERIES

Smaller, lighter electric car batteries that don't have to sacrifice longevity to be petite could be one benefit of basic research into lithium-ion battery nanomaterials at The University of Alabama in Huntsville. A $502,000 National Science Foundation Faculty Early Career Development Program grant is funding research into nanomaterial cathodes for the batteries by George Nelson, assistant professor of mechanical and aerospace engineering. Nanomaterials may make the trade-off between high battery power and smaller size a more favorable one over the wide temperature variations experienced by cars and other devices.

Traditionally, cathodes are made of larger materials on the micron scale that fit together more loosely than smaller nanomaterials. Nanomaterials have much greater surface area for the chemical interactions that create electric current, resulting in more power for their size. However, that can be a drawback when it comes to lifespan over a wide temperature range.

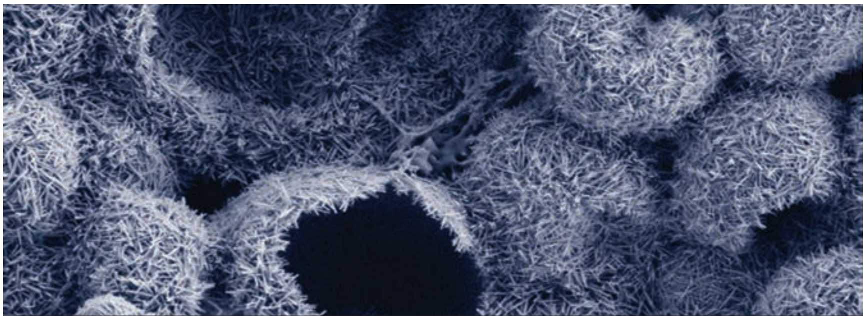
"We suspect that increased temperature will shorten battery life for these materials, more so than traditional materials," says Nelson. Therefore, researchers are charging and discharging batteries made with different cathode compositions at various temperatures and using x-ray nanotomography to observe changes in the cathode structure to help determine which higher-power nanomaterial has the longest lifespan. *For more information: George Nelson, george.nelson@uah.edu, www.uah.edu.*

Batteries made with different cathode compositions are being charged and discharged at various temperatures using x-ray nanotomography to help determine which nanomaterials have the longest lifespan.

BRIEFS

The Global Climate and Energy Project (GCEP) at **Stanford University,** Calif., awarded $10.5 million for seven research projects designed to advance a broad range of renewable energy technologies. The funding will be shared by six Stanford research teams and an international group from the U.S. and Europe. These new awards bring the total number of GCEP-supported programs to 117 since the project's launch in 2002. GCEP has awarded $161 million to researchers at Stanford and 40 other institutions worldwide. *gcep.stanford.edu.*

SURFACE ENGINEERING

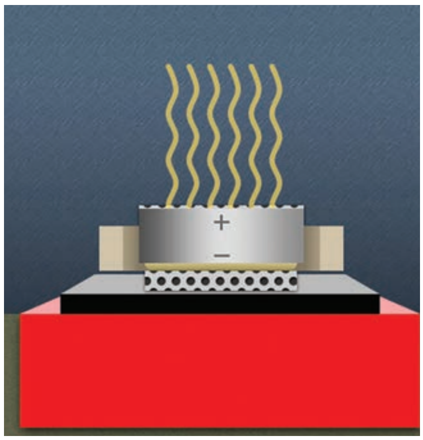


Hollow spheres of aluminum oxide are filled with gas and manufactured economically. Courtesy of Fraunhofer ICT.

COATINGS HELP TURBINES HANDLE THE HEAT

Scientists at the Fraunhofer Institute for Chemical Technology ICT, Germany, developed a coating technique to protect turbine engine and waste incinerator components against heat and oxidation. A topcoat from micro-scaled hollow aluminum oxide spheres provides heat insulation and has already proven more economical than conventional techniques in the lab.

The basic coating layer forms during interaction of aluminum particles and the metallic component. Aluminum powder is deposited on the surface of the metal and is heated to a suitable temperature over several hours. The result is an aluminum-rich coating on the component's surface that protects against oxidation at high temperatures. With the new procedure, the topcoat from the hollow aluminum oxide spheres is formed as well. *www.ict.fraunhofer.de/en.html.*



This coated battery still conducts electricity when compressed, but not if accidentally ingested.

COMPOSITE COATING MAKES BATTERIES SAFER

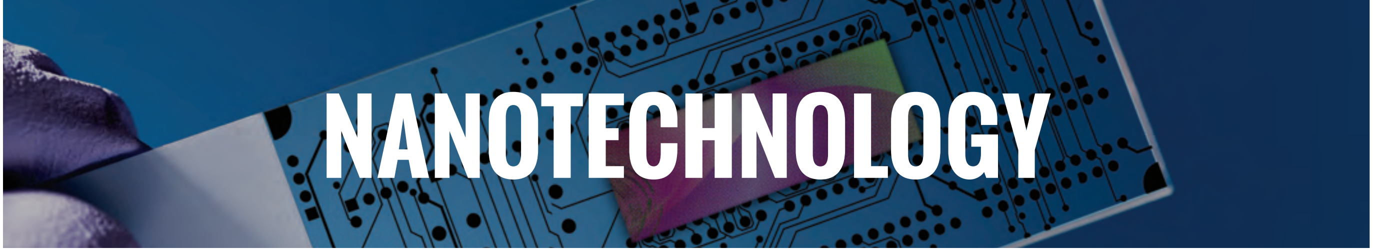
Every year, nearly 4000 children go to emergency rooms after swallowing button batteries—the flat, round batteries that power toys, calculators, and many other devices. Ingesting these batteries has severe consequences, including burns that permanently damage the esophagus, tears in the digestive tract, and in some cases, even death. To help prevent such injuries, researchers at Massachusetts Institute of Technology, Cambridge, Brigham and Women's Hospital, and Massachusetts General Hospital devised a new way to coat batteries with a special material that prevents them from conducting electricity after being swallowed. In animal tests, they found that such batteries did not damage the gastrointestinal (GI) tract.

Researchers coated the batteries with a material that would allow them to conduct when under pressure, but would act as an insulator when the batteries are not being compressed. Quantum tunneling composite (QTC), an off-the-shelf material commonly used in computer keyboards and touchscreens, fit the bill perfectly. QTC is a rubber-like material, usually made of silicone, embedded with metal particles. Under normal circumstances, these particles are too far apart to conduct an electric current. However, when squeezed, the particles come closer together and start conducting. This allows QTC to switch from an insulator to a conductor, depending on the applied pressure. Because QTC is relatively inexpensive and already used in other consumer products, researchers believe battery companies could easily implement this type of coating. *web.mit.edu.*

HARDIDE COATINGS LTD., UK, INCREASED ITS INSTALLED CAPACITY BY NEARLY 50% TO COPE WITH GROWING DEMAND FOR NANOSTRUCTURED TUNGSTEN CARBIDE COATINGS. *hardide.com.*

BRIEFS

Picosun Oy, Finland, created a new atomic layer deposition (ALD) process for copper and niobium oxide. The low-temperature (<150°C) processes for niobium oxide and copper are made possible by the second generation of the Picohot 300 source system, which allows even lower vaporization temperatures and efficient, uniform distribution of the precursor vapor in the reaction chamber even at low substrate temperatures. *picosun.com/en/home*.



NANOTECHNOLOGY

Treated carbon-60 molecules can recover valuable metals from liquids, including water and potential pollutants. In testing various metals, charge and ionic radius were found to influence how metals bind to hydroxylated buckyballs. Courtesy of Jeff Fitlow/Rice University.

BUCKYBALLS BIND TO METAL

Andrew Barron, Rice University, Houston, discovered that carbon-60 fullerenes (buckyballs) that have undergone hydroxylation can aggregate into pearl-like strings as they bind to and separate metals from solutions. Barron says treated buckyballs handle metals with different charges in unexpected ways, which could make it possible to pull specific metals from complex fluids while ignoring others.

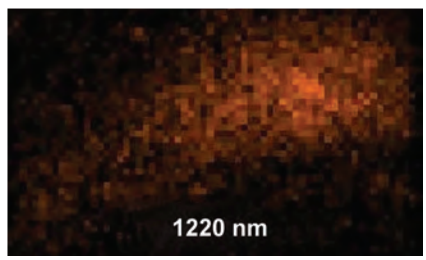
A series of experiments explored the relative binding ability of fullerenols to a range of metals. Fullerenols combine with a dozen metals, turning them into solid cross-linked polymers. In order of effectiveness, these include zinc, cobalt, manganese, nickel, lanthanum, neodymium, cadmium, copper, silver, calcium, iron, and aluminum. Barron says fullerenols act as chelate agents, which determine how ions and molecules bind with metal ions. *For more information: Andrew Barron, arb@rice.edu, barron.rice.edu.*

GRAPHENE 3D LAB INC., CALVERTON, N.Y., COMMISSIONED AN INDUSTRIAL SCALE THERMOPLASTIC EXTRUDER LINE TO BE USED IN THE PRODUCTION OF CONDUCTIVE GRAPHENE FILAMENT. THE NEW EQUIPMENT CAN PRODUCE 10 KG PER HOUR OF 3D PRINTER FILAMENT. *graphene3dlab.com.*

PREDICTING PROPERTIES OF METAMATERIALS

Scientists with the DOE's Lawrence Berkeley National Laboratory, Calif., and the University of California, Berkeley show that it is possible to predict the nonlinear optical properties of metamaterials. Confocal microscopy was used to observe the second harmonic generation from metamaterial arrays whose geometry was gradually shifted from a symmetric bar-shape to an asymmetric U-shape. Second harmonic light is a nonlinear optical property in which photons with the same frequency interact with a nonlinear material to produce new photons at twice the energy and half the wavelength of the originals.

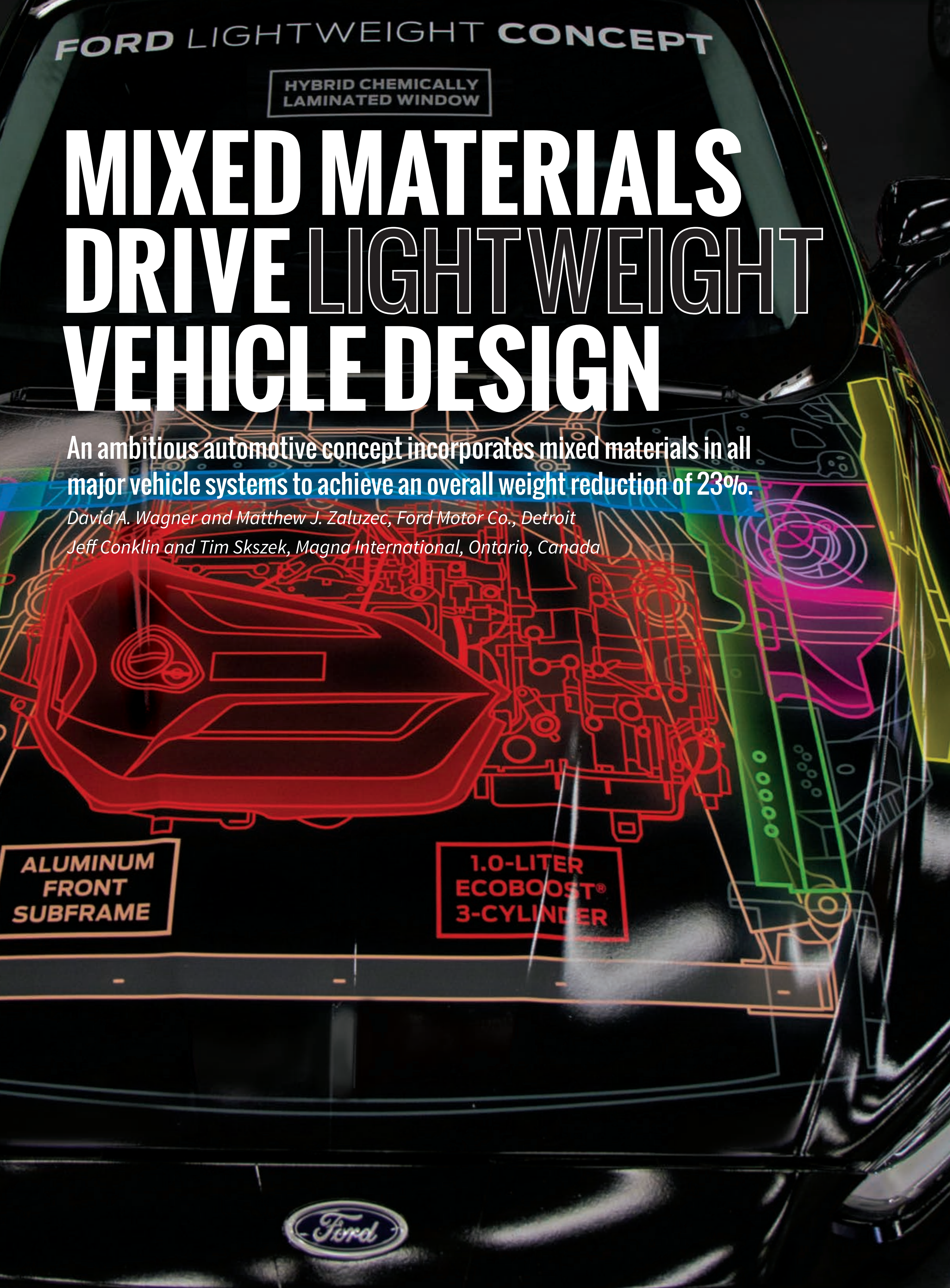
"Our results show that nonlinear scattering theory can be a valuable tool in the design of nonlinear metamaterials not only for second-order, but also higher order, nonlinear optical responses over a broad range of wavelengths," says Xiang Zhang, director of Berkeley Lab's Materials Sciences Division. "We're now using these experimental and theoretical techniques to explore other nonlinear processes in metamaterials, such as parametric amplification and entangled photon generation." *For more information: Xiang Zhang, xzhang@me.berkeley.edu, lbl.gov.*



Confocal microscopy confirms that the nonlinear optical properties of metamaterials can be predicted using a theory about light passing through nanostructures.

BRIEFS

Graphene Energy Storage Devices Corp. signed a research agreement with the Research Foundation of **Stony Brook University (SBU),** N.Y, to develop new supercapacitor designs for energy storage. The goal is to develop low-cost, integrated ultra-high voltage supercapacitor units using a high-rate reel-to-reel process. SBU will design the electrode and electrolyte formulation, while the Graphene ESD team will work on device assembly and testing. *graphene-esd.com, stonybrook.edu.*



MIXED MATERIALS DRIVE LIGHTWEIGHT VEHICLE DESIGN

An ambitious automotive concept incorporates mixed materials in all major vehicle systems to achieve an overall weight reduction of 23%.

David A. Wagner and Matthew J. Zaluzec, Ford Motor Co., Detroit
Jeff Conklin and Tim Skszek, Magna International, Ontario, Canada

A new multi-material lightweight vehicle (MMLV) design demonstrates the potential for lightweighting of a five-passenger sedan while maintaining critical vehicle performance and occupant safety metrics. The design incorporates commercially available materials and production processes, achieving a 364 kg (23.5%) full vehicle mass reduction compared to the 2013 Fusion baseline. In turn, this weight savings enables use of a 1.0-liter three-cylinder engine, significantly improving fuel economy and reducing CO_2 emissions. This article explores the vehicle design and material usage details, system by system.

Over the past 20 years, numerous studies have investigated the impact of mass reduction on vehicle fuel efficiency. Generally, a 10% reduction in vehicle mass improves fuel efficiency by approximately 3-4%. However, when mass decompounding is applied, i.e., the opportunity to further reduce powertrain and chassis system weight, a 6-7% improvement in fuel economy can be realized while maintaining vehicle performance. The 364 kg weight reduction from the baseline 2013 Fusion results from redesigning and lightweighting five vehicle systems including the body and closures, interior, chassis, powertrain, and electrical components.

Table 1 describes weight reductions according to the major systems within each vehicle subsystem. The MMLV project allows functional and drivable vehicles to participate in selected performance tests. Durability, crash, corrosion, and NVH (noise, vibration, and harshness) tests enable the design team to ensure that the weight-reduced vehicle meets specified requirements.

Magna International led design efforts on the body-in-white, closures and bumper structures, subframes and control arms. Ford designed the powertrain, select chassis components, interiors, electrical, and all other systems. Referencing the 2013 Fusion, Magna was responsible for the lightweight design of components and systems weighing approximately one-third of the 1559 kg curb weight. The Ford team was responsible for the lightweight design of components and systems weighing approximately two-thirds of the 2013 Fusion curb weight.

TABLE 1–MMLV DESIGN WEIGHT DISTRIBUTION BY VEHICLE SUBSYSTEM

Subsystem description, kg	2013 Fusion	MMLV Mach-I design
Body exterior and closures	**594**	**456**
Body-in-white	326	250
Closures-in-white	98	69
Bumpers	37	25
Glazings – fixed and movable glass	37	25
Misc. – trim, mechanisms, paint, seals, etc.	96	87
Body interior and climate control	**207**	**161**
Seating	70	42
Instrument panel	22	14
Climate control	27	25
Misc. – trim, restraints, console, etc.	88	80
Chassis	**350**	**253**
Front and rear suspension	96	81
Subframes	57	30
Wheels and tires	103	64
Brakes	61	49
Misc. – steering, jack, etc.	33	29
Powertrain	**340**	**267**
Engine (dressed)	101	71
Transmission and driveline	106	92
Misc. – fuel, cooling, mounts, etc.	133	104
Electrical	**69**	**59**
Wiring	28	25
Battery	14	8
Misc. – alternator, starter, speakers, etc.	27	26
Total vehicle weight	**1560**	**1196**

Weight saved compared to 2013 Fusion = 23.3%.

BODY EXTERIOR AND CLOSURES

The body-in-white and closures-in-white account for 424 kg of the 594 kg in the 2013 Fusion. Magna designed the body-in-white with all three forms of aluminum: sheet, extrusion, and castings. Advanced high-strength steel sheet was used for the primary safety structures such as crush rails, b-pillars, and selected cross car beams. The resulting design weighs 250 kg—a savings of 76 kg (23%). Figure 1 shows the body structure with material distribution.

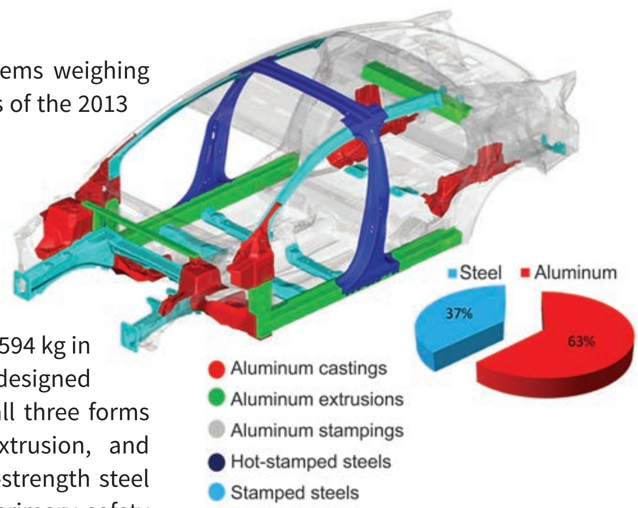


Fig. 1 — MMLV design body-in-white mixed aluminum and steel.

The new MMLV design includes extruded aluminum bumper and crush cans at 11.1 kg (6.2 kg front and 4.9 kg rear)—a savings of 9.3 kg (46%) from the prior bumper structures. The fascia systems for the design also include chemically foamed plastic covers, which shave 2.1 kg (13%) from the previous fascia systems.

The side doors, fenders, and deck lid are primarily made of aluminum with boron steel intrusion beams and a cast magnesium sail (mirror mount) part on the front doors. The Fusion hood is already made of aluminum, so only a small amount of weight is saved using the aluminum hinges and latch housing. The closure-in-white design (69 kg) reduces 29 kg (30%) from the 2013 Fusion weight. The front door-in-white, which includes a magnesium sail casting, an extruded and machined aluminum hinge pillar reinforcement, stamped aluminum, stamped steel, and a boron intrusion beam weighs 10.7 kg, which equals a 35% reduction (5.9 kg). Figure 2 illustrates the material distribution for the side doors.

Door designs also include cast aluminum hinges, tape-on secondary dynamic seals, and lightweight glazing. Laminated hybrid glazing reduces the movable glazing from 13.8 kg (4.3 kg front and 2.6 kg rear) by 4.7 kg (34%). The door glazing is made up of a 1.8-mm layer of tempered (soda lime) glass and a 0.8 mm acoustic PVB (polyvinyl butyral) layer strengthened with a 0.7 mm chemically toughened glass layer (Corning Gorilla Glass). Side door glazings use a chemically toughened glass layer located on the exterior side with tempered glass on the inside surface.

The fixed glazing includes a laminated hybrid windscreen with a weight of 9.1 kg—a 36% (5.1 kg) weight savings from the prior Fusion windscreen with an additional 4.5-mm-thick polycarbonate backlite that weighs just 5.9 kg—a 27% savings. The layered laminate on the windshield is the same composition as the side door glazing, but the chemically toughened glass layer is on the interior. An additional 2.2 kg (15%) reduction from the functional and black trim, enabled by using chemically foamed plastics and 0.4 kg (~20%) in each of four window regulators, increases the overall weight savings.

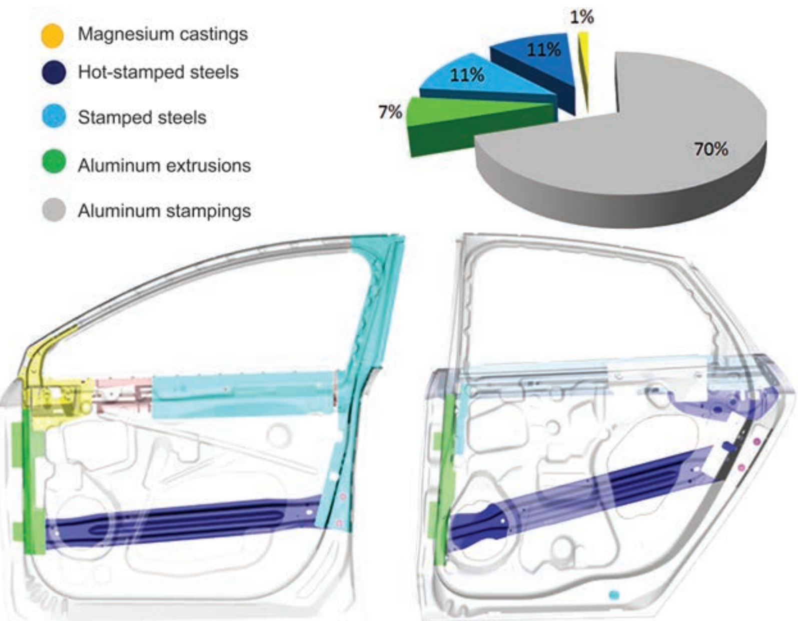


Fig. 2 — MMLV design door-in-white materials.

BODY INTERIOR AND CLIMATE CONTROL

The greatest savings in the body interior and climate control systems come from the seats and instrument panel. Of the 45 kg saved in this system, 36 kg comes from carbon fiber composite use in structural portions of the seats and instrument panel. The additional 9 kg of weight savings are made possible through use of chemically foamed plastics for interior trim that eliminate the dual control mode in the HVAC system. These chemically foamed plastics are created using catalysts introduced during the injection mold process, under controlled conditions that result in a thin solid outer skin with a foamed inner core.

Seat structures made of carbon fiber composite along with reduced foam and lightweight back panels reduce the

Fig. 3 — Carbon fiber composite seat parts and material distribution.

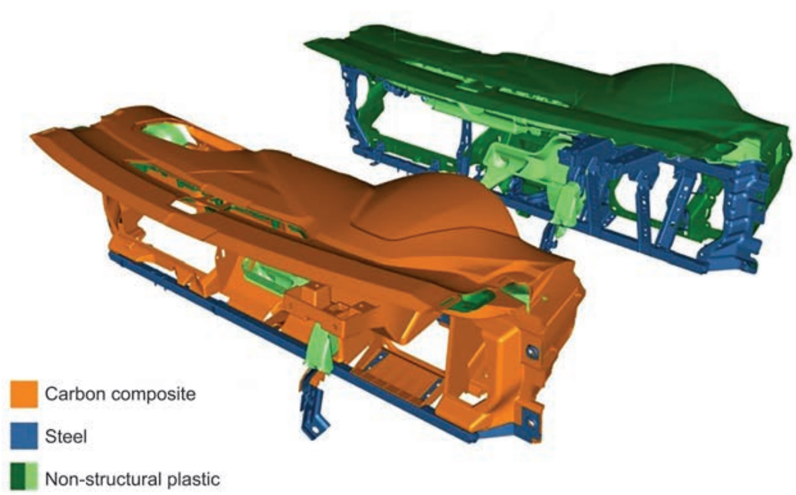


Fig. 4 — Fusion and MMLV design instrument panel beams and HVAC ducts.

front seat weight by approximately 8 kg (Fig. 3). The MMLV design includes a 12 kg (42%) reduction in the rear seat by use of carbon fiber composite structures and reduced weight foam and fabric trim.

The instrument panel beam uses carbon fiber composites with integrated HVAC ducts and chemically foamed nonstructural parts to reduce weight by 8 kg (36%) from the 2013 Fusion instrument panel beam. Figure 4 shows the Fusion and instrument panel designs and materials.

CHASSIS

The MMLV design chassis system boasts an overall 98 kg (28%) weight reduction from the 350 kg Fusion chassis. The wheels and tires subsystem is 39 kg (38%) lighter than the 103 kg Fusion. This is achieved by eliminating the spare wheel and tire, plus reducing the road wheels and tire weight. The MMLV design incorporates 5J×19 wheels and a tire design and material change from 225/50R17 to 155/70R19. The wheel weight was set at 7.5 kg per wheel, which is achieved with efficient cast aluminum or carbon fiber designs. The Fusion 7.5J×17 cast aluminum wheels weigh 10.74 kg each. (Note: The MMLV prototype includes carbon fiber 5J×19 wheels at 6.15 kg each, Fig. 6.) The tire size change saves 3.35 kg (29%) per tire from the Fusion—down to 8.25 kg for the MMLV tires.

The subframe designs reduce weight by 27 kg (47%) by using cast and extruded aluminum instead of stamped steel. The front subframe castings are high-pressure die castings, while the rear subframe side castings are low-pressure hollow castings. The aluminum extrusions are MIG (metal inert gas) welded to the castings. Figure 5 shows the MMLV subframe designs and materials.

The front and rear suspensions for the MMLV design include hollow steel stabilizer bars that save 1.7 kg (39%) in the front and 2.9 kg (59%) in the rear, reduced weight knuckles and shocks from material substitutions of aluminum for steel, and lightweight coil springs. Glass fiber-epoxy composite springs are used in the front while hollow steel springs are used in the rear. The composite front spring weighs 1.2 kg vs 2.8 kg—a 57% savings. The hollow steel rear spring reduces the weight by 1.6 kg and results in a 37% savings (from 2.7 kg vs 4.3 kg).

An 11 kg weight savings in the brake systems comes from materials substitution. Traditional cast iron brake rotors were replaced with cast aluminum rotors with a 1-mm-thick, thermally sprayed two-wire arc stainless steel alloy coating to provide a durable and wear resistant surface. Figure 7 shows the aluminum cast front rotor and the prototype thermal spray process.

Other weight savings in the chassis system include reductions in the capacity for the steering system, replacing the jack system with a flat tire repair kit, and anticipated reductions in fasteners due to use of lighter components.

POWERTRAIN

The MMLV design powertrain saves 73 kg (21%) over the current production engine used in the 2013 Ford Fusion. The Fusion control model has a 1.6-liter four-cylinder gasoline turbocharged direct injection (EcoBoost) engine and 6F35 six-speed automatic transmission. The new MMLV design incorporates a 1.0-liter three-cylinder gasoline turbocharged direct injection (Fox EcoBoost) engine with a lightweight design and a lighter 6F15 six-speed automatic

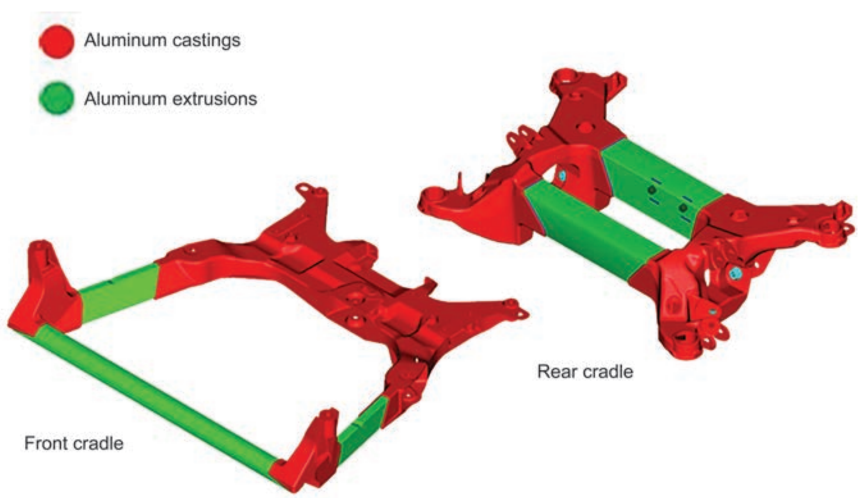


Fig. 5 — MMLV front and rear aluminum subframes.

Fig. 6 — MMLV glass fiber composite spring and carbon fiber wheel.

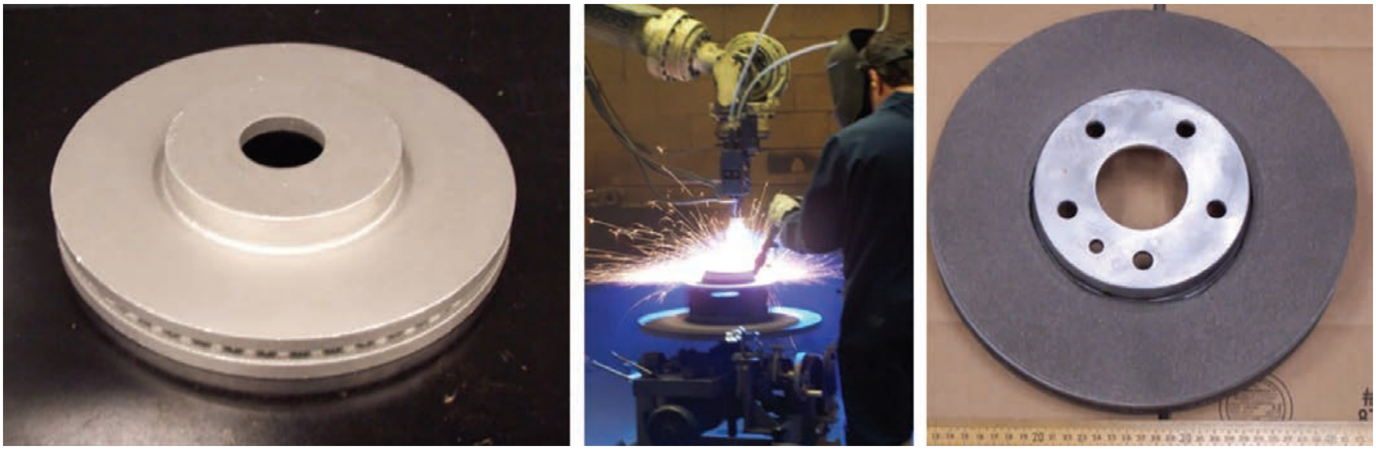


Fig. 7 — Cast aluminum front rotor, thermal spray process, and finished brake rotor.

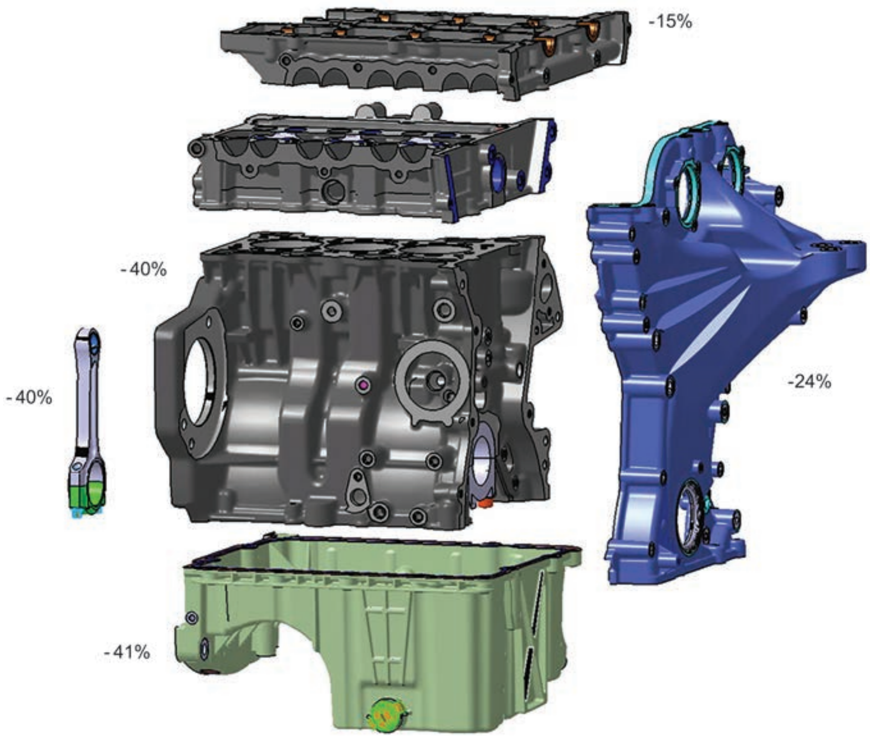


Fig. 8 — Design lightweight engine action for the 1.0-liter Fox Engine.

transmission. Weight reduction in the powertrain system also comes from a smaller gasoline tank (four gallons less in capacity) while maintaining the same driving range of the lighter Fusion.

The MMLV design engine includes:

- Aluminum block with CGI bulkhead inserts—11.8 kg (48%) reduction
- Aluminum connecting rods—0.7 kg (40%) reduction
- CF/PA oil pan—1.2 kg (40%) reduction
- CF/PA front cover—1.0 kg (24%) reduction
- CF/Al cam carrier—1.3 kg (20%) reduction

All together, these actions reduce the weight of the Fox engine from 88 to 72 kg—or 18%. The down-sized 1.6-liter I4 to the 1.0-liter I3 brings the total engine system savings to 30 kg (30%). Figure 8 illustrates the five material substitution lightweight actions in the engine.

Material substitution for the 6F15 six-speed automatic transmission reduces transmission weight to 77 kg from the prior 6F35 transmission weight of 89 kg. Actions taken to reduce the transmission weight include using a cast magnesium case in place of the aluminum case, and using an aluminum pump cover, magnesium valve body, and a mixed material aluminum with steel clutch hub. Combining these savings with an additional 3 kg from carbon fiber half shafts and lightweight CV joints yields a 14 kg (13%) reduction in the transmission and driveline system. Other lightweight design actions in the powertrain system include reduced cooling and engine mounts for the smaller, lighter engine.

ELECTRICAL

A 3 kg weight reduction in the MMLV electrical system results from switching to lightweight plastic insulation (from aluminum conductors) while an additional 6 kg are saved by replacing the lead-acid battery with a lithium-ion 12 volt starter battery as well as minor savings in the alternator, starter motor, and speakers. This accounts for a 10 kg (14%) total weight reduction in the electrical system (from 69 to 59 kg).

MATERIAL DISTRIBUTION

The MMLV design uses more aluminum and composites and less steel than the Fusion. Tables 2 and 3 present the weight savings by system and materials.

TABLE 2–MMLV WEIGHT REDUCTION ON A VEHICLE SUBSYSTEM BASIS

Vehicle systems and subsystems	2013 Ford Fusion weight, kg	MMLV weight, kg	MMLV curb weight, %	MMLV weight reduction, kg	MMLV weight reduction, %
1. Body	525.0	400.4	33.5%	–124.6	–23.7%
2. Interior	260.4	202.7	17.0%	–57.7	–22.2%
3. Chassis	355.0	260.0	21.8%	–95.0	–26.8%
4. Powertrain	337.0	263.1	22.0%	–73.9	–21.9%
5. Electrical	57.0	49.5	4.1%	–7.5	–13.1%
A. Assembly	25.0	19.5	1.6%	–5.5	–22.0%
Total vehicle	**1559.4**	**1195.2**	**100%**	**–364.2**	**–23.4%**

Based on the system definition from the International Organization for Standardization (ISO) standards.

TABLE 3–MAIN MATERIAL COMPOSITION PER VEHICLE ARCHITECTURE

Material	2013 Ford Fusion weight, kg	2013 Ford Fusion weight, %	MMLV weight, kg	MMLV weight, %
AHSS	417.5	27%	66.9	6%
Conventional steel	413.7	27%	289.8	24%
Cast iron	50.0	3%	19.6	2%
Forged iron	16.0	1%	10.0	1%
Stainless steel	19.1	1%	9.7	1%
Die-cast aluminum	146.4	9%	147.7	12%
Cold-rolled aluminum	12.8	1%	143.8	12%
Extruded aluminum	15.6	1%	66.9	6%
Forged aluminum	0.0	0%	9.8	1%
Magnesium	2.3	0%	16.0	1%
Copper	33.7	2%	29.3	2%
Titanium	0.0	0%	3.3	0%
CFRP	0.0	0%	54.2	5%
GFRP	0.0	0%	3.4	0%
Plastic	235.4	15%	177.1	15%
Rubber	72.6	5%	52.0	4%
Glass	37.5	2%	26.4	2%
Ceramics	0.8	0%	0.8	0%
Batteries	14.0	1%	8.0	1%
Paint	8.0	1%	7.7	1%
Fluid, adhesive, and other	64.1	4%	52.8	4%
Total vehicle	**1559.5**	**100%**	**1195.2**	**100%**

SUMMARY

The multi-material lightweight vehicle design reduces the weight of a CD class five-passenger sedan by more than 350 kg—a savings of over 23%. By designing major structural systems using mixed materials, incorporating aluminum as well as steel, and using lightweight materials in all major vehicle systems and components, the MMLV design sets a mark for vehicle weight reduction.

Future efforts will build and test physical prototypes of the MMLV design. Completed testing to date includes a 150-K mile equivalent durability test with no major structural issues in the body, closure, chassis, interior, or electrical systems. Safety testing for the new car assessment program (NCAP) full frontal crash, Insurance Institute for Highway Safety (IIHS) 40% offset deformable barrier, side pole impact, and rear impact testing evaluates the joining and energy absorption of lightweight architecture. Safety test results are complete and under review.

Select NVH (noise, vibration, and harshness) testing measures the typically deleterious effects of lightweighting on these vehicle attributes. NVH data are also under review. Full vehicle accelerated corrosion tests are underway on two MMLV vehicles. Many of the technologies incorporated into the MMLV are near term, but not necessarily cost effective. Ford, Magna, and the automotive industry continue to investigate innovative ways to incorporate lightweight materials that are both cost effective and affordable. Overall, this concept vehicle is one of the most comprehensive studies of a multi-material lightweight vehicle using technologies that in the near future will contribute to lightweight vehicles, better fuel economy, and lower emissions. **~AMP**

Acknowledgment

The authors thank their colleagues in Ford Research & Advanced Engineering who assisted with the design and research for the MMLV. Additionally they thank their Magna partners for design and engineering efforts. More than 100 research scientists and engineers contributed to this project. Finally, the authors thank the U.S. Department of Energy, Vehicle Technologies Office for support and ongoing guidance and reviews. This material is based on work supported by the DOE National Energy Technology Laboratory under Award No. DE-EE0005574.

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MATERIALS RESEARCH FOR ADVANCED POWER ENGINEERING IN EUROPE

From September 15-17, 2014, more than 160 delegates—including researchers from 19 European countries, the U.S., Japan, and India—met in Belgium for the 10th Liège Conference on Materials for Advanced Power Engineering.

John Shingledecker, Electric Power Research Institute, Charlotte, N.C.*

Amit Shyam, Yukinori Yamamoto, Oak Ridge National Laboratory, Tenn.*

Bernd Kuhn, Forschungszentrum Jülich, Germany

Alliance Hotel Liège, left, and Palais des Congrês, right, in Liège, Belgium.

The Liège Conference, held every four years, serves as the focal point for dissemination of research results from European collaborative projects on advanced materials technology in large-scale power generation applications. The conference was sponsored by Forschungszentrum Jülich in Germany, Cranfield University in the UK, and the University of Liège in Belgium, and featured invited talks from European leaders and international experts, along with a poster session encouraging technical exchanges among researchers on specific topics. An electronic volume of the conference proceedings including 75 papers is available for download[1]. This article presents conference highlights, including the current state of European materials research for advanced power engineering applications; European multinational programs in this area; and critical research topics including creep-fatigue, new alloy development, and materials developments for gas turbines.

*Member of ASM International

EUROPEAN LANDSCAPE

Three major themes repeated throughout the conference involve key drivers for the European electric generation industry: Lowering the carbon footprint through higher efficiency, more flexible operations, and energy security. The European Commission's (EC's) energy roadmap lays out clear goals over the next 35 years with the ultimate objective of reducing greenhouse gases by 80% by 2050, compared to 1990 levels. As part of the EC's Horizon 2020 program and Strategic Energy Technology Plan, the immediate need to reduce carbon use through higher efficiency is the major topic area for national programs focused on higher temperature materials. Additionally, the plan's emphasis on renewable energy (wind and solar) has resulted in a focus and funding on materials topics related to the flexibility of both existing and new large-scale power generation, which often must respond quickly to grid demands. Concerns over the natural gas supply in Europe underscore the need for high efficiency gas turbines and the desire for fuel diversity.

MULTINATIONAL PROGRAMS

Results from the European NextGenPower project, which has a goal of demonstration and component fabrication of nickel-base alloys and protective coatings for fossil-fuel-fired steam power plants up to 750°C, were also disseminated at the conference. The current state-of-the-art ultrasupercritical power plants operate with main steam temperatures up to 600°C and reheat temperatures up to 620°C based on steel technology. The NextGenPower project is a four-year initiative that began in 2010 made up of material suppliers, boiler and steam turbine manufacturers, research institutes and universities, and a utility from eight different European countries.

The endeavor follows successful European efforts to use solid solution-strengthened nickel-base alloys to achieve 700°C service. Unique to this project is its concentration on age-hardenable alloys for boilers, steam turbine rotors, and steam turbine casing, with a focus on nickel-base alloy 263. The project is coordinated by DNV-GL, with Doosan Babcock leading the boiler effort, Skoda Power leading the steam turbine work, and DNV-GL integrating the practical results with modeling efforts. Major activities include fireside corrosion testing using boiler probes; laboratory work to understand and model fireside corrosion and steam oxidation; optimization of nickel-base alloy 263; forging trials up to 1000 mm in diameter on alloy 263 (Fig. 1); demonstration of rotor welding; and casting development, including development of a new nickel-base casting (G130 by Goodwin) for heavy sections.

To improve coordination of the various multinational programs funded by the European Union (EU) with national government programs, a special Energy Materials working group (WG2) was formed as part of the Knowledge-Based Multifunctional Materials Virtual Institute in 2012. One goal of this program is addressing the materials gap between the current 600°C steel technologies for fossil power plants and the extensive research taking place in Europe, the U.S., and Japan on >700°C materials technology. The group is currently coordinating efforts for industrial scale demonstrations using the Japanese originated MARBN (martensitic microstructure with boron and nitrogen control) steel concept. MARBN steels contain highly controlled levels of boron and nitrogen, which are reported to increase high-temperature long-term (>100,000 hours) creep strength of steels up to 650°C while helping retain good weld strength. These steels are undergoing long-term creep testing of weldments to confirm improved heat-affected zone (HAZ) creep strength, while forging and tubing production for in-plant testing and cast MARBN steel and subsequent testing are also being developed.

Overall, efforts were impressively coordinated among the various parties involved, including partners from academia, research institutions, manufacturers, and utilities. From the standpoint of steam power plant technology, Europeans were the first to develop and demonstrate materials for a 700°C power plant, with U.S. and Japanese programs developing materials for temperatures up to 760°C later. EU efforts in both >750°C steam operation and incremental improvements to steels for operation at 650°C, presented at the conference, demonstrate broad global competitiveness in this technology area.

CREEP-FATIGUE

One key development discussed extensively is the need for flexible operation of conventional power plants. This recent flexibility requirement is largely due to the mandate to supply a larger fraction of power from renewable sources. For example, the total power generated from renewable sources in Germany increased threefold over the past 10 years, and is expected to continue. The residual load characteristic (difference between total electric energy consumption and supply by renewable sources) of a time period in 2008 compared to the same projected time period in 2050 is shown in Fig. 2. The loading spectrum of power plants will change dramatically in the coming years, a process that has already begun.

The changing operation mode of conventional power plants has created the need for improved tools that can predict creep-fatigue damage interaction in materials. Organizations such as the Electric Power Research Institute (U.S.) and VGB (Germany) have formed working groups to standardize testing, analysis, and design procedures associated with creep-fatigue damage. A simple example illustrating these changing requirements is one associated with thick-walled components—going to thicker sections to alleviate creep damage can have a negative influence on the component's thermal fatigue lifetime. At least two analysis procedures to quantify creep-fatigue damage were presented at the conference, one involving creep-fatigue damage summation diagrams and the other focused on fracture-mechanics-based cyclic crack tip opening displacement parameters.

Creep-fatigue damage assessment tools must be developed in parallel with higher performance materials with improved creep-fatigue resistance. For power plant steels, creep-fatigue damage development is reported to be influenced by the temperature and strain range, strain rate, hold time, creep strength, and creep ductility of the material. The traditional understanding of creep-fatigue interactions is based on studies of low alloy ferritic and austenitic steels. However, this understanding may not translate well to new advanced materials with significantly different deformation and oxidation responses.

For example, for 9% to 11% Cr steels at temperatures above 525°C, the dominant source of damage accumulation comes from fatigue-oxidation rather

Fig. 1 — Full scale, 1000-mm-diameter alloy 263 rotor forging during solution annealing and quenching. Courtesy of Saarschmiede, Germany.

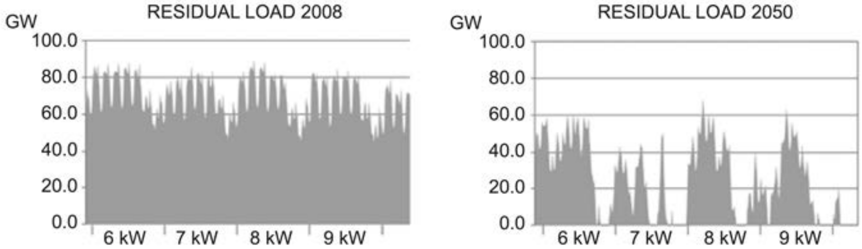

Fig. 2 — Comparison of the residual load characteristic between 2008 and 2050 (projected), illustrating the growing need for predictive tools in the creep-fatigue interaction regime and higher performance materials with better creep-fatigue resistance[1].

than fatigue-creep interactions. Nevertheless, the creep-fatigue resistance of different material classes scales with their known response to temperature. The creep-fatigue crack initiation endurance limit for NiCr23Co12Mo (solid solution strengthened nickel-base alloy) at 700°C is similar to that for 9% to 11% Cr steels at 600°C and 1CrMoV steel at 550°C. The development of materials with improved elevated temperature strength may be a first step toward the development of creep-fatigue-resistant materials.

NEW MATERIALS

Six invited talks and seven poster presentations comprised the "new materials" category, including seven on bainitic, ferritic-martensitic (F-M), and ferritic steels, four on austenitic stainless steels, and two on Ni-base alloys. Alloy development trends in the area of high-temperature structural materials for power generation systems can be grouped into three main categories: Strength improvement of 9-12Cr F-M steels; higher Cr ferritic steels strengthened by stable intermetallic compounds; and newly developed high Cr-high Ni austenitic stainless steels with the unique capability of either high-temperature strength or oxidation resistance. Most new alloy development activities focus on Fe-base materials rather than Ni-base, as cost-effectiveness is one of the main drivers of material down-selection for applications in power generation systems.

Unique alloy design strategies were presented that use different types of second-phase precipitates for strengthening: Cr(V,Nb)N-type Z-phase in F-M steels, Fe_2W-type Laves phases in high Cr ferritic steels, and σ-FeCr-phase and Fe_2Nb-type Laves phases in austenitic stainless steels. These second-phase precipitates were recognized as "poisons" for long-term creep properties due to their detrimental effects, e.g., promoting decomposition of strengthening nanoscale carbonitrides and decreasing toughness and creep ductility due to their brittle nature. However, research proves their effective use for improving creep properties through proper alloying additions, thermomechanical treatments, and microstructure control. Computational thermodynamics also play an important role in the design of such steel alloys.

An example of improved creep properties in high Cr ferritic steels strengthened by Laves-phase precipitation (Toda, et al.[1]) is shown in Fig. 3, which demonstrates much longer creep-rupture life of the developed steels than that of T92 (9Cr-2W F-M steel). Because ferritic steels are fundamentally free from Type IV failure issues (premature creep failure at the HAZ) found in F-M steels and offer advantages in thermomechanical fatigue life in comparison to all other material types, such alloy design strategies hold promise for next-generation high-temperature structural materials. Development of alumina-forming austenitic stainless steels was also presented by one of the authors (Yamamoto, et al.[1]), who proposed a unique approach to provide a promising oxidation-resistance via protective, external alumina scale instead of using conventional chromia scales on commercially available stainless steels.

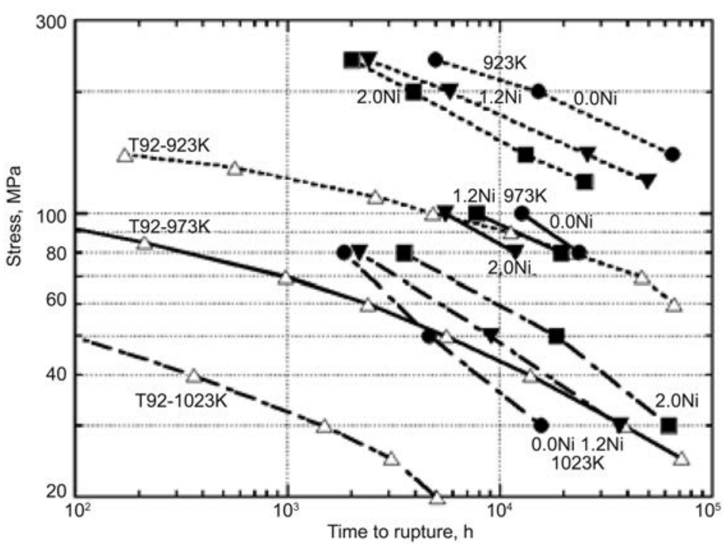

Fig. 3 — Creep stress vs. time to rupture curves for 15Cr ferritic steels without Ni (solid circles), with 1.2% Ni (solid triangles), and 2.0% Ni (solid squares), developed by Toda, et al. Data of conventional T92 steel (open triangles) are plotted for comparison[1].

GAS TURBINES

With regard to coatings, new materials that can overcome the temperature limit (1200°C) of partially stabilized zirconia (YSZ) have been researched for several decades. Gadolinium zirconate (GZO) coatings fabricated on top of a bottom layer of YSZ (Fig. 4) are among the options investigated. GZO coatings feature improved temperature capabilities, but do not possess the mechanical resistance of YSZ coatings. However, newly reported double-layer designs overcome this limitation and show increased spallation lifetime in thermal cycle testing. Lifetime simulation procedures and test method development for double-layer coatings were also reported.

SUMMARY

The 10th Liège Conference on Materials for Advanced Power Engineering continues the long-standing tradition of collaborative European materials research. Environmental concerns, flexible operation, and energy security are global issues that necessitate high-temperature materials development. The authors were honored to participate and present some recent U.S. efforts in the spirit of strengthening worldwide collaboration.

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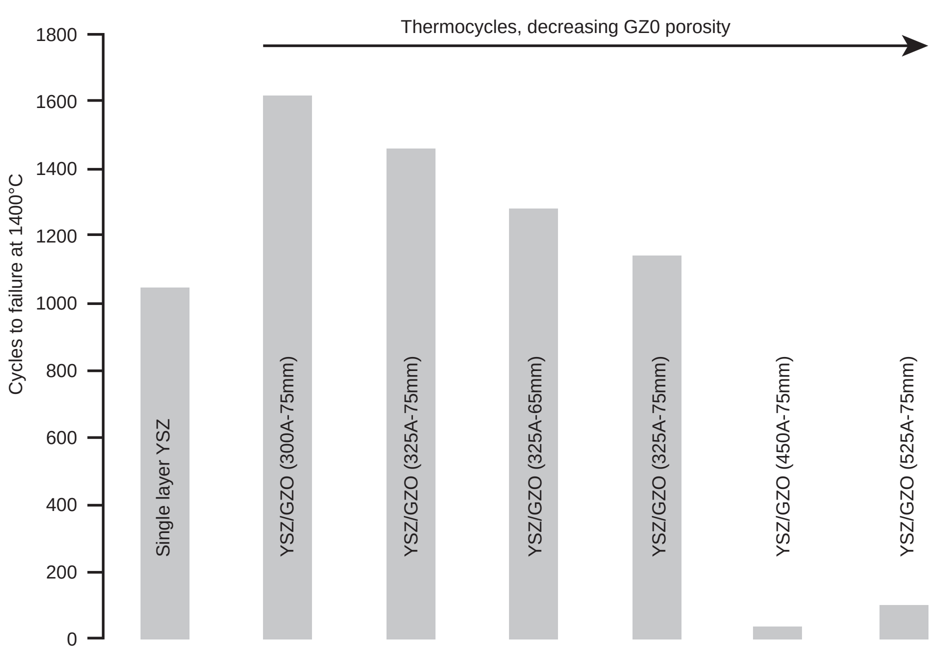

Fig. 4 — Burner rig test results of GZO-YSZ double-layer systems and standard YSZ tested at a surface temperature of 1400°C[1].

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ADDITIVE MANUFACTURING MAKES TITANIUM USE MORE FEASIBLE

Titanium, the ninth most abundant element in the earth's crust, holds the highest strength-to-weight ratio of any metallic element. It is 45% lighter than steel and highly corrosion-resistant—an extremely valuable combination for many industrial and medical applications.

The reason titanium is not more widely used boils down to expense. As a raw material, it can cost up to two orders of magnitude more than structural steels. Therefore, titanium is mostly used in high-end applications where the price can be justified by performance requirements.

IMPROVING COST EFFECTIVENESS

Additive manufacturing (AM) is changing the outlook for titanium in ways that are exciting and important for design engineers to understand, especially as opportunities for AM reach mainstream parts production. As an example, producing an I-beam from a forging would machine away approximately 50% of the titanium used to make it—*subtractive manufacturing.* The value of the machining chips pales in comparison to the metal cost. However, *additive manufacturing* and new powder technologies can now reduce waste to 2%, making titanium much more practical and cost effective.

AM CHALLENGES

Additive manufacturing and its supplementary technologies must overcome several challenges to achieve market viability across diverse applications and industries. One is the relatively high cost of titanium powder. However, some companies are developing novel technologies that are poised to reduce cost and increase capacity. One such company is Puris LLC, which brought 300,000 lb of new capacity online last year. At these levels, powder cost becomes a much smaller percentage of overall component cost. Machine manufacturers are also developing processing parameters to increase powder recycling potential. For powder bed technologies, this means that much of the powder used during buildup, which does not become part of the printed component, may be recycled cleanly and efficiently.

Another challenge is that the final geometry is only near-net shape, so it requires extra machining. Further, for many complex components, initial setup work represents the majority of machining time and cost not offset by material waste reduction. To solve this, machine and powder advances continue to improve the complexity and accuracy of AM part geometry. Predictive numerical tools enable fine tuning of parts to limit shrinkage and distortion during manufacturing. Many parts are now designed as *selectively-net shape,* which means certain features or surfaces are printed net, while others are left near-net. Allowing a material envelope on noncritical surfaces facilitates machining to bring other features into net shape.

Yet another challenge stems from the use of laser or electron beams in 3D printing, which introduce thermal

Additively manufactured components produced by the ExOne printer.

stresses that contribute to component distortion during the building process or in post-build heat treatment and machining. Solutions to this problem vary based on the specific 3D printing technology:

- In laser-based systems, build can be paused and the component removed for stress relief, albeit with a negative effect on production speed and cost.
- Arcam, Sweden, successfully preheats and elevates the powder bed during the print cycle.
- ExOne, North Huntingdon, Pa., a binder jet system manufacturer, prints at room temperature to alleviate thermal stresses. Subsequent steps performed at higher temperatures for binder removal and consolidation do not appear to form thermal stresses.

A fanatical approach to cleanliness and patented technologies ensures that Puris' titanium powder is free from contamination.

Each printer is housed in separate clean rooms to further ensure part cleanliness and integrity.

Finally, the heat source used to melt the powder in order to fuse respective layers may transform the desirable microstructure of the raw powder into a less desirable, coarse microstructure. Ongoing studies seek to understand the extent of microstructure change in various systems and its impact on final component properties. The patented family of eTi alloys from Puris, for example, was developed to alleviate this issue. Precipitates formed in-situ during powder manufacturing pin grain boundaries and retard grain growth during all subsequent processing. These alloys enable forged-quality microstructures and properties in AM-produced parts, regardless of the process used. At the production level, solutions vary by technology:

- Laser-based and electron-beam systems rely on processing parameters to facilitate rapid cooling and minimize detrimental microstructure changes.
- Binder-jet systems process at room temperature with the option of not reaching the material's liquidus during subsequent processing. This preserves the desirable microstructure.

INNOVATIVE MATERIALS HOLD PROMISE

While titanium powder materials are not new, the advent of additive manufacturing presents new and exciting applications. AM allows components to be designed more purely to maximize structural integrity and performance, with less consideration given to manufacturability. The result is that a higher percent of the material is used for the part, significantly reducing waste. While still more expensive than steel as a raw material, titanium powders are finding their way into these newly simplified parts when they would not be viable using traditional processes.

Among the new material systems in development, two show promise based on unique properties well suited to AM. The eTi powders are modified titanium alloys that offer a 30% increase in strength and stiffness over their wrought counterparts. Another new base alloy gaining acceptance in AM applications is SM-100, with a base chemistry of Ni-40Ti. SM-100 offers excellent corrosion and wear properties. It is difficult to process with conventional machining and processing, but is well suited for AM. Among the recent uses for SM-100 are bearing and valve components for offshore oil and gas production. With these and other recent advances taking place in the AM field, additional applications and alloy development efforts will continue to make strides.

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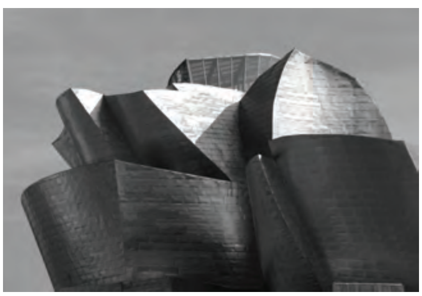
METALLURGY LANE

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 I

THE ONLY PROCESS AVAILABLE FOR PRODUCING TITANIUM WAS PATENTED BY WILLIAM J. KROLL IN 1940, MARKING THE DAWN OF A NEW METALS INDUSTRY.

Titanium is found in many popular consumer items, such as jewelry, watches, golf clubs, eyeglass frames, bicycle and auto engine parts, and handguns. More recently, it has been used in the biomedical field in the form of knee and hip joints. Titanium's most spectacular use may be for the architectural covering of the Guggenheim Museum in Bilbao, Spain, designed by Frank Gehry. However, these consumer uses were not anticipated in the late 1940s and 1950s when the metal was primarily considered a promising structural material for defense applications.



The Guggenheim Museum Bilbao, designed by architect Frank Gehry, is made of titanium, glass, and limestone. Courtesy of Wikimedia Commons.

Hip joint prosthetic made of titanium alloy, center. Courtesy of Wellcome Images, operated by Wellcome Trust, UK, wellcomeimages.org.

Titanium was discovered in 1790 by William Gregor, an English clergyman and amateur chemist. It was rediscovered in 1795 by Austrian chemist Martin Heinrich Klaproth while studying the mineral rutile. It was Klaproth who named this new metal after the Titans, deities with tremendous strength in Greek mythology.

Titanium is element 22 on the periodic table. Its density is 4.5 grams/cm^3, midway between aluminum at 2.7 and iron at 7.86. Its melting point is 1812°C (3294°F), compared with 1535°C (2795°F) for iron. Its low density and high melting point compared with iron indicate a metal with impressive structural qualities. Corrosion resistance further expanded titanium's potential applications. It seemed to be the ideal answer to the need for a strong, lightweight, and corrosion-resistant metal for numerous structural designs. In the late 1940s and early 1950s, these advantages looked promising to military units on the cutting edge of developing jet engines, supersonic aircraft, missiles, and lighter weight trucks, tanks, landing craft, and other hardware for both the Cold War and Korean War.

William J. Kroll, inventor of the titanium sponge production process. Courtesy of Oregon State University.

The only problem was the lack of a process and an industry for titanium production. In May 1940, a middle-aged research engineer emigrated from Luxembourg to the U.S. with a patented method for making titanium. Dr. William J. Kroll's novel process would soon become the basis for the titanium industry.

WILLIAM J. KROLL

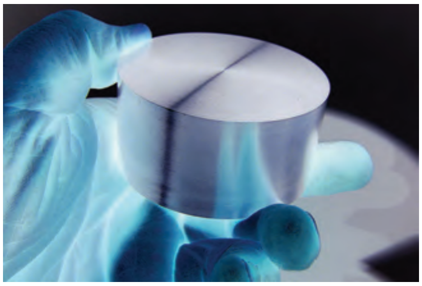
William J. Kroll was born in 1889 in Esch, Luxembourg. He earned a Doctor of Engineering degree in metallurgy from the Royal Institute of Technology in Charlottenburg, Germany, in 1917. After several years of employment in Germany, Austria, and Hungary, Kroll established his own research laboratory in a home he purchased in his native Luxembourg where he conducted groundbreaking research in metallurgy and electrochemistry. Kroll received some financial help for his titanium research from the German firm of Siemens & Halske AG. When the company lost interest in supporting his work, he obtained control of the foreign patent rights and invested his own funds to continue development in his private laboratory. By 1938, he had produced 50 pounds of metal.

The very first published report on Kroll's process was a paper he presented at the 1940 meeting of The Electrochemical Society. That same year, he was issued U.S. Patent 2,205,854 for his invention. His process involved a modification of the sodium reduction of titanium tetrachloride used by Matthew Hunter at General Electric Corp. in the early 1900s. Kroll, however, used magnesium instead of sodium as the reducing agent. The resulting metallic product was a spongelike collection of particles that required removal of residual magnesium and magnesium chloride contaminants. After cleaning, the sponge was crushed to powder, compacted, and heated at a high temperature to sinter it into a solid mass.

BUREAU OF MINES RESEARCH

The U.S. Bureau of Mines (BOM) began investigating Kroll's process at the Salt Lake City Experimental Station during WWII. Titanium was made in 15-lb batches by 1944. The first steps beyond the BOM work occurred in 1946 when a contract was awarded to Battelle Memorial Institute in Columbus, Ohio, to study the properties, welding, and fabrication characteristics of titanium and its alloys. BOM supplied the titanium, with funding covered by the U.S. Air Force by way of Douglas Aircraft Co. Every branch of the armed forces—as well as all government agencies with an interest in this new metal—eagerly followed the research work at Battelle through its progress reports. This was the first broad scope, independent research to evaluate titanium's practical capabilities.

After a two-year study, a final classified report was issued in 1948 concluding that titanium and its alloys had great engineering potential and further development should be pursued. This report and other evidence from work at the BOM, Wright-Patterson Air Force Laboratory, and the Army Ordnance Dept. at Watertown Arsenal provided the foundation for promoting a new industry based on titanium. E.I. du Pont de Nemours and Co. (DuPont) was the first commercial organization to commit resources to producing titanium. In late 1948, DuPont sold titanium sponge for $5 per lb from its production of 100 lb per day. The Remington Arms division of DuPont conducted research on metal made from this sponge and would later be a major partner in producing titanium for the aerospace market.



A titanium cylinder. Courtesy of Wikimedia Commons, Alchemist-hp.

FIRST TITANIUM CONFERENCE

The first major conference on titanium was held in Washington on December 16, 1948. It was organized by Nathan Promisel of the Navy's Bureau of Aeronautics and Julius Harwood of the Office of Naval Research, and held at the National Academy of Sciences. This meeting is considered titanium's official debut. Many factors came together at this time that influenced all levels of government to cooperate in this endeavor. All through WWII there were shortages of certain materials vital to the war effort. Metals such as tungsten, nickel, chromium, manganese, and others were controlled by the War Production Board and released on priority bases for only the most important applications. The initiation of Korean hostilities in June 1950 provided additional incentive to develop a new metal with such promising properties and ready availability in the U.S. It was believed at this time that the U.S. was self-sufficient in rutile, the major ore of titanium.

When sample quantities of BOM material became available, they were distributed to interested laboratories across the country including those of the Army, Navy, and Air Force, as well as some industrial companies, such as the National Lead Co. and Kennecott Copper Co. Studies revealed properties of immediate interest, notably corrosion resistance and strength. It was further suggested that titanium might replace both aluminum and steel in many defense applications. Enthusiasm for titanium reached the highest levels at the Department of Defense where funding was obtained for further research and development. One of the earliest studies in the search for alloys with superior mechanical properties was the Rand Program

Titanium strips inside a glass jar. Courtesy of Wikimedia Commons.

of the Air Force Materiel Command. This program financed a laboratory project at Battelle Memorial Institute to study a wide range of alloy additions for their effect on both the physical and mechanical behavior of titanium.

STEEL INDUSTRY INTEREST

Several steel producers began to show interest in titanium including Allegheny Ludlum Corp., Crucible Steel Co., Republic Steel Corp., and Sharon Steel Co. These companies were attracted to titanium for its excellent properties, which might be exploited as new business, and also because titanium could become a serious competitor to their regular business, stainless steel. During 1949-1950, they bought titanium sponge from DuPont and turned it into bar and sheet products. The material was primarily used for testing by various defense laboratories, universities, and industrial firms. National Lead Co. came on stream in 1950 as a second producer of sponge, taking over sponge production through a contract with the BOM at the Boulder City Experimental Station in Nevada. A new metals industry was about to form.

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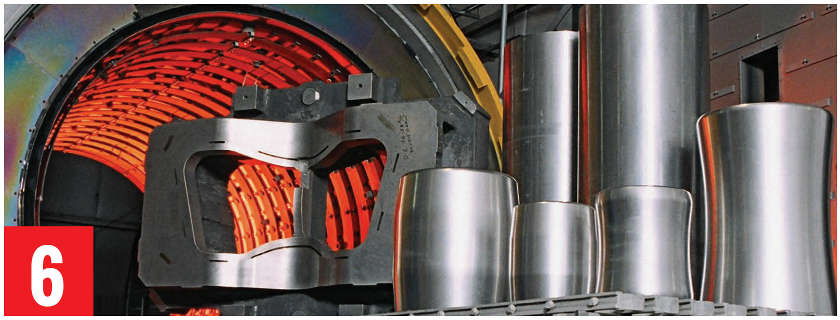

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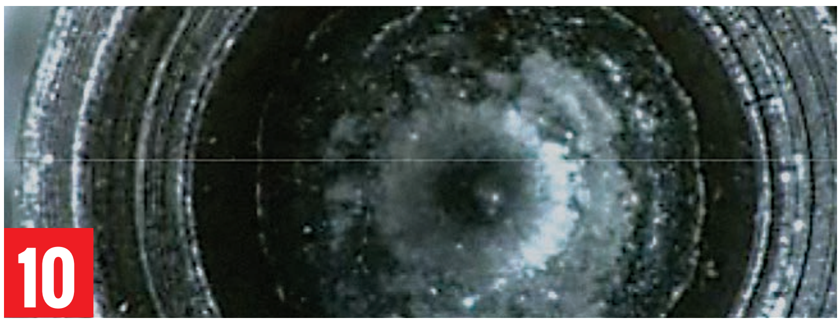

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ABOUT THE COVER

Large tooling ready for hardening in an 84-in. diameter × 12-ft long vacuum furnace. Solar Atmospheres Inc., solaratm.com.

ASM HEAT TREATING SOCIETY WORKING TO DELIVER HIGH VALUE

Maintaining the value of our Society requires improving areas such as education, dissemination of technical information, volunteerism, and membership. HTS is continually evaluating new ideas to keep members at the cutting edge of technology, products, and processes.

Every so often, we ask our members how the Society is doing and what it could do better in the future to serve member needs. With this in mind, a survey was sent out recently and we will look closely at the feedback to prioritize efforts in the areas that require attention.

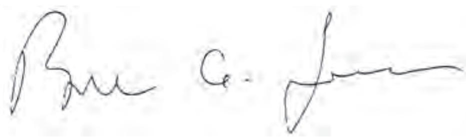
Training is of prime importance, and the HTS Education Committee is evaluating current courses to improve content and value, as well as looking at areas where there is a need for additional high-value, practical training materials. This is an ongoing project to make sure the Society is delivering the right products to our members and the industry as a whole.

Last year, ASM published four new handbook volumes on heat treating, replacing the old single volume—Vol 4: *Heat Treating* handbook—published in 1991. These volumes contain huge amounts of new material about state-of-the-art heat treating technology, some of which has never been published before. The new volumes include: Volume 4A: *Steel Heat Treating Fundamentals and Processes*; Volume 4B: *Steel Heat Treating Technologies*; Volume 4C: *Induction Heating and Heat Treatment*; and Volume 4D: *Heat Treating of Irons and Steels*. Our thanks goes to the hard work of the Volume chairs and all of the contributors to these prestigious works. Be sure to visit the HTS web site to learn more about these references.

We are looking forward to the Heat Treat 2015 conference and exposition, co-located with the American Gear Manufacturers Association, taking place October 20–22 in Detroit. Conference chair Richard Sisson and the organizing committee are preparing another top-notch technical program. At the show, we will present the first ASM HTS/Surface Combustion Emerging Leader Award, established to recognize an outstanding early-to-midcareer heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. I hope to see you in Detroit.

The HTS Board also approved holding a regional event in 2016 in Mexico. This follows the successful HTS regional conference on induction surface modification held in Monterrey, Mexico, in 2012. The event, ASM Heat Treating Society Global Event: Advanced Thermal Processing Technology, will be held in Queretaro in September 2016.

The importance of the ASM Heat Treating Society has never been greater as the heat treating industry moves forward in the 21st century. Together we can continue to build a strong Society with a high value proposition for decades to come.



Roger A. Jones
President, Heat Treating Society

ASM HEAT TREATING SOCIETY 2015
CONFERENCE & EXPOSITION

HEAT TREAT 2015 - 28TH ASM HEAT TREATING SOCIETY CONFERENCE AND EXPOSITION

October 20–22, 2015
Cobo Convention Center
Detroit

The ASM Heat Treating Society and the American Gear Manufacturers Association once again are co-locating to create an exciting mix of education, technology, networking, and exposition opportunities—all at the 28th Heat Treating Conference and Exposition and Gear Expo. The event is recognized by industry, academia, and government professionals as the premier heat treating gathering in North America. It will offer a full technical program covering a broad scope of heat treating technology, networking opportunities, and a firsthand look at equipment, supplies, and services from exhibitors.

Visit the HTS website for details on the technical program or to register at asminternational.org/web/hts/home.

FIRST ASM HTS/SURFACE COMBUSTION EMERGING LEADER AWARD TO BE PRESENTED AT HEAT TREAT 2015

The ASM HTS/Surface Combustion Emerging Leader Award was established in 2013 to recognize an outstanding early-to-midcareer heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. The award was created in recognition of Surface Combustion's 100-year anniversary in 2015.

The award acknowledges an individual who sets the highest standards for HTS participation and inspires others to dedicate themselves to the advancement and promotion of vacuum and atmosphere heat treating technologies.

Rules for submitting nominations:

- Candidates must be a member and an active participant in ASM International and HTS.
- Nominees must be 40 years of age or younger and employed full time in the heat treating industry for a minimum of five years.
- Candidates must be submitted by an ASM International or HTS member.
- Three letters of recommendation must be submitted with the nomination form. Nominations should clearly state the nominee's impact on the industry and/or service and dedication to the future of the HTS.
- The award shall be presented to one recipient every two years at the General Membership Meeting at the HTS Conference and Exposition.
- **Recommendations must be submitted to ASM Headquarters no later than April 1**.

Winner receives a plaque and $4000 cash award funded by Surface Combustion.

For complete rules and nomination form, visit the HTS community website at asminternational.org/web/hts/home and click on Membership & Networking and HT Awards. For more information or to submit a nomination, contact Joanne Miller at 440.338.5151, ext. 5513, joanne.miller@asminternational.org.

HEAT TREATING SOCIETY SEEKS BOARD NOMINATIONS

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

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

HTS SEEKING STUDENT BOARD MEMBER APPLICATIONS

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

Opportunities include:

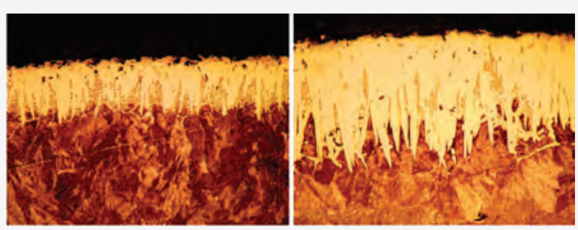
- All expenses to attend meetings paid for by the Society
- Take an active role in shaping the future of your professional Society
- Actively participate in your professional Society's Board meetings
- Gain leadership skills to enhance your career
- Add a unique experience to your resume
- Represent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

Student Board Members are required to attend two Board meetings (October 19 during Heat Treat 2015 and spring 2016) and participate in four teleconferences. The term begins in September 2015.

Application deadline is April 1. Visit asminternational.org/students3 for complete form and rules.

CORRECTION

In the November-December 2014 issue of *HTPro* in *AM&P* (p 44), Fig. 7 in the article "Deep Case Boriding for Extreme Wear Resistance" is inaccurate (both left and right micrographs are the same). Below is the correct photo, which shows the two different layers.



CHTE CELEBRATES 16 YEARS OF BRINGING INNOVATION TO THE HEAT TREATING INDUSTRY

In 1999, Diran Apelian, Alcoa-Howmet Professor of Mechanical Engineering at Worcester Polytechnic Institute (WPI) and director of the Metal Processing Institute had a vision of bringing industry and academia together to pursue research that would further innovation in the heat treating industry. With two founding organizations, the Metal Treating Institute (MTI) and the ASM Heat Treating Society (ASM-HTS), he established WPI's Center for Heat Treating Excellence (CHTE). As it celebrates 16 years of success this year, the center has grown to 21 members in North America and Europe and continues to grow under the guidance of Apelian and Richard Sisson, George F. Fuller Professor of Mechanical Engineering and director of CHTE.

In 1999, Surface Combustion Inc., Maumee, Ohio, became CHTE's first member. William Bernard Jr., the company's president and CEO recalls, "At the end of Diran's introductory presentation, I walked up and handed him our check. That brought a big smile. Many in the industry questioned how industry and academia could work together, but we saw CHTE as a great new opportunity."

Bernard became CHTE's first chairman, and the company has been a member ever since. "We've continued our membership with this outstanding organization because it is a good way to network and learn what is going on in the industry. The academic backgrounds of members and faculty are impressive, and the synergy of talent is unsurpassed," says Bernard. He also stresses that CHTE is a well-managed, hardworking organization that generates R&D ideas that impact the industry.

CHTE member, Steve Ferdon, director of engineering services, fuel systems business, Cummins Inc., Columbus, Ind., seconds this notion. Ferdon says he is passionate about his company's membership in the organization. "We joined because of the dynamic resources available. No other consortium provides hands-on assistance with the challenges the heat treating industry is facing."

Steve Ferdon of Cummins Inc., whose fuel systems enable engines to meet increasing emissions regulations while maximizing fuel economy and performance. To learn more, visit cummins.com/fuelsystems.

As the recently appointed chair of CHTE's board of directors, Ferdon's vision is to get more companies engaged in the center, expand its global footprint, and advance manufacturing technology, which will help bring jobs back to America.

He would also like to give back to the industry and to this organization. "Materials science is based on apprenticeship and mentorship, and we want to do our part to help preserve what we have here at CHTE, and to expand its benefits to the rest of our profession," he says.

CHTE's research projects are selected by members. Most focus on technology that will help industry control the microstructure and properties of metallic components, reduce energy consumption, process time, production costs, achieve zero distortion, increase furnace efficiency, achieve zero emissions, and improve quality.

ABOUT CHTE

The CHTE collaborative is an alliance between the industrial sector and university researchers to address short-term and long-term needs of the heat-treating industry. Membership in CHTE is unique because members have a voice in selecting quality research projects that help them solve today's business challenges.

MEMBER RESEARCH PROCESS

Research projects are member driven. Each research project has a focus group comprising members who provide an industrial perspective. Members submit and vote on proposed ideas, and three to four projects are funded yearly. Companies also have the option of funding a sole-sponsored project. In addition, members own royalty-free intellectual property rights to precompetitive research, and are trained on all research technology and software updates.

CHTE also periodically undertakes large-scale projects funded by the federal government or foundations. These endeavors keep members informed about leading edge technology.

CHTE projects now in progress include:

- Improving Alloy Furnace Hardware Life
- Induction Tempering
- Gas Quench Steel Hardenability
- Cold Spray Nanomaterials (supported by ARL)

CHTE is located in Worcester, Mass., on WPI's New England campus. The university was founded 150 years ago this year.

For more information about CHTE, its research projects, and member services, visit wpi.edu/+chte, call 508.831.5592, or email Rick Sisson at sisson@wpi.edu, or Diran Apelian at dapelian@wpi.edu.

USING WORKLOAD-EMISSIVITY FACTORS TO PROJECT HEATING RATES IN A VACUUM FURNACE

Emissivity is a term used to define the ability of a surface to emit and absorb radiation. At any given temperature, the emissivity of a body (or surface) equals its absorptivity.

Reàl J. Fradette and Trevor Jones,* Solar Atmospheres Inc.

Development work on a vacuum carburizing process revealed the need to better understand the effect of workload surface emissivity and the proper use of dummy thermocouple test blocks. The process involved carburizing areas of a partially copper-plated alloy steel part; areas of the part that were not to be carburized were copper plated. Because part configuration made it impossible to place a thermocouple inside, a dummy test block made of carbon steel with approximately the same cross section as the workpiece was used for the process thermocouple without proper consideration (as determined subsequently) of the test block surface.

Using the test block as the control, carburizing was initiated when it reached the predetermined temperature. Examination of the part at the end of the test showed that the depth of carburized case was shallow in areas that were not plated. This indicated that the carburizing cycle did not hold the part at the correct temperature long enough before carburizing. Thus, it was concluded that when using dummy test blocks to control process times and temperatures, many factors must be considered including surface emissivity. This led to evaluating the effects of surface condition and workpiece size on emissivity and time to heat to temperature.

PART SURFACE EMISSIVITY

In a vacuum furnace, heat is imparted to a workload via radiation from the furnace heating elements. In practice, most materials and surfaces are "gray bodies," having an emissivity factor less than 1.0. For practical purposes, it is assumed that a good reflector is usually a poor absorber.

The surface condition of a material can greatly affect its ability to absorb radiant energy. To heat the same material with equal cross section and mass to final temperature can take up to twice as long, depending on surface condition. Table 1 shows the approximate emissivities of various metals and surface conditions.

In vacuum furnace heating, several complex factors affect the total time it takes for materials to reach uniform process temperature, including load weight, part cross section, and heating rate. As stated previously, emissivity is also an important factor directly affecting the heat absorption capability of the material being processed.

*Member of ASM International and Heat Treating Society

TABLE 1– EFFECT OF SURFACE CONDITION ON EMISSIVITY OF SELECT METALS

Metal	Surface condition		
	Polished	Rough	Oxidized
Aluminum	0.04	0.055	0.11–0.19
Brass	0.03	0.06–0.2	0.60
Chromium	0.08	--	0.17
Copper	0.018–0.02	--	0.57
Gold	0.018–0.035	--	--
Steel	0.12–0.40	0.75	0.80–0.95
Stainless steel	0.11	0.57	0.80–0.95
Lead	0.057–0.075	0.28	0.63
Nickel	0.045–0.087	--	0.37–0.48
Silver	0.02–0.035	--	--
Tin	0.04–0.065	--	--
Zinc	0.045–0.053	--	0.11
Galvanized iron	0.228	--	0.276

Knowing the emissivity of a material is most critical when using separate dummy thermocouple blocks to simulate actual workload temperature. The thermocouple block must not only represent the average cross section of parts, but also must represent the surface condition (color, roughness, or amount of oxidation) of the material being processed.

TEST PROCEDURE

To illustrate the importance of the emissivity factor in load heating and dummy thermocouple blocks, six carbon steel blocks with different surface conditions were prepared for testing. Blocks measured 2.5×2.5×2.5 in., with a 0.093 in. diameter hole drilled 1.25 in. deep at the center into which a thermocouple was inserted. Block surface modifications included oxidized, grit blasted, copper plated, nickel plated, polished shiny, and chrome plated (Fig. 1).

Dummy blocks were loaded into a workbasket with generous spacing between blocks and relatively equal distance from the heating elements. Thermocouples were inserted into the blocks (Fig. 2), and the workbasket was placed into the furnace. Process cycle steps were as follows:

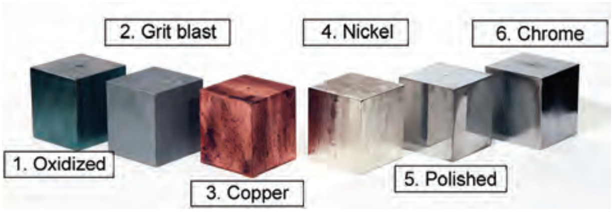


Fig. 1 — Carbon-steel test blocks with different surface conditions and emissivities used to determine heating times to temperature.

Fig. 2 — Carbon-steel test blocks with inserted thermocouples used to determine the effect of surface condition on times to heat to temperature in a vacuum furnace.

1. Pump furnace down to initial vacuum of less than 1×10^{-3} torr
2. Heat furnace to 1000°F at 15°F per minute
3. Hold at 1000°F until all blocks are within 10°F of set point and hold 15 minutes
4. Heat furnace to 1700°F at 15°F per minute
5. Hold at 1700°F until all blocks are within 10°F of set point and hold 15 minutes
6. Cool load and furnace back to unloading temperature

Figure 3 shows the plots of thermocouple readings as a function of time. The curves illustrate the important role that emissivity or absorptivity plays relative to heating materials in a vacuum furnace. Table 2 shows the effects of emissivity and surface condition on heating time for the same part size. Carbon steel blocks of the same size can take up to twice the time to heat to temperature, depending on surface condition. The approximate emissivity value of the surface condition is closely reflected in the relative heating times. This information enables predicting relative heating rates for different surface conditions and their respective emissivity values (Fig. 4).

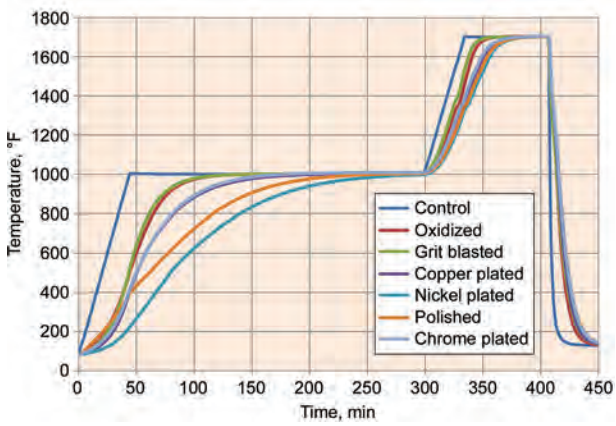


Fig. 3 — Effect of surface condition and corresponding emissivities on time to heat carbon-steel test blocks in a vacuum furnace.

EFFECTS OF TEST BLOCK MASS AND CROSS SECTION

A second series of test blocks was used to further demonstrate the importance of correct cross section and surface condition in thermocouple test blocks. Pairs of three different block sizes (1, 1.75, and 2.5 in. cube) consisted of polished and oxidized blocks.

Dummy blocks were loaded into a workbasket similar to that described above (Fig. 5), and the workbasket was placed into the furnace. Process cycle steps were as follows:

1. Pump furnace down to initial vacuum of less than 1×10^{-3} torr
2. Heat furnace to 1150°F at 15°F per minute
3. Hold at 1150°F until all blocks are within 10°F of set point and hold 15 minutes

TABLE 2–EFFECT OF SURFACE CONDITION AND EMISSIVITY ON TIME TO HEAT CARBON STEEL TEST BLOCKS IN VACUUM FURNACE(a)

Surface condition	Approximate emissivity	Heating time to 1000°F, min	Heating time from 1000° to 1700°F, min	Total heating time, min
Grit blasted	0.75–0.80	111	49	160
Oxidized	0.80–0.95	114	54	168
Chromium plated	0.20–0.40	152	68	220
Copper plated	0.04–0.57	168	68	236
Polished	0.12–0.40	241	74	315
Nickel plated	0.045–0.08	264	75	339

(a) 2.5 in. cubes with different surface conditions

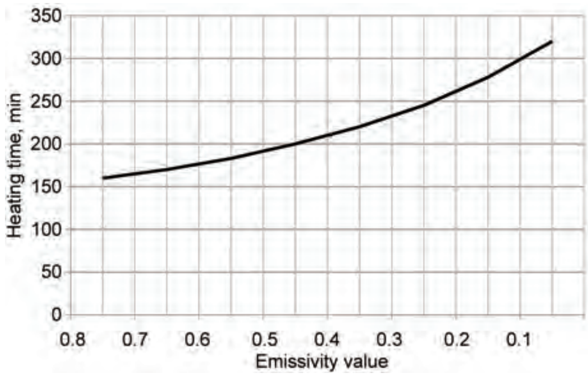


Fig. 4 — Projected heating times based on material surface condition and corresponding emissivity.

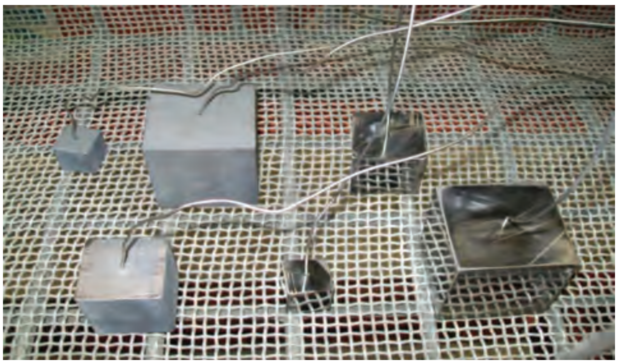


Fig. 5 — Carbon-steel test blocks with thermocouples used to determine the effects of size and surface condition on times to heat to temperature in a vacuum furnace.

4. Heat furnace to 1700°F at 15°F per minute
5. Hold at 1700°F until all blocks are within 10°F of set point and hold 15 minutes
6. Cool load and furnace back to unloading temperature

Figure 6 shows the plots of thermocouple readings as a function of time, and Table 3 shows the effects of size and surface condition for the same emissivity. This further emphasizes that consideration must be given to thermocouple test blocks regarding mass, cross section, and surface condition. For example, a 1 in. cube of polished carbon steel took longer to heat to temperature than a 2.5 in. cube of oxidized carbon steel.

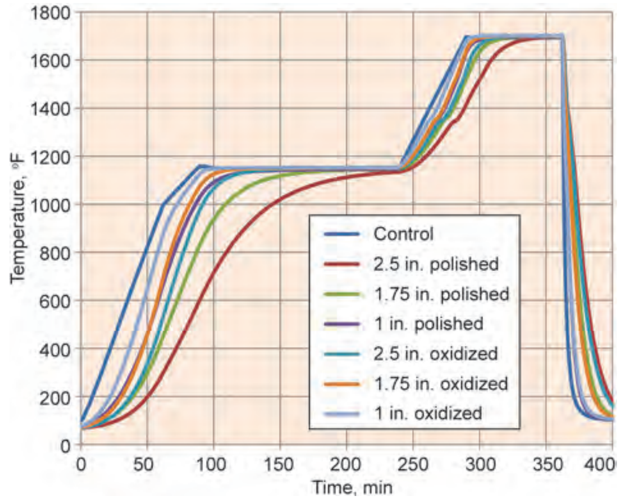


Fig. 6 — Effect of size and surface condition on time to heat carbon-steel test blocks in a vacuum furnace.

The following conclusions are derived from this study:

- Radiation heating of materials in a vacuum furnace is greatly affected by the material's emissivity and absorptivity
- Bright, polished materials take much longer to heat than materials with dull, dark surfaces
- Material surface roughness affects heating rate, because rough surfaces heat faster than smooth, reflective surfaces
- When using thermocouple blocks to simulate actual load parts, the material and cross section must not only be similar, but also the surface condition (color and texture) must be the same
- Thermocouple test blocks should be periodically reconditioned to maintain proper surface smoothness and appearance
- A workload with a particular surface condition compared with a workload of the same material with another surface condition could take up to twice as long to reach the desired temperature

For more information: Reàl Fradette is senior consultant, Solar Atmospheres Inc., 1969 Clearview Rd., Souderton, PA 18964, rfradette@solaratm.com, solaratm.com.

TABLE 3–EFFECT OF SIZE AND SURFACE CONDITION ON TIME TO HEAT CARBON STEEL TEST BLOCKS IN VACUUM FURNACE

Test block size/surface condition	Approximate emissivity	Heating time to 1000°F, min	Heating time from 1000° to 1700°F, min	Total heating time, min
1 in. cube/ oxidized	0.80–0.95	68	39	107
1.75 in. cube/ oxidized		79	46	125
2.5 in. cube/ oxidized		98	48	146
1 in. cube/polished	0.12–0.40	100	53	153
1.75 in. cube/polished		135	55	180
2.5 in. cube/polished		166	73	239

ADVANCING SELF-PIERCE RIVET TECHNOLOGY THROUGH ALLOY DEVELOPMENT

Stephen Van Hall and Kip Findley,* Colorado School of Mines, Golden

Automotive manufacturers are increasing their use of high-strength steel with lightweight aluminum body components to achieve stringent Corporate Average Fuel Economy (CAFE) standards through weight reduction, without compromising passenger safety and vehicle durability[1]. Joining aluminum to different materials by welding presents challenges due to the formation of oxides and different material melting points[2]. However, it is possible to produce joints with adequate strength and durability using mechanical spot-joining methods, which enables using different material combinations in vehicle design.

SELF-PIERCE RIVETING

One mechanical spot joining technique of particular interest is self-pierce riveting (SPR), which is used in the construction of the 2015 Ford F-150 pickup truck[3]. SPR provides a robust joint, which often outperforms clinching and spot welding under both static and fatigue conditions, while providing fast cycle times, zero waste, and the ability to join different material combinations[4].

Rivets used in automotive applications are cold forged from a range of steel wire alloys. AISI 10B37 is one of the most widely used grades (Table 1). Rivets are heat treated to achieve a fully martensitic microstructure, which provides the high strength required for a successful joint. A schematic of the joining process is shown in Fig. 1. The joint is formed by forcing (piercing) a semi or fully tubular rivet through top sheet(s) using a robotically actuated C-frame containing a servoelectric punch and opposing die. The die forces the rivet to flare into the bottom sheet without perforating the sheet, producing a significant interlock that provides joint strength. The potential for corrosion is minimal because previously applied coatings are preserved in the process.

Joining steel and aluminum using SPR is well established and widely used in the automotive industry. Increasing interest in using very high-strength steel alloys for vehicle construction offers an opportunity to extend the use of current SPR by further developing rivet material. SPR technology can be applied to a wide range of materials using rivets with different hardness levels depending on the application. For example, rivets with low and medium hardness are used to join soft materials, providing a large degree of flare, which creates a large mechanical interlock (more than 0.4 mm) that resists rivet pull through and produces a strong joint. For joining high-strength steels, only 0.2 mm of rivet flare is required to resist rivet pull through and produce a strong joint.

RIVET MATERIAL DEVELOPMENT

Joining very high-strength steels requires using rivets at the top end of the rivet-hardness scale and with improved mechanical properties, which enable producing these challenging joints. Rivet development is of particular interest for

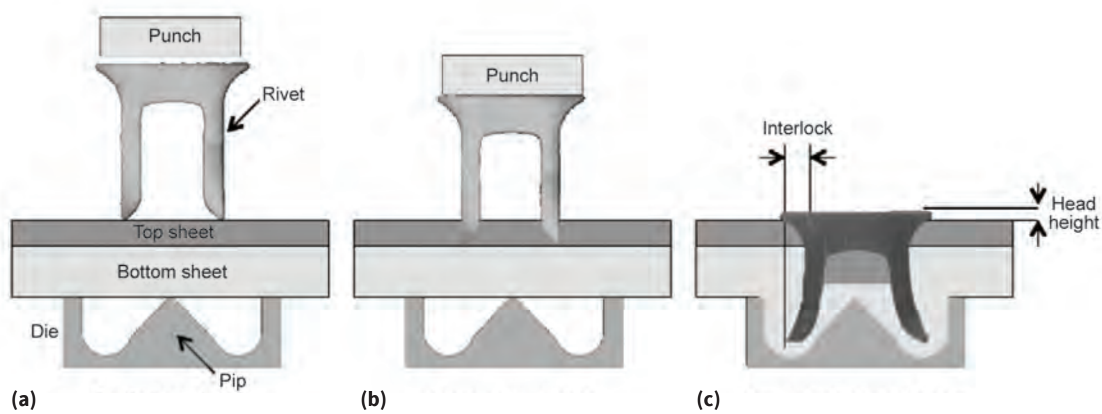


Fig. 1 — Schematic showing the SPR process of joining two sheet materials: (a) Setting stack up, (b) piercing the top sheet, and (c) flaring into bottom sheet. Joint strength is provided by the mechanical interlock between the rivet and top sheet.

*Member of ASM International

joining press-hardened steel (1500 MPa tensile strength) to 6000 series aluminum. Joining high-strength steel requires a rivet skirt hard enough to pierce the material, strong enough to resist compressing and buckling, and ductile enough to flare outwards at least 0.2 mm without cracking.

This application requires sufficient rivet column strength and ductility to provide flaring into the bottom sheet to create a strong interlock. The joint cross section in Fig. 2a shows that if the rivet hardness is too high without the required ductility, fractures form on the periphery of the rivet tail. Fractures are visible in the bottom view of the extracted rivet (Fig. 2b); joints in which fractures occur in the rivet cannot be used in automobiles. The cross section of a rivet (Fig. 2c) tempered to obtain sufficient ductility to accommodate the flare without forming fractures in the rivet tail shows that tempering also reduces column strength, which can cause buckling when piercing press-hardened steel. Development of a rivet material that provides greater ductility at the required column strength would enable the use of SPR technology for a greater range of high strength steel-to-aluminum joints.

New rivet materials also could simplify production. Currently, dozens of rivet and die combinations are required to join the wide range of different stack material combinations in a vehicle body. A rivet with the necessary ductility at strength levels that prevent buckling could simplify assembly by reducing the total number of unique rivet and die combinations and the associated robotic machinery. The process of reducing the number of different combinations to reduce cost and complexity is referred to as "*commonization*." In addition, in joints where a slightly longer rivet can be used, selecting a rivet material with increased ductility could enable achieving even more commonization. In joints where higher ductility allows using a different rivet hardness, more commonization benefits are realized by reducing the number of different rivet hardness levels.

Improved ductility at high rivet hardness would increase possible SPR applications. Fractures on the periphery of the rivet tail (Fig. 2a) are believed to develop from a tensile hoop stress at the rivet tail that evolves during flaring. Alternative steel alloys and thermal processing techniques are under investigation to provide improved ductility.

Prototype 4340 alloy steel rivets were evaluated in riveting trials. The chemical composition of the 4340 alloy used is provided in Table 1. Rivets were machined from wire rod by Henrob Corp., New Hudson, Mich., and heat treated to various hardness levels under laboratory conditions. They were inserted into a press-hardened steel and 6000 series aluminum sheet metal stack (Fig. 2) to evaluate the impact of improved mechanical properties on rivet performance. Figure 3a shows a joint cross section containing a prototype rivet tempered to a high hardness. Interlock distances for 10B37 rivets and prototype 4340 rivets are shown in Table 2. Initial

TABLE 1–CHEMICAL COMPOSITION OF SELECT STEEL RIVETS

Steel grade	Element, wt%					
	Fe	C	Mn	Si	Cr	B
10B37	Bal	0.35–0.41	0.7–0.8	0.1 max	0.2–0.3	0.005 max
4340	Bal	0.41	0.73	0.29	0.84	…

TABLE 2–CHARACTERISTICS OF 10B37 FORGED RIVETS AND 4340 MACHINED PROTOTYPE RIVETS

Steel grade	Hardness (HV)	Interlock distance, mm	Failure mode
10B37	590	0.47	Tail fracture
10B37	550	0.62	Buckling
4340	595	0.64	None apparent

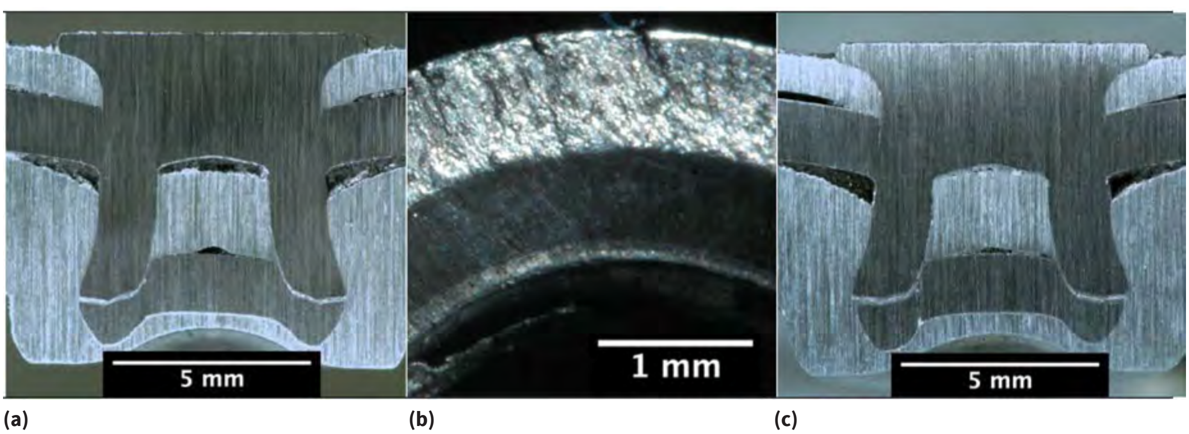
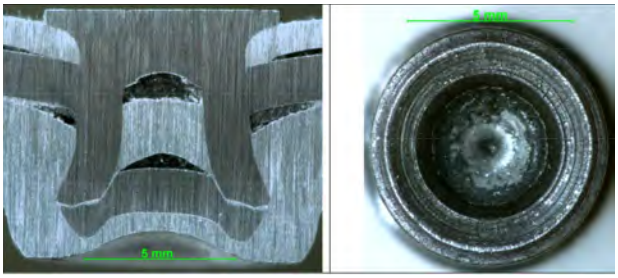


Fig. 2 — (a) Cross section of an aluminum-press-hardened steel-aluminum joint with a rivet tempered to a high hardness level; (b) bottom view of rivet extracted from joint shown in (a), which indicates cracking in the rivet tail; and (c) cross section of an aluminum-press-hardened steel-aluminum joint with a rivet tempered to a lower hardness level, where no rivet tail cracking occurred.



(a) (b)

Fig. 3 — AISI 4340 prototype rivets joining press-hardened steel to 6000 series aluminum: (a) no obvious rivet failures and significant interlock between steel and aluminum sheets, (b) no fractures along rivet periphery.

results indicate that the prototype rivets can accommodate a higher degree of flaring before fractures occur. A bottom view of the rivet (Fig. 3b) demonstrates the ability of the rivet to sustain significant flare without fractures forming. Assessment of alternative alloys including 4340 and other ultra-high-strength steel alloys is ongoing.

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For more information: Kip Findley is associate professor, Colorado School of Mines, Golden, CO 80401, 303.273.3906, kfindley@mines.edu, www.mines.edu.

ASMNEWS

Robert Fulton to Chair 2015 Nominating Committee

Members of the 2015 Nominating Committee have been selected and **Robert J. Fulton, FASM,** president (retired), Hoeganaes Corp., Bonita Springs, Fla., was elected to serve as chair by the ASM Board of Trustees. Fulton has been a member of ASM International since 1966 and served as ASM Treasurer and Chair of the ASM Finance Committee from 2010-2014. He continues to serve as a member of the Finance Committee and Investment Committee, and was active in the ASM Lehigh Valley Chapter in the 1960s and 1970s serving as chapter chair. He received the Philadelphia Liberty Bell Chapter's Eisenman Award, ASM Distinguished Life Membership (2007), and is an ASM Fellow (2013). Fulton is also a member of SAE and ASPMI.


Fulton

ASM Officers Appoint Members

In accordance with the ASM International Constitution, ASM president **Dr. Sunniva R. Collins, FASM,** vice president **Mr. Jon D. Tirpak, FASM,** and immediate past president **Prof. C. Ravi Ravindran, FASM,** appointed nine members to the Nominating Committee from among candidates proposed by chapters, committees, councils, and ASM Affiliate Society boards. The committee is responsible for selecting a nominee for vice president-trustee (one-year term) and for nominating three trustees (three-year terms). Members do not select a candidate for president of the society, because Article IV, Section 3 of the Constitution states that the office of president shall be filled for a period of one year by succession of the vice president. The 2015 Nominating Committee's nominee for vice president will serve as ASM's president in 2017.

Nominating Committee members for 2015 include:

Beth Armstrong, research staff member, Oak Ridge National Laboratory, Tenn. (nominated by Volunteerism Committee); **Prabir Chaudhury,** global technical director designate, Metals Technology, Exova, Santa Fe Springs, Calif. (nominated by Phoenix Chapter); **Susan Hartfield-Wunsch,** technical fellow, General Motors, Livonia, Mich. (nominated by Detroit Chapter); **John Hayden,** chairman, Hayden Corp., West Springfield, Mass. (nominated by Thermal Spray Society); **John Marcin,** FASM, manager, United Technologies-Pratt & Whitney, East Hartford, Conn. (nominated by New Products and Services Committee); **Michael O'Brien,** senior project leader, The Aerospace Corp., Los Angeles (nominated by Los Angeles Chapter); **Anthony Petric,** FASM, professor, McMaster University, Hamilton, Ontario (nominated by Ontario Chapter); **Marissa Reigel,** senior engineer, Savannah River National Laboratory, Aiken, S.C. (nominated by Savannah River Chapter); **Maria Winnicka,** senior staff R&D engineer, Fabricated Products Group, H.C. Starck Inc., Cleveland (nominated by Chapter Council).

The Nominating Committee will meet on April 16-17 and its recommended slate of officers will be published in the June issue of *ASM News*.

In This Issue

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Fulton Chairs Nominating Committee	SMST Announces New Board	Canada Council Awards	Chapter News	Members in the News

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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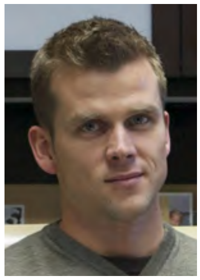
Contact ASM International at 9639 Kinsman Road, Materials Park, OH 44073 | P 440.338.5151 ext. 0 or 800.336.5152 ext. 0 (toll free in U.S. and Canada) | F 440.338.4634 | E MemberServiceCenter@asminternational.org | W asminternational.org

HIGHLIGHTS COMMITTEE COUNCIL CHAIRS


Daly


Schaffer

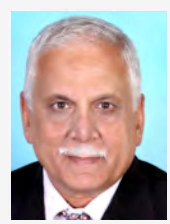

Stebner


Mertmann


Pelton

SMST Announces New Officers and Board Members

In accordance with their Rules of Governance, the International Organization on Shape Memory and Superelastic Technologies (SMST) completed its elections for officers and board members for 2015. **Aaron Stebner,** assistant professor, Colorado School of Mines, was appointed president of SMST, while **Jeremy Schaffer,** engineer, Fort Wayne Metals, was appointed vice president/finance officer. **Matthias Mertmann,** president, Redsystem GmbH, remains on the board as immediate past president. The officers serve a two-year term. The SMST membership elected new board members **Samantha Daly,** associate professor, The University of Michigan, and **Alan Pelton,** chief technical officer and secretary, G. Rau Inc. Both new directors will serve three-year terms.


Premkumar

Correction

Aurora Premkumar is now chair of the India Council. This was listed incorrectly in *ASM News,* January issue.

ASM INTERNATIONAL | 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 members 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

JOB OPPORTUNITY

CMDNetwork™

ASM Seeks Technical Director to Lead CMD Network

ASM International is searching for qualified candidates to fill a newly created position—Technical Director, Computational Materials Data. Reporting directly to ASM's managing director, the role will provide technical leadership and management for ASM's Computational Materials Data (CMD) Network, which supports, facilitates, and promotes collection, dissemination, and management of materials data. Launched in response to the U.S. Materials Genome Initiative, the network aims to advance materials development and deployment by facilitating information sharing within the materials community.

The technical director will lead development efforts and engage with the materials data community to conceptualize, design, develop, deliver, and promote CMD Network programs and services, including data curation projects, workshops and events, and education courses. In addition, the new director will provide technical guidance and management for CMD Network data initiatives, including management of support staff. Qualifications include an advanced degree in materials science, mechanical or chemical engineering, data analytics, or a related discipline plus 10 years of professional experience as a research scientist/engineer or a combination of education and experience. For a complete job description, visit http://bit.ly/1HncCpe. To apply, send a cover letter and curriculum vitae to hr@asminternational.org.

For more information, contact Scott Henry at 440.338.5401 or scott.henry@asminternational.org.

HIGHLIGHTS STEM EDUCATION

FROM THE PRESIDENT'S DESK


Collins

On Becoming a Role Model and Mentor

Over the past several years, I've read many studies about the state of engineering in the U.S., and the problems with workforce development. Here are some interesting metrics from these studies:

- 80% of students who enter STEM fields have had calculus and physics by the time they finish high school.
- The choice of science and math level for 9th grade is a strong indicator of whether a student is prepared to enter an engineering curriculum at college. Most 8th grade students don't know that by opting for the "easier" math, they are making a decision that eliminates an entire class of highly compensated employment options.
- Achievement levels for boys and girls on standardized math and science tests are comparable until about 10th grade; the variation has less to do with ability and more to do with confidence.

I realized that I couldn't be a role model and mentor by just sitting in my office, so I judged science fairs and spoke to any group that asked me about my career. In 2000, I was able to attend the first ASM Materials Camp ever held. The excitement of the students and their mentors was infectious. From this simple start, the ASM Foundation's flagship program has evolved into camps for both students and teachers, tailored to local needs and dependent on the untiring efforts of volunteers. Our efforts are part of the increased focus on STEM education across the country, and they are paying off. If you want to help prepare the next generation of engineers, here are some ideas:

- Start thinking about yourself as a role model and mentor. Your unique experience is worth sharing so others can learn from you.
- Judge a science fair, attend a career day, tutor students in math, or have lunch with a student interested in engineering.
- Find a mentoring opportunity that you enjoy and stick with it! Your efforts are needed and appreciated.

Sunniva R. Collins
sunniva.collins@case.edu

AUTHOR SPOTLIGHT


Chattopadhyay

Ramnarayan Chattopadhyay

Dr. Ramnarayan Chattopadhyay published his new book, *Green Tribology, Green Surface Engineering, and Global Warming*, with ASM in 2014. Chattopadhyay is also the author of *Surface Wear: Analysis, Treatment, and Prevention* (ASM, 2001), *Advanced Thermally Assisted Surface Engineering Processes*, (Kluwer Academic Publishers, 2004), and co-author of *Global Warming, Origin, Significance, and Management* (Global Vision Publishing House, 2012).

His new book describes green engineering concepts that improve energy efficiency by reducing energy losses due to friction and wear in metalworking operations, and by extending component life. Reducing energy consumption lowers emissions and conserves resources, thereby improving sustainability. He said he had a great experience working with ASM on this book because he was able to concentrate on the manuscript and "leave the rest to the professional teams."

Chattopadhyay has presented and published more than 100 research and technical papers at national and international conferences on diverse subjects such as tribology, surface engineering, welding, and powder metallurgy. He is recognized for his books, contributions to solving critical wear problems in major industries, and support of research and academic training.

Detroit Rewards Student Achievement

As part of its Student Outreach Program, the ASM Detroit Chapter judged a "Best Use of Materials Award" at the 2015 Michigan Regional Future Cities Competition. A nationwide competition, Future Cities challenges middle school students to design and create a futuristic city. Henderson Academy, Detroit, won "Best Use of Materials" for their city, "Magic 7." Their teacher, Ms. Wanda Bryant, is an alumnae of a 2014 ASM Materials Teachers Camp and was recently honored as the Detroit Chapter's 2014 Peg Jones Teacher Scholar. The chapter thanks James Boileau, Jon Carter, Mark Harper, Melissa Kamai-Arambula, Pete Klass, Eric McCarty, JP Singh, and Veronica Thelander for serving as judges.

Left to right, James Boileau, Precious Moon, Tabita Hunter, and Wanda Bryant. Courtesy of ESD.

Detroit Recognizes Teacher Scholars

As part of its Student Outreach Program, the Detroit Chapter created the Teacher Scholar Program to assist Materials Camp alumni in demonstrating materials science to their students. The Scholar Award consists of a $250 grant to be used for equipment and supplies needed to perform materials experiments. The Chapter's first class of Teacher Scholars include Pamela Opolsky (Academy of International Studies, Hamtramck); Wanda Bryant (Henderson Academy, Detroit); Judy Armstrong-Hall (Larson MS, Troy); Stephen Barry (Harper Creek HS, Battle Creek); Jaime Hilliard (Macomb Mathematics Science Technology Center); and Michelle Sauter-Portelli (Central Academy, Ann Arbor). The Chapter is also proud to name two of the scholarships for Kathy Hayrynen and Peg Jones. Both have greatly contributed to the formation, organization, and operation of the Materials Camp for Teachers in Ann Arbor for many years.

ASM President Sunniva Collins (far left) and Peg Jones (far right) with the 2014 ASM Detroit Teacher Scholars, left to right: Michelle Sauter-Portelli, Pamela Opolsky, Judy Armstrong-Hall, and Wanda Bryant.

Peoria Hosts Engineering Workshops

On January 28, the Peoria Chapter's student outreach volunteers participated in a hands-on engineering workshop organized for 5th and 7th graders at Thomas Metcalf School, Normal, Ill., on the campus of Illinois State University. Students learned about some of the fundamentals of materials science, including the importance of chemical reactions, heat treating, and casting on materials behavior and properties. The students were engaged and interested throughout the program. At the end of the session, several declared they wanted to be engineers when they grow up.

Colombia Chapter Celebrates

A new Materials Advantage student chapter in Colombia is ready for action.

Montreal Holds Poster Competition

On February 11, the Montreal Chapter staged its most successful Student Poster Competition event at Concordia University's downtown campus. Thirty-seven posters by students from local universities attracted 93 students, academics, and industry members—the highest number in many years. A total of eight prizes with an overall value of $2450, donated by corporate and academic sponsors, were awarded by a panel of judges at either the Ph.D. or Master's level. After a break for beer and pizza, the group enjoyed a review of cold spray technology by Prof. Bertrand Jodoin from the University of Ottawa.

A jury member evaluates one of the Montreal research posters.

Suriano Receives DOE Research Award

Anne-Marie Suriano, a South Dakota School of Mines & Technology Ph.D. candidate, will receive the 2015 Science Graduate Research Award from the DOE's Office of Science. Suriano, who is pursuing her doctorate in the materials engineering and science program, will investigate the electrodeposition of ultra-high purity copper alloys for use in low background experiments such as those at the Sanford Underground Research Facility (SURF). Suriano's one-year DOE appointment will begin in May at the Pacific Northwest National Laboratory in Richland, Wash.

Das Elected to NAE

Santosh Das, FASM, was among the 67 individuals recently elected to the National Academy of Engineering (NAE). Das, who retired as vice president, Polymer Technologies Inc., Clifton, N.J., was elected for his contributions to the understanding of the composition, structure, property, and processing interrelationships of rapidly solidified amorphous and microcrystalline alloys. He earned engineering degrees from Indian Institute of Technology, Kharagpur, and the University of California, Berkeley in materials science and engineering. After graduation, he worked as a scientist at Argonne National Laboratory and then as manager of materials science for corporate R&D, Honeywell Inc., Morristown, N.J. Das has authored more than 130 research publications and holds 43 patents in the field of rapid solidification.

IN MEMORIAM

William White, FASM, Life Member, was born on July 25, 1939, in Toronto and passed away recently. He was just 22 when a workplace accident left him a paraplegic. After dropping out of school in grade 13, he later completed a three-year engineering diploma at Ryerson in 1966. He then became a research assistant at the University of Saskatchewan and attained his Ph.D. in mechanical engineering in 1977. He worked as a professor at University of Calgary and became head of Petro-Canada's University Research Lab in 1982. He returned to Ryerson in 1987 as Dean of Engineering and Applied Science. Six engineering programs were accredited under his leadership, allowing Ryerson to become a university. White was also a longtime member of the International Metallographic Society.

Alfred J. Babecki died on January 17 at age 89. He was born an August 23, 1925, in Glen Lyon, Pa. A World War II veteran, he served in the U.S. Army during the Battle of the Bulge from Dec. 1944 to Jan. 1945, in Belgium and Luxembourg. Babecki graduated from Penn State University with a B.S. in metallurgy. He worked as metallurgist, initially at ACF in Berwick, Pa., and later at the Naval Research Laboratory in Washington. In 1962, he transferred to NASA's Goddard Space Flight Center in Greenbelt, Md., where he received patents for chemical processes and resolved spacecraft failures until he retired from NASA in 1984.

QuesTek Joins ASM in Full Force

As part of the ASM Power of One Membership Drive, five colleagues at QuesTek Innovations have joined our Society! Pictured here is the lead recruiter, **Jason Sebastian** (rear), with new members **Nick Hatcher** and **James Saal** (middle, left to right), and **Jagan Padbidri, Dave Snyder,** and **Weiwei Zhang** (front, left to right). Not pictured are veteran ASM members **Aziz Asphahani, FASM, Jeff Grabowski, Clay Houser, Greg Olsen, FASM,** and intern **Tom Kozmel (student member)**.

CMDNetwork™ ASM INTERNATIONAL

Employment Opportunity

Technical Director, Computational Materials Data

Help guide the future of materials data!

ASM International is seeking candidates for the new position of Technical Director, Computational Materials Data. Reporting directly to the ASM Managing Director, the position will provide technical leadership and management for ASM's Computational Materials Data (CMD) Network.

- → **Lead development of and engagement with the materials data community** to conceptualize, design, develop, deliver, and promote CMD Network programs and services, including data curation projects, workshops and events, and education offerings.
- → **Provide technical guidance and management** for CMD Network data initiatives, including management of support staff.
- → **Provide leadership for the CMD Network** in developing a community of dedicated and involved members and partners.
- → **Serve as a highly visible ambassador, expert, and thought leader** on data issues, including best practices for management and curation of materials data and integration with modeling, simulation, and analysis programs.

KEY RESPONSIBILITIES

- Serve as the single point of accountability in successfully delivering new programs and services
- Serve as a technical expert to the engineering community on behalf of the CMD Network on concepts related to the management and curation of materials data and integration with modeling, simulation, and analysis programs
- Provide technical expertise and guidance for data management and database development projects
- Lead the development of new conferences, symposia, and workshops in areas related to materials data
- Lead the development of new education course offerings in areas related to materials data
- Provide technical direction and leadership for new and established ASM programs, products, and services
- Support ASM staff in their understanding and effective utilization of technical concepts and terminology
- Informally mentor ASM and CMD Network staff members to help them flourish in their careers
- Develop and deliver presentations and reports for internal staff, ASM Committees, and partners; deliver talks at relevant conferences and workshops

REQUIRED QUALIFICATIONS

- Advanced degree in materials science, mechanical or chemical engineering, data analytics, or a related discipline
- Ten years of professional experience as research scientist/engineer or a combination of education & experience; some of this experience in a leadership or management role
- Recognized expertise in topics related to the development, use, curation, and management of data

ASM International offers a competitive compensation and benefits package. Salary will be commensurate with experience.

ASM International is committed to equal opportunity employment regardless of race, color, national origin, age, sex, sexual orientation, marital status, citizenship, religion, disability, veteran status, or genetic information and all protected categories. ASM is an E-Verify organization.

TO APPLY: Send a cover letter and your curriculum vitae to hr@asminternational.org

For Additional Information: Scott D. Henry, Director of Content and Knowledge Based Solutions, ASM International, scott.henry@asminternational.org or 440.338.5401

About ASM International

ASM International, www.asminternational.org, was founded in 1913 as the American Society for Metals. Today, ASM is the world's largest association of metals-centric materials scientists and engineers with more than 30,000 members worldwide. ASM is dedicated to informing, educating and connecting the materials community to solve problems and stimulate innovation around the world. ASM's iconic headquarters facility is located in Materials Park, east of Cleveland.

About the Computational Materials Data Network

The Computational Materials Data Network (CMD Network) supports, facilitates, and promotes the collection, dissemination, and management of materials data. Launched in response to the U.S. Materials Genome Initiative, the network aims to advance materials development and deployment by facilitating information sharing within the materials community. Additional information about CMD Network initiatives is available at www.cmdnetwork.org.

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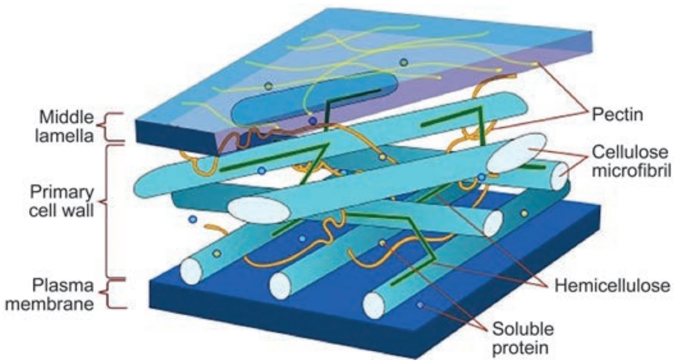
SUCCESS ANALYSIS

SPECIMEN: EARTH-FRIENDLY COMPOSITES



Schematic of a wood cell wall, showing the substructure of load-bearing cellulose microfibrils. Courtesy of U.S. Forest Service.

Joshua Otaigbe, The University of Southern Mississippi.

John Nairn, Oregon State University

VITAL STATISTICS

A new technology aims to use natural wood fibers to reinforce plastic materials. If successful, researchers believe it could revolutionize the composites industry, especially manufacturing sectors that rely on these materials, such as automotive and aerospace. Currently, the composites industry combines wood *particles*—rather than *fibers*—with its polymers. "This saves money, but is a less optimum way of doing it," says Joshua Otaigbe, a professor in The University of Southern Mississippi's School of Polymers and High Performance Materials. "We are extracting fibers, which are different from particles. The fiber is a lot stiffer and stronger than the wood particles, and provides the reinforcing capability for the plastic."

SUCCESS FACTORS

Using wood fibers instead of particles in the direct conversion of polymer building blocks called monomers also allows manufacturers to eliminate the melting stage, when materials are shaped and later solidified into various products. "With fibers in the polymer matrix, we can shape it without having to melt it," says Otaigbe.

The process under development involves taking the wood fibers, usually within paper, placing them in a mold, and then injecting a reaction mixture used to make the polymers. Scientists then raise the temperature to 150°C, relatively low compared to traditional melting methods. "The mixture forms a composite in a matter of minutes," explains Otaigbe. Lower temperatures are important because wood fibers tend to degrade at temperatures above 190°C.

ABOUT THE INNOVATORS

The National Science Foundation is funding the work through its structural materials and mechanics program of the division of civil, mechanical, and manufacturing innovation. Otaigbe is collaborating with John Nairn, the Richardson Chair in wood science and engineering at Oregon State University. The two researchers are sharing the grant.

WHAT'S NEXT

Otaigbe is also studying ways to generate nanostructured hybrid glass/organic polymer materials via molecular level mixing of the components in a liquid state, creating novel hybrids impossible to produce using conventional methods. These products could translate into improved energy efficiency for such applications as high-powered laser fusion systems, biomaterials, storage materials for nuclear wastes, and as a component in load-bearing organic-inorganic hybrid composites.

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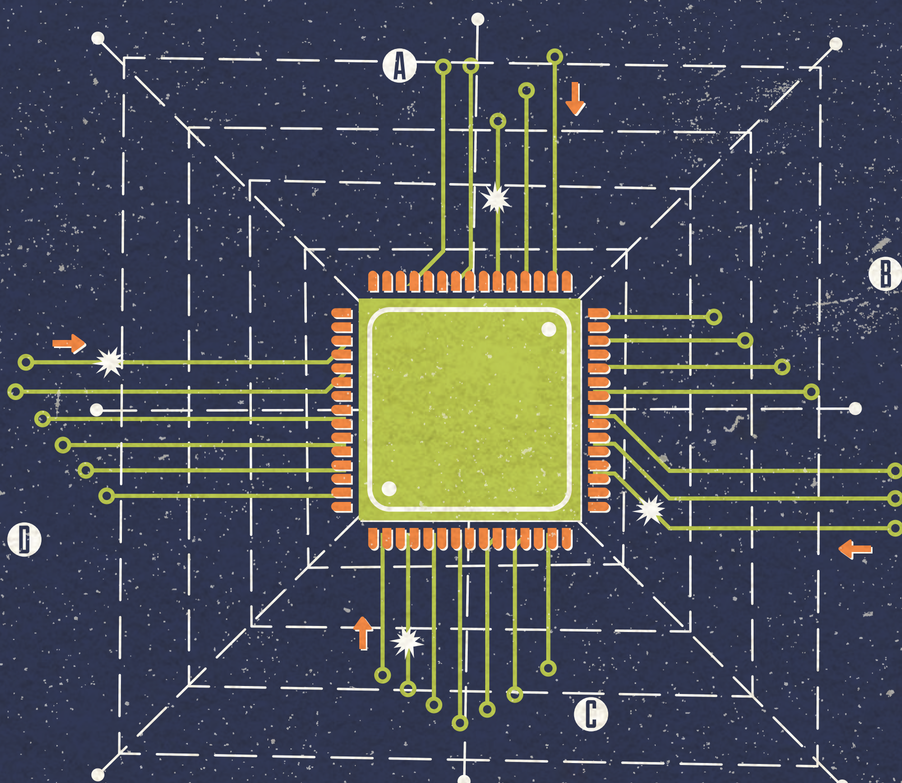

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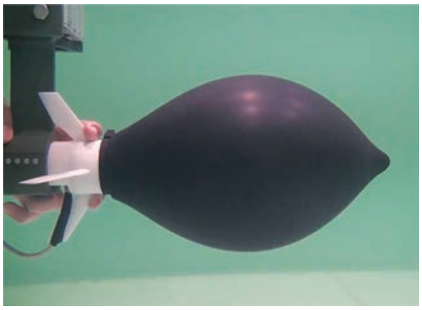

Octopus robot. Courtesy of University of Southampton.

OCTOBOT FEATURES 3D-PRINTED SKELETON

Scientists from the University of Southampton, UK, Massachusetts Institute of Technology (MIT), Cambridge, and the Singapore-MIT Alliance for Research and Technology built a deformable octopus-like robot featuring a 3D-printed skeleton with no moving parts and no energy storage device other than a thin elastic outer hull. The 30-cm-long self-propelling robot is inflated with water and then rapidly deflates by shooting water out through its base to power propulsion and acceleration, despite starting from a non-streamlined shape. It works like blowing up a balloon and then releasing it to fly around the room. However, the polycarbonate skeleton keeps the balloon tight and the final shape streamlined, while fins on the back keep it going straight. *www.southampton.ac.uk, web.mit.edu, smart.mit.edu.*

THE UNSTAINABLE T-SHIRT

Dubbed *The Cavalier,* a new 100% cotton t-shirt created by Threadsmiths, Australia, incorporates lotus leaf-inspired nanotechnology that completely repels dirt and liquids, leaving the surface of the fabric crisp, dry, and stain-free. The fibers of the shirt were created with new "water-fearing" nanotechnology. While other white t-shirts are stained and ruined by liquids such as coffee and wine, The Cavalier's hydrophobic properties cause liquids to bead up and fall off the fabric—cleaning it in the process. The patented fabric is free of carcinogens and completely safe, according to company sources. Threadsmiths hopes to expand the technology to other industries such as medical, hospitality, and sports in the near future. *www.threadsmiths.com.au.*

Veronica Berns, a 2014 chemistry Ph.D., wrote and illustrated a comic book to make the science in her thesis more accessible. Her studies concerned rule-breaking structures called quasicrystals.

CHEMISTRY THESIS IS THE STUFF OF COMIC BOOKS

As thesis writing approached, University of Wisconsin-Madison graduate student Veronica Berns faced a conundrum. She knew how hard it was to describe her work to friends and family—pretty much anybody outside the tight clan of structural chemists. And that was particularly true because she concentrated on a category of should-be-impossible structures called quasicrystals.

Berns liked drawing and using "normal, English-language words," and so about a year before graduation, she opted to accompany her traditional Ph.D. thesis with a comic book version. About a year before graduation, she began drawing with pen and ink on paper, then scanned and digitally colored the images. Berns had one ground rule for the comic treatment: "It was really important to me that I not simplify the science until it wasn't true. I learned a lot about how to talk about my work from drawing and writing the comic book." *wisc.edu.*