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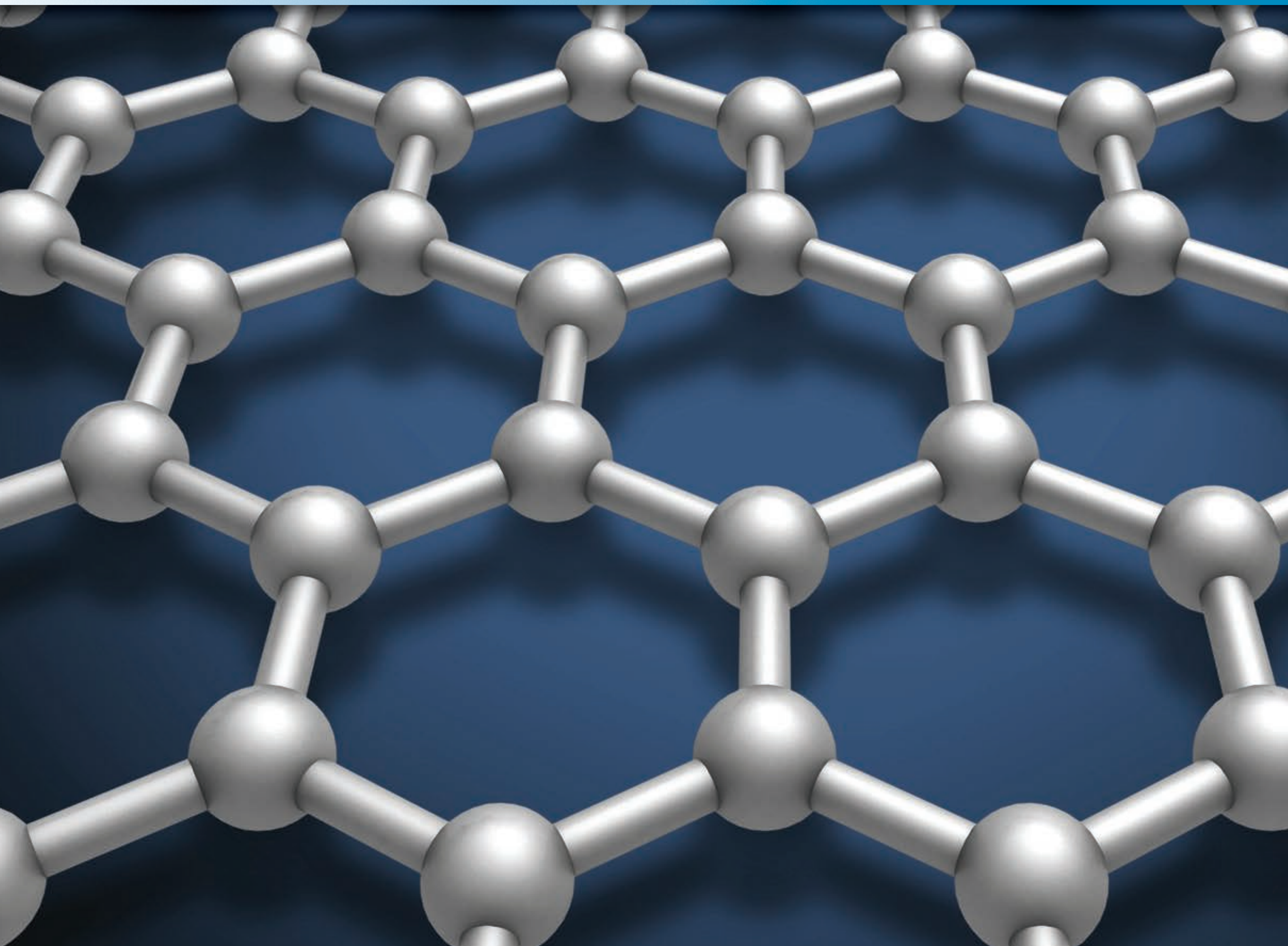
NOVEMBER-DECEMBER 2014 • VOL 172, NO 11



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Materials Testing/Characterization

INCLUDED IN THIS ISSUE

Graphene Surface Modification •

Automotive Spot Weld Testing •

Software for Materials Testing •

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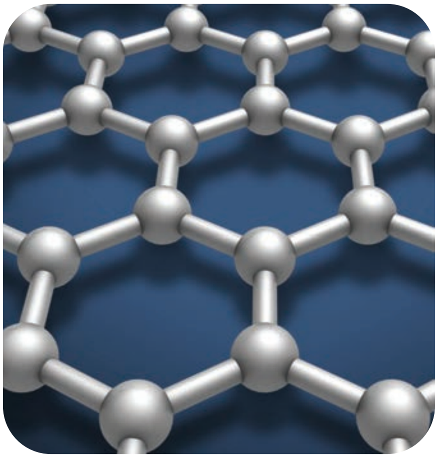

ON THE COVER:
Graphene has incredible intrinsic properties, showing great potential for industrial and commercial applications across a wide range of industries. Courtesy of Haydale Ltd., Carmarthenshire, UK. haydale.com.

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See 2015 Education Courses Insert on Page 49!

DEPARTMENTS

Check out the digital edition online at amp.digitaledition.asminternational.org

ASM International serves materials professionals, nontechnical personnel, and managers worldwide by providing high-quality materials information, education and training, networking opportunities, and professional development resources in cost-effective and user-friendly formats. ASM is where materials users, producers, and manufacturers converge to do business.

Advanced Materials & Processes (ISSN 0882-7958, USPS 762080) is published monthly, except bimonthly November/December, by ASM International, 9639 Kinsman Road, Materials Park, OH 44073-0002; tel: 440.338.5151; fax: 440.338.4634. Periodicals postage paid at Novelty, Ohio, and additional mailing offices. Vol. 172, No. 11, November-December 2014. Copyright © 2014 by ASM International. All rights reserved. Distributed at no charge to ASM members in the United States, Canada, and Mexico. International members can pay a $30 per year surcharge to receive printed issues. Subscriptions: $461. Single copies: $45. POSTMASTER: Send 3579 forms to ASM International, Materials Park, OH 44073-0002.

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materials witness

Looking forward to a fantastic 2015

In ways both large and small, it seems this past year has flown by in a whirlwind of activity culminating in a flurry known as MS&T. This year's action-packed conference in Pittsburgh treated attendees to a wealth of technical sessions, intriguing lectures, fun networking opportunities, and the entertaining ASM awards dinner. It's a real treat to socialize with colleagues and honorees dressed to the nines in tuxes and evening gowns, bringing some Hollywood style glamour to the world of materials science and engineering. Watching our new class of Fellows and other award winners graciously accept honors that represent a lifetime of effort is truly inspiring.

Another enjoyable part of MS&T is the "big picture" lectures, including the Alpha Sigma Mu talk, ASM/TMS Distinguished Lectureship, and other special events such as the inaugural and uplifting Women in Materials Engineering Breakfast and opening plenary session. Alex King, director of the DOE's Critical Materials Institute, kicked off the plenary with a rather harrowing reality check with regard to shortages of (no surprise) critical materials. He gave examples involving rhenium for jet engine turbine blades, NdFeB magnets for disk drives, and lithium and cobalt for advanced batteries. He predicts these shortfalls will likely become worse in the future due a globally emerging middle class who desire the same creature comforts we often take for granted in western cultures—you know, "basics" like cars and cell phones. Another scary point King makes is that ore grades are declining, so it takes more mining to extract the same amount of useful material. He ended the talk with a few ideas for mitigating criticality including diversifying raw sources, developing alternatives to today's materials, and making better use of existing supplies.

Several other speakers and ASM committee members talked about the importance of a multi-material strategy for manufactured goods, especially within the automotive and aerospace industries. As University of Michigan professor Alan Taub put it, "The days of mono-material design are over." He went on to discuss the importance of advanced high-strength steels, increased use of aluminum in cars and trucks, and the rise of carbon fiber composites. Taub stressed that we are now in the midst of "mixed materials optimization" and that the number one problem we are now facing is the joining of dissimilar materials, a thought echoed by many others at this year's conference. Look for articles on this topic in upcoming issues of *AM&P*.

Speaking of *AM&P*, exciting plans are in store for 2015! To coincide with ASM's recent branding initiatives, we just completed a design overhaul to better reflect the leading-edge materials science content within our pages and provide a fresh, updated look for both readers and advertisers. Since 1930, when *Metal Progress* first debuted, our magazine has morphed into several iterations to keep up with the times. Our latest look is set to launch in January. We hope you like it!

On another note, as the holidays are fast approaching, you may be scratching your head about what to buy your loved ones (or as a treat for yourself). ASM has a new lineup of premium apparel items for any situation! Lounge around in a comfy materials science tee or ultra-soft tri-blend hoodie, or decorate your office with artwork featuring original drawings by R. Buckminster Fuller. Check it out at asmgear.com. In the meantime, we wish you all a very happy and healthy holiday season.

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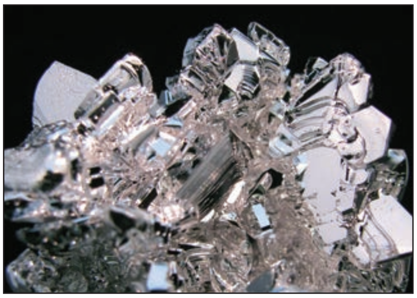
market spotlight

Global lightweight materials market to surpass $186 billion by 2020

A new report titled "Lightweight Materials (Aluminum, Titanium, High Strength Steel, Magnesium, Polymer & Composites and Others) Market for Defense, Energy, Transportation and Other Applications—Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2014-2020," by Transparency Market Research, Albany, N.Y., explores many of the materials used in today's lightweighting efforts across multiple industries. According to the report, the global lightweight materials market was valued at $126.3 billion in 2013 and is anticipated to reach $186.35 billion by 2020, expanding at a compound annual growth rate (CAGR) of 5.8% from 2014 to 2020.

Increasing environmental concerns and regulations to reduce CO_2 emissions from vehicles are anticipated to boost the lightweight materials market, especially in the transportation sector, say analysts. Additionally, reducing vehicle weight increases fuel efficiency, driving demand for lightweight materials in both the automobile and aviation sectors. Aluminum, titanium, and composites are widely used in aircraft structures to support high payload capacity and enhance energy efficiency. However, the high cost of these materials in comparison to conventional metals such as steel is expected to slow global growth of the lightweight materials market during the next few years.



Pacific Northwest National Laboratory (PNNL), Richland, Wash., is developing a new production method for magnesium, a key lightweight material, that would be 50% more energy efficient than the current manufacturing process used in the U.S. Courtesy of PNNL.

Key product segments include aluminum, titanium, high strength steel, magnesium, polymers and composites, and others. Aluminum alone accounted for 30.4% of the worldwide lightweight materials market in 2013 and is expected to experience substantial growth over the next few years. Composites such as glass fiber reinforced plastics, carbon fiber reinforced plastics, metal matrix composites, ceramic composites, and other hybrid materials are anticipated to gain importance in the near future owing to functional benefits over other lightweight materials. These composites are likely to experience significant growth, although their higher cost is expected to restrain usage during the forecast period. Titanium is also expected to experience significant growth in the near future especially in the aviation industry, say analysts.

Transportation—primarily automobiles, aircraft, and railways—remains the largest application segment, accounting for more than 85% of demand for lightweight materials in 2013. Other key sectors include defense and energy. Lightweight materials are employed on a large scale in defense, notably in vehicles and body armor. Another growing application area for lightweight materials is wind energy systems (specifically rotor blades), projected to be the fastest growing segment in terms of volume and expanding at a CAGR of 5.8% from 2014 to 2020. For more information, visit transparencymarketresearch.com/lightweight-materials-industry.html.

feedback

Reader urges sensitivity to native cultures

I happened to note the caption under the photo of the Fort Pitt Block House on page 34 of the September issue (MS&T14 Preview). The description states that this structure is the oldest building west of the Allegheny Mountains, which didn't ring true to me. My first job after graduate school was at Los Alamos and I fondly remember the pueblos of northern New Mexico, which I thought had been continuously inhabited for over 1000 years, as well as some of the old Spanish colonial buildings in Santa Fe. Sure enough, a quick survey of the "List of the Oldest Buildings in the United States" on Wikipedia shows that the statement in the caption needs a qualifier—namely, the oldest "colonial" building and in this case "colonial" referring to the original 13 colonies. Nevertheless, it did pique my curiosity enough to plan a visit to the Block House during my visit to Pittsburgh for MS&T.

Stuart Wright

Fort Pitt Block House in Pittsburgh, circa 1764. Oldest building west of the Allegheny Mountains? Not so much.

Taos Pueblo, a multi-storied residential complex in New Mexico, circa 1450 A.D. Courtesy of Luca Galuzzi, www.galuzzi.it.

Historical metallurgy files seek new home

After running a notice in the June "Feedback" department, several of ASM Life Member J. Gray Bossard's historical books and files have found new homes. A few gems remain: Pittsburgh Chapter Directories, 1979 to 2006; Ronson Metals-Cerium Metals and Alloys Division brochures on rare earth metals; and a Molybdenum Corp. data file on rare earth metals in steel. If interested, send an email to frances.richards@asminternational.org.

Editors

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

of material interest

Tomato fibers could be used to develop plant-based composite materials for use in automobiles.

Tom-auto: Car-ketchup collaboration enables plant-based plastic

Researchers at Ford Motor Co., Dearborn, Mich., and H.J. Heinz Co., Pittsburgh, are investigating the use of tomato fibers in developing sustainable composite materials for use in vehicle manufacturing. Specifically, dried tomato skins could become vehicle wiring brackets or the storage bin a driver uses to hold coins and other small objects.

Nearly two years ago, Ford began collaborating with Heinz, The Coca-Cola Co., Nike Inc., and Procter & Gamble to accelerate development of a 100% plant-based plastic to be used to make everything from fabric to packaging and with a lower environmental impact than petroleum-based packaging materials. At Heinz, researchers were looking for ways to repurpose peels, stems, and seeds from the more than two million tons of tomatoes the company uses annually to produce its best-selling product: Heinz Ketchup. Company leaders contacted Ford.

"We are delighted that the technology has been validated," says Vidhu Nagpal, associate director, packaging R&D for Heinz. "Although we are in the early stages of research and many questions remain, we are excited about the possibilities for both Heinz and Ford, and the advancement of sustainable 100% plant-based plastics." *ford.com, heinz.com.*

Inflatable concrete holds promise for large structures

A concert pavilion is one potential application for a new concrete dome construction method.

Large shell structures made of concrete or stone are rarely built today because construction requires large and expensive supporting assemblies. A new technique for creating concrete shells developed at the Vienna University of Technology, Austria, uses inflatable air cushions instead. A flat concrete slab hardens on the ground while an air cushion below the plate is inflated, bending the concrete and quickly forming a sustainable shell.

"It is similar to an orange peel, which is regularly cut and then flattened out on the table," says professor Johann Kollegger. "We do it the other way around, starting with a flat surface and then bending it to a shell." Kollegger and Benjamin Kromoser, also of TU Vienna, developed the new technique, which was successfully tested on the Aspang Grounds in Vienna.

A flat slab is first created using standard concrete and it is crucial to get the geometric shape exactly right. The slab consists of several segments. Wedge-shaped spaces are left between these segments, so they fit together perfectly when the structure is bent. Once the slab is hardened, an air cushion below is inflated. The cushion consists of two plastic sheets welded together. At the same time, a steel cable is tightened around the concrete segments, so that the concrete is lifted up at the center and pushed together from outside. To ensure that all the concrete segments move in perfect synchronicity, they are connected with metal beams. In the experiment, the entire process was finished after about two hours and the final height was 2.9 m. *www.tuwien.ac.at.*

Self-cleaning nanopaint promises pristine vehicles

The Nissan LEAF electric vehicle might just be the most pristine car on the planet. It uses a new self-cleaning paint called Ultra-Ever Dry that repels mud, rain, and dirt. The nanopaint creates a protective layer of air between the paint and environment, effectively stopping standing water and road spray from creating dirty marks on the car's surface. Nissan is one of the first automakers to apply this technology to a vehicle. The coating, which is being marketed and sold by UltraTech International Inc., is undergoing testing by engineers at Nissan Technical Center Europe. So far, it has responded well to common conditions including rain, spray, frost, sleet, and standing water. *nissanusa.com.*

Created to demonstrate potential use in future production vehicles, this Nissan LEAF's exterior was treated with a specially engineered superhydrophobic and oleophobic paint designed to repel water and oils. Courtesy of Business Wire.

briefs

Spectra Shield ballistic material created by **Honeywell,** Morris Township, N.J., is being used as a critical component for body armor plates recently introduced by **Reed Composite Solutions,** Aberdeen, Wash. The material is used in rigid plates inserted into law enforcement and military vests. Spectra Shield is a composite material made of an ultra-high-molecular-weight polyethylene fiber 15 times stronger than steel, yet light enough to float. Parallel strands of synthetic fiber lying side-by-side are held in place with a resin system. Material layers are then cross-plied at right angles and fused into a composite structure under heat and pressure, allowing it to stop projectiles more effectively than existing options. honeywell-spectra.com.

AK Steel, West Chester, Ohio, completed its acquisition of **Severstal North America's** integrated steelmaking assets located in Dearborn, Mich. The transaction also includes a cokemaking facility and interests in three joint ventures that process flat-rolled steel products. AK Steel paid $707 million in cash for the acquisition, which includes $314 million for working capital. The new facility, Dearborn Works, produces high quality, flat-rolled steels primarily for the automotive, construction, and appliance markets. More than $1.2 billion was invested in state-of-the-art equipment and various operational improvements. aksteel.com.

ASM International partners with AQM to offer classes overseas

ASM International, Materials Park, Ohio, announces a new education collaboration agreement with AQM, a primary technical services center in northern Italy. Through this new partnership, AQM is now an educational support location in Europe for ASM International. Starting this fall, several metallurgical blended and online courses are planned using AQM's metallurgical laboratories and metallography and heat treatment schools. Classes will be taught by ASM International instructors. Topics include:

- Metallurgy for the Non-Metallurgist
- Practical Interpretation of Microstructures
- Corrosion
- Principles of Failure Analysis
- Failure Analysis in the Oil and Gas Industry
- Metallographic Interpretation

Starting this fall, several metallurgical blended and online courses using the metallurgical laboratories and metallography and heat treatment schools of AQM will be taught by ASM International instructors.

Participants in the ASM International-AQM courses will receive a complimentary one-year ASM International membership. This will allow participating students to share ideas and solutions with other members about technologies and application processes while building personal and professional networks around the world. They will also have free access to online journals and technical publications, as well as access to special offers available only to members. *asminternational.org, www.aqm.it.*

Engineering plastics proven safe for railways

Quadrant Engineering Plastic Products (EPP), Germany, recently introduced a range of high performance plastics materials for the railway industry. Due to enhanced properties such as optimized gliding (self-lubrication), light weight, and impact strength, the materials not only can be used to improve rolling stock, but also in infrastructure applications such as rail tracks. The company also introduced Nylatron 66 SA FR—a newly developed flame retardant PA66, which meets the requirements of EN 45545-2 and UL94 V0, but does not contain hazardous materials. Its flame retardant properties fulfill the requirements of electrical applications in rail and for general functional components weighing less than 2000 grams.

The material provides all the advantages of a PA66 vs. standard nylon, making it possible to extrude even large diameter shapes of flame retardant nylon. Materials are available in rods and plates, all colored black. The range of materials encompasses UHMW polyethylene, nylon, and ultra-high performance polymers such as PEEK and PEI that resist operating temperatures above 180°C. All have been tested according to the EN 45545-2 railway standard. *quadrantplastics.com.*

Secondary air suspension system protector for the railway industry made of Nylatron RIM 3000.

Antimicrobial copper protects ice arena from bacteria

Hussey Copper, Pittsburgh, announces that Gilmour Academy Ice Arena, Gates Mills, Ohio, converted more than 200 touch points to the first EPA-registered antimi-

MD-Cu29 door plates protect against bacteria. Courtesy of PRNewsFoto/ Hussey Copper.

crobial solid touch surface to help protect against bacteria. MD-Cu29 antimicrobial copper features an economical surface that kills more than 99.9% of MRSA, E. coli, and other bacteria within two hours of exposure. The school converted door handles, door push plates, and locker pulls to MD-Cu29 antimicrobial copper. Other installations include retrofitting existing surfaces to reduce the cost of purchasing new components. MD-Cu29 copper delivers continuous and ongoing antibacterial action, continuing to kill 99% of bacteria even after repeated contaminations. *gilmourarena.com.*

Researchers print their own syringes

A team led by Michigan Technological University (MTU), Houghton, published an open-source library of designs that will let scientists design syringe pumps, which are used to dispatch precise amounts of liquid in applications such as drug delivery or mixing chemicals in a reaction. Syringe pumps often cost hundreds or even thousands of dollars. MTU's Joshua Pearce and his team created the free library of pump designs, which anyone can make on a RepRap 3D printer for only the cost of the plastic filament. Designs are completely customizable.

"Not only have we designed a single syringe pump, we've designed all future syringe pumps," says Pearce. "Scientists can customize the design of a pump for exactly what they are doing, just by changing a couple of numbers in the software." The library includes recipes for most components of a syringe pump. A small electric stepper motor that drives the liquid, some simple hardware, and the syringe itself must be purchased, but are all inexpensive.

The team also went a little further, incorporating a low cost, credit card-sized Raspberry Pi computer as a wireless controller. "That way, you can link the syringe pump to the network, sit on a beach in Hawaii, and control your lab," explains Pearce. "Plenty of people can have access, and you can run multiple experiments at the same time. Our entire single-pump system costs only $50 and can replace pumps that typically run between $250 and $2500." *For more information: Joshua Pearce, 906.487.1466, pearce@mtu.edu, mtu.edu, appropedia.org/Open-source_syringe_pump.*

briefs

NSL Analytical Services Inc., Cleveland, an independent commercial testing laboratory, received renewed accreditation for ISO/IEC 17025. The accreditation certificates from **ACLASS,** the ILAC-approved accreditation body for NSL, are available for download at nslanalytical.com/accreditations.

A research group led by Kazuhiro Hono at the **National Institute for Materials Science,** Tsukuba, Japan, synthesized a new magnetic compound that requires fewer rare earth elements than the currently used neodymium iron boron compound. The ratio of neodymium, iron, and nitrogen in the new compound, $NdFe_{12}N$, is 1:12:1. Its neodymium concentration is 17% compared to 27% for $Nd_2Fe_{14}B$, the main component used in the strongest permanent magnets. Further, the new compound's intrinsic hard magnetic properties were found to be superior to those of $Nd_2Fe_{14}B$. www.nims.go.jp/eng.

Bruker Corp., Fremont, Calif., completed divestiture of its gas chromatography (GC) and GC single-quadrupole (GC-SQ) mass spectrometry products to **Techcomp Europe Ltd.,** a subsidiary of Techcomp (Holdings) Ltd, on October 31. Techcomp will continue to manufacture the former Bruker GC and GC-SQ Scion products in the Fremont factory previously occupied by Bruker's Chemical and Applied Markets division. Bruker will continue to provide service and support for all GC and GC-SQ products worldwide. bruker.com.

New calibration service tunes high-power lasers

NIST's new calibration service for high-power lasers is controlled from behind a protective barrier. Paul Williams (left) and Joshua Hadler operate the service, which can calibrate lasers with up to 10 kW of power for manufacturers and military customers. Courtesy of Burrus/NIST.

The National Institute of Standards and Technology (NIST), Gaithersburg, Md., launched a new calibration service for high-power lasers used by manufacturers for applications such as cutting and welding metals, as well as by the military for more specialized applications like defusing unexploded land mines. The new service is offered for power levels up to 10 kW. NIST recently completed its first high-power calibration, for a commercial 5 kW laser power meter. The measurement had an uncertainty of about 1% over two standard deviations, the accuracy and precision threshold necessary for military and advanced manufacturing applications.

"That level of uncertainty at multi-kilowatt levels is unprecedented," says calibration leader Josh Hadler. Exact laser output must be known to achieve effective, safe performance in virtually all applications at these power levels. To establish the new service, a 10 kW fiber laser was purchased and a laboratory was extensively renovated to meet electrical requirements and add appropriate safeguards such as walls with high damage tolerance and special optics and beam controls for the laser. Running lasers are viewed from behind a protective barrier, using a multi-camera system for monitoring and control. Laser light is absorbed by a conventional calorimeter surrounded and cooled by flowing water. The temperature difference between incoming and outgoing water is measured and used to calculate laser power.

The new facility will also be used for research on the fundamental physical processes that occur during laser welding. The study aims to overcome technical challenges such as welding of materials that are dissimilar or have different thicknesses. Further, the ability to join dissimilar materials with vastly different properties could help overcome longstanding design and cost hurdles associated with welding. *nist.gov/pml/div686/calibrations/laser.cfm.*

Specialized microscope captures nanotube defects

University of Oregon chemists devised a way to see the internal structures of electronic waves trapped in carbon nanotubes (CNTs) by external electrostatic charges. CNTs are touted as exceptional materials with unique properties that allow for extremely efficient charge and energy transport, with the potential to enable more efficient types of electronic and photovoltaic devices. However, these traps, or defects, in ultrathin nanotubes can compromise their effectiveness. Using a custom-built microscope capable of imaging matter at the atomic scale, researchers are able to visualize the traps, which can adversely affect the flow of electrons and elementary energy packets called excitons.

According to physical chemistry professor George V. Nazin, the study modeled the behavior often observed in carbon nanotube-based electronic devices, where electronic traps are induced by stochastic external charges in the immediate vicinity of the nanotubes. The external charges attract and trap electrons propagating through nanotubes. "Our visualization should be useful for developing a more accurate picture of electron propagation through nanotubes in real-world applica-

University of Oregon professor George Nazin uses a scanning tunneling microscope fitted with a closed-cycle cryostat to uncover traps, or defects, that disrupt electronic waves in nanotubes.

tions, where nanotubes are always subjected to external perturbations that potentially may lead to the creation of these traps," he explains.

Research is conducted with an ultrahigh vacuum scanning tunneling microscope coupled to a closed-cycle cryostat, built for use in Nazin's lab. The cryostat allows the team to lower the temperature to 20 K to freeze all nanoscale motion and visualize the internal structures of nanoscale objects. The device captures the internal structure of electronic waves trapped in short sections, just several nm long, of nanotubes partially suspended above an atomically flat gold surface. *uoregon.edu.*

Phoenix Nuclear Labs (PNL), Monona, Wis., received a one-year, $3 million contract by the **U.S. Army** to build an advanced neutron radiography unit. The imaging system will be used for nondestructive inspection of munitions, pyrotechnics, and other critical defense components. The new system is expected to generate 10 times the amount of neutrons, enabling faster performance, and will produce digital images that will improve the unit's ability to analyze and store data. phoenixnuclearlabs.com.

Research grants focus on aerospace metal fatigue

University of Texas at Arlington engineering professors received a $451,781 Air Force Office of Scientific Research grant to examine the material surface at the micro and nano-scale level that will provide clues for predicting fatigue in aircraft parts. Haiying Huang, professor of Mechanical and Aerospace Engineering, says the new technology and process will be better and more efficient than taking x-rays of an aircraft's wing.

"We'll be able to determine metal fatigue at very early stages when we look at it on this scale," explains Huang. "Certain patterns of surface roughness changes will tell us how the material will behave when put under the fatigue of flying."

In addition, the team received a $348,385 grant from the Defense University Research Instrumentation Program (DURIP) of the Air Force Office of Scientific Research to purchase two pieces of equipment that will help gauge the wear on these aircraft parts. The grant allows Huang to purchase a scanning whitelight interferometric surface profiler integrated with a compact mechanical tester and an electron backscatter diffraction module. The surface profiler provides researchers with in-situ 3D surface profiling of fatigued specimens. The diffraction module will be retrofitted with a scanning electron microscope to allow researchers to measure dislocation patterns in the fatigued material. *uta.edu.*

briefs

Graphene Frontiers LLC, Philadelphia, received U.S. Patent 8,822,308—Methods and Apparatus for Transfer of Films among Substrates—which covers the transfer of graphene films between surfaces using roll-to-roll manufacturing processes. According to company officials, this was the final hurdle in creating a cost-effective production process for graphene. With the etch-free transfer solution, manufacturers now have the option of not dissolving or consuming the substrate metal. The company also entered into an agreement with **The Colleges of Nanoscale Science and Engineering at SUNY Polytechnic Institute,** Albany, N.Y., to increase production. graphenefrontiers.com.

An international research group led by Danny Porath of the **Hebrew University of Jerusalem** reports reproducible and quantitative measurements of electricity flow through long molecules made of four DNA strands, signaling a significant breakthrough toward development of DNA-based electrical circuits. Molecules were produced by the group of Alexander Kotlyar from **Tel Aviv University,** who has been working with Porath for 15 years. Collaborators include groups from Denmark, Spain, the U.S., Italy, and Cyprus. http://new.huji.ac.il/en.

Prof. Danny Porath. Courtesy of Hebrew University.

Body-degradable metals make headway

University of Pittsburgh researchers received an additional $1.5 million from the National Science Foundation to continue a combined multi-university, private industry effort to develop implantable medical devices made of biodegradable metals. Body-degradable metals—usually magnesium based—are not new, but according to project director William Wagner, "The question comes when you start to design medical devices for a specific application and a clinical partner says they want it to be gone in a month or they want it to be there for a year."

Anterior cruciate ligament (ACL) rings. Courtesy of The Engineering Research Center for Revolutionizing Metallic Biomaterials.

To address these different requirements, the Pitt team and collaborators at the University of Cincinnati (UC) and North Carolina Agricultural and Technical State University (N.C. A&T) are creating new alloys and manufacturing processes. The consortium seeks to design devices that can adapt to changes in a patient's body and dissolve once healing has occurred, reducing follow-up procedures and potential complications. So far, the group has created screws and plates for facial reconstruction, a stent for kidney dialysis, a nerve guide, and a ring to assist in pulling together ruptured ligaments. The group also created a stent for pediatric patients whose tracheas are underdeveloped at birth and prone to collapse. Wagner says once the stent is implanted it will dissolve, avoiding a second procedure.

The original 2008 grant was for a total of $18.5 million over five years, shared by Pitt, UC, and the project's lead institution, N.C. A&T. The grant extension total is $4 million, including the $1.5 million received by Pitt. *pitt.edu.*

Shape-shifting carbon fiber composites enable lightweight aircraft

Researchers at Airbus, France, and Massachusetts Institute of Technology (MIT), Cambridge, are developing shape-shifting materials to make aircraft simpler and lighter, potentially saving fuel. Made of carbon fiber composites, materials can shift between two or more shapes in response to changes in heat, air pressure, or other environmental factors. In addition, they can be easily integrated into aircraft, replacing more complex actuators, motors, and hinges. Initial application might involve a jet engine air intake valve, which must adjust as the plane changes altitude.

Time-lapse photograph shows a carbon fiber composite bending in response to heat. Courtesy of MIT.

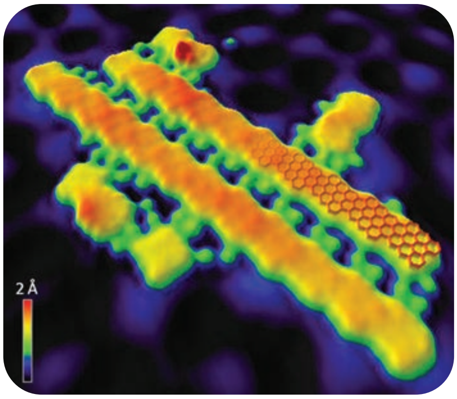
Although shape-changing materials have been around for decades, many cannot handle demanding aerospace conditions such as extreme temperature changes, says Christophe Cros, a technology program leader at Airbus. In the MIT approach, carbon composites can be paired with a variety of shape-shifting materials that respond to different environmental triggers. Another benefit is that the new materials do not require the electrical connections that other shape-changing composites need.

Skylar Tibbits, director of MIT's Self-Assembly Laboratory, uses novel carbon fiber composites developed by startup company Carbitex, Kennewick, Wash., which are made with a variety of matrix materials that impart a range of properties. Some result in carbon composites that are floppy like a cotton sheet and others that are springy like a sheet of metal.

A 3D printer applies materials that are known to shrink or grow under certain conditions. As they change, they force the carbon composite on which they are deposited to bend or twist in various ways, depending on the pattern produced by the printer. Tibbits' team is developing software that simulates the way different patterns of these materials, printed onto different kinds of composite materials, will behave under various conditions. So far, Tibbits has demonstrated materials that respond to light, water, and heat, and says it should be possible to make ones that respond to air pressure and other stimuli as well. *airbus.com, mit.edu.*

Self-assembly method promises perfect graphene

Scientists from University of California, Los Angeles (UCLA) and Tohoku University, Japan, discovered a new self-assembly method to produce defect-free graphene nanoribbons with periodic zigzag-edge regions. In this bottom-up technique, a copper substrate's unique properties are used to change the way the precursor molecules react to one another as they assemble into graphene nanoribbons. This allows scientists to control the ribbons' length, edge configuration, and location on the substrate.



Graphene nanoribbons imaged by scanning tunneling microscopy. Zigzag edges are highlighted by the red structure. Courtesy of Patrick Han.

Researchers say the new method of graphene fabrication by self-assembly is a stepping stone toward production of self-assembled graphene devices that will vastly improve the performance of data storage circuits, batteries, and electronics. Paul Weiss, distinguished professor of chemistry and biochemistry and a member of UCLA's California NanoSystems Institute, developed the method for producing the nanoribbons with Patrick Han and Taro Hitosugi, professors at the Advanced Institute of Materials Research at Tohoku University in Sendai, Japan. *cnsi.ucla.edu.*

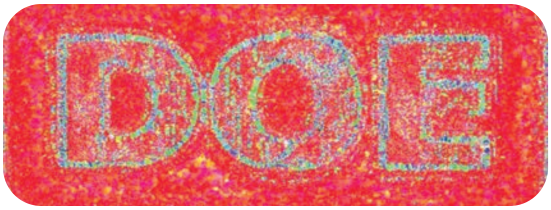
New process controls properties of 3D printed metal parts

Researchers at DOE's Oak Ridge National Laboratory (ORNL), Tenn., demonstrated an additive manufacturing method to control the structure and properties of metal components with precision that is reportedly unmatched by conventional manufacturing processes. Ryan Dehoff, staff scientist and metal additive manufacturing lead at ORNL's Manufacturing Demonstration Facility, presented the research in an invited presentation at the Materials Science & Technology 2014 conference in Pittsburgh, in October.

"We can now control local material properties, which will change the future of how we engineer metallic components," says Dehoff. "This new manufacturing method takes us from reactive design to proactive design. It will help us make parts that are stronger, lighter, and function better for more energy-efficient transportation and energy production applications such as cars and wind turbines."

Researchers demonstrated the method using an ARCAM electron beam melting system (EBM), in which successive layers of a metal powder are fused together by an electron beam into a 3D product. By manipulating the process to precisely manage solidification on a microscopic scale, scientists demonstrated 3D control of the microstructure of a nickel-based part during formation. Applications from microelectronics to high-temperature jet engine components rely on tailoring of crystallographic texture to achieve desired performance characteristics.

"We're using well established metallurgical phenomena, but we've never been able to control the processes well enough to take advantage of them at this scale and at this level of detail," explains Suresh Babu, the University of Tennessee-ORNL Governor's Chair for Advanced Manufacturing. "As a result of our work, designers can now specify location-specific crystal structure orientations in a part." *ornl.gov.*

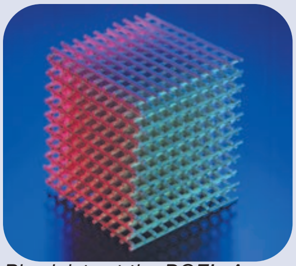


Electron backscatter diffraction image shows variations in crystallographic orientation in a nickel-based component, achieved by controlling 3D printing at the microscale. Courtesy of ORNL.

briefs

In October, **The Boeing Co.** celebrated the groundbreaking of its 777X Composite Wing Center in Everett, Wash. Permitting for the new 1-million-sq-ft facility was completed approximately seven weeks early. The new building is expected to open in May 2016 with the first 777X delivery targeted for 2020. To date, 300 orders and commitments have been received. Two models will comprise the new family—the 777-8X, with 350 seats and a range of more than 9300 nautical miles, and the 777-9X, with 400 seats and a range of more than 8200 nautical miles. boeing.com.

President Barack Obama announced an upcoming competition, sponsored by the **U.S. Department of Defense (DoD),** that will provide an award of up to $110 million in federal funds to launch an **Institute for Manufacturing Innovation (IMI)** whose work involves photonics. The **Integrated Photonics IMI** is the fourth DoD-led manufacturing institute to be announced since the pilot project was launched in August 2012. Beginning early this month, the DoD will collect proposals from teams of nonprofit organizations, universities, and private companies to head the institute. The $110 million available over five years must be matched by at least $110 million in nonfederal commitments. defense.gov.



Physicists at the DOE's Ames Laboratory developed the first model of a photonic band-gap crystal. Courtesy of U.S. Department of Energy.

briefs

A research team led by Mark Hersam, professor of materials science and engineering and the Bette and Neison Harris Chair of Teaching Excellence at **Northwestern University's McCormick School of Engineering,** Evanston, Ill., created a new type of carbon nanotube (CNT) solar cell that is twice as efficient as its predecessors. It is also the first CNT solar cell to have its performance certified by the **National Renewable Energy Laboratory.** The secret lies in the CNT's chirality, which is a combination of tube diameter and twist. When a thin sheet of carbon is rolled into a nanotube, several hundred different chiralities are possible. mccormick.northwestern.edu.

Graphene 3D Lab Inc., Calverton, N.Y., submitted a provisional application to the U.S. Patent and Trademark Office regarding materials and methods for 3D printable batteries. The ability to 3D print electrochemical devices, such as batteries and supercapacitors, will contribute to significant expansion of commercial applications for additive manufacturing. 3D printed batteries have several advantages over traditional ones—their shape, size, and specifications can be easily adjusted to fit the particular device design. graphene3dlab.com.

Paul Chu, founding director of the **Texas Center for Superconductivity** at the **University of Houston** will lead a group of investigators as they build a unique piece of equipment designed to further their research and ultimately help make superconductivity and thermoelectricity more commercially viable. The work will be covered under a $780,000 grant from the Department of Defense, as part of the Defense University Research Instrumentation Program. The program supports the purchase of state-of-the-art equipment to improve or develop university capabilities for performing cutting-edge defense research and graduate student training. For more information: Paul Chu, 713.743.8222, cwchu@uh.edu, tcsuh.com.

Harvesting power from the air

A centuries-old clock built for a king is the inspiration for a group of computer scientists and electrical engineers who hope to harvest power from the air. The clock, powered by changes in temperature and atmospheric pressure, was invented in the early 17th century by a Dutch builder. Three centuries later, Swiss engineer Jean Leon Reutter built on that idea and created the Atmos mechanical clock that can run for years without needing to be wound manually.

A new thermal power harvester uses naturally changing ambient temperature as its power source.

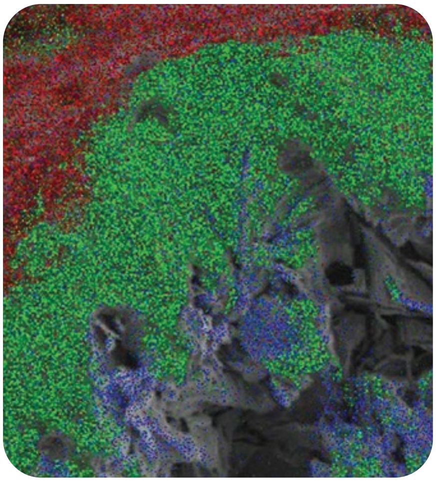
University of Washington, Seattle, researchers took inspiration from the clock's design and created a power harvester that uses natural fluctuations in temperature and pressure as its power source. The device harvests energy in any location where these temperature changes naturally occur, powering sensors that can check for water leaks or structural deficiencies in hard-to-reach places and alerting users by sending out a wireless signal.

A metal bellows about the size of a cantaloupe is filled with a temperature-sensitive gas. When the gas heats and cools in response to outside air temperature, it expands and contracts, causing the bellows to do the same. Small cantilever motion harvesters are placed on the bellows and convert the kinetic energy into electrical energy. This powers sensors attached to the bellows, and the data is sent wirelessly to a receiver. *For more information: temperature-harvester@uw.edu, washington.edu.*

Modified titania shows potential as superconductor insulator

Research from North Carolina State University, Raleigh, shows that a type of modified titania, or titanium dioxide, holds promise as an electrical insulator for superconducting magnets, allowing heat to dissipate while preserving the electrical paths along which current flows. Superconducting magnets are being investigated for use in next-generation power generating technologies and medical devices.

"Superconducting magnets need electrical insulators to ensure proper operation," says Sasha Ishmael, a postdoctoral researcher at NC State. "Changing the current inside the superconductor is important for many applications, but this change generates heat internally. The magnets will operate much more safely if the electrical insulators are able to shed excess heat. Otherwise, the higher temperatures could destroy the superconductor. This titania-based material is up to 20 times better at conducting heat than comparable electrical insulators. It has characteristics that are very promising for use as electrical insulators for superconducting technologies." *For more information: Sasha Ishmael, 919.515.5063, saishmael@ncsu.edu, ncsu.edu.*



Energy dispersive x-ray spectroscopy image taken within a scanning electron microscope illustrates a Bi2212 wire shown in blue and green, coated with the titania-based insulation shown in red. Courtesy of Sasha Ishmael.

Simulations reveal how to better protect DLC coatings

By performing atom-level simulations of nanoscale friction, Ling Dai and coworkers from the A*STAR Institute of High Performance Computing, Singapore, uncovered critical clues for designing better systems to lubricate and protect diamond-like-carbon (DLC) coatings. Perfluoropolyether (PFPE) is a Teflon-like polymer commonly sandwiched between DLC-coated substrates to reduce friction and protect against damage. Understanding the friction mechanisms between these ultrathin films is tricky; the materials have contrasting hard and soft mechanical properties, and the sandwich arrangement obscures any direct observation of atomic structure and activity.

Device longevity can be improved by using computer models that optimize the friction properties of diamond-like coatings used in hard disk drives. Courtesy of Janka Dharmasena/iStock/Thinkstock.

To better understand how nanoscale lubrication works in microdevices, researchers constructed an atomic DLC–PFPE–DLC triple layer using a 3D computer modeling program. They set one DLC slab as a substrate and the other as a "slider." Molecular dynamics techniques simulate how the lube film responds when the slider moves. Simulating frictional motions at different speeds and PFPE film thicknesses reveals that the lubricating film behaves as a solid—the polymer retains its shape without deforming from internal shearing. *www.ihpc.a-star.edu.sg.*

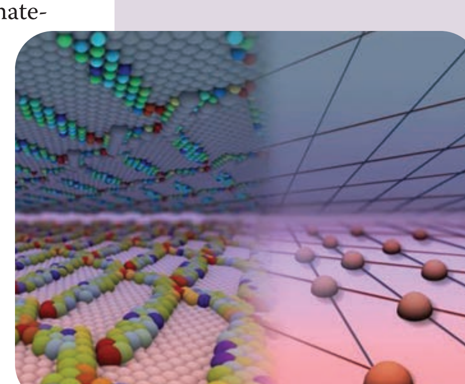
Carbon nanotubes turn resin coatings into conductors

Resin coatings are widely used in various industries, such as aerospace and automotive, particularly for protecting structural components. Research by the UPV/EHU-University of the Basque Country, Spain, uses carbon nanotubes (CNTs) to improve the properties of these coatings. The research was conducted within the POCO European project and seeks to develop strategies to spread CNTs properly throughout different polymers. CNTs improve coating conductivity, repair scratches, and feature excellent mechanical properties. They are also tough, rigid, and electrically conductive. Epoxy resins, by contrast, are insulating materials. By adding nanotubes, the resin coatings are also turned into conductors. *www.ehu.es/p200-shenhm/en.*

Material interfaces can be patterned to control properties

Scientists at Massachusetts Institute of Technology, Cambridge, added a new wrinkle to research on the patterning of surfaces. While most research focuses on patterns on the outer surfaces of materials, associate professor Michael Demkowicz and his team are exploring the effects of patterned surfaces deep within materials—specifically, at the interfaces between layers of crystalline materials. Demkowicz explains that much research aims to create layered composites with desired strength, flexibility, or resistance to vibrations, temperature changes, or radiation. But actually controlling the surfaces where two materials meet within a composite is a tricky process.

"People don't think of them as surfaces," says Demkowicz. "If they do, they think of it as a uniform surface, but as it turns out, most interfaces are not uniform." To control the properties of these materials, it is essential to understand and direct these nonuniform interfaces. The team took classical equations used to describe average surface properties and adapted them to instead describe variations in these surfaces location by location. "That's not easy to do experimentally, but we can do that directly in our computer simulations," says Demkowicz. *For more information: Michael Demkowicz, 617.324.6563, demkowicz@mit.edu, web.mit.edu.*



Interfaces between solid materials are surfaces with an intricate, internal structure (left). To control that structure, and use it for specific applications, researchers model it in a simplified way (right). Courtesy of Niaz Abdolrahim and Jose-Luis Olivares/MIT.

briefs

Abakan Inc., Miami, completed initial field testing on full-sized production equipment of its nanocomposite liquid metal corrosion-resistant coating, PComP M, with a leading steel producer. Abakan is also working with several other steel companies to validate component life extension on zinc pot rolls used extensively in the continuous hot dip galvanizing process, as well as other components used to handle and process molten metals. PComP M demonstrates improved molten metal corrosion resistance, combined with increased durability and reliability in the rapidly changing temperature environment encountered in molten metal contact, compared to conventional materials. abakaninc.com.

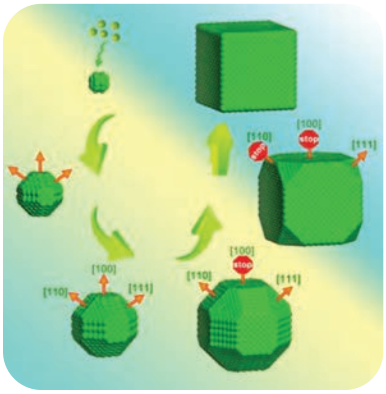
Sematech, Austin, Texas, and the newly merged **SUNY College of Nanoscale Science and Engineering/SUNY Institute of Technology,** N.Y., launched their joint **Patterning Center of Excellence (CoE).** The CoE will enable lithography equipment and lithographic materials manufacturing companies access to a vertically integrated semiconductor processing facility. The new center aims to reduce the costs of developing critical lithography materials for individual semiconductor companies. kevin.cummings@sematech.org, public.sematech.org, sunycnse.com.

NANOTECHNOLOGY

Effective understanding and design of nanocrystals

Researchers at the DOE's Lawrence Berkeley National Laboratory, Calif., used highly sophisticated transmission electron microscopes (TEM) and an advanced high-resolution, fast-detection camera to capture the physical mechanisms that control the evolution of facets on the surfaces of platinum nanocubes formed in liquids. Understanding how facets develop on a nanocrystal is critical to controlling the crystal's geometric shape, which in turn is critical to controlling its chemical and electronic properties.

Working with platinum, Haimei Zheng and her team initiated the growth of nanocubes in a thin liquid layer sandwiched between two silicon nitride membranes. This microfabricated cell can encapsulate and maintain the liquid inside the high vacuum of a TEM for an extended period of time, enabling in situ observations of single nanoparticle growth trajectories. *lbl.gov, science.energy.gov.*



Researchers found that differences in ligand mobility during crystallization cause the low index facets—{100}, {110} and {111}—to stop growing at different times, resulting in the crystal's final cubic shape. Courtesy of Haimei Zheng group, Berkeley Lab.

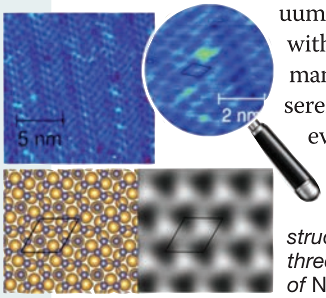
Fully wearable and flexible devices closer to reality

A new prototype is a first example of how the partnership between the Cambridge Graphene Centre and Plastic Logic, both in the UK, will accelerate commercial graphene development. The prototype is an active matrix electrophoretic display, similar to the screens used in e-readers, but it is made of flexible plastic instead of glass. In contrast to conventional displays, the pixel electronics, or backplane, of this display includes a solution-processed graphene electrode. The new 150 pixel per inch backplane was made at low temperatures (<100°C) using Plastic Logic's organic thin film transistor technology. The graphene electrode was deposited from solution and subsequently patterned with micron-scale features to complete the backplane, which was then combined with an electrophoretic imaging film to create an ultra-low power and durable display. *www.graphene.cam.ac.uk, plasticlogic.com.*

A flexible display incorporating graphene in its pixels' electronics was successfully demonstrated—the first time graphene has been used in a transistor-based flexible device.

Meet graphene's cousin, germanene

Germanene, which is made up of just a single layer of germanium atoms, is expected to exhibit impressive electrical and optical properties and could be widely integrated across the electronics industry in the future. Germanene, first proposed in 2009, has remained elusive until now. Much like silicene, the proposed method for synthesizing germanene is to deposit individual germanium atoms onto a substrate under high temperatures and in an ultra-high vacuum. The breakthrough by a European research team was made in parallel with an independent team from China who reported evidence that germanene has been synthesized onto a platinum substrate. The European team serendipitously discovered that gold could also be used as a substrate, an event which professor Guy Le Lay, from Aix-Marseille University, France, described as "like passing through the looking glass." *www.univ-amu.fr.*



A 16.2 × 16.2 nm STM image of the modulated honeycomb √7×√7 superstructure. Atomic structures (side and top views) and simulated STM images of three different models of germanene on the √7×√7 Au(111) surface. Courtesy of New Journal of Physics*/IOP Publishing.*

briefs

Morgan Advanced Materials, Windsor, UK, announced a new joint development agreement with **The University of Manchester,** aimed at scaling up a novel process for manufacturing graphene. The partnership will explore the full potential of graphene, with a particular interest in understanding and optimizing the relationship between the manufacturing process and materials science, and was established to improve the prospects of bringing this material to commercial reality. morganadvancedmaterials.com, manchester.ac.uk.

Applied Nanotech Holdings Inc., Deerfield Beach, Fla., and **NanoHoldings Inc.**, Rowaton, Conn., created a new company called **PEN Inc.** to focus on commercialization of advanced nanotechnology-enabled products. PEN unites staff and resources in nanotechnology research and development with experience in specialty product commercialization. appliednanotech.net, nanoholdings.com, pen-technology.com.

Stanford University, Calif., materials scientists detailed a key step in storing energy and information in nanomaterials by studying how metallic nanoparticles composed of palladium absorb and release hydrogen atoms. Hydrogen absorption in ensembles of metallic nanoparticles has been previously studied, but this approach makes it difficult to infer information about how the individual nanoparticles behave. The new work reveals that behavior by measuring the hydrogen content in individual palladium nanoparticles exposed to increasing pressures of hydrogen gas. stanford.edu.

Low Temperature Plasma Process Effectively Modifies Surface of Graphene

Martin Kemp
Haydale Ltd.
South Wales, UK

Harnessing graphene's potential for commercial use requires attaining homogeneous dispersion and strong chemical bonding with the matrix of a target material. This can be achieved by effective surface modification.

Graphene has long been hailed as a super-material with the potential to revolutionize industry. Concepts surrounding electronic and mechanical applications have been around since the 1950s, but it was not until 2004 that researchers isolated the 2D material by separating graphite using adhesive tape. Andre Geim and Konstantin Novoselov's groundbreaking research elevated this material onto the world stage.

Graphene's potential for industrial and commercial applications is staggering—experimental characterization reveals that this promising material is mechanically 200 times stronger than steel, has in-plane electrical and thermal conductivity higher than copper, and features a surface area greater than 2500 m^2/g (Fig. 1).

The term *graphene,* which originally described a single 2D sheet of carbon atoms, has gradually expanded to encompass both sheet and flake carbon materials that can be produced by different methods. Engineering applications tend to focus on graphene nanoplatelets (GNPs), which can be produced by a *top-down* production method that involves exfoliating mined graphite to produce flakes, or a *bottom-up* method such as chemical vapor deposition from a carbon source. Both techniques have advantages and disadvantages and, for potential end users, represent alternative sources to ensure a consistent, secure supply.

Global interest in graphene has been stimulated by its extraordinary properties, which are not only of interest to the academic world, but also investors and industry stakeholders seeking to incorporate the wonder material into commercial products. Its properties appear to have nearly limitless uses, including composite materials for aerospace, energy harvesting and storage in batteries and supercapacitors, flexible displays and optical electronics, and numerous applications in healthcare and medical devices.

IDTechEx Ltd., UK, estimates that the graphene industry will grow from its current market value of $20 million to more than $390 million by 2024[1], with the greatest expansions forecast in energy storage, transparent conductive films, and composite materials. These markets alone represent significant benefits, but even with clearly defined market needs, translating scientific developments into commercial reality is a complex process rife with technological hurdles.

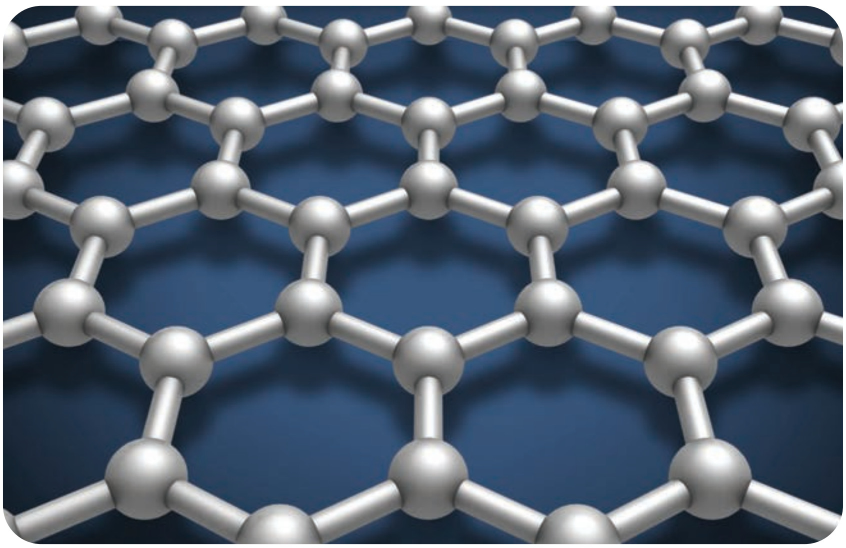


Fig. 1 — *Graphene has incredible intrinsic properties, showing great potential for industrial and commercial applications across a wide range of industries.*

Graphene for commercial use

The substantial number of graphene related patents reported by the UK's Intellectual Property Office (IPO) indicates not only graphene's potential, but that both academic and industry believe it can be made to work. By February 2013, 8416 patents had been published worldwide, and rose to 11,372 at the beginning of 2014[2]. Patents are applied for continually, with approximately 80% held by organizations in China, the U.S., Korea, and Japan. Most relate to potential applications and products, as opposed to raw material production.

Despite the rapid growth of patent applications, many academic, commercial, and financial critics express doubts as to whether the material can become a commercial success through incorporation into next-generation products and applications. It is well known that excellent laboratory results do not always translate into large-scale applications, particularly if there is a cost premium.

While a significant proportion of graphene research currently focuses on producing uniform single-layer graphene sheets (predominantly by Asian electronics giants LG and Samsung for use in electrical applications), an alternative approach is more relevant to solving engineering challenges. The approach focuses on the particulate graphene form, which

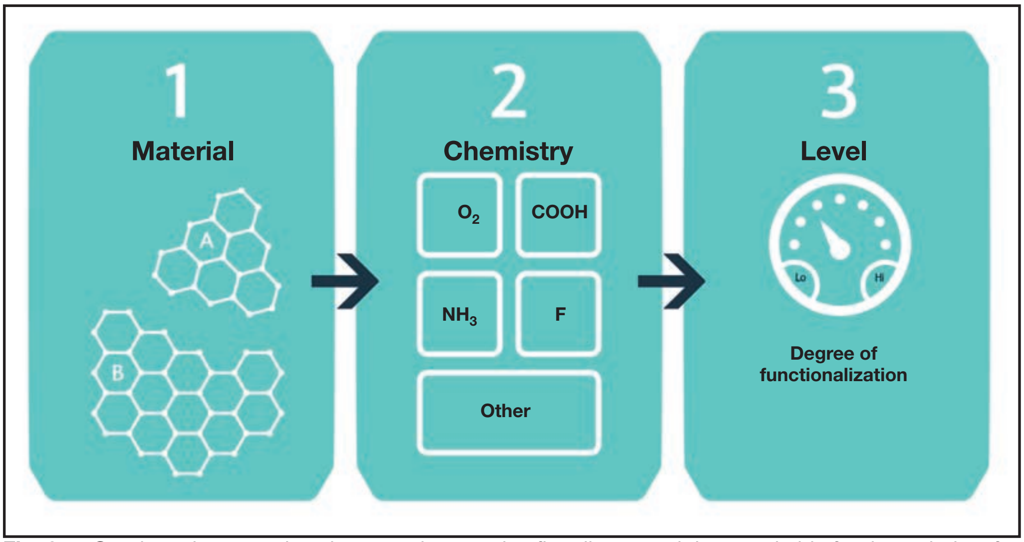


Fig. 2 — *Graphene is a complex picture and a one-size-fits-all approach is not suitable for the majority of potential applications.*

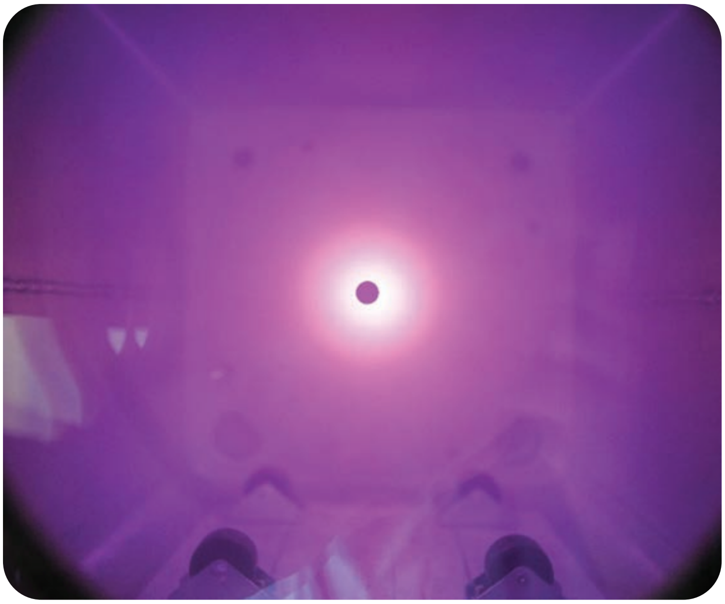


Fig. 3 — *By tailoring the degree of functionalization and achieving optimal dispersion, the low temperature plasma process (>100°C) produces graphene with specific properties and superior performance for customization. Plasma is generated via the central electrode inside the rotating drum.*

can be produced in large quantities in various thicknesses. *Few-layer graphene* (FLG) has several atomic layers of carbon while *many-layer graphene*, or graphene nanoplatelets (GNPs), typically has 5-50 layers. Another important factor is that graphene is effectively inert, meaning that the surface chemistry can be a critical factor affecting processability, and therefore its potential application.

Graphene challenges

Graphene technology has many different target markets, each requiring different material specifications, performance, and cost targets, which further complicates the path to commercialization. In addition, there are many types of graphene, each with a different set of properties depending on the form in which it is produced. Average flake size, number of graphene layers, and the chemical groups on the flake surfaces can all vary.

The number of production techniques further complicates matters, with each technique delivering a different material, cost structure, and scalability. It is no surprise that research departments struggle to find a material that works for their application yet meets other requirements. While there is a real need to standardize the growing number of graphene variants—recognizing the cost benefits of each family and establishing applications for which they are most suitable—a one-size-fits-all approach will not work for many potential applications (Fig. 2).

Chemical vs. plasma surface modification

Graphene supply is unlikely to be a problem, at least in the case of GNPs due to the range of production methods already discussed. However, surface chemistry was only recently identified as a key factor in realizing the full potential of nanomaterials. Incorporating nanomaterials into polymeric and liquid phase applications requires a homogenous dispersion within the secondary phase. This is not an easy task as the natural tendency of nanomaterials to agglomerate or separate out means that good dispersions can only be attained by engineering the material's surface via a modification process.

Chemical treatments can effectively modify the surface of graphene, but significant environmental and ecological costs associated with their use can outweigh the benefits. Although these processes are scalable, they use aggressive chemicals and tend to create defects in the material structure and introduce impurities. Further, the surface chemical functional groups are limited to those inherent in the available acids.

An alternative functionalization route via plasma avoids environmental issues and can aid dispersion and chemical bonding with a matrix. With the correct chemical functionalization such as incorporating a compatible chemical side group, there is a much greater possibility of achieving homogeneous dispersion during processing and chemical bonding (such as covalent bonding) with the matrix.

Researchers discovered that graphene and graphene oxide show promise as reinforcements in high-performance nanocomposites and should have outstanding mechanical properties[3]. In order to obtain the optimum mechanical and conductive properties, a strong interface between the reinforcement and the polymer matrix is required[3].

Plasma process offers tailored surface modification

An alternative surface modification route, which avoids wet chemistry while providing a highly tailored material for both raw material producers and application manufacturers, uses a plasma-based processing route (Fig. 3).

A low temperature plasma (>100°C) patent-pending process was developed that overcomes this key barrier. Costs are significantly reduced due to low energy input requirements, while modifying the surface of a target material with a wide range of chemical groups such as O_2, COOH, NH_3, and F is also possible. By tailoring the degree of functionalization (surface modification) and achieving optimal dispersion, it is possible to produce graphene with specific properties and superior performance.

Non-aggressive plasma surface modification effectively eliminates the risk of damage to the material being processed and is potentially capable of actually removing impurities inherent in the raw material while also repairing lattice defects. From an environmental perspective, the process is characterized by low energy consumption and avoids unnecessary disposal of hazardous waste chemicals.

Case study: Improving mechanical properties of composites

The mechanical performance of graphene is of particular interest as a filler for composites in industrial applications. For 50 years, carbon fiber reinforced polymers (CFRP) have been increasingly used in high performance applications such as passenger aircraft and wind turbine blades, and their use is a testament to the high performance levels that can be achieved.

Recently, Aerospace Corp., El Segundo, Calif., demonstrated significant steps toward the manufacture of hierarchical or multiscale composites. It must now be determined if these materials can be used commercially to achieve performance benefits resulting in lighter weight and more damage tolerant materials.

The study details the nanoreinforcement of resin by GNPs functionalized via plasma. The epoxy material reinforced by GNPs exhibits unprecedented performance levels, with a 200% increase in tensile strength and modulus over the original resin, and an increase in toughness of more than 125%[4]. Due to the promotion of dispersion and chemical bonding with the epoxy matrix, results point to surface functionalization as the key parameter influencing the effectiveness of nanoreinforcement.

The future of graphene

With widespread interest and excitement regarding the potential for graphene to revolutionize a plethora of markets, including electronics, energy, transport, and consumer products, there is a considerable global push to achieve successful commercialization. Using a top-down or bottom-up manufacturing route in conjunction with surface modification processes, these materials can be incorporated into inks, polymers, composites, and coatings to exploit electrical or thermal conductivity or add enhanced mechanical performance.

Realizing graphene's potential lies in attaining homogeneous dispersion and strong chemical bonding with the matrix of a target material, and these properties can be achieved by effective surface functionalization. Of the range of available technologies, the low temperature plasma process has proven effective in achieving the required surface functionalization. Compared to acid-based processes, functionalization via plasma is a clean, low energy process that avoids generating hazardous waste chemicals.

The potential of nanomaterials to solve engineering challenges and develop new and improved products is being implemented. Successful commercialization depends on a multitude of factors, and in the case of graphene, market demand is widespread and the raw material sources are numerous. With functionalization identified as a critical factor and a commercial route established, graphene's full potential can now be realized. ❍

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Accurate Spot Weld Testing for Automotive Applications

*Yu-Ping Yang**
Fabian Orth
Warren Peterson
Jerry Gould
EWI
Columbus, Ohio

Typical vehicles contain more than 3000 spot welds—whose failure must be accurately predicted in crash simulations. A new test method is proving useful for accurately defining spot weld failure parameters.

Resistance spot welding (RSW) remains the most common joining method in the automobile industry, where it is used to weld sheet metal to form vehicle bodies and other parts. The main advantages of RSW include high speed and low cost, the ability to weld a wide range of joint configurations with the same gun, lack of weld consumables, and ease of high volume automation. RSW is used to join many ferrous and non-ferrous alloys such as carbon steels, high strength low-alloy steels, stainless steels, aluminum and light alloys, nickel alloys, and galvanized sheets.

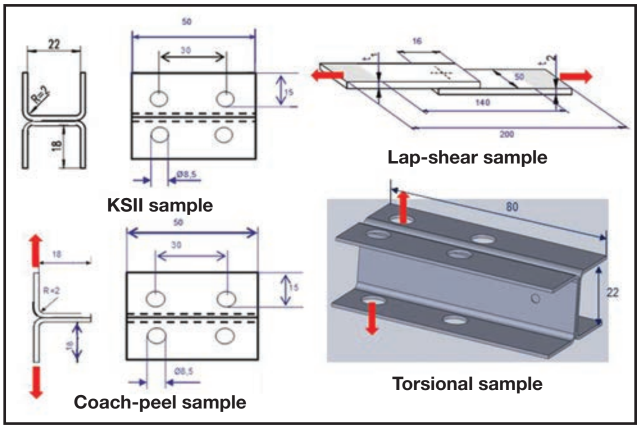

Fig. 1 — *Small sample types used to develop spot weld failure parameters.*

Because a typical vehicle contains approximately 3000 spot welds, their joint strength is important to the overall structural integrity and safety. To reduce weight and improve vehicle safety, higher strength materials are continuously implemented with each new generation of vehicles. Spot weld failure during automotive crash testing is a critical issue due to the high hardness and brittleness of these welds for high and ultra-high strength steels. To achieve optimal vehicle design, spot weld failure must be accurately predicted in crash simulations. Over the past few decades, several failure models have been developed and implemented in the widely used LS-DYNA software to predict crash performance. Equation 1 shows one of the spot weld failure models[1,2]:

$$f = \left(\frac{\sigma_N}{S_N\left(\dot{\varepsilon}_{eff}\right)}\right)^{n_N} + \left(\frac{\sigma_B}{S_B\left(\dot{\varepsilon}_{eff}\right)}\right)^{n_B} + \left(\frac{\tau}{S_S\left(\dot{\varepsilon}_{eff}\right)}\right)^{n_S} \geq 1 \quad (1)$$

where σ_N, σ_B, and τ are axial, bending, and shear stress, respectively, $\dot{\varepsilon}_{eff}$ is effective strain rate, and $S_N(\dot{\varepsilon}_{eff})$, $S_B(\dot{\varepsilon}_{eff})$, and $S_S(\dot{\varepsilon}_{eff})$ are strain-rate dependent axial, bending, and shear strength. The model includes six empirical failure parameters (S_N, S_B, S_S, n_N, n_B, and n_S). By providing a set of failure parameters, a failure surface can be defined by Equation 1. If a stress state is outside the surface ($f > 1$), the spot weld will fail.

These failure parameters are specific to each weld size and material stack-up. Until now, there was not a standard testing method for developing these parameters and few research programs have tried to create one[1-4]. A testing protocol developed at EWI for the purpose of creating spot weld failure parameters has been used since 2010 to establish these parameters for automotive manufacturers for a range of steel and aluminum stack-ups. Crash simulations in full-vehicle models show that the failure parameters created by this method are accurate for predicting the initiation of spot weld failure by comparing results with experimental data.

Test sample design

Small samples including one spot weld were designed based on past experience as shown in Fig. 1[2,4]. Sample designs can be classified into four basic types—KSII, lap-shear, coach-peel, and torsional. The *KSII sample* is designed to test spot weld axial strength when a load is applied in a 90° direction (normal to the spot weld interface), and the spot weld shear strength when a load is applied in a 0° direction (parallel to the spot weld interface). The KSII sample can also be used to evaluate joint strength for a combination of axial, shear, and bending load by testing in a 30° and 60° direction. The *lap-shear sample* is designed to evaluate both tensile and shear joint strength, as the joint rotates during loading due to the sheet metal's low stiffness. *Coach-peel* and *torsional samples* are designed to evaluate spot weld bending strength and shear strength (for a torque load), respectively.

The *T-section sample* as shown in Fig. 2 is designed to test spot weld failure at the component level by applying a transverse load and

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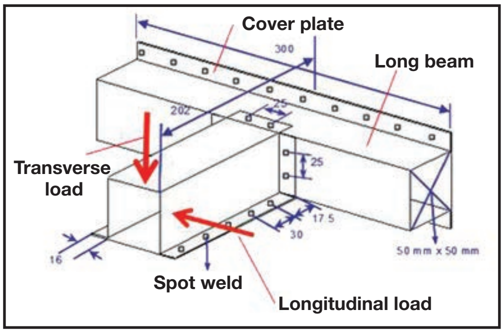
Fig. 2 — *A component sample used to validate spot weld failure parameters.*



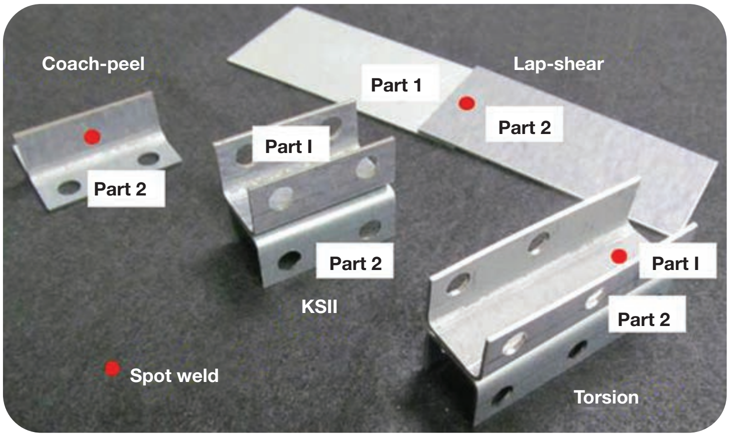


Fig. 3 — *Welded versions of small samples.*

longitudinal load, respectively[5]. Testing was modeled using finite element analysis (FEA) to predict spot weld failures by inputting the failure parameters developed from the small samples, and then comparing these with testing results to validate the spot weld failure parameters.

Sample fabrication

Sheet metal was cut and formed into the C-channel shape according to the dimensions shown in Fig. 1. Weld fixtures were designed to prepare the samples and welding procedures were supplied by the automotive manufacturer. Figure 3 shows the welded KSII, coach-peel, lap-shear, and torsional samples with one spot weld. Weld size could be either the minimum size (normally $4\sqrt{t}$, where t is the sheet thickness in mm) or the actual weld size used in the vehicle. If the minimum size is selected, the developed failure parameters will be conservative, which is preferred for automotive structure design.

Holes were drilled in samples prior to welding, for bolting samples to fixtures and eliminating slippage during testing. Holes were also added to the cover plate on the long beam of the T-section sample, to attach the plate to the fixture.

Small sample testing

Sample testing must be conducted with different strain rates because a spot weld's axial strength, shear strength, and bending strength is a function of strain rate as shown in Equation 1. Typically, three strain rate tests are conducted including static testing for low strain rate, intermediate speed testing for medium strain rate, and high-speed testing for high strain rate. Note that high-speed testing is more important than static testing because most crash impact testing is conducted at high speeds, such as 50 mph or higher.

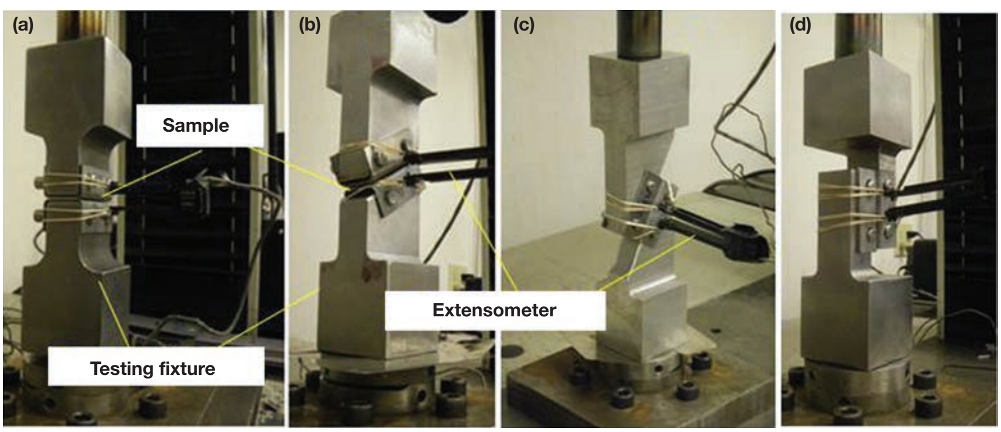
Testing fixtures are designed to simulate the rigid conditions in automotive spot welded structures for small sample testing. Figures 4 and 5 show the testing fixture used for KSII-90°, KSII-60°, KSII-30°, KSII-0°, lap-shear, coach-peel, and torsional samples. The same testing fixtures are used for static, intermediate, and high-speed testing.

Both static and intermediate speed tests are performed with an electromechanical test system at a 50 mm/min and 50 mm/second crosshead speed, respectively. Sample displacement is measured using both an extensometer, as shown in Figs. 4 and 5, and the crosshead positioning system. Load is recorded by a load cell.

Figure 6 shows a typical *load vs. time* and *displacement vs. time* graph for a spot weld static test. Five tests were conducted for the same conditions to check data repeatability. Small variations resulting from weld size differences were found, and the peak load was used to determine spot weld joint strength for developing failure parameters. Load curve after peak load was used to determine damage parameters. Figure 7 shows broken samples for KSII, coach-peel, and lap-shear testing. KSII and coach-peel samples exhibit pullout-button failure, while the lap-shear sample shows interfacial failure.

High-speed tests were performed on a modified Dynatup Model 8250 (General Research Corp.) instrumented drop weight tower, shown in Fig. 8. Consistent with static tests, the same upper and lower sample holders using bolts

Fig. 4 — *KSII sample testing: (a) 90° loading, (b) 60° loading, (c) 30° loading, and (d) 0° loading.*



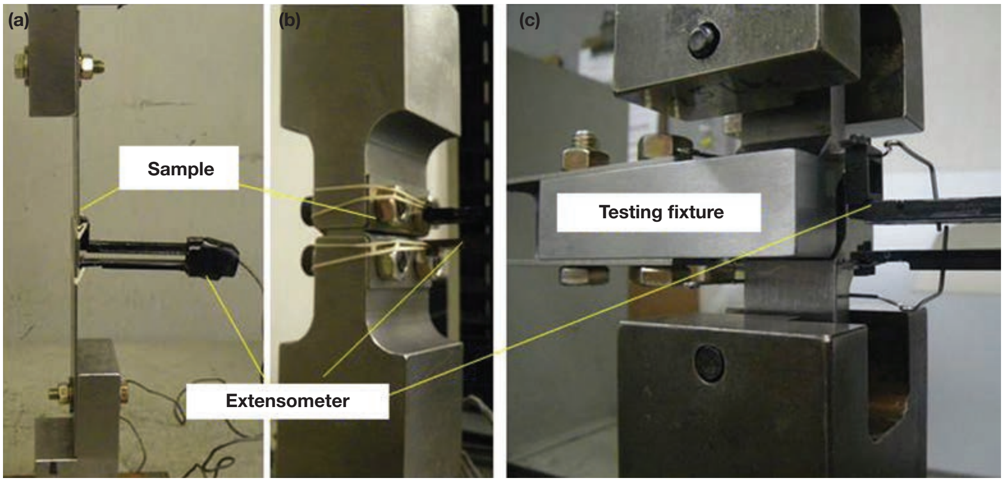


Fig. 5 — *Testing of (a) lap-shear, (b) coach-peel, and (c) torsional samples.*

or pin connections were used for high-speed testing. Impact load was measured at the reaction point during the impact event using a strain gauge-type load cell attached below the rigid table structure. The load cell was connected to the welded coupon through the upper sample holder. The moving head was dropped from a free-fall height of 2.59 m (8.5 ft). The moving mass contacted an impact bar extending through the structure and connected to the lower sample holder. Load was transmitted directly to the bottom attachment point of the test coupon. Sample displacement was measured using a linear voltage displacement transducer (LVDT) placed between sample attachment points.

T-section sample testing

Longitudinal and transverse loading were applied during T-section sample testing, as illustrated in Fig. 2. T-section static testing was conducted with an electromechanical test system and a fixture was designed to rigidly secure the T-section sample during testing. The fixture includes a 45 × 45-mm backing bar inside the long beam to bolt the sample to the fixture base through the holes in the cover plate (Fig. 2).

High-speed testing was conducted using an MTS drop tower, instrumented with an LVDT and load cells. The same rigid test fixture used for the static tests was used in the high-speed testing. Figure 9 shows broken T-samples for transverse and longitudinal loading. For transverse loading, spot welds were broken at the cover plate joined to the long beam. For longitudinal loading, spot welds were broken at the long beam to short beam intersection. FEA was conducted using the failure parameters developed from the small samples to predict spot weld failure and validate the final failure parameters.

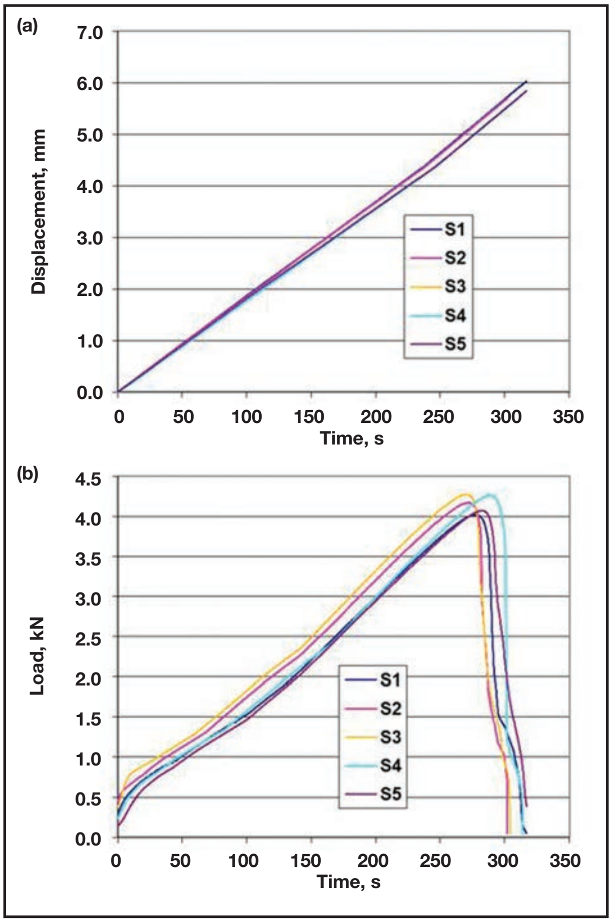


Fig. 6 — *Typical static testing results for KSII 90° samples: (a) Displacement and (b) load curve for a spot weld.*

Summary

A test method was developed to create spot weld failure parameters (joint strength at axial, shear, torsional, and combined loading) for crash simulation during automotive structure design. The method includes testing small samples and T-section samples. Small samples consisting of KSII, lap-shear, coach-peel, and torsional configurations were designed to evaluate the axial, shear, and bending strength of spot welds, as well as the strength during combined axial, shear, and bending loads. T-section samples were de-

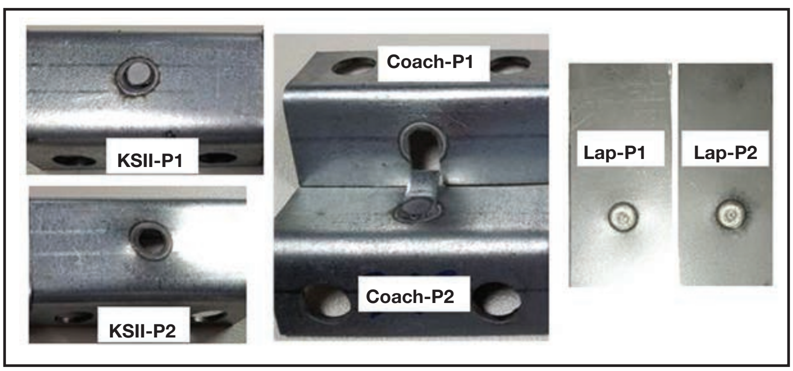


Fig. 7 — *Typical broken samples for KSII, coach-peel, and lap-shear testing.*

Fig. 8 — *Drop tower for high speed sample testing.*

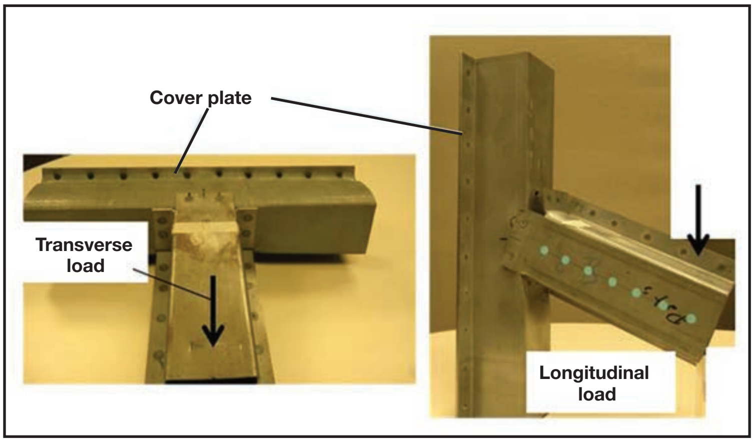


Fig. 9 — *Broken T-Section samples.*

signed and tested to validate failure parameters at the component level. ❍

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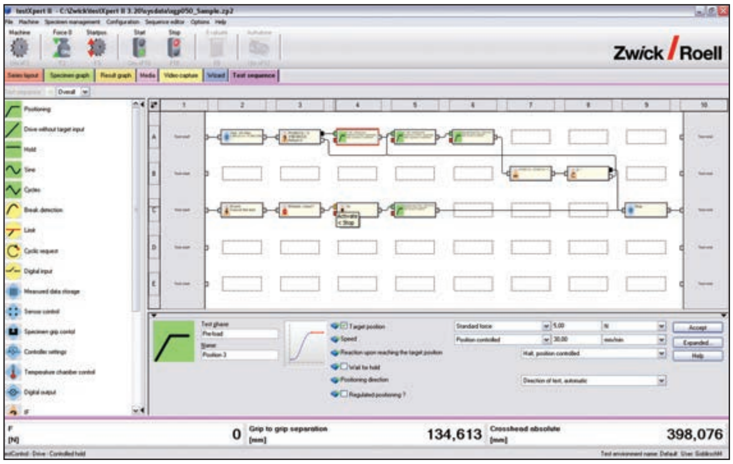
Dedicated Software Maximizes Efficiency in Materials Testing

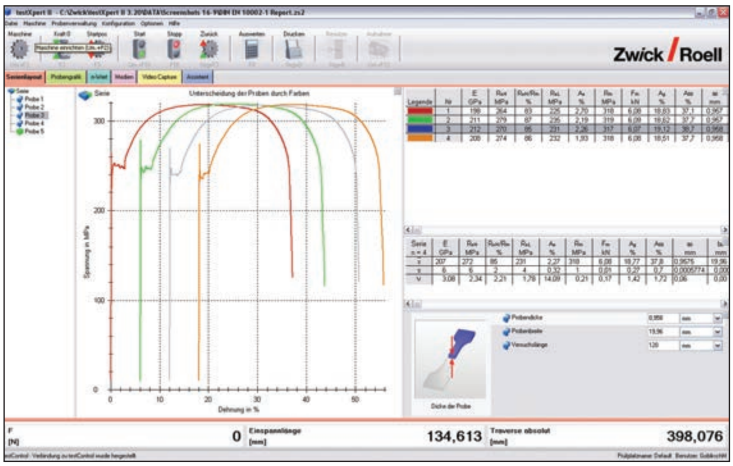
The emergence of novel alloys and high strength steels in support of automotive lightweighting initiatives is changing manufacturing processes as well as supply chain centers. Metals producers, seeking advantage in an increasingly competitive global market, are emphasizing differentiation. Physical properties and mechanical properties, in particular, play a major role in product performance. These factors, in combination with challenging new applications, are creating new requirements for materials testing.

"Production of novel alloys, aluminum, and emerging grades of steel is scaling up to address high visibility engineering challenges such as global demand for lighter passenger vehicles. Alcoa, Novelis, and ArcelorMittal are leading market growth in these sectors and we are beginning to see new complexities for materials testing emerge," says Manfred Goblirsch, software development manager for Zwick/Roell, a manufacturer of materials testing equipment based in Ulm, Germany. "Thorough materials characterization is required for both product development and quality assurance. We recognize, however, that for end users to achieve their growth objectives, testing must not impact productivity."

While responding to evolving market conditions, manufacturers must also prepare for an increase of engineering professionals approaching retirement. Over the next decade, engineering and technical fields are expected to see a talent shortage, stimulating the need for recruitment and training programs as well as employee retention efforts. Testing labs are charged with addressing the convergence of these issues while maintaining productivity and delivering accurate measurement results to internal customers.



Drag and drop simplicity within the graphical sequence editor function of testXpert II software supports rapid changeover times between tests and helps reduce measurement errors.



Software enables rapid comparison of results for analysis and reporting purposes.

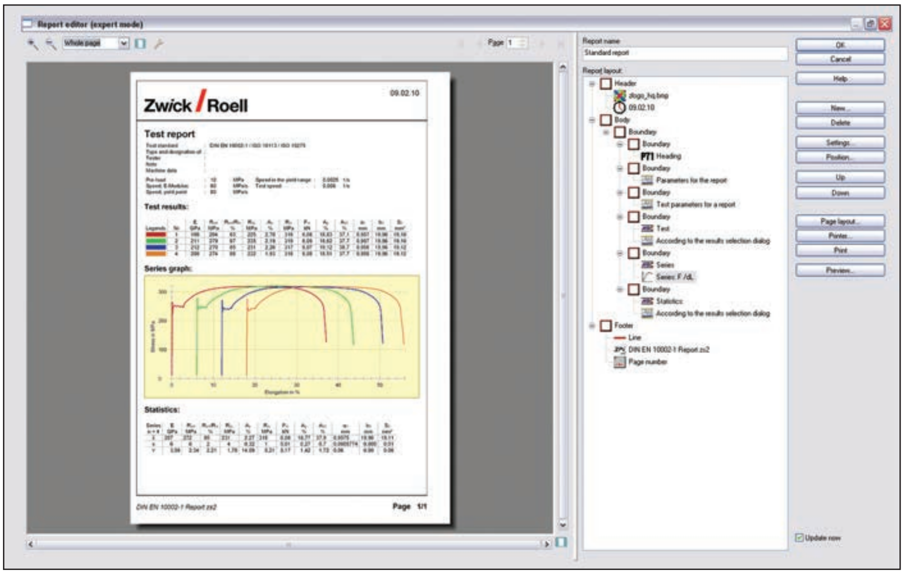
Software solutions

Software specifically designed for materials testing environments and quality control laboratories offers a solution to many of these challenges. Measurement and control software governs every action undertaken by testing systems and—working together with the electronics—delivers the required functionality. All software elements, from the architecture and its capacity to support complex algorithms demanded by some of the most challenging applications, to flexibility such as accepting external channels and handling data export to proprietary applications, help support test procedures in labs. As standardized testing protocols and methods across global facilities are sought, testing equipment must maximize the potential to synchronize the entire testing process to reduce errors and enhance consistency.

"As an example, our corporate software licensing program enables a company with global test sites to centralize testing protocols and subsequently dispatch them to various sites within the company network. Our customers have also indicated that this functionality is particularly helpful in coordinating round robin tests. With a corporate software license, a central lab can also specify the appearance of the user interface and scale this out globally," explains Goblirsch.

The Zwick testXpert II software includes built-in tutorials in order to simplify training. Organized to mentor new operators as well as experienced technicians seeking tips on operational efficiency, the tutorials shorten training time, allowing users to begin testing shortly after setup. In addition, user management capabilities suggest privilege restrictions and allowances at various levels in order to support lab supervisors managing complex workflows.

While responding to changing needs at the user level has spurred simplification of the user interface, other factors have influenced the software design as well. Perhaps



A report generation function facilitates data export and organizes key information into a simplified format.

most prominent among these is enhancing test efficiency. As metals producers demand greater throughput, they seek an increased return on assets and look to instrumentation suppliers for solutions that will assist them in accomplishing more with their testing systems.

"testXpert II was designed to maximize testing efficiency, to save time in the setup process. For example, the test environment is stored, so the user simply engages the tools that are to be used and the software automatically recalls the load cell, grips or platens, movement direction, extensometer, hard limits, soft limits, and the test space," says Goblirsch.

With more than 500 test programs available, the software enables test performance in compliance with over 900 standards. In addition, automatic unit conversion ensures that the software speaks the customer's language—units correspond with industry standards. The software also features standard test programs, which pre-store protocols in accordance with specific standards. For labs that run a wide range of standards, a master test program is available to support a host of standards for tensile, compression, flexure, tear, cyclic, melt flow, pendulum impact, and hardness tests.

The software can also perform compliance testing on its own routines. A specialized function called *Tenstand verification* can validate the procedure in the software to demonstrate that the software itself is meeting test requirements. Learning new testing routines takes time and requires a learning curve to achieve a high level of competency. Incorporating a consistent user interface allows standardization of training and testing routines from system to system around the world.

Support for regulatory compliance

As regulatory bodies continue to focus on elevating safety and traceability, testing and verification processes that occur as part of product development and quality assurance routines are emerging as documentation centers. Measurement and control software for materials testing systems helps support the establishment of audit trails and process controls. These factors are particularly important in the medical industry, where regulation has undergone substantial change in the past decade. Meeting stringent requirements associated with FDA and EMA (European Medicines Agency) regulations represents a significant and ongoing challenge for participants in the medical products industry.

Recordkeeping requirements are described under FDA 21 CFR Part 11. This mandate requires pharmaceutical and medical device manufacturers, biotech companies, and other FDA-regulated industries to implement controls, including audits, system validations, audit trails, electronic signatures, and documentation for software and systems involved in processing electronic data required to be maintained by FDA predicate rules, or used to demonstrate compliance to a predicate rule. Users define the degree of actions to be logged and justified according to specifications, which can originate from the QM manual or external requirements. In specific cases, this could involve recording every change in a parameter relevant to testing.

To support the needs for rigorous test data maintenance, a unique electronic recordkeeping function is part of the testXpert II software. This function provides complete digital documentation of all safety-critical tests. Test results can be automatically stored within a customer database through the standard Windows interface as well as the traditional ASCII format, further improving data integrity.

Summary

As new developments in metallurgical engineering continue to generate growth opportunities for metals producers, the need to validate performance via materials testing is anticipated to rise. Facing the dual challenge of addressing increased demand for testing services and maintaining an adequate level of skilled operators, lab managers are looking to instrumentation suppliers for support. Modern measurement and control software incorporates elements that have been specifically designed to meet these new requirements, offering solutions that add substantial value to test lab operations. ❍

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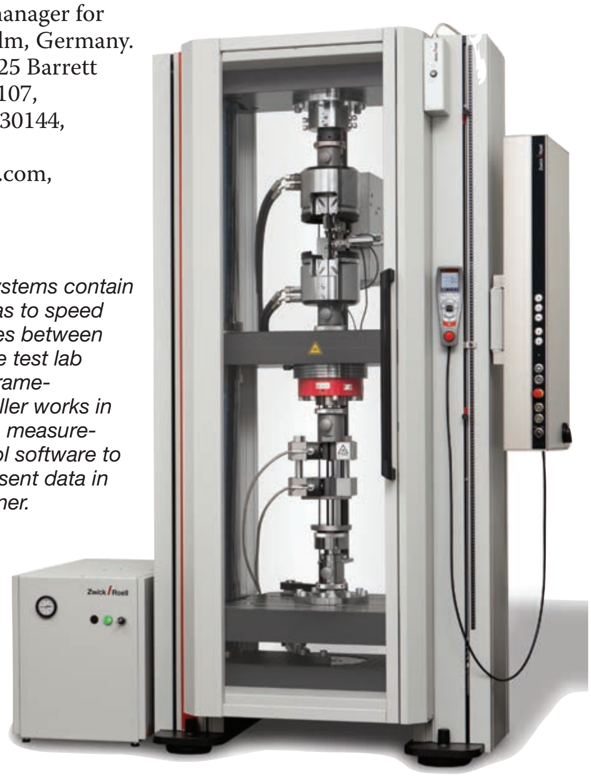


Allround-Line systems contain dual testing areas to speed changeover times between tests and elevate test lab efficiency. The frame-mounted controller works in concert with the measurement and control software to capture and present data in an intuitive manner.

Femtosecond Laser Processing Overcomes Barriers for Use in Medical Device Manufacturing

Microsecond (ms) fiber lasers have been successfully used in medical device applications such as hypo tube and stent cutting for years. While precise and fast, parts require a number of post processing operations after they are cut, which can damage mechanically delicate parts and add cost. A new ultra-short femtosecond (fs) laser technology produces pulses that do not leave a thermal fingerprint on parts. These disk-based femtosecond lasers offer sub-400 fs pulses, high beam quality, and peak power that enable a high quality cold ablation cutting process rather than a melt ejection process. Resulting cuts require minimal post processing and the small beam size allows machining of very fine details.

The process works well for production of medical devices such as catheters, heart valves, and stents, for medical and glass cutting and marking applications, and 3D-structuring of ceramic material for dental implants. Perhaps the most interesting potential use involves an entirely new class of bioabsorbable materials—polymers that safely remain in the body for a certain time before absorbing. They are being developed as an alternative to traditional polymers or metal parts.

In the past, fs lasers were considered too slow for commercially viable operations. However, recent studies evaluated cutting time per part and post processing steps, and demonstrate a return on investment for a disk femtosecond laser in less than 12 months (in many cases), especially for high value components. A key aspect of realizing the fs laser's potential is the system platform. Two companies working to address this issue include Jenoptik and Miyachi America, who are jointly developing both stage and scan head platforms to achieve new levels of quality and precision for micro treatment.

Femtosecond laser basics

Femtosecond (fs) light pulses are ultra-short pulses (USPs). One fs equals 10^{-15} seconds and as a calibration point, a 300 fs pulse equates to a physical pulse length of only 90 µm. Because there is no thermal processing as there would be in nanosecond (ns) pulses, USPs offer certain advantages, including:

- Unchanged material characteristics without thermal tension
- No shock waves or structural changes
- Smooth processed surfaces without microcracks
- Elimination of melting effects and structural changes
- Surface damage is eliminated and rework or post processing is not required
- Cleaning is unnecessary and there is no debris
- Clean surfaces due to lack of ejected material
- Smooth edges because there is no recast layer

Figure 1 shows these effects on an application using a long pulse laser (for example, µs) compared to that of an ultra-short pulse laser like an fs laser.

Femtosecond laser technology is not new—it has been widely used in institutions and research centers for more than 30 years, but commercial fs technology that can endure an industrial environment with 24/7 qualification was only developed within the last decade. Originally used for wafer dicing and scribing of P1, P2, and P3 solar panels or

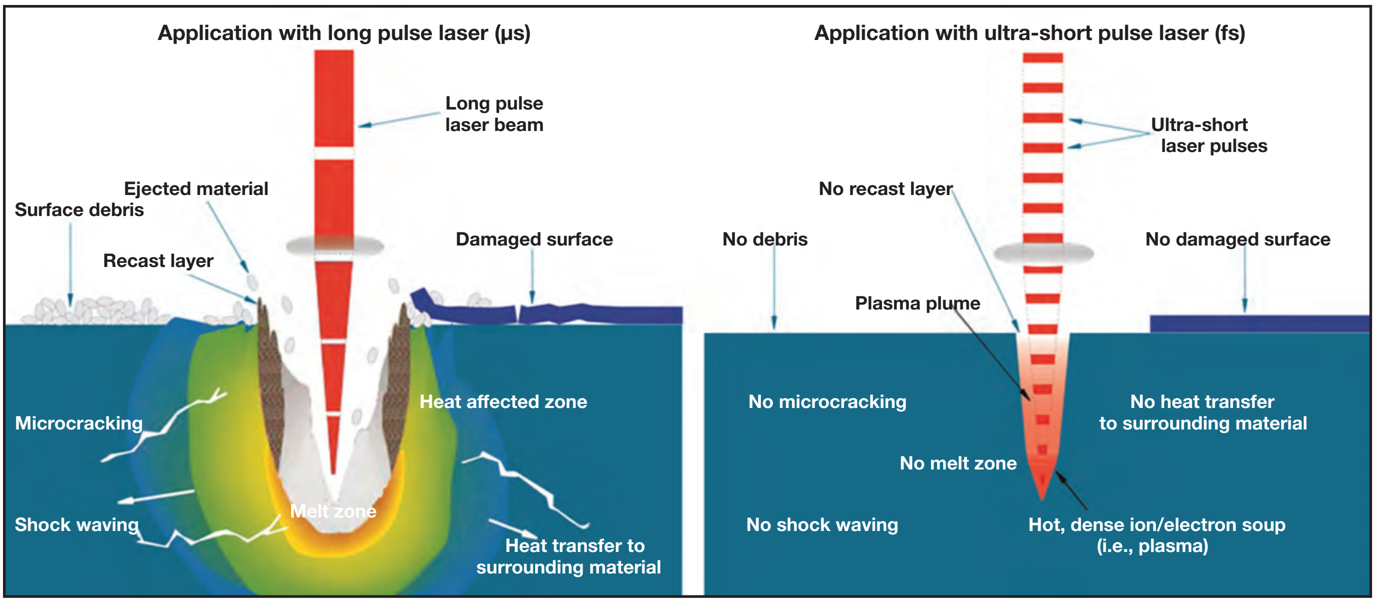


Fig. 1 — *Schematic processing comparison of microsecond to femtosecond lasers.*

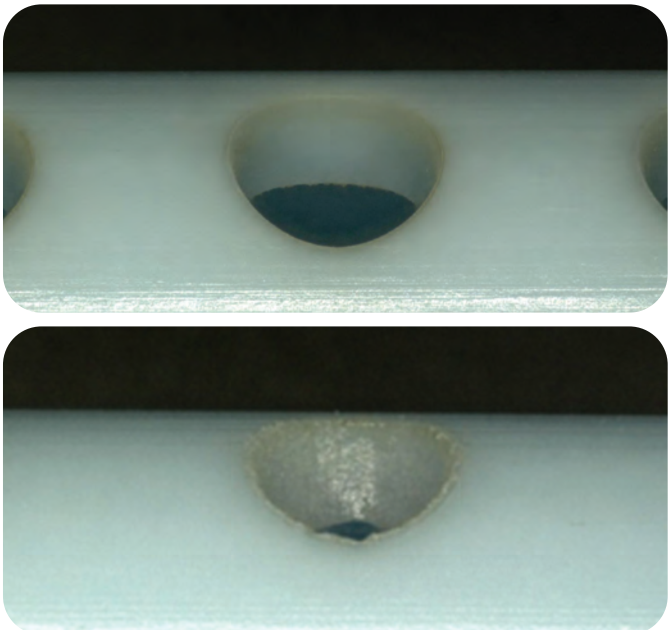


Fig. 2 — *Comparison of 1030-nm fs disk laser (top) to a 355-nm ns laser (bottom) when drilling polypropylene.*

creating channels in panels for electrodes, fs lasers are now advancing into a new wave of machining capabilities, and many medical devices are suitable candidates given the high cost of machined components.

In addition to minimized post processing, fs disk lasers create unique features previously impossible due to quality concerns, particularly in polymer processing. Figure 2 shows a comparison of a nanosecond 355-nm source and a 1030-nm fs disk laser source processing polypropylene. The disk fs hole shows little taper, no melting, and no heat effect distortion around the hole, enabling product design freedom to maximize functionality without compromising manufacturing.

Femtosecond lasers for medical devices

The edge quality possible with a femtosecond laser for both metals and plastics makes it useful for machining heart, brain, and eye stents (both nitinol and cobalt-chrome), catheters, heart valves, and polymer tubing. The nearly cold cutting process allows very fine feature sizes to be cut into the thinnest material, while maintaining mechanical and material integrity. Internal water cooling is unnecessary for even the smallest diameter nitinol tubes.

Quality improvements and reduced post processing requirements have made fs laser technology a promising theoretical possibility, but until about six years ago there was little commercial interest in its use for medical devices due to concerns about the expense and slow speed compared to other technologies. That changed when an ROI tool was developed to illustrate the true cost of post processing. The tool can be used to determine overall costs, including laser equipment purchase, post processing capabilities, and machine and handling time. Calculations demonstrate that femtosecond lasers are actually faster, because they reduce several time consuming post processing steps.

For example, the coronary stent—one of the first devices to be manufactured with a fiber laser—must first be machined, then honed, and finally deburred. A chemical etch process

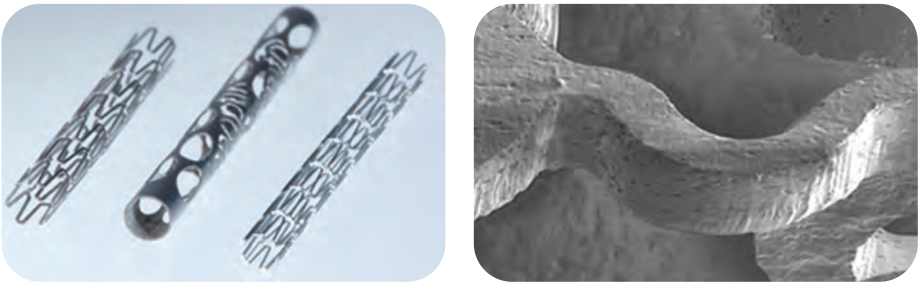


Fig. 3 — *Cut quality for nitinol stent. Nitinol stents (left). Close-up of a 100-µm-thick nitinol stent (right). Edges feature the same finish as the material surface.*

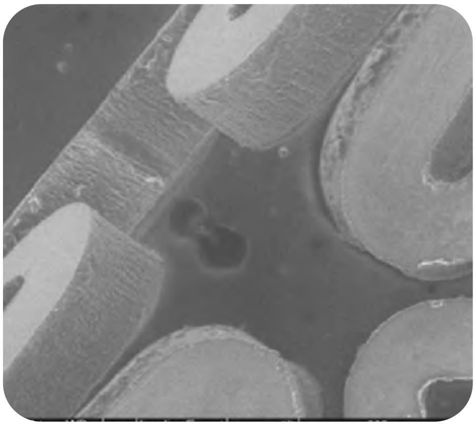


Fig. 4 — *Disk fs laser cut of a bioabsorbable stent.*

then cleans up around the edges, followed by electropolishing. These steps are time consuming and can also cause the part to become brittle, deformed, and potentially exhibit microcracks. Yields are in the 70% range, with significant loss of end product.

By contrast, the fs laser is a dry format—no water or heat is introduced in the part. The number of steps is drastically reduced; the part is machined and then undergoes an electrochemical process to round the edges. Part integrity is improved, several steps are eliminated, and yields are closer to 95%.

Figure 3 shows the high cutting quality of the fs laser when working with nitinol stent material. Using the fs laser prevents burr, and the slight roughness of the cutting edge achieves a suitable precondition for the electropolishing process. Removal rate in this example is 0.25-5 mm/sec and material thickness up to 400 µm is possible.

Femtosecond laser technology is also the only available process appropriate for machining medical products out of new bioabsorbable polymers, which can be safely implanted in the body for controlled lengths of time before absorbing, without causing harm or adverse interactions. Next-generation advanced bioabsorbables (also called aspirants) provide an alternative to traditional polymers or metal components and are being designed to meet precise degradation rates and other specifications.

Bioabsorbable materials can be machined into any profile used for stents, but must be processed correctly without inducing heat. Failure to do so could lead to crystallization, which degrades the material's structure and lifespan as well as its ability to dispense medicine at the correct rate. Also, because bioabsorbables dissolve, they cannot be cleaned like most plastics, and cannot come into contact with any liquid solutions.

Bioabsorbables are already being used for coronary stents in the European Union, although they have not yet received FDA approval for use in the U.S. Mostly composed of polyesters, primarily homopolymers and copolymers of poly(lactic acid) and poly(glycolic acid), bioabsorbables are showing promise for a variety of uses, including cardio stents for patients who may have been stented numerous times and can no longer tolerate a traditional fixed stent. The material is also being used to deliver medicines directly to organs. For example, a plastic spongelike material is doped with medicine and inserted into the liver, dispensing medicine at a consistent rate and lasting from six months to three years before dissolving. Figure 4 shows an fs laser cut of a bioabsorbable stent.

After years of clinical trials, several firms are awaiting approval and already planning for the new innovation to hit the U.S. market, and several have been qualifying use of fs laser equipment to gear up for the precision micromachining required.

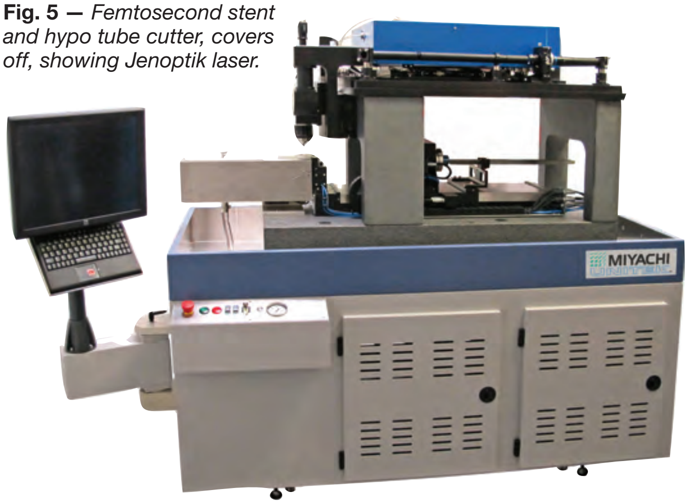
Femtosecond lasers for micromachining

The industrial strength of the disk fs laser must be matched to an equivalent system to deliver the consistency and reliability required by the medical device industry. Today's fs lasers cannot be fiber-delivered and are therefore directed and delivered to the focusing optics by fixed mirrors—a challenge for designing a beam delivery system for a four-axis tube cutter that can make off-axes cuts while maintaining alignment. The optical path design must ensure that the beam expander and fine-tuning attenuator are easily accessible for process development. System design requires full mechanical isolation, and in some cases ambient temperature stability, to provide a foundation for process repeatability.

To gain the system integration capabilities needed to move the femtosecond laser capability into the marketplace, a platform was developed based on Miyachi's Sigma Tube cutter (Fig. 5). First, the end user's process must be understood in order to determine a specific application's system needs. This level of understanding can only come from running the application in-house. Although this knowledge is important with any process, it is magnified with ultrafast systems. An in-house femtosecond processing lab provides transition from application development to the define-design-deliver approach for both standard and custom system fulfillment.

While mechanical stiffness and isolation are required, they are only a starting point. Determining how delicate parts and materials will be repeatedly positioned or clamped, implementing in-system part inspection and incorporating real-time optical beam diagnostics are other key pieces. For example, mirrors direct the beam through the system, so optical alignment is important, but this is only the first step. Ensuring that beam profiles and power levels are maintained requires optical diagnostic tools—and these tools must be in line and nonintrusive, providing real-time information. The tool is usually mounted directly after the laser and the last turning mirror in the beam path to enable deviations to be isolated to the laser or the optical beam path. Being in line and nonintrusive enables data collection during processing that can be time and date stamped as part of the manufacturing data.

Fig. 5 — *Femtosecond stent and hypo tube cutter, covers off, showing Jenoptik laser.*



Conclusions

The femtosecond disk offers unique process capabilities with high beam quality and peak powers. To maximize the process capability for production, the laser must be integrated into a system that enables high quality and repeatable processing. ❍

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Metallurgy Lane

Aluminum: The Light Metal—Part III

Alcoa's aluminum monopoly continued throughout the 1920s and 1930s—a serious problem when World War II demands far exceeded production capacity.

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.

Alcoa acquired the laboratory of the Aluminum Casting Co. in 1920 as payment for the debt owed on aluminum purchases made during World War I. Two metallurgists with aluminum experience came with the laboratory—Zay Jeffries and Robert Archer. During WWI, Jeffries worked on aluminum casting problems, mainly with ordinance fuses and the Liberty Aircraft Engine. Jeffries and Archer continued to make major contributions to the field of cast and forged aluminum alloys throughout the 1920s, working in the Cleveland laboratory.

With two lab facilities dedicated to research and development throughout the 1920s and 1930s, more than 20 new alloys were added to Alcoa's product line. The first new sheet alloy—called 17S—was based on the German alloy, Duralumin. It made its debut in the 1920s and was used to build the first commercial all-metal passenger airplane in the U.S., the Ford Trimotor, with roughly 200 manufactured in the late 1920s and early 1930s. Production ceased as the Great Depression deepened and the 10-15 passenger design became cost prohibitive for commercial service.

The precipitation hardened 17S alloy also lacked sufficient corrosion resistance in a salt spray atmosphere. This problem was solved by a new process that bonded a more corrosion resistant layer of pure aluminum to both sides of the 17S sheet metal. These two layers make up about 10% of total sheet thickness. This product—named Alclad—is still used in aluminum alloy applications exposed to corrosive atmospheres.

Alcoa's 17S sheet alloy was based on the German alloy, Duralumin, and was used to build the first commercial all-metal passenger airplane in the U.S., the Ford Trimotor. Shown here is the Ford 5-AT-B "City of Columbus" flown by Charles Lindbergh. Public domain image.

Alloy development

In the 1930s, Alcoa developed a higher strength alloy called 24S. The major change from 17S to 24S involved boosting the magnesium level from 0.5% to 1.5%. This increased the design strength of 24S to 50,000 psi, from 40,000. In addition, moderate cold working, such as stretching or rolling the sheet material immediately after water quenching and then aging it, further increased 24S design strength to 57,000 psi. All of these properties could be produced with Alfred Wilm's original room temperature treatment called *natural aging.** The new alloy was used to construct the first commercially successful passenger plane, the Douglas DC-3 in 1935.

Another precipitation hardening alloy system developed by Alcoa in the 1930s adds 1% magnesium, 0.6% silicon, and 0.3% copper to aluminum. This alloy—called 61S (now 6061)—is the structural material for a great tonnage of ordinary engineering applications. A number of alloys based on 6061 contain additional alloying elements and are widely available as well. These alloys are known for ease of fabrication, corrosion resistance, and low cost compared to high-strength aircraft alloys. They feature design strengths of 35,000 to 50,000 psi and have excellent characteristics for general industrial applications, such as trucks, buses, rail cars, trailer tanks, storage tanks, building construction, and light aircraft. Some of the numerous mill products made of these alloys include sheet metal, forgings, extrusions, bar, tubing, pipe, and wire.

Aluminum for WWII

Alloy 24S was the aluminum used for nearly all of the 300,000 planes built in the U.S. during World War II. The quantity of aluminum needed for this vast undertaking greatly exceeded the capacity of Alcoa, the only aluminum manufacturer in the country. In 1939, the U.S. produced 148,000 tons

The Douglas DC-3, the first successful passenger plane, was built with 24S alloy, 4% Cu and 1.5% Mg. From 1935 until production ceased in 1945, 18,000 were built for commercial and military use. Public domain image.

The Boeing B-17 Flying Fortress and nearly all of the 300,000 planes built during WWII used the 24S alloy. The aluminum industry tripled in output to meet wartime demand. Public domain image.

of aluminum, compared with 200,000 tons in Germany. Preparing for war drove the German demand. By 1943, when wartime production reached its peak, the U.S. produced 835,000 tons against 250,000 tons in Germany. In addition, Canadian production increased from 75,000 tons in 1939 to 450,000 tons in 1943. Overall production for the five war years reached 4 million tons in the U.S. and Canada versus 1.4 million tons in Germany.

To meet the increased demand, numerous aluminum plants were financed by the U.S. government, but were built and operated by Alcoa. These plants included four to produce aluminum oxide, eight to reduce the oxide to metal, and 10 to manufacture finished product. These government plants produced twice the aluminum of the Alcoa owned plants. After the war, the government plants were sold to Reynolds Metals Co. and Kaiser Aluminum and Chemical Co., ending the Alcoa monopoly that had existed since 1888. With the new aluminum industry, the old system of identifying alloys was modified. The new system used the 2000 series for aluminum-magnesium alloys. Thus, 24S became 2024 and remains a major high-strength alloy, although stronger alloys have been developed for the most critical applications.

Modern alloy introductions

Aluminum that contains zinc, magnesium, and copper was originally studied in Germany. Alloys featuring zinc as a major alloying element exhibit very high strengths, but are prone to crack under stress when exposed to corrosion. Nevertheless, research on these alloys was performed at Alcoa and the first commercial composition was 76S, used for aircraft propellers in 1940. Later, stress corrosion cracking was significantly reduced by adding small amounts of chromium to the alloy. This lead to the commercial alloy 75S (now 7075), which contains 5.5 % zinc. This innovative alloy was introduced during WWII as the structural metal on Boeing's B-29 Superfortress long-range bomber. The 75S alloy could be artificially aged to design strengths of 73,000 psi, while a modified version with 6.8% zinc (7178) introduced in 1951 can develop strengths as high as 78,000 psi.

The Boeing 777 uses several new alloys developed by Alcoa. Alloy 7055 contains 8% Zn, 2.3% Cu, and 2.0% Mg. Other new alloys are modifications of 2024 with lower impurities. Courtesy of United Airlines.

A more recent alloy developed by Alcoa called 7055 contains 8.0% zinc, 2.3% copper, and 2.0% magnesium, and provides exceptionally high compression strength. Strength levels of 90,000 psi are achieved in plate and 97,000 psi in extrusions. This strength level is 10% higher than the best previous alloy and 25% higher than the original aluminum-zinc alloy, 7075, developed during WWII. In 2002, Alcoa received the ASM International Engineering Materials Achievement Award for the development of 7055.

The Alcoa Building, erected in 1953 in Pittsburgh, was the first all-aluminum-clad high-rise, built to serve as the company's headquarters. Public domain image.

These latest high-strength alloys from Alcoa are used on the Boeing 777, with the main structure of the plane constructed of two basic aluminum alloys. Because they are the most highly stressed components, the upper wings are built of 7055 alloy. The lower wings are constructed of modified versions of 2024, specifically 2224 and 2324. They have lower impurity content, which improves toughness. The fuselage is made of 2524, another version of 2024 that contains even lower levels of impurities for greater toughness.

Aluminum has come a long way since its early days of pots and pans. With the discovery of precipitation hardening as a mechanism for increasing its strength, aluminum now holds a major position in modern technology as a structural metal with unlimited use.

*More information on precipitation hardening is included in "The Discovery of Strong Aluminum," *Advanced Materials & Processes,* p 35-36, Aug. 2011.

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For more metallurgical history, visit metals-history.blogspot.com.

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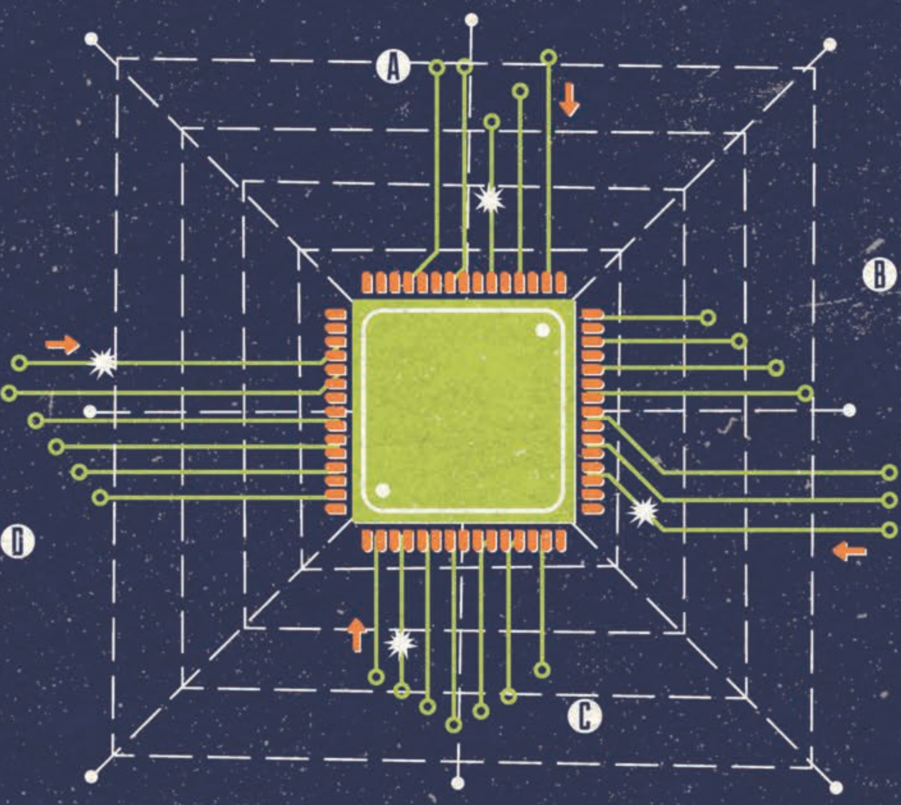

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HTPRO

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BORIDING FOR WEAR RESISTANCE

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PAGE 11

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Heat Treat Knowledge

Keeping Your Vacuum Furnace System Healthy and Pumping

Just as is it is important to keep your heart healthy and pumping, it is crucial to keep your vacuum furnace system healthy and pumping. Get the best performance out of your vacuum furnace by selecting the most appropriate pumping system for your process and following a few simple tips.

Let's start with the basics. In order to evacuate atmospheric pressure from the vacuum chamber to the required ranges for your specific processes, vacuum furnace systems must utilize various types of pumping system combinations. It is essential to maintain the pumping system as specified in the operator's manual, taking into consideration any special accommodations the specific process being conducted may require.

Read the full article at **www.IpsenUSA.com/Pumping** to learn more about maintaining your pumping system and preventing a pump's worst enemy.

Scan this code to read the article.

Enhancing Your Atmosphere Furnace's Process and Part Quality

Heat treatment is consistently viewed as a critical step for adding value to the parts produced. This is why, when producing quality parts in atmosphere furnaces, it is essential to follow these tips for utilizing the carburizing and quenching processes, as well as applicable modern technology.

To start, when carburizing and quenching parts in a batch atmosphere furnace, it is essential to achieve uniformity of temperature and gassing, optimize flow and aim for uniform quench speeds. Ipsen's Carb-o-Prof® control software helps maintain balance by regulating, documenting and archiving the carburizing processes in atmosphere furnaces. The software is able to adapt the process to unforeseen events, preventing the potential waste of parts and resources.

Read the full technical article at **www.IpsenUSA.com/AtmosphereFurnaceTips** to view tips for enhancing processes and producing high-quality parts with reduced distortion.

Scan this code to read the article.

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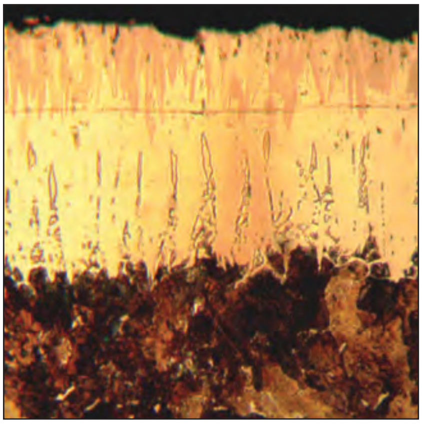
Editorial Opportunities for *HTPro* in 2015

The editorial focus for *HTPro* in 2015 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

March	Thermal Processing in the Aerospace Industry
June	Testing and Control
October	Thermal Processing in Automotive Applications
November	Atmosphere/Vacuum Heat Treating

To contribute an article to one of the upcoming issues, please contact Frances Richards at frances.richards@asminternational.org. To advertise, please contact Erik Klingerman at erik.klingerman@asminternational.org.



ABOUT THE COVER:
Dual-phase layer consisting of Fe_2B (lighter colored deep "teeth") and FeB (darker colored shallow teeth) contains stress-related cracks that run parallel to the material surface. Bluewater Thermal Solutions, bluewaterthermal.com.

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HTPro™ is published quarterly by ASM International®, 9639 Kinsman Road, Materials Park, OH 44073, 440.338.5151, asminternational.org. Vol. 2, No. 4.

TMI ATC Project Making Headway

The Thermal Manufacturing Industries Advanced Technology Consortium (TMI ATC) AMTech project led by ASM International was formed to lead and coordinate a national effort that identifies common thermal manufacturing needs across industries and solicits input from key stakeholders. Roadmapping workshops, such as those held during October at Furnaces North America in Nashville and at the MS&T conference in Pittsburgh, will identify technologies ready for implementation in thermal manufacturing industries, as well as high-priority areas for development.

Advanced thermal technologies have the potential to improve efficiency, productivity, and global competitiveness for a wide range of thermal manufacturing processes. These methods rely on heat-driven techniques such as drying, smelting, heat treating, curing, and forming. Thermal manufacturing is estimated to directly and indirectly affect the employment of over 5 million people in the U.S. in more than 100,000 establishments.

Previous efforts to identify and pursue these technology advancements have occurred independently from one another (e.g., Heat Treating Technology Roadmap). However, a number of key technologies and process improvements are widely applicable to the many industries that comprise the broad thermal manufacturing community.

To help move this project forward, TMI ATC compiled a review of state-of-the-art thermal manufacturing with the aim of developing a foundation for the needs and opportunities related to advanced thermal manufacturing technologies across relevant industries and involving all key stakeholders. Consortium project managers reviewed previous industry roadmaps to identify critical needs and opportunities in thermal manufacturing, interviewed nearly two dozen experts in the thermal manufacturing community, and searched websites of relevant organizations to provide an overview of recent and current work related to thermal manufacturing.

These efforts resulted in identifying the most important needs and opportunities as well as recent efforts being conducted in several areas including:

- Modeling and Simulation
- Sensors
- Heat Generation Methods
- Process Intensification
- Energy and Emissions Reduction
- Automation and Robotics
- Advanced Materials

Developing and implementing these technologies in parallel will provide optimum value. Read the complete review by visiting the TMI ATC website at asminternational.org/web/tmi-atc/home under Resource Library and then State of the Art.

Stan Theobald
Senior Director,
Business Development
ASM International

Petrus Inducted as ASM Fellow

Gregory J. Petrus, president, Forged Right First LLC, Hinckley, Ohio, was inducted as an ASM Fellow at the MS&T14 Awards Ceremony on October 14 in Pittsburgh. He is recognized "for significant contributions to physical metallurgy through development of innovative solutions using simulation tools for enhancing metalworking and heat treating to exploit a wide array of materials structure/property/processing relationships."

Gregory Petrus (left) accepts his ASM Fellow citation from ASM President Ravi Ravindran, FASM.

2014 ASM HTS/Bodycote Best Paper in Heat Treating Awarded

Anthony Lombardi (left), Ph.D. candidate in mechanical engineering at Ryerson University and winner of the 2014 HTS/Bodycote Best Paper in Heat Treating Award, is congratulated by ASM President Ravi Ravindran, FASM, at the ASM Leadership Awards Luncheon on October 13, 2014, during MS&T in Pittsburgh. Lombardi's paper is entitled "Development of Methodology to Improve Mechanical Properties of 319 Al Alloy Engine Blocks through Cost-Effective Heat Treatment Optimization."

Connelly is 2014 Recipient of the George A. Roberts Award

Michael B. Connelly (right), vice president, Casey Products, Woodridge, Ill., accepts the 2014 George A. Roberts Award from Amy Ebeling, granddaughter of George A. Roberts. Connelly is one of the founding volunteers of the ASM Materials Camp program and participated in the Eisenman Camp for 15 years. He also participated in the start-up of the Materials Explorer's Camp in France and served on the ASM Materials Education Foundation Board.

First ASM HTS/Surface Combustion Emerging Leader Award to Be Presented in 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 around him/her to dedicate themselves to the advancement and promotion of vacuum and atmosphere heat treating technologies.

Nominations must be submitted to ASM Headquarters no later than April 1, 2015.

For rules and nomination form for the ASM HTS/Surface Combustion Emerging Leader Award, visit the Heat Treating Society Community Website at http://hts.asminternational.org and click on Membership & Networking and HT Awards.

For additional information, or to submit a nomination, contact Joanne Miller at 440.338.5151, ext. 5513, joanne.miller@asminternational.org.

Soliciting Papers for ASM HTS/Bodycote 'Best Paper in Heat Treating' Contest

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

The contest is open to all students, in full time or part time education, at universities (or their equivalent) or colleges. It also is open to those students who have graduated within the past three years and whose paper describes work completed while an undergraduate or post graduate student. The winner receives a plaque and check for $2500.

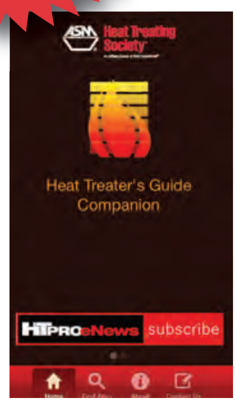
To view rules for eligibility and paper submission, visit the Heat Treating Society website at http://hts.asminternational.org/portal/site/hts/HTS_Awards.

Paper submission deadline is December 12, 2014. Submissions should be sent to Joanne Miller, ASM Heat Treating Society, 9639 Kinsman Rd., Materials Park, OH 44073, 440.338.5151 ext. 5513, joanne.miller@asminternational.org.

Heat Treating App Update Released by ASM Heat Treating Society

Available for iPhone, iPad and Android

ASM International and the ASM Heat Treating Society released Version 2 of the free mobile app, the *Heat Treater's Guide Companion*. Version 2 provides ready reference data on more than 330 steel alloys, nearly doubling the number of alloys in the previous release. In addition to carbon and alloy steels, the app now includes stainless steels, tool steels, and ultrahigh-strength steels, and also features enhanced searching.



Content includes chemical composition, similar steels, characteristics, and recommended heat treating practices. The app can be used by itself or as a companion to the ASM *Heat Treater's Guide* print and online database products, which provide additional heat treating data such as representative photomicrographs, isothermal transformation diagrams, cooling transformation diagrams, tempering curves, and data on dimensional change.

Heat Treater's Guide Companion, Version 2 is available in the Apple and Google App Stores. Download the app today! For quick links to the Apple and Google App Store listings, go to http://hts.asminternational.org. For more information, contact linda.vermillion@asminternational.org, or 440.338.5151, ext. 5561.

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, 2015**.

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

CALL FOR PAPERS

HT 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 are co-locating to provide an exciting mix of education, technology, networking, and exposition opportunities at the 28th Heat Treating Conference and Exposition and Gear Expo, the premier heat treating gathering in North America. The event will offer a full technical program covering a broad scope of heat treating technology, networking opportunities, and a first-hand look at equipment, supplies, and services from exhibitors.

HTS 2015 organizers are seeking original, previously unpublished, noncommercial papers for oral and poster presentations.

Abstract submission deadline: January 26, 2015. Visit the HTS website at http://hts.asminternational.org for details on suggested program topics and submitting an abstract, and click on Events tab.

Heat Treating Society Looking for Volunteers

The HTS Board is seeking enthusiastic, committed members to serve on various HTS Committees that monitor technical advances and other areas of member interest to bring new information to members through products and services. HTS members are requested to consider serving on one of the following committees:

- Awards and Nominating Committee
- Education Committee
- Technology & Programming Committee
- Exposition Committee
- Finance Committee
- Membership Committee
- Research and Development Committee

Interested members should review the Committee Purpose on the HTS website at http://hts.asminternational.org and contact joanne.miller@asminternational.org.

CORRECTION

In the September 2014 issue of *HTPro* in *AM&P* (p 58), the photo of the vacuum furnace hot zone should have been credited to Solar Atmospheres, Souderton, Pa. We apologize for any inconvenience this may have caused.

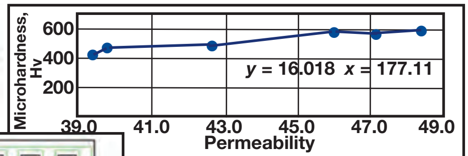
Breakthroughs in Nondestructive Measuring Techniques

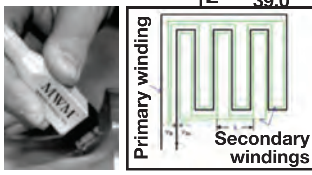
The Center for Heat Treating Excellence (CHTE) at Worcester Polytechnic Institute (WPI) in Massachusetts is conducting a cutting-edge research project aimed at measuring the surface hardness and case depth on carburized steels for process verification and control. The results will enable companies to improve the quality of heat-treated products faster and more cost-effectively.

"This is the first time a project like this is being undertaken," explains Lei Zhang, CHTE researcher and Ph.D. candidate at WPI. "Our focus is on developing new measurement techniques that will enhance product quality."

According to lead researcher Richard Sisson, Jr., George F. Fuller Professor of Mechanical Engineering at WPI, and CHTE director, the heat treating industry needs rapid, accurate nondestructive techniques to measure surface hardness and case depth on carburized steels for process verification and control. "Current measurement methods require destructive testing with traveler specimens that cannot always represent the configurations of the production part, nor the associated subtleties of thermal history, carbon atmosphere, and geometry influenced diffusion. Our research will eliminate much of the guesswork."

Another industry challenge with the traveler specimen-measurement method is that it often requires periodic sectioning of production parts to validate the hardness and case depth after carburization, especially for critical shaft and gear teeth configurations. "This method is labor intensive, expensive, and susceptible to operator error, as well as counterintuitive to the end result of high quality, usable heat-treated parts," explains Sisson.





Meandering winding magnetometer (MWM) used to measure surface hardness. At a high frequency (5 MHz), permeability measured by the MWM sensor has good correlation with surface hardness.

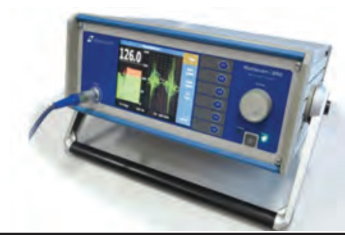
A key challenge of the project is to distinguish between hardness and residual stress, because most techniques currently used to measure case depth are not only sensitive to hardness distribution, but also to residual stress distribution.

Nondestructive techniques being evaluated initially include eddy current, meandering winding magnetometer (MWM), Barkhausen noise testing, and alternating current potential drop.

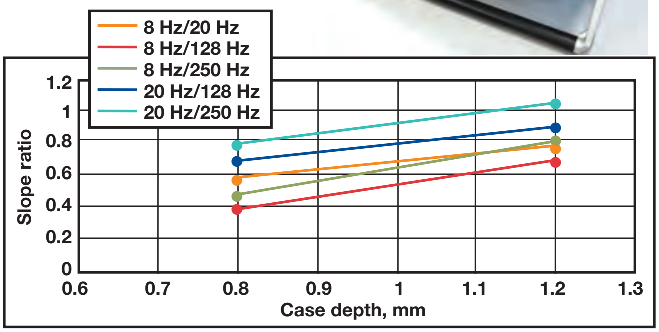
The project focuses on four tasks:

- Identify nondestructive techniques to measure surface hardness and case depth and develop a fundamental understanding of their mechanisms. Select nondestructive techniques for testing based on project objective and equipment availability.
- Select alloys and design heat treating conditions to be used to create testing standards using the simulation method, and fabricate and characterize the standards.
- Conduct nondestructive tests to determine the correlations between the destructive test results and the known results in the standard.
- Determine correlations among nondestructive test measurements, hardness, and microstructure for the standards. Verify the effectiveness of the respective nondestructive test technique in industry.

Completion of the research project is expected in 2016.



Barkhausen noise unit used to measure case depth. The magnetization voltage sweep method has been applied, and the slope ratio reflects the case depth variation of the tested part.



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 current research portfolio

Other projects now in progress include:

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

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.

DEEP CASE BORIDING FOR EXTREME WEAR RESISTANCE

THE ABILITY TO PRODUCE DEEPER CASE BORIDE LAYERS THAT ARE NOT PRONE TO SPALLING MAKES THE BORIDING PROCESS COMPETITIVE WITH SOME CONVENTIONAL DEEP-CASE AND THICK-COATING PROCESSES.

Craig Zimmerman* and Nick Bugliarello-Wondrich,* Bluewater Thermal Solutions

Boriding (also known as boronizing) is a diffusion-based case-hardening process for metals that creates an ultrahigh hardness case (1500–2200 HV) below the surface of the parts being treated. It produces exceptional wear resistance for metal parts that operate in severely abrasive and erosive operating conditions and also improves anti-galling properties. Boriding typically more than triples the service life of high wear parts compared with other traditional heat treatments such as carburizing, carbonitriding, nitriding, nitrocarburizing, thin PVD coatings, and platings like hard chrome. Boriding creates a wear layer with higher hardness than many wear resistant thermal spray coatings, such as tungsten carbide and chrome carbide. It is not mechanically bonded to the surface, but instead is diffused below the surface of the metal, making it less prone to peeling and breaking off treated parts.

Boriding is performed by diffusing boron atoms into a metal surface and allowing the boron to react with elements present in the substrate to form metal-boride compounds. Upon diffusing enough boron into the surface, a metal-boride compound layer with high hardness precipitates and grows below the surface of the part. Different types of metal-boride layers are possible, the composition of which depends on the material being treated. For example, iron-boride layers form in steels and cast irons and nickel-boride layers form in nickel-base alloys. Other compounds possible include cobalt and titanium borides. This article discusses only boriding of ferrous alloys.

Two iron-boride compounds formed when boriding steel are Fe_2B (at lower boron concentrations) and FeB (at higher boron concentrations), each having different structures, densities, and mechanical properties as shown in Table 1[1].

**Member of ASM Heat Treating Society*

TABLE 1 — PROPERTIES AND CHARACTERISTICS OF IRON-BORIDE COMPOUNDS

	FeB	Fe_2B
Boron content, wt%	16.23	8.83
Structure	Rhombic	Tetragonal
Residual stress on cooling	Tensile	Compressive
Coefficient of linear thermal expansion, $\times 10^{-6}$/K	23	7.9–9.2
Hardness (HV0.1)	1900–2100	1800–2000
Density, g/cm^3 (lb/in.^{3})	6.75 (0.244)	7.43 (0.268)

Single-phase Fe_2B layers. As boron diffuses into a steel surface, concentration at the surface starts out at zero and begins to increase until the concentration just below the surface reaches a level where Fe_2B compounds begin to precipitate and grow. Fe_2B is the first phase to form, as it contains a lower boron concentration (33%) than FeB, which requires 50% boron concentration. A solid continuous single-phase Fe_2B layer forms below the surface and grows deeper over time as boron concentration increases. An Fe_2B single-phase layer is the ideal result and is the desired microstructure after boriding ferrous materials.

Dual-phase Fe_2B-FeB layers. Boriding the part for longer times to create a deeper case makes it more likely the boron concentration just below the surface will exceed 33%, which leads to the formation of the more boron-rich FeB compound in addition to the already formed Fe_2B.

Powder pack cementation is the most commonly used method for boriding. A drawback of the process is that the boron activity of the powder pack is fixed; it cannot be varied during the process. This makes it impossible to perform a diffusion process similar to the boost-diffuse methods used in carburizing and two-stage Floe nitriding. In these processes, carbon and nitrogen potentials of the furnace atmosphere can be reduced to lower values during later stages of the process to avoid oversaturating the surface with excessive carbon or nitrogen, which are responsible for carbide networking, excessive retained austenite, and/or nitride networking. Therefore, boriding to deeper case depths with a fixed high boron activity during the entire process eventually oversaturates the surface with boron, forming a second FeB layer on the outside of the original Fe_2B layer.

Most commercially available boriding powders create high boron activity levels, and are good for quickly forming high-quality thin boride layers with short cycle times. However, there is a limit to the depth of the single-phase layer that can be formed with longer cycle times before undesirable FeB begins to precipitate resulting in a dual-phase FeB-Fe_2B layer. The limit on depth depends on the material as each one has a different boron diffusivity rate.

Plain carbon and lower alloy steels generally have higher boron diffusivity rates and enable rapid diffusion to deeper depths without a buildup of high boron concentration at the surface. More highly alloyed steels have lower boron diffusivity rates, which tends to trap boron near the surface. This increases surface boron concentration, forming

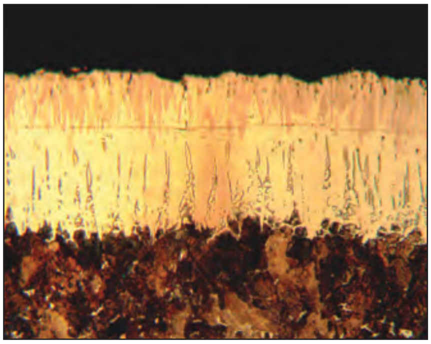


Fig. 1 — *Dual-phase boride layer with FeB (darker "teeth" near surface) and Fe_2B (lighter teeth). Cracks have formed between the FeB and Fe_2B layers upon cooling.*

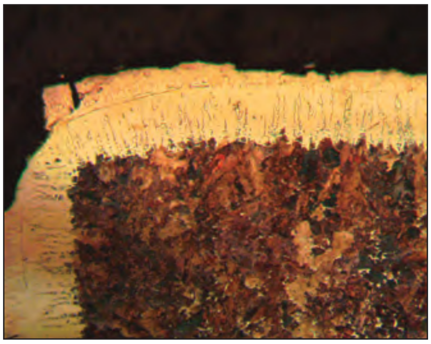


Fig. 2 — *Dual-phase boride layer with cracks between the FeB and Fe_2B layers. The FeB boride layer at the corner spalled off the surface.*

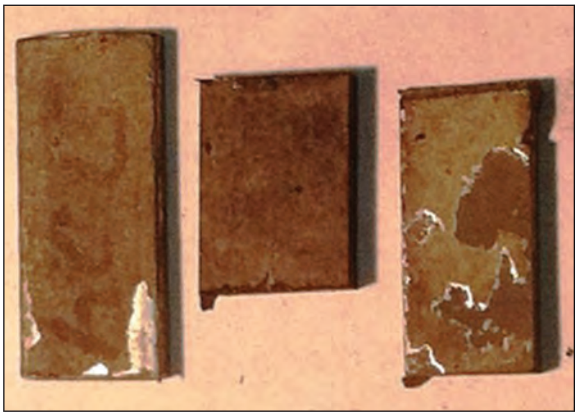


Fig. 3 — *Spalling (small silver-colored relective spots) on three different materials that were borided together: (left) 304 stainless steel, (center) 440C stainless steel, and (right) duplex stainless steel.*

dual-phase FeB-Fe_2B layers earlier in the cycle at shallower boride layer depths. For example, 1018 plain carbon steel can be boronized to about 0.004 in. deep using commercially available Ekabor 1 boriding powders before any FeB begins to form. A higher alloy 4140 steel can only be borided to about 0.003 in. deep before FeB begins to form using the same boriding agent. Materials having even higher alloy content, such as Types 304, 440, and 17-4 stainless steels, form FeB at depths less than 0.001 in. Thus, plain carbon steels are attractive candidate materials for boriding, as they can be borided deeper while still maintaining a single phase Fe_2B layer. They also are less expensive than higher alloy steels.

Dual-phase boride layers are undesirable compared with an F_2B single-phase layer. The main problem with dual phase layers is that their coefficients of thermal expansion and densities differ with respect to one another. The boride layers are formed at relatively high temperatures (1550°–1750°F) and these layers contract at different rates when cooled to ambient temperature, generating stresses between them. The Fe_2B layer on the steel substrate is in a state of compressive residual stress (desirable) and the FeB layer on the surface of the Fe_2B layer is in a state of tensile stress. This can cause cracks to form between the layers, and the FeB layer often spalls off the surface during cooling. Figure 1 shows a dual-phase boride layer consisting of Fe_2B (lighter colored deep "teeth") and FeB (darker colored shallow teeth) near the surface. Stress-related cracks in the dual-phase layer run parallel to the material's surface. Cracking is even more prevalent in borided parts having outside corners and edges where surface boron concentration is high due to simultaneous boron diffusion into the surface from multiple angles. Figure 2 shows an example of spalling at the corner of a borided part where cracks formed between the FeB and Fe_2B layers, resulting in the FeB layer spalling off at the corner. If spalling does not occur immediately during cooling, residual tensile stresses in the FeB layer make it very easy to chip and break during handling and in the field. Spalled areas appear as small silver-colored reflective spots (Fig. 3).

Deep case boriding

Historically, information on boriding in the literature states that boriding deeper than 0.005 in. is not recommended on many materials due to dual-layer formation, which is prone to spalling and fracture of the layer. However, many design engineers want to form deeper boride layers to provide longer wear life. Recognizing this need, Bluewater Thermal Solutions developed new deep-case boriding processes for several different material grades. While the use of high temperatures and longer cycle times enables this, the challenge is to create deeper layers while maintaining a single-phase Fe_2B layer. Figure 4 shows an example of borided 4140 alloy steel using standard commercially available boriding powders to a layer depth of 0.020 in. Nearly one half of the total boride layer depth is FeB, which is not a desirable structure.

Deep boriding with a single-phase Fe_2B layer in concept is simply to prevent boron concentration at the surface from rising to a level where FeB begins to form while allowing boron to continue to diffuse deeper. However, the powder pack process makes this difficult due to a fixed boron activity level. There are a number of alternative approaches to accomplish deep boriding with a single-phase Fe_2B layer:

(1). The boriding process can be carried out at a high boron potential, then cool the parts to ambient temperature, remove them from the powder pack, and reheat in a protective inert atmosphere with no boron present to allow further boron diffusion, while reducing the surface boron concentration. A limitation of this approach is spalling of the boride layer during cooling. In many cases, boride layers spall off part surfaces immediately as they are removed from the boriding process. It is also difficult to predict what post-boriding diffusion cycles are necessary to reduce surface boron concentrations to a level where all the FeB borides are dissolved and reduced back into a single-phase Fe_2B boride layer.

Figure 5 shows an example of deep-case borided 4140 alloy steel with FeB present at the surface after boriding. The material was reheated in an inert atmosphere to diffuse away FeB that formed at the surface. However, the diffusion treatment on the piece was insufficient to reduce all of the FeB present. The near surface has fully reverted from FeB (darker teeth) into Fe_2B (lighter teeth), but there is still some FeB present at depths between 0.001 and 0.002 in. that was not converted into Fe_2B. It is crucial in this process to ensure that spalling does not occur between the boost and diffuse steps and that the diffuse process is sufficient to ensure that all FeB is reduced into Fe_2B by the end of the process.

(2). The entire boriding process can be carried out at lower boron potentials so FeB never forms. This requires the development of a customized boriding powder different from most of the standard commercially available boriding powders. With many different boron sources, activators, and diluents available to choose from, a wide array of different results are possible through the development of customized boriding powders. However, each grade of material will boride differently as they all have different boron diffusivity rates necessitating a different customized powder for each material. Another drawback of boriding at lower boron potentials is that the boron enters the parts very slowly, requiring longer cycle times. Substantial knowledge, testing, experimentation, and research are required to develop customized deep-case boriding powders for different materials and desired boride layer depths.

(3). A method where a boost-diffuse type process comparable to gas carburizing and gas nitriding, such as electrolytic salt-bath boriding, could be used. The method involves immersing parts into a borax salt bath held at austenitizing temperatures. Parts are connected to a dc power supply (cathodes) and graphite plates are connected to the powder supply and immersed into the salt bath (anodes). Boriding occurs as electric current flows through the system with borax reacting with both parts and anodes to free up boron atoms that diffuse into the part surfaces. The boost-diffuse process is possible because boriding only occurs as electric current is applied. When current is off, boron continues to diffuse into the parts at austenitizing temperature. Thus, a deeper boride layer forms while reducing the boron concentration at the surface of the parts. The process, called phase homogenization in electrochemical boriding (PHEB), was developed by G. Kartal, S. Timur, V. Sista, O.L. Eryilmaz, and A. Erdemir[2].

The process has not yet gained widespread industrial acceptance due to various problems such as salt residues being difficult to remove from parts, difficulties in building and maintaining a borax salt-bath furnace, and questions about reliability and safety of high electrical current flowing through a high-temperature borax salt bath. Another concern is the ability to maintain uniform electrical connectivity of the parts to the fixtures as the fixture material degrades.

(4). Another boost-diffuse boriding process could use boriding gases in an atmosphere furnace for a portion of a cycle and then replace the boriding gases with an inert gas, or adjust the gases to reduce the boriding potential during later stages of the process. Bluewater Thermal Solutions is developing this type of process, but details are proprietary and are not discussed at length here.

Results of deep-case boriding

Bluewater Thermal Solutions has developed several deep-case boriding processes, which are currently being performed commercially. Parts treated using these processes outperform conventionally borided parts with shallower boride layers in several applications including oilfield drilling equipment, industrial pumps, high wear agricultural machinery parts, and ground-engaging tools, all subject to harsh abrasive and erosive wear conditions.

Materials including 1018 plain carbon steel, 4140 alloy steel, and O1, A2, D2, and S7 tool steels have been deep case borided with a single-phase Fe_2B layer with no spalling problems. Steels like 1018 and 4140, traditionally borided to a depth of 0.003 to 0.005 in., are now able to be deep case borided to a depth of 0.010 to 0.020 in. Tool steels like O1, A2, and S7, traditionally borided to a depth of 0.001 to 0.003 in., can be deep case borided to a depth of 0.008 to 0.012 in. Martensitic and PH grade stainless steels, traditionally borided to a depth of 0.001 in., can be borided to a depth of 0.004 in. with no spalling problems. Figure 6 shows a photomicrograph of 4140 alloy steel deep case borided to a depth of 0.015 in. where the structure is predom-

Fig. 4 — *AISI 4140 alloy steel deep case borided to a depth of 0.020 in. using commercially available boriding powder. The boride layer consists of about 50% FeB (dark colored teeth near surface) and 50% Fe_2B (lighter teeth) below the FeB layer, an undesirable condition prone to spalling.*

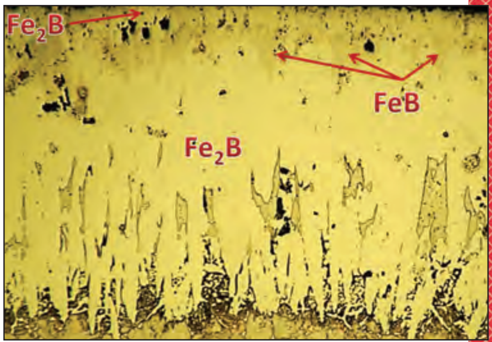


Fig. 5 — *AISI 4140 alloy steel deep case borided to a depth of 0.011 in. followed by a vacuum diffusion treatment. Some FeB near the surface converted back to single-phase Fe_2B (light colored teeth) while some FeB (darker teeth) is still present at slightly deeper depths. Single-phase Fe_2B is present below.*

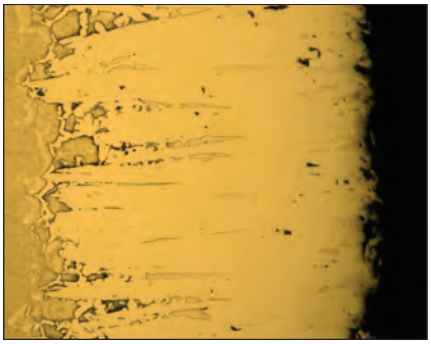


Fig. 6 — *AISI 4140 alloy steel deep case borided to a depth of 0.015 in. consisting of nearly 100% single-phase Fe_2B with only minor traces of FeB (darker colored teeth) near the surface.*

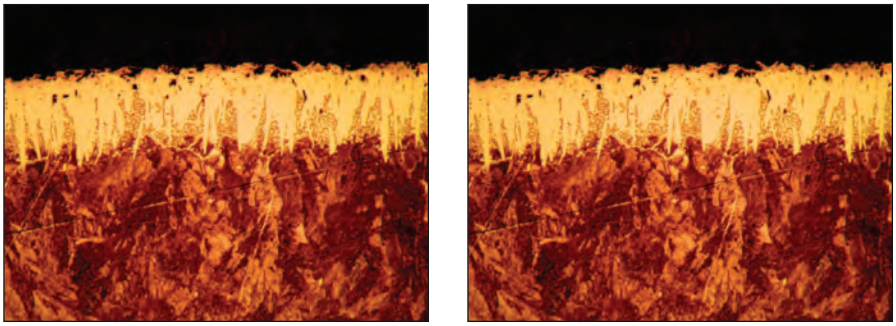


Fig. 7 — *AISI 4140 alloy steel ground-engaging tools conventionally borided to a depth of 0.004 in. (left) and deep case borided to a depth of 0.010 in. (right). Boride layers in both are single-phase Fe_2B.*

Fig. 8 — *AISI 1045 plain carbon steel high-wear agricultural machinery parts borided to a depth of 0.005 in. (left) and deep case borided to a depth of 0.014 in. (right). After service on the same machine for the same amount of time, the conventional borided part shows significant material loss due to wear, while the deep case borided part shows virtually no wear.*

inately Fe_2B with only minor traces of FeB present at the surface.

To design a process capable of creating a specific boride layer depth comprising single-phase Fe_2B, each steel grade requires different processing parameters in terms of cycle time, temperature, and boron potential for each stage of the process. For instance, processing parameters used for deep case boriding 1018 plain carbon steel are quite different than the parameters for A2 tool steel to produce a 0.015 in. deep single-phase Fe_2B layer.

Applications and performance

Deep case boriding of parts provides greater depth of the ultrahigh hardness boride layer, which extends the wear life of parts. For example, a ground-engaging tool manufactured with a carbide wear insert is now being borided with improved wear life. Two sets of the tool were provided to a manufacturer for field testing to compare service life-to-failure of tools treated with a conventional 0.004 in. boride layer depth and a deep case borided 0.010 in. layer depth. Figure 7 shows the microstructures of each tool set. After multiple field trials, the manufacturer of these tools elected to have the deep boriding process specified for its tools, even at a higher cost than the conventional boriding process or tools made with a carbide insert. According to the manufacturer, the 0.010 in. boride depth versus the 0.004 in. boride depth is 75 to 100% more durable under varying soil conditions. The relative wear properties of the parts with deeper boride treatment are superior in a cost-benefit analysis.

An oilfield drilling-tool company is specifying the deep boriding process for its tools, which are exposed to high pressure flow of abrasive particles. Deep boriding improved tool performance to the point of lasting for the entire well-drilling process compared with previous parts that wore out and failed during drilling, requiring costly downtime to replace the tools.

Bluewater provided two sets each of a conventionally borided and deep case borided high-wear part to an agricultural machinery manufacturer to compare wear performance in abrasive crop and soil conditions. Conventional boriding more than doubled the expected life of these parts over heat treating alone. At the point where the conventional boride layer wore off, the deep case borided parts still had quite a bit of boride layer depth present and did not show much signs of wear. Figure 8 shows the wear surface of the two components where the shallow borided part shows significant material loss while the deep borided component shows very little material loss due to wear.

Bluewater Thermal Solutions' custom designed deep-boriding processes were successful for each project. The ability to customize the process for different steel grades and application requirements can make boriding a more popular choice to treat parts exposed to harsh wear environments. Deep case boriding enables producing wear layer depths comparable to competitive processes such as carburizing, nitriding, thermal spray coatings, and hardfacing. In addition to having a comparable wear-resistant depth, boride layers are much harder than carburized and nitrided cases, and have similar or higher hardness than many flame spray and hardface coatings, while maintaining better dimensional tolerances than the coating processes, which add material. Deep case boriding could be the solution to wear problems in many applications where parts are exposed to extreme wear in harsh operating environments. HTPRO

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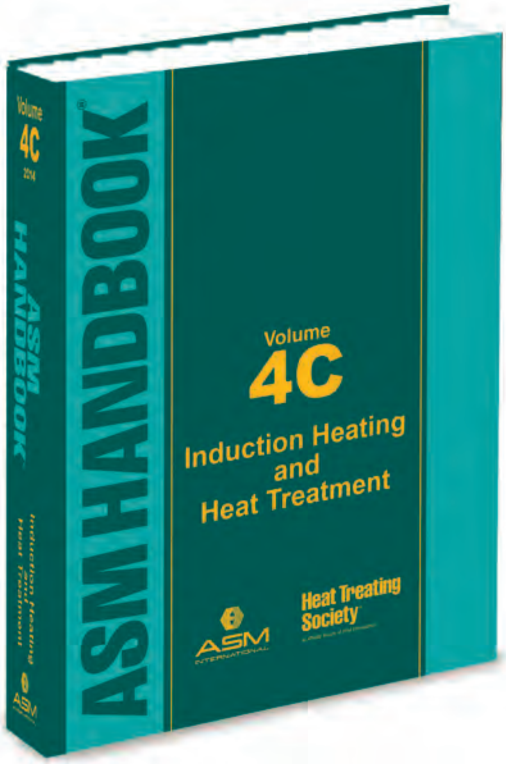
NEW TECHNICAL RESOURCE FOR INDUCTION HEATING PROFESSIONALS

THE RECENTLY PUBLISHED *INDUCTION HEATING AND HEAT TREATMENT*, VOL 4C, *ASM HANDBOOK*, IS THE RESULT OF AN AMBITIOUS UNDERTAKING TO COMPILE AN ALL-NEW, COMPREHENSIVE RESOURCE ON INDUCTION THERMAL PROCESSES.

Dr. Valery Rudnev,* FASM, Inductoheat Inc.



Heating by means of electromagnetic induction is a topic of major significance, and the technology continues to grow at an accelerated rate. Thermal applications include hardening, tempering, stress relieving, brazing, soldering, melting, normalizing, annealing, and coating, as well as reheating ferrous and nonferrous metallic materials prior to warm and hot working. The recently published *Induction Heating and Heat Treatment*, Vol 4C, *ASM Handbook*, is the result of an ambitious undertaking to compile an all-new, comprehensive resource on induction thermal processes to meet the needs of the induction heating and heat treating communities.

Continuing in the tradition of the *ASM Handbook* series, Vol 4C combines practical knowledge in ready-to-use diagrams, technical procedures, guidelines, know-how, and good practices with up-to-date knowledge emphasizing the specifics of induction processes compared with alternative technologies. Common misconceptions, erroneous assumptions, and misleading postulations are clarified and explained using easy-to-understand computer modeling charts, practical data, and numerous case studies.

This technical resource provides a practical, comprehensive reference on the technologies and applications of induction heating and heat treatment. It is written for design, manufacturing, and materials engineers. Internationally recognized experts from leading universities, research laboratories, and industrial corporations from 10 countries contributed to this handbook.

Following is a brief glimpse of the breadth of content in Volume 4C, which begins with a review of electrical, electromagnetic, heat transfer, and material science fundamentals related to induction heating. Other critical facets associated with induction heating technologies are also discussed, such as the nonequilibrium nature of phase transformations and other metallurgical subtleties related to the specifics of induction hardening, tempering, and stress relieving. Attention is given to the effect of prior microstructure on the selection of required temperatures and process parameters, and guidelines are presented that reflect the differences in stel response to the short heating times.

Subtleties of induction hardening of critical components such as shafts, gears, axle shafts, camshafts, crankshafts, and other components used in automotive and off-road machinery, aeronautic and aerospace, farming, appliance, and oil and gas industries are also covered. Several articles introduce novel technologies and know-how that enable minimizing part distortion dramatically after heat treating, which potentially could lead to elimination of secondary operations such as straightening. For example, regardless of the complexity of camshaft geometry, shape of lobes (Fig. 1), and positioning, novel induction hardening techniques often make it possible to obtain accurate contour hardness patterns. This produces uniform fine-grain martensitic surface layers and almost undetectable distortion (Fig. 2), which, in turn, improves overall process cost-effectiveness, energy efficiency, and quality of heat treated components[1].

A critical review of ASTM and SAE


Fig. 1 — *Automotive cam lobe shape varies depending on engine design. Courtesy of Inductoheat Inc.*


Fig. 2 — *True contour hardening of camshaft lobes. Courtesy of Inductoheat Inc.*

**Member of ASM International and Heat Treating Society* standards and guidelines for properly measuring hardness of the case and heat affected zone, as well as a review of issues and complications related to different hardness measuring techniques are also included. Case studies of pattern specifications are presented, and special attention is given to proper monitoring of induction processes, destructive and nondestructive testing, and quality assurance.

The new handbook also includes in-depth analysis of ways to develop robust, efficient, and high-quality processes; the formation of initial, transient, and residual stresses and their effect on the performance of heat treated components, shape distortion, and cracking potential. Studies have been conducted to evaluate stress formation during heating and spray quenching in workpieces with classical shapes and parts with geometrical irregularities such as fillets, diameter changes, and holes. For example, Figs. 3 and 4 show finite-element mesh with nodal locations in the proximity of an oil-hole and the variation of maximum principal stress during spray quenching, respectively[2]. A quench delay has a significant effect on the appearance of transient and residual stresses.

Selection of critical process parameters and review of inductor designs, heat pattern control, intricacies in using magnetic flux concentrators, and spray quench design considerations are included as well.

Another topic area covers subtleties in determining temperature requirements when induction heating plain carbon and alloy steels, superalloys, titanium, aluminum and copper alloys, and other materials prior to hot and warm working. Novel technological developments in heating billets, bars, tubes, rods, and other metallic workpieces, as well as a concept for controlling a billet's true temperature are discussed.

Development of optimization procedures, principles of multiobjective optimization, and strategies for obtaining optimal process control algorithms based on various technological criteria, real-life constraints, and cost functions (e.g., maximizing throughput, temperature uniformity, energy effectiveness, minimizing required shop floor space, metal loss, etc. is also explored.).

Failure analysis and prevention, which are associated with product quality, process cost-effectiveness, downtime losses, and other issues are discussed as well. Many publications covering failure analysis are devoted primarily to heat treating processes other than induction, therefore several articles in this handbook discuss various aspects of failure analysis of components heat treated using electromagnetic induction. Typical defects, abnormal characteristics, and root causes of different failures are discussed, as well as the effects of metallurgical factors and abnormalities such as excessive grain coarsening, presence of decarburized layers, inclusions, seams, laps, mixed structures, and overheated and burned steels. Causes of surface, transverse, and longitudinal internal cracks and their prevention are reviewed.

The new volume also includes good practices in designing and fabricating long-lasting inductors and ways to avoid their premature failures. A fishbone diagram of premature failure

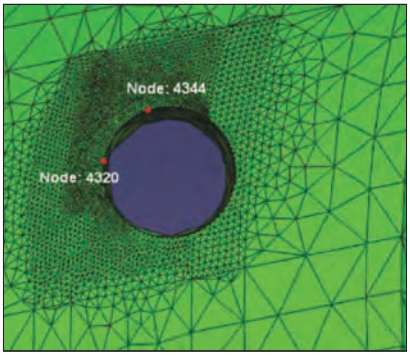


Fig. 3 — *Nodal locations on oil-hole edge of crankshaft bearing section.*

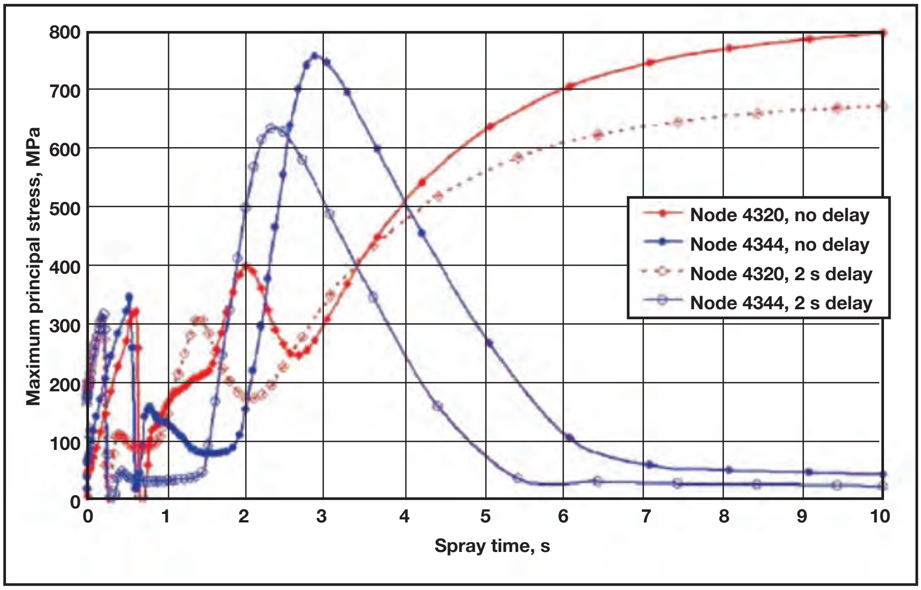


Fig. 4 — *Maximum principal stress at node locations in Fig. 3 as a function of spray quench time.*

of induction coils serves as a guide in determining potential root cause(s) of premature coil failures.

Special applications of electromagnetic induction, including melting of glasses and oxides, optical fiber drawing, nanoparticle heating, and hyperthermia applications are also discussed.

Design principles and operation specifics of modern transistor and thyristor power supplies used for induction heating are described using conventional and advanced circuits. An appreciable amount of material is devoted to practical aspects, including review of transformer designs and load-matching facets and standard and customized induction equipment.

Volume 4C also contains numerous case studies that illustrate the challenges and solutions in obtaining required thermal conditions for a workpiece, as well as the subtleties of computer modeling of induction thermal processes.

Special attention is given to describing the aspects of process monitoring, maintenance, and water cooling, as well as safety procedures, energy efficiency, and environmental factors including control of electromagnetic field (EMF) exposure. EMF is invisible and is associated with the operation of any electrical device. Several international organizations raised concerns related to external EMF exposure, developing awareness regarding nonionizing radiation, and the evaluation of health risks associated with EMF exposure. These organizations include:

- The World Health Organization (WHO)
- The Institute of Electrical and Electronic Engineers (IEEE)
- The U.S. Occupational Safety & Health Administration (OSHA)
- The International Radiation Protection Association (IRPA)

Studies were conducted to evaluate direct and indirect effects of EMF exposure on health, passive and active medical implants, hypersensitivity, etc., leading to the creation of a number of international standards, guidelines, and regulations. Being unaware of basic principles related to electromagnetic field exposure and unfamiliar with the results of studies conducted by various professional societies and international health organizations can result in incorrect assumptions. One article in this handbook aims to clarify this subject by reviewing key concepts regarding occupational exposure to electromagnetic fields encountered in industrial activities with which professionals should be aware, measures used to evaluate these situations, and rules and international standards applicable to a 50 Hz to 10 MHz frequency range[3].

Summary

This reference provides practitioners, students, engineers, and scientists with the knowledge to better understand the various interrelated physical phenomena of induction heating and heat treating. Much of the content in the 62 articles in this handbook has not been published before. To provide a snapshot of the wealth of information contained in Vol 4C, a series of brief articles highlighting some of material in different chapters are now being published in subsequent issues of *HTPro*. The review articles are authored by Valery Rudnev (Professor Induction), who together with George Totten served as co-editors of the handbook. **HTPRO**

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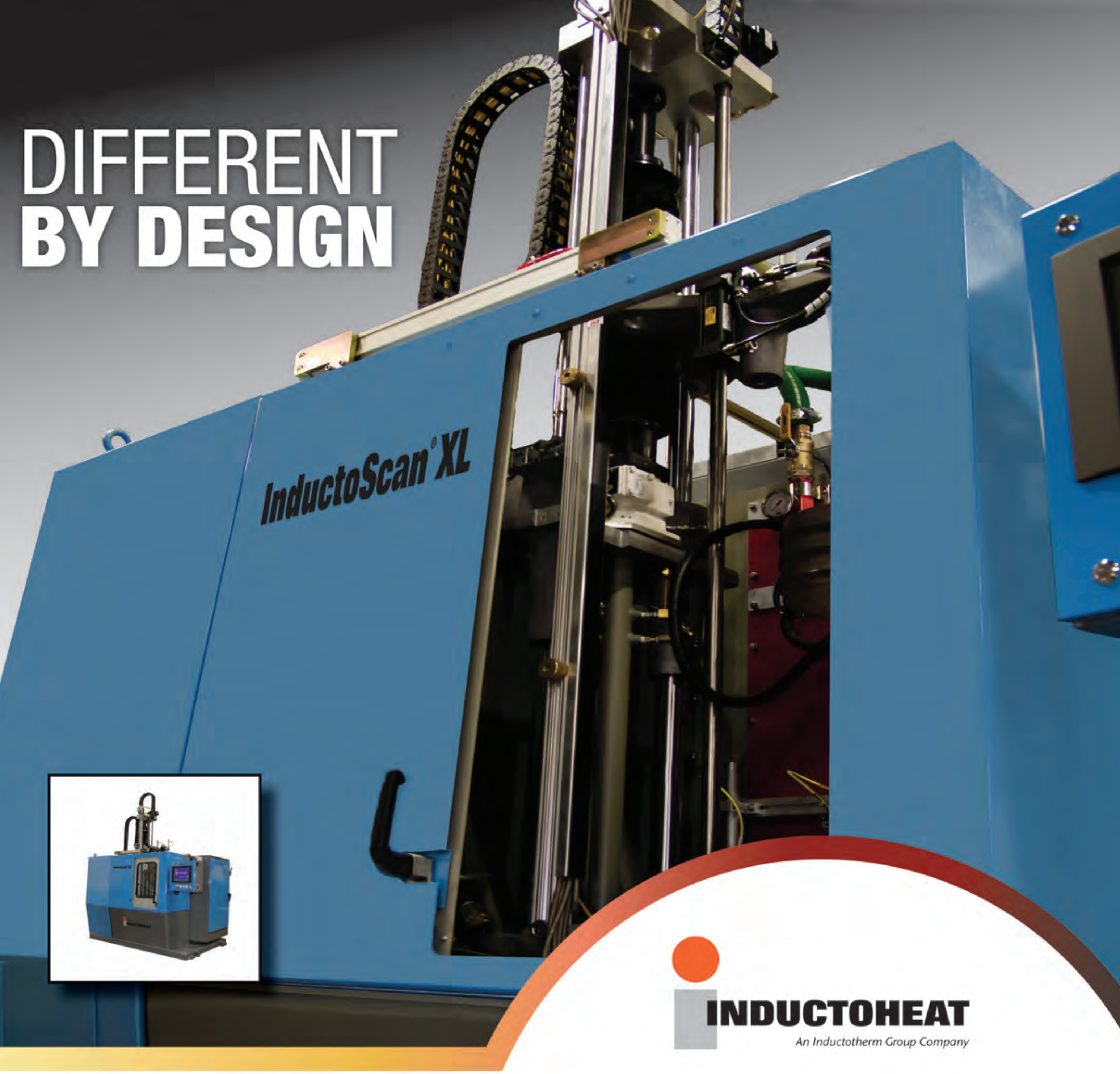

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Departments

About the cover
Sensor application using direct write technology, an innovative and economical materials deposition process that integrates conductive traces, antennas, circuits, and sensors onto components or embeds them within structures. Courtesy of MesoScribe Technologies Inc., Setauket, N.Y., mesoscribe.com.

Editorial Opportunities for iTSSe in 2015

The editorial focus for iTSSe in 2015 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

February	Aerospace Industry/Military Applications
May	Energy & Power Generation
August	Automotive & Industrial Applications
November	Emerging Technologies/Applications & Case Studies

To contribute an article to one of these issues, please contact the editors c/o Julie Lucko at Julie.Lucko@asminternational.org. To advertise, please contact Kelly Thomas, Kelly.Thomas@asminternational.org.

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Thermal spray advances into emerging markets

Advancements in technology ultimately benefit the whole of society. Cost reductions from longer equipment life and efficiency improvements, cleaner environments, shorter recovery times for hospital patients, and improved communication methods are among the many benefits routinely experienced today. Thermal spray has become integrated in many products as an enabling technology and in manufacturing processes as critical tooling, making it one of the most important surface modification methods available.

Countless research papers are published annually detailing new developments in thermal spray coatings for the gas turbine market. Driving forces include efficiency and longevity enhancements. Even a 1% efficiency gain can translate to millions of dollars in savings for utility providers. Typically, increases in gas inlet temperatures enable efficiency improvements. As such, constant research and development in new low-conductivity thermal barriers has resulted in recent implementation by some OEMs. Higher firing temperatures also require improvements for other coatings used in the turbine such as abradables, bond coats, and wear coatings. Ceramic components in next-generation turbines, especially SiC-SiC composite materials, will also require more reliant environmental barrier coatings (EBCs) as protection in high moisture and molten salt environments.

Thermal spray coatings for medical applications offer further opportunities for improvement. Plasma sprayed titanium and hydroxyapatite for implants as well as alumina for laparoscopic procedures are well established. Generally, plasma sprayed titanium and hydroxyapatite are not hydrophilic, but next-generation coatings will have this requirement to shorten recovery times. This will likely require post processing of sprayed coatings.

Coatings applied to tooling and fixtures used for semiconductor processing always demand high-quality formulas to decrease particulates and improve yield. Higher density, highly adherent, cost effective yttria and alumina coatings will need to be applied to better control particulate matter as the node size decreases. This may require better application equipment such as cascading guns, or at least pulse width modulated power supplies, to improve upon conventional spray systems.

In this final 2014 issue, yet another emerging thermal spray technique is presented—an innovative direct write method using plasma spray. A special aperture system enables fabrication of thermocouples, antennas, and other sensors directly onto components thereby creating "smart structures," illustrating the emerging markets and technologies available for thermal spray. Also included in this issue is the second part of a safety article that reviews best practices in the thermal spray industry.

Be sure to share all of your innovations at next year's International Thermal Spray Conference and Exhibition. This mega event is being co-Located with AeroMat and Microstructural Characterization of Aerospace Materials and Coatings from May 11-14 in Long Beach, California. We hope to see you there!

Rajan Bamola
iTSSe co-editor
Surface Modification Systems Inc.

International Thermal Spray Conference and Exposition (ITSC) 2015

ITSC 2015
CONFERENCE & EXPOSITION

ITSC, taking place May 11-14, 2015, in Long Beach, Calif., is the world's foremost international conference and exposition for thermal spray technologists, researchers, manufacturers, and suppliers. The conference is co-located with both AeroMat and Microstructural Characterization of Aerospace Materials and Coatings. Whether attendees are thermal spray experts, experienced engineers or scientists, or new to the field, the 2015 ITSC technical program features something for everyone—from the latest in advanced technology, research, and development to a wealth of resources about processes that can be applied immediately to impact critical issues such as corrosion, wear, and abrasion. The conference also features a special presentation by John Grotzinger, chief scientist and head of strategic planning for NASA's Mars Exploration Rover mission. Visit asminternational.org/web/itsc-2015/home for more information.

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ASM Headquarters, Materials Park, Ohio
Instructor: Mr. Richard A. Sayman

Thermal spray has evolved from a technology designed to be a cost effective method of repairing worn components and machined parts to a process used to provide improved part performance and add longer life to components. As the thermal spray profession has changed, so has the need to ensure safe and consistent methods for thermal spray operators. ASM International brought together the leaders in the Thermal Spray Society to compile their knowledge and experience in a comprehensive, easy to understand course.

Visit asminternational.org/education for more details.

TSS Announces New Board Members and Officers

The ASM Thermal Spray Society elected officers and board members for 2015. **Christian Moreau, FASM,** TS-HoF, professor, Concordia University, succeeds as President of TSS, while **Luc Pouliot,** COO, Tecnar Automation Ltd., remains on the Board as Immediate Past President. **Douglas Puerta,** VP, Materials Testing, IMR Test Labs, is elected Vice President. Officers serve a two-year term.

New board members elected for a three-year term include: **Christopher Dambra,** manager, CSC Americas, Oerlikon-Metco; **Daniel Hayden,** president, Hayden Corp.; and **Kumar Sridharan, FASM,** distinguished research prof., University of Wisconsin-Madison. **Ann Bolcavage, FASM,** chief, Materials-Capability Acquisition, Rolls-Royce Corp., continues on the board and accepted the role of secretary/treasurer.


Dambra


Hayden


Sridharan

TSS Members Honored at MS&T 2014

ASM President **C. Ravi Ravindran, FASM,** welcomed three new TSS members to the 2014 Class of Fellows at MS&T 2014 in Pittsburgh in October.

Javad Mostaghimi, FASM, professor, University of Toronto. His citation reads, "In recognition of pioneering developments related to thermal plasmas and thermal spray coatings."

Ashim Kumar Mukhopadhyay, FASM, scientist G, Defense Metallurgical Research Laboratory, Hyderabad, India. His citation reads, "For sustained and significant technical and scientific contributions in the areas of physical and mechanical metallurgy of aluminum alloys, and for the development and commercial production of these materials for structural applications."

Dongming Zhu, FASM, senior materials engineer, NASA Glenn Research Center, Cleveland. His citation reads, "For technical achievements in the design and characterization of novel and advanced materials for gas turbine engine components, specifically in the areas of thermal and environmental barrier coatings."


Mostaghimi


Mukhopadhyay


Zhu

Nominations Sought for ASM Thermal Spray Society Board

The ASM TSS Nominating Committee is currently seeking nominations to fill two board member positions. Candidates for these director positions may come from any segment of the thermal spray community, but ideally will have a focus on the service or government research segments.

Nominees must be a member of the ASM Thermal Spray Society and must be endorsed by five TSS members. Board members whose terms are expiring may be eligible for nomination and possible re-election on an equal basis with any other candidate.

Nominations must be received no later than March 1, 2015. Forms can be found at tss.asminternational.org. Contact Luc Pouliot, ASM TSS Nominating Committee Chair, at lpouliot@tecnar.com for more information.

ASM Handbook, Volume 5A: Thermal Spray Technology

Volume 5A is a replacement for the *Handbook of Thermal Spray Technology,* edited by J.R. Davis (2004) and provides an introduction to modern thermal spray processes including plasma spray, high velocity oxy-fuel, and detonation gun deposition, as well as a description of coating properties and their wear, corrosion, and thermal barrier characteristics. Principles, types of coatings, applications, performance, and testing/analysis also are covered. A greatly expanded selection of applications includes examples and figures from various industries, including electronics and semiconductors, automotive, energy, and biomedical. Emergent thermal spray market sectors such as aerospace and industrial gas turbines, and important areas of growth such as advanced thermal barrier materials, wear coatings, clearance control coatings, and oxidation/hot corrosion resistant alloys also are reviewed. Visit asminternational.org to learn more.

Join the TSS discussion group

The TSS email discussion group is an email-based discussion list, wherein subscribers only may post messages to the group. Messages are received individually by the subscribers, or a subscriber can select a once-daily digest. Individuals may subscribe and unsubscribe as they wish. Visit asminternational.org/web/tss/membership/forum to learn more.

Smart Deposition Process Integrates Sensors and Heaters into Coatings

Jeff Brogan
MesoScribe Technologies Inc.
Setauket, N.Y.

Direct write technology is an innovative and economical materials deposition process that integrates conductive traces, antennas, circuits, and sensors onto components or embeds them within structures. The technology was initially developed under the Defense Advanced Research Projects Agency's (DARPA) Mesoscopic Integrated Conformal Electronics (MICE) program by Stony Brook University, N.Y., and its partners. The process has been in development since 2002 for use in aerospace, military, and energy markets.

Fig. 1 — *Sensor application using direct write technology.*

Direct write technology basics

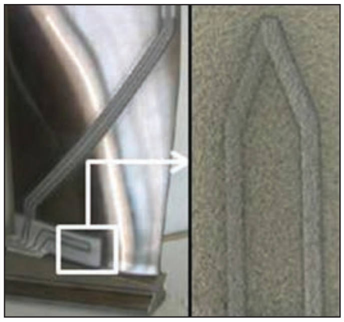
The direct write process uses a small torch and aperture system to fabricate patterned material traces and coatings onto complex surfaces. The print head generates a highly collimated, well defined particle stream capable of fabricating low profile, fine feature conductor patterns and ceramic dielectrics onto critical components, as shown in Fig. 1.

Patterns are printed with typical feature sizes ranging from 250 µm to 3 mm wide and roughly 50 µm thick (thinner and thicker deposits are possible). A 7-axis robotic system ensures pattern placement accuracy and manufacturing consistency afforded by 20 µm tool path repeatability. The process enables a wide range of materials to be deposited including ceramic dielectrics, high quality copper and precious metal conductors, sensor alloys, and functional ceramic oxides. The process is also compatible with most substrate/component materials including polymer laminates, fiber-filled composites, and metallic structures.

Advantages include the ability to conformably print onto 3D geometries, operation in standard atmosphere (no vacuum or inert atmosphere required), and robust deposits that withstand high temperatures (>1000°C) and are both erosion resistant and strain tolerant. Direct write printing is used to construct aerospace components by enabling embedded circuitry, and in high temperature propulsion systems by incorporating diagnostic sensors (temperature and heat flux) for structural health monitoring. The technology has also been used to integrate UHF/VHF/L-Band antennas into air and space vehicle components for advanced communications and signals intelligence.

Printed thermocouple sensors

Many types of thermocouple systems can be fabricated to provide integrated sensing for operational components.



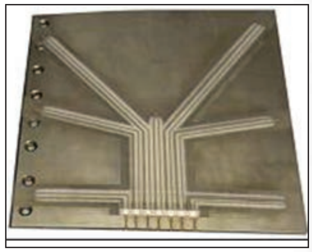


Fig. 2 — *Thermocouples created with direct write. Instrumented compressor blade (above), TC array onto a metallic structure (above right), TC array onto cylindrical component (right).*

A variety of NIST standard alloys including types T, E, K, and N as well as precious metals can be used to achieve the requisite performance and durability. The latter have been tested in oxidizing environments at 1000°C for 8000 hours, exhibiting >4% drift. Thermocouple sensors (TCs) are printed directly and conformally onto structures and embedded within protective coatings if necessary. Leads are routed to convenient locations for signal acquisition. TCs have been printed onto a range of materials including polymers, fiber composites, metals, and ceramic matrix composites (Fig. 2). Temperature measurements provide information relative to the materials response in specific thermal environments and offer a means of monitoring the component via closed-loop control. Through interactions with OEM partners, sensors were successfully used in gas turbine engines at full load as well as in hypersonic scramjet engine tests.

Benefits of using printed thermocouples to measure temperature include:

- Direct printing onto 3D components or polymer laminates for composite integration
- Low profile design, generally 50 µm thick
- Repeatable installation using robotics
- Embedding within thermal barrier coatings or other protective surface treatments
- Creation of "smart" components for health monitoring and assessment
- Accuracy improvement of prognostic models by measuring part temperature

Printed heat flux sensors

Heat flux sensors were developed based on multilayered thermopile architectures to supplement temperature measurements in monitoring engine transients for advanced hypersonic scramjet control systems. Extensive testing was performed at the Air Force Research Lab (AFRL) under an SBIR Phase II contract, within the combustor at simulated Mach 5 flight conditions, where gas temperatures often exceed 1900°C.

Sensors provide a direct measure of heat flow to components exposed to high temperatures or other harsh environments. Heat flux sensors can be printed directly onto parts or integrated as sensor plugs or inserts. Sensors offer fast response times vital for optimal control system implementation and do not require water cooling. Direct write technology is also well suited for construction of multilayer sensor architectures such as the thermopiles shown in Fig. 3.

Printed sensors, heaters, and fine feature patterns offer a low profile design without the need for water cooling, high temperature resistance, and have no adhesive/carrier limitations. They also feature high sensitivity and fast response time, are available in custom sizes, and can be printed onto parts or as standalone sensors.

Printed heaters

High quality heaters can be printed onto polymer laminates and onto conformal metallic structures. Uniform thickness control and precision patterning enable high heat flux heaters (500 W/cm^2) to be successfully deployed in applications ranging from aerospace and automotive to the electronics industry. In addition, heater patterns can be combined with thermocouples for closed loop control and embedded within a ceramic coating.

Heaters feature high efficiency, low contact resistance, and the ability to quickly heat parts. They also offer high temperature resistance, no adhesive/carrier limitation, high heat flux, high reliability (by eliminating adhesive-related failures), and a reduced need for redundancy. Heaters can be printed directly onto complex conformal surfaces as well. Examples of heaters printed using direct write technology are shown in Fig. 4.

Printed conductors and antenna patterns

Direct write copper conductor networks can replace conventional wiring techniques with integrated wiring schemes for a variety of power management and signal distribution applications. Incorporating wiring networks onto components and structures, in either surface mount or embedded configurations, enhances reliability and eliminates cumbersome wiring bundles. Conductor trace networks are customizable and exhibit exceptional electrical properties and durability.

Direct write can also be used to fabricate antenna patterns onto air vehicle structures. Copper patterns are printed directly onto composite structures with features conforming to complex surface contours. Integrated communications eliminates the need for protruding structures such as radomes, which are often detrimental to operation, particularly for aerodynamic surfaces. Design iterations aimed at tuning performance characteristics can be rapidly incorporated into the process, in turn expediting new product development.

Direct write technology combines antenna design and performance modeling with conformal fabrication to enable multiple antennas that span different frequency bands (VHF/UHF/GPS) to be incorporated onto a single structure

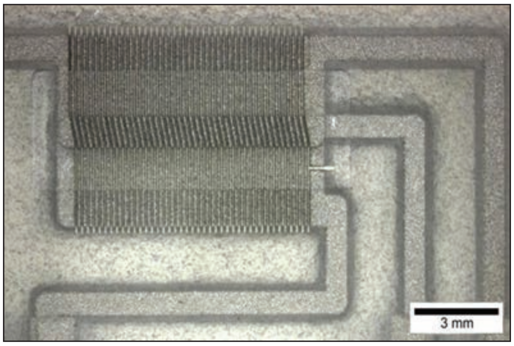
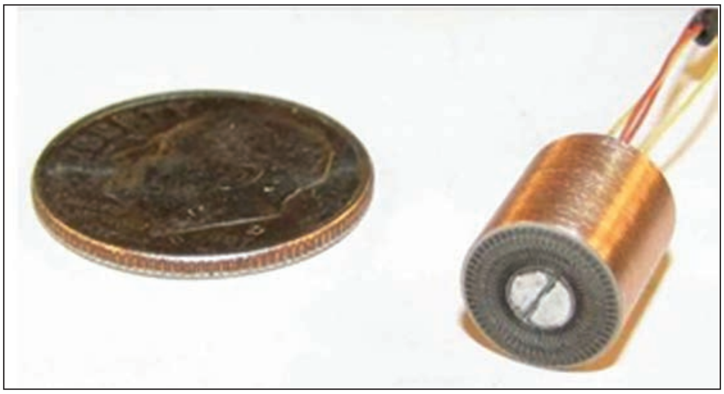
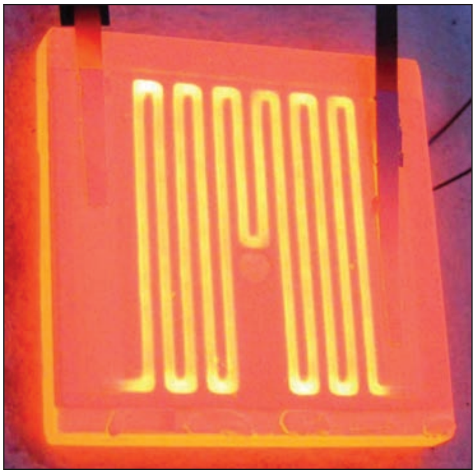


Fig. 3 — *Printed heat flux sensors based on differential thermopile design.*





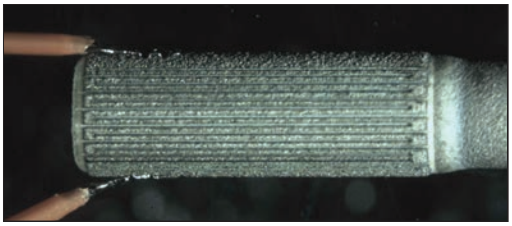


Fig. 4 — *High quality heaters printed onto structures. Sizes range from 2 × 2 in. (far left) to 0.1 in. diameter, 0.25 in. long (left) to 12.0 in. diameter (below).*

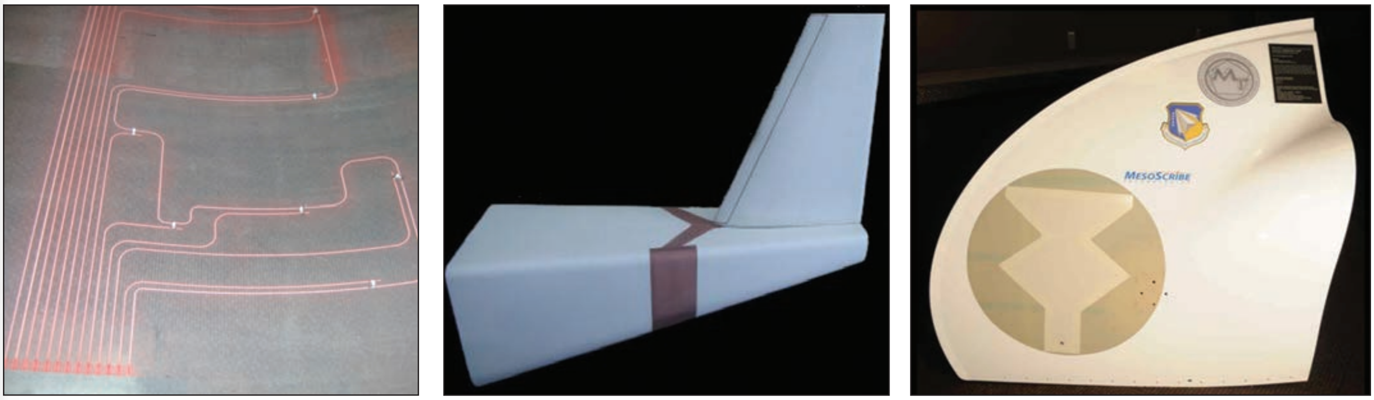


Fig. 5 — *Printed copper conductors and antenna patterns. Integrated wiring (left), UHF/VHF/GPS antenna on UAV (middle), structurally integrated VHF antenna onto an aircraft wing to body fairing (right).*

such as a UAV tail (Air Force Contract FA8650-09-C-1620). The technology also embeds antenna patterns within composite aerostructures, representing a unique class of systems involving conformal load bearing antennas (CLAS). Other advanced RF devices are also fabricated by the technology, including rectifying antennas (for wireless power transmission) and frequency selective surfaces for reconfigurable broadband antennas. Examples of printed conductor networks and antenna patterns are shown in Fig. 5.

Looking forward

Structural electronics is a rapidly growing business, driven primarily by aerospace applications, but with significant opportunities in many other industries including power generation, automotive, oil and gas, and electronics. The ability to print heaters, temperature/heat flux sensors, and circuitry onto conformal structures without masking and without post-heat treatment allows for new ruggedized designs and improved product performance. Direct write technology provides a cost-effective method to produce smart structures by integrating sensors and heaters within coatings. The technology advances state-of-the-art design in component instrumentation, diagnostic/distributed sensing, communication, and multifunctional structures. **iTSSe**

For more information: Jeff Brogan is the CEO of MesoScribe Technologies Inc., 100 N. Country Rd., Setauket, NY 11733, 631.686.5710, jbrogan@mesoscribe.com, mesoscribe.com.

Safety in Thermal Spray Settings: Part 2

Much of the following material was developed by members of ASM International's Thermal Spray Society Safety Committee.

Workplace safety is not a subject that typically captivates an audience, but in thermal spray environments, hazards of all types are faced on a daily basis. Unlike truly dangerous workplaces, such as shipyards or construction sites, where situational awareness is necessary to stay alive and well, the extra cost and time of safety programs can make them unattractive in comparatively comfortable thermal spray shops. However, compelling reasons to embrace the safety topic still exist. The first part of this article series [August 2014 *iTSSe,* p 7] addresses dust and fume hazards. We will now explore noise, mechanical hazards, and other safety issues common in thermal spray environments.

Noise

Noise is a common workplace hazard in thermal spray operations. Excessive noise exposure not only damages hearing, but also can cause tinnitus (ringing in the ears), stress, hypertension, and sleep disturbance. Because excessive noise is common in thermal spray applications, a variety of methods are available to ensure the safety and health of technicians. Table 1 outlines the actions required per noise level at key time-weighted-average exposures.

Because most thermal spray guns continually emit noise in excess of 95 dBA several layers of protection are required. The most effective is a hearing conservation program in which employees' hearing is tested annually by a professional in a controlled environment. Regular testing enables detection of hearing changes before permanent damage occurs. Environmental controls, such as sound deadening enclosures and isolated control rooms, can also shield technicians from noise and substantially lower exposure. Wearing earplugs and earmuffs in close proximity to processes is also required.

Mechanical hazards

Though less obvious than noise and dust, mechanical hazards are also common in thermal spray environments. Modern industrial robots are some of the best engineering tools available for limiting operator exposure to both dust and noise. However, robots move at much faster speeds than humans, and with greater force and agility. Even when running familiar programs, robotic motion can sometimes be unpredictable. Therefore, it is essential to stay well outside a robot's range of motion. To ensure this, most robotic systems incorporate either mechanical or electronic means for restricting the arm's movement about its base axis—creating a safe zone where the robot cannot reach. Whether restricted or not, a robot's range of motion should be marked on the floor around it. Door interlocks and external enabling devices also ensure that safety enclosures are fully closed and operators are outside before the automatic robot program is initiated.

Miscellaneous hazards

Other hazards, such as electrical (both high voltage and high current), compressed gas, and material handling systems are also present in thermal spray environments. Plasma and twin wire arc spray systems both use high current, low voltage power supplies—similar to many commercial welding power supplies—that are designed for safe industrial use. However, due to the nature of spray operations, nearly every electrical gun presents a shock hazard—particularly because conductive metal dust and water from cooling lines are often present, as is abrasive grit, which can deteriorate electrical insulation.

Compressed gases, such as bottled oxygen, fuel, or shielding gas, bulk liquid or gaseous storage, or even compressed shop air, are also often found in production facilities and pose a constant threat of leaks. Safe handling practices, such as ensuring all gas bottles are secured from tipping and venting all equipment at the end of a shift, can minimize this threat.

Conclusions

This article covers basic hazards found in thermal spray environments. Regarding compliance, in addition to following workplace safety regulations, OSHA typically only requires completion of three basic forms:

- *Form 300—Log of Work-Related Injuries and Illnesses* records basic information about each occurrence of a recordable injury or illness.
- *Form 301—Injury and Illness Incident Report* is completed for each recordable incident of a work-related injury or illness, and includes details about the individual case, including any treatment given and the likely cause.
- *Form 300A* summarizes all incidences recorded for the calendar year on Form 300, and for most businesses is the only form that must be annually submitted to OSHA.

Evidence of an organized safety program, including regular training documentation, will likely go a long way toward demonstrating maintenance of a safe workplace in the event of an audit. These topics and many others (sidebar) afford ample training opportunities. Given the range of topics, safety can easily become a regular part of workplace conversations. Training materials and much more are available online at osha.gov. **iTSSe**

COMMON SAFETY TOPICS IN THERMAL SPRAY ENVIRONMENTS

Safety orientation
Bloodborne pathogens
Confined spaces
Control of hazardous energy (lockout/tagout)
Electrical safety
Emergency response plans
Fire extinguisher use
Hazard communication
Hazardous materials storage and handling
Hazardous waste
Hearing conservation
Hoists and cranes
Housekeeping
Machine guarding
Medical surveillance
Personal protective equipment
Powered industrial trucks (forklifts)
Respiratory protection
Spill prevention
Storm water control

TABLE 1 — NOISE EXPOSURE GUIDELINES

Noise exposure*	Required actions
<85 dBA (action level)	Recommend hearing protection use.
>85 dBA to <90 dBA (permissible exposure limit)	Hearing conservation program (HCP), exposure monitoring, provide hearing protection devices.
>90 dBA	Provide hearing protection and HCP; feasible engineering and administrative controls must be implemented above 90 dBA.
<105 dBA (integrated)	Same as above; supply and ensure use of earplugs and earmuffs.
<115 dBA	Workers are not permitted to be exposed to sound levels above 115 dBA.

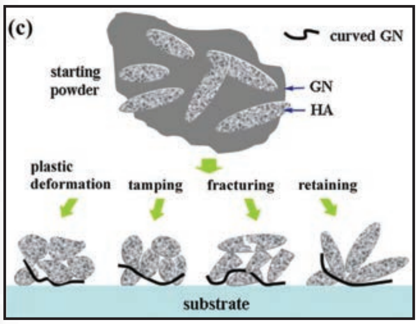
*Eight-hour time-weighted-average exposure

The *Journal of Thermal Spray Technology (JTST),* the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal spray information transfer, its mission is to synergize the rapidly advancing thermal spray industry and related industries by presenting research and development efforts leading to advancements in implementable engineering applications of the technology. Articles from the October and December issues, as selected by *JTST* Editor-in-Chief Christian Moreau, are highlighted here. The October issue is a special issue on "Nanocomposite Coatings," organized by guest editors Rehan Ahmed and Christopher Berndt. The first two articles highlighted below are from this special issue. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

"Nanostructural Characteristics of Vacuum Cold-Sprayed Hydroxyapatite/Graphene-Nanosheet Coatings for Biomedical Applications"

Yi Liu, Jing Huang, and Hua Li

Hydroxyapatite (HA)/graphene nanosheet (GN) composite coatings were deposited by vacuum cold spray (VCS). Significant shape changes of HA nanograins during the coating deposition occurred. The nanostructural features of HA together with curvature alternation of GN give rise to dense structures. Based on the microstructural characterization, a structure model was proposed to elucidate the nanostructural characteristics of the HA-GN nanocomposites. Results show that addition of GN significantly enhances fracture toughness and elastic modulus of HA-based coatings, which is presumably accounted for by crack bridging offered by GN in the composites. VCS HA-GN coatings show potential for the repair or replacement of hard tissues.

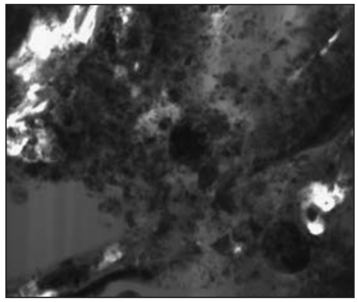


Schematic illustration demonstrates the formation mechanisms of the HA-GN nanocomposite coating.

"Nanocomposite Fe-Al Intermetallic Coating Obtained by Gas Detonation Spraying of Milled Self-Decomposing Powder"

Cezary Senderowski

The nanocomposite structure of Fe-Al intermetallic coatings, created in situ during gas detonation spraying (GDS) of as-milled self-decomposing powder and containing disordered 8 nm FeAl nanocrystals, was analyzed using scanning electron microscopy (SEM) with energy-dispersive x-ray (EDX) spectroscopy, transmission electron microscopy (TEM), selected-area electron diffraction (SAED), and x-ray diffraction methods. The Fe-Al coating is characterized by a sublayer morphology consisting of flattened and partially melted splats containing a wide Al range from about 26 to 52 at.%, as well as Al_2O_3 oxides, created in situ at the internal interfaces of splats during the GDS process. Complex oxide films, identified as amorphous Al_2O_3, which are formed in the nanocrystalline Fe-Al matrix of the GDS coating, behave like a composite reinforcement in the intermetallic Fe-Al coating. The combined presence of nanosized subgrains in the Fe-Al matrix and the Al_2O_3 nanoceramic dispersoids significantly increases microhardness.

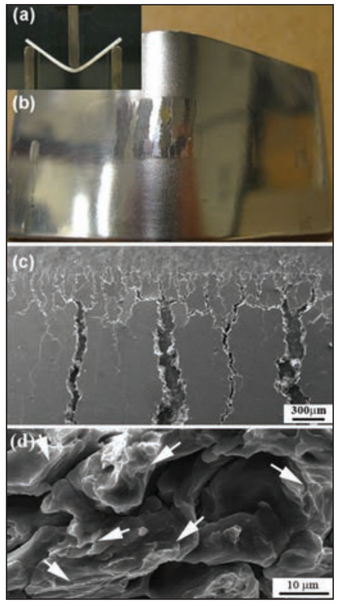


TEM bright-field micrographs of grains of as-sprayed coating with nanocrystalline particles of aluminum oxides.

"Aircraft Skin Restoration and Evaluation"

M. Yandouzi, S. Gaydos, D. Guo, R. Ghelichi, and B. Jodoin

Cold spray technology enables the deposition of low porosity and oxide-free coatings with good adhesion and minimal changes in the microstructure of coated parts. The use of low-pressure cold spray was used to repair damaged Al-based aircraft skin, hoping to obtain dense coatings with strong adhesion to the Al2024-T3 alloy. In order to prove the feasibility of using cold spray as a repair process for aircraft skin, series of characterization/tests including microstructures, microhardness, adhesion strength, three-point bending, surface finish, fatigue test, and corrosion resistance were performed. Results reveal that cold spray is suitable for the repair of aircraft skin.



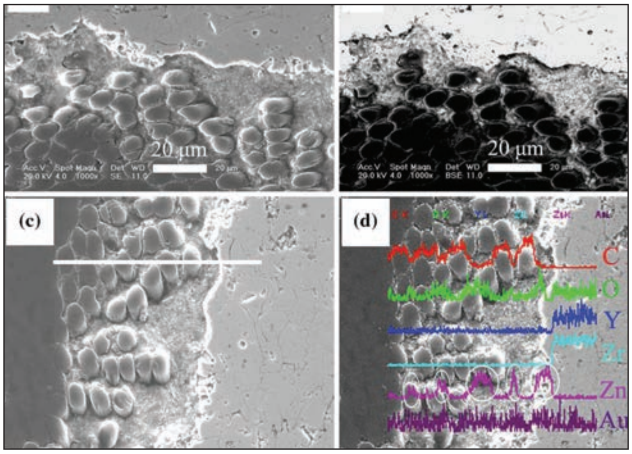
Repaired sample during the three-point bending test and after 90° bending, respectively (a, b). SEM images at different magnifications revealing the fracture nature that took place during bending (c, d).

"Thermal Shock Resistance of Stabilized Zirconia/Metal Coat on Polymer Matrix Composites by Thermal Spraying Process"

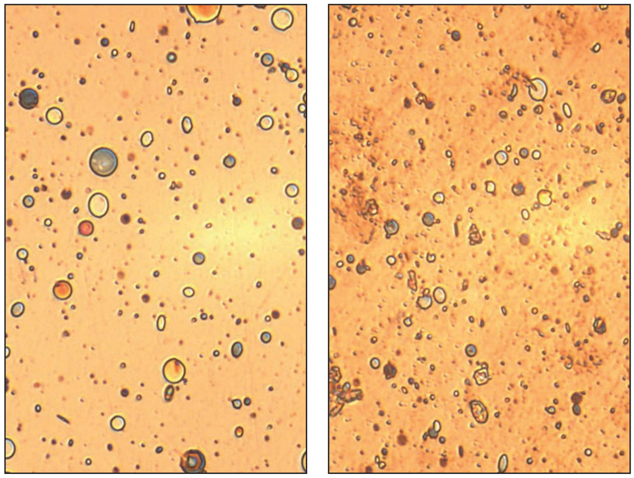
Ling Zhu, Wenzhi Huang, Haifeng Cheng, and Xueqiang Cao

Stabilized zirconia/metal coating systems were deposited on the polymer matrix composites by a combined thermal spray process. Effects of the thicknesses of metal layers and ceramic layer on thermal shock resistance of the coating systems were investigated. According to the results of thermal shock lifetime, the coating system consisting of 20 µm Zn and 125 µm 8YSZ exhibited the best thermal shock resistance. Based on microstructure evolution, failure modes and failure mechanism of the coating systems were proposed. The main failure modes were the formation of vertical cracks and delamination in the outlayer of substrate,

Continued on page 12



Typical cross-sectional microstructure (a) and corresponding backscattered image of coating Z20Y125 (b); EDS line scanning results of the cross-section of the coating (c, d).



Splats obtained by solution precursor plasma spray from ZrCl-LaNH (a) and ZrCl-LaNEt (27.8 g/L) (b).

and the appearance of coating spallation. Residual stress, thermal stress, and oxidation of substrate near the substrate/metal layer interface caused coating failure, while oxidation of the substrate near the substrate/coating interface was the dominant one.

"$La_2Zr_2O_7$ (LZ) Coatings by Liquid Feedstock Plasma Spraying: The Role of Precursors"

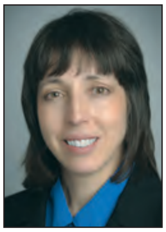
William Duarte, Sylvie Rossignol, and Michel Vardelle

Solution precursor plasma spray (SPPS) is used to obtain finely structured coatings from metallic salt solutions. Lanthanum and zirconium precursors were studied to understand their influence on lanthanum zirconate ($La_2Zr_2O_7$) synthesis by SPPS. Thermal analysis reveals the nature of the precursor and solvent affects mixture decomposition by changing the decomposition temperature. The surface tensions of precursor solutions in various media reveal the influence of the nature of the countercation. Different solutions of precursor mixtures were used to obtain $La_2Zr_2O_7$ splats on metallic substrates. A decrease in solution surface tension led to an increase in splat size. Coating mechanisms by SPPS are governed by the nature of the precursors and solvents.

ASMnews®

ASM Affiliate Societies Announce **New Officers and Board Members**

In accordance with their Rules of Governance, four ASM Affiliate Societies have completed their elections for officers and board members for 2014. Please join us in welcoming the following appointments.


Hartfield


Walraven


Wang


Vanderlinde


Henderson


Delagado


Li


Su


Jones


Kowalski


DeHennis


Hutton


Zurecki


Clements


Komolwit


Rothleutner


Blackwell


Elsayed

Electronic Device Failure Analysis Society

Cheryl Hartfield, business manager, Oxford Instruments, succeeds as president of EDFAS, while **Jeremy Walraven,** technical staff, Sandia National Laboratories, remains on the board as immediate past president. **Zhiyong Wang,** vice president, Maxim Integrated Products, is elected vice president. In addition, **William Vanderlinde, FASM,** Laboratory for Physical Sciences, is elected secretary, and **Chris Henderson,** Semitracks Inc., is reappointed as finance officer for one year. Other officers serve a two-year term. **Sandra Delagado,** Nanolab Technologies; **Susan Li,** device analysis lab manager, Spansion Inc.; and **David Su,** director, TSMC, were elected to the EDFAS board for a four-year term.

ASM Heat Treating Society

HTS president, **Roger Jones**, corporate president, Solar Atmospheres Inc., and HTS vice president, **Stephen Kowalski,** president, Kowalski Heat Treating Co., welcome the following new members to the HTS board for a three-year term: **Timothy DeHennis,** senior metallurgist, The Boeing Co**., Eric Hutton,** vice president of operations, Automotive North America, Bodycote Thermal Processing Inc., and **Zbigniew Zurecki,** research associate, Air Products & Chemicals Inc. **Thomas Clements**, engineering manager, Metals and Thermal Processes, Caterpillar Inc., remains on the board as immediate past president. Officers serve a two-year term. **Piyamanee Komolwit,** senior engineer, surface technology, Kennametal, was appointed young professional board member and **Lee Rothleutner,** Colorado School of Mines, was appointed student board member. Both appointments are for one year.

International Metallographic Society

Richard Blackwell, FASM, general manager, Buehler Canada, announced the appointment of **Abdallah Elsayed,** as student board member for one year. The other appointments did not change.

ASM Thermal Spray Society

The TSS electorate elected a vice president and three new members to the board and the TSS Executive Committee. See page 3 of *iTSSe* in this issue for the full story.

...in this issue

Submit news of ASM and its members, chapters, and affiliate societies to
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P 440.338.5151 ext. 5662 | **F** 440.338.4634 | **E** joanne.miller@asminternational.org

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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

ASM INTERNATIONAL

Pittsburgh Hosts MS&T14: Photo Gallery of Conference Highlights

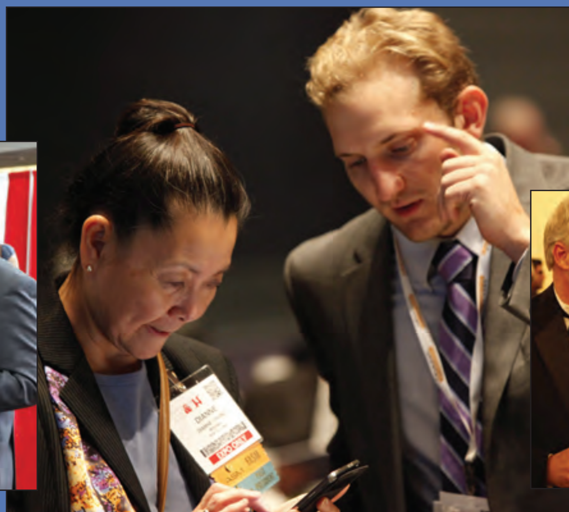
ASM Treasurer Craig Clauser addresses the membership at the ASM Annual Meeting.

ASM managing director Thom Passek welcomes incoming president Sunniva Collins, FASM, to her new role.

Dave Spencer (left), ASM Foundation chair, congratulates the University of Maryland for winning the Undergraduate Design Competition.

Amy Ebeling (left) with Katrina Boos, two-time winner of the George A. Roberts Scholarship.

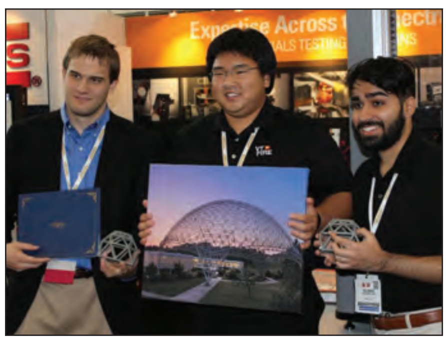
ASM networking and comradery at its finest.



Andie Nydam volunteers at the Mini Materials Camp on the show floor.

2014-2015 ASM Board of Trustees.

2014 Class of ASM Fellows.



Virginia Tech wins the first annual DomesDay competition.

Mary Judas receives her ASM Fellow award from outgoing ASM president, C. Ravi Ravindran, FASM.

Amber Genau accepts the Bradley Stoughton Award for Young Teachers.

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

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

The ASM Gold Medal is awarded to Tresa Pollock, FASM.

Honorary Membership is bestowed on Chandra Shekhar Pande.

Marie Cole and her IBM team accept the Engineering Materials Advancement Award.

Managing director Thom Passek (left) and ASM Past Presidents.

Emerging Professionals were on the scene in style.

George Krauss, FASM, listens at the Edward DeMille Campbell Memorial Lecture.

Robert Schafrik, FASM, presented the 2014 ASM/TMS Distinguished Lecture in Materials and Society on Monday.

Attendees of the first Women in Materials Engineering Breakfast enjoyed Kathy Buse's thoughts on why women persist in STEM professions.

See more MS&T photos on pages 36, 53, and 72.

From the President's Desk

Review and Retrospection

It is time to rejoice in our accomplishments of this past year. I had the unique honor of starting my presidency during ASM's centenary celebration in Montreal and then developed succinct goals for advancing our Society into our second century. Ideas were based on ASM's uniqueness, membership and chapter development, partnering with other societies, students as vanguards of our future, quality and quick access to content, lifelong learning, and government initiatives.

This past year, we launched a new logo representing our values to bring us closer to our affiliate societies, represent revitalization, and promote our products and services. We are in the midst of our first membership drive since 2001, engaging members, students, employees, and Board members. We also have new ASM-IIM North America Lectureships, and monthly meetings of ASM Canada Council. Based on success in Montreal, we are considering another mega MS&T, possibly in Toronto in 2017. In the past year, we introduced several new handbooks (4B, 4C, and 4D) enhancing the ASM Heat Treating Series, and two technical books. We also released an improved version of our first App, the Heat Treater's Guide Companion, plus a new Aluminum App. We started new courses on superalloys, component failure analysis, and thermal spray safety, to name a few.

Much have I seen and known... I am a part of all that I have met... To strive, to seek, to find, and not to yield

— From the poem "Ulysses" by Alfred, Lord Tennyson

With commitment of the Foundation and volunteers, we met our goal of hosting 50 materials camps in 15 years. We are also developing a Camp Alumni Portal, linking chapters, members, and alumni to enable more internships and job opportunities. ASM is a key driver in government initiatives including the Lightweight Materials Manufacturing Institute, America Makes (additive manufacturing), and the CMD Network. ASM is also leading the Thermal Manufacturing Industries Advanced Technology Consortium and is receiving a significant NIST grant.

As the brand ambassador of ASM, I visited vibrant chapters in Detroit, Chicago, Los Angeles, India-Mumbai, Chennai, Bangalore, Pune, Montreal, Ontario, North Texas, Notre Dame, Savannah, Hartford, Vancouver, Calgary, Edmonton, and more. Lifelong professional and personal relationships make ASM a powerful community. I thank the members, volunteers, Board, and all employees for this opportunity to provide a new vision to our great Society. *Au Revoir!*

C. (Ravi) Ravindran,
ravi.ravindran@asminternational.org

From the Managing Director

The Business Side of ASM

During the course of casual conversations, I am often asked what I do for a living. When I say that I run a professional society for materials scientists and engineers, people often wonder what that means. I explain that ASM serves 30,000 members in nearly 100 countries by collecting the most up-to-date technical information, distilling it through a value-added peer review process, and then disseminating it globally in a variety of print, online, and in-person formats. These include resources for professional development, conferences for sharing technical knowledge, products and services of value to the materials community, and networking opportunities for building both personal and professional relationships.

I often close my "elevator speech" by explaining that ASM is a not for profit organization. A common response is, "So you're not a real business." Wrong. We are a real business. However, for the privilege of not paying taxes, we do certain things that traditional for-profit businesses don't do. While explaining this, I began to wonder if ASM has ever shared this with our membership. In my 26+ years here, I do not recall seeing anything and I think it is time to discuss this.

ASM generates roughly $15 to $17 million dollars in revenue each year. We typically operate just above a break-even point, so margins are narrow. Our budgets are presented to ASM's Finance Committee, made up of highly qualified individuals, many of whom are business owners or past and present CEOs of major organizations. After careful review, committee members recommend the various operating budgets to our Board of Trustees for approval. ASM staff is then charged with managing operations within these budgets and providing regular updates to both the Finance Committee and Board.

In contrast to traditional for-profit businesses, ASM essentially invests its resources in three areas or "buckets." The first bucket includes activities we do for the good of the materials community, knowing there is no direct return on the financial investment. Examples include supporting ASM's awards programs, committee and council activities, an extensive chapter network, student programs, website development, and funding our ASM Foundation that encourages young people to pursue careers in science and engineering. We do all of these activities at a financial loss.

The second bucket includes products and services that need to break even or come close to covering expenses. Examples include providing magazines and newsletters, launching new technical conferences, maintaining and updating our technical content, and ensuring that we are being good stewards of our extensive knowledge base and intellectual capital.

This leaves us with our last bucket—activities we rely on to generate revenue. These items include our information products and services, education programs, and proceeds from our Access Market where companies promote products and services to our members via magazine and newsletter advertising, webinars, trade show exhibitions, website promotions, and various sponsorship opportunities. This revenue generation is essential to support the activities in the first bucket and ensure that we are able to sustain ASM's future.

ASM is on financially solid ground and we have a substantial investment portfolio built over the decades that allows us to weather economic downturns as well as invest in new initiatives. This has been accomplished through a partnership between talented ASM staff and volunteer leaders who have provided sound oversight and direction in the past and continue to deliver such counsel today.

NOMINATION DEADLINES

◆ ASM Nominating Committee Nominations

Due Dec. 15, 2014

Contact leslie.taylor@asminternational.org, 440.338.5151, ext. 5500, or visit asminternational.org/about/governance/nominating-committee.

◆ Nomination Deadline for the 2015 Class of Fellows is Fast Approaching!

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

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

Deadline for nominations for the class of 2015 is **November 30, 2014.**

Complete information including the rules, interpretive comments, and online nomination forms are available on the ASM website at: asminternational.org/membership/awards/asm-fellows, or by contacting Christine Hoover at 440.338.5151, ext. 5509, christine.hoover@asminternational.org.

◆ Annual ASM Award Nominations Due Feb. 1, 2015

The deadline for the majority of ASM's awards is February 1, 2015, and we are actively seeking nominations for all, a sampling of which is listed below. View instructions and download nomination forms online at asminternational.org/membership/awards. For more information, email christine.hoover@asminternational.org.

Edward DeMille Campbell Memorial Lectureship
Distinguished Life Membership
William Hunt Eisenman Award
Gold Medal
Silver Medal
Historical Landmarks
Honorary Membership
Medal for Advancement of Research
Allan Ray Putnam Service Award
Albert Sauveur Achievement Award
Albert Easton White Distinguished Teacher Award
J. Willard Gibbs Phase Equilibria Award

◆ Nominations Sought for ASM-IIM Visiting Lecturer for 2015

The cooperative Visiting Lecturer program of ASM International and the Indian Institute of Metals (IIM) is seeking lecturers for 2015. Criteria for the 2015 ASM-IIM Visiting Lecturers can be found at: asminternational.org/nominate.

The award carries with it an $800 honorarium to be used for travel expenses within India during the lecturer's visit and a certificate of recognition to be presented at the ASM Leadership Awards Luncheon scheduled for October 2015 in Columbus, Ohio, during MS&T15. Deadline for application is **December 1.**

◆ Nominations Sought for ASM-IIM North America Visiting Lecturer for 2015

The cooperative Visiting Lecturer program of ASM International and the Indian Institute of Metals (IIM) is seeking lecturers for 2015. Criteria for the 2015 ASM-IIM North America Visiting Lecturers are as follows: Candidates must be IIM members currently residing in India and have experience delivering technical presentations and be available between June 1 and December 30.

IIM provides $1000 and ASM will provide a matching award of $1000 for a total of $2000. The program honorarium is to be used for travel within the United States and/or Canada during the lecturer's visit and a certificate of recognition will be presented at the ASM Leadership Awards Luncheon scheduled for October 2015 in Columbus, Ohio, during MS&T15. Deadline for application is **December 1.**

THE POWER OF ONE | Membership Drive

The True Value of ASM Membership:
Building Connections

Dave Krashes, FASM,
and ASM President, 1982

Dave Krashes earned his Ph.D. in metallurgy in 1958 at Rensselaer Polytechnic Institute. As a professor at Worcester Polytechnic Institute, he taught courses in metallurgy and nonmetallic materials and helped develop a new metallurgy department. In 1962, he founded Massachusetts Materials Research Inc., still in business today. In 1970, Krashes became part of ASM's inaugural class of Fellows, later serving as a national trustee, treasurer, vice president, and president. We recently caught up with him to hear his thoughts on the value of ASM membership.

Why should current ASM members ask others to join the Society?

Every member knows how important the organization is to both their personal and professional lives. They also know that their colleagues could benefit. It's a logical step—why not ask others to join?

Have you been involved in past membership drives?

When I was Chairman of the Membership Drive in the late 1970s, we grew membership by 54%. Our plan was simple: We got all of the existing members to understand the value of ASM camaraderie, and that as part of the ASM team, they should support the drive and recruit more members. It turned out to be a great strategy.

If you could share just one ASM success story, what would it be?

When I was a young college professor, I didn't know much outside the world of metallurgy, so I started attending ASM meetings. I was very fortunate to meet ASM's president because he put me on a few committees, which in turn gave me access to leaders of the profession. After only five years as an ASM member, I started my own business. As I became more active with my local chapter and on committees, other members told me where to find customers and made referrals to me, which helped grow my business. I am proud to say my business is still in operation today, 50 years later! Of course, I owe a lot to ASM.

Chapter News

Naperville Teachers' Camp

Participants of the North Central Teachers' Camp sponsored by the Naperville, Ill., Chapter, were treated to a tour of DS Containers in Batavia, where steel high-pressure containers are manufactured for a variety of aerosol and non-aerosol products. Here, precoated steel is formed into food-safe cans with integral domes using state-of-the-art manufacturing and quality assurance. The plant is reportedly the first in the world to manufacture containers with this combination of materials and processes, requiring an understanding of materials science principles regarding corrosion resistance, strength, and reliability.

Connecticut Chapters Reach New Heights

Members of the **Hartford and Southern CT Chapters toured the Otis Elevator Test Tower** and Quality Control Lab in Bristol, Conn., in September. The tower is 383 ft (117 m) high. The facility has a quality control and new product testing lab as well as 13 test elevator shafts. After the tour, members enjoyed a talk by retired Otis engineer Nick Marchitto, in which he described some of the challenges in designing and manufacturing elevators. In the photo, members are gathered by a reproduction of the original Otis safety elevator, which Elisha Otis used in a dramatic demonstration at the Crystal Palace Exposition in New York in 1854. Past Hartford Chair Harley Graime, far right in the front row of the photo, arranged the tour and talk.

Williams Receives 2013 APDIC Award

ASM President Sunniva Collins presented the 2013 APDIC Industrial Award to Peter Williams, P.E., chief scientist, Swagelok Co., during the Cleveland Chapter meeting held at ASM International Headquarters in May. The award acknowledges eminent achievements reached by industries in raising awareness of the economic, societal, and technical importance of applied knowledge in phase diagrams and related data within commercial organizations. The ASM Alloy Phase Diagram Committee nominated Swagelok, Solon, Ohio, for the award on behalf of ASM International.

Alloy Center Database & Corrosion Analysis Network

High Temperature Corrosion Data Added!

A new High Temperature Oxidation data table was recently added to the corrosion performance database in the ASM Alloy Center and Corrosion Analysis Network products. Many thanks to the ASM Materials Properties Database Committee (MPDC), Corrosion Subcommittee panel of experts for their guidance in helping to conceive and develop this important content addition: Steven A. Bradley, FASM, Barry Hindin P.E., George Lai, James Powell P.E., Howard W. Sizek, and Ian G. Wright. The Alloy Center Database release includes newly added standards and commercial grades records, enriched chemical composition data, updated coatings data, including expanded paint coatings information, and more than 100 new datasheets. Both of the product software platforms have been updated to Granta MI Version 7. For more information, contact Denise.Sirochman@asminternational.org.

Brand New ASM Gear Is In!

ASM has a brand new lineup of sleek, premium apparel items for any situation. Lounge around in a super soft materials science tee, try the ultra-comfortable tri-blend hoodie in the chilly fall weather, or decorate your dorm with artwork featuring original drawings by R. Buckminster Fuller. Whatever you choose, the new ASM collection promises comfort, style, and quality—and is great for easy gifts! **Visit asmgear.com.**

IMS Salutes Metkon for Continued Support

The International Metallographic Society (IMS) relies on corporate financial support to maintain its excellent awards program. The Society extends sincere appreciation to IMS Benefactor **Metkon Instruments Ltd.** for continued support.

metkon
Technology behind Specimen

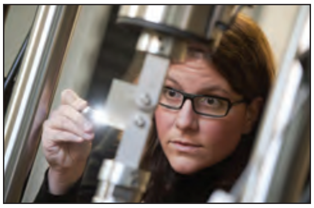
For a complete list of 2015 Education Courses, save the pullout insert between pages 48 and 49.

Members in the News

Singh inducted as a Fellow in the Royal Society of Chemistry

Prof. N.B. Singh, FASM, of the University of Maryland Baltimore County, a Fellow of ASM International, SPIE-The International Society of Optics and Photonics, and OSA-The Optical Society of America (OSA), was inducted as a Fellow of the Royal Society of Chemistry (RSC). Singh is internationally recognized for research in the area of electronic, optical, energy storage, radiation sensor bulk and thin film materials, and managerial leadership.

New NSF Award Funds Novel Manufacturing Method



Diana Lados, associate professor of mechanical engineering at Worcester Polytechnic Institute (WPI), Mass., and founding director of the university's Integrative Materials Design Center (iMdc), received a three-year, $424,000 award from the National Science Foundation (NSF) to support the development of a new way to manufacture metal-ceramic composites, which can be used to make vehicles lighter and more energy efficient, while significantly increasing their performance. Research will focus on ceramic-reinforced metal matrix composites. Lados was the winner of the 2013 ASM Silver Medal.

Hickton Assumes Presidency of ITA Board

Dawne S. Hickton, vice chair, president, and chief executive officer (CEO) of RTI International Metals Inc., Pittsburgh, has been tapped as the first female president of the executive board for the International Titanium Association (ITA). Hickton says she would like to establish a permanent path for other women to follow, so that they too can develop meaningful careers in the global titanium industry. She plans to establish a "Women in Titanium" committee as a way to inspire young women to consider careers and leadership roles in the industry.

Buehler Best Paper Award

The Awards Committee of the International Metallographic Society presents an annual award for the best paper in the IMS journal: *Metallography and Microstructural Analysis* (*MMA*). The 2014 Buehler Best Paper award winners are: S. Nafisi of Evraz North America, Regina, Saskatchewan, and R. Ghomashchi, University of Adelaide, Australia, for their research paper titled, "Microstructural Evolution of Electromagnetically Stirred Feedstock Semi-Solid Metal (SSM) Billets During Reheating Process," *MM&A*, Vol 2, p 96-106. Presenting the award to Dr. Shahrooz Nafisi is Richard Blackwell, FASM, IMS president, and Country Manager of Buehler Canada.

IN MEMORIAM

Word has been received at ASM Headquarters of the death of Life Members **Nev Gokcen, FASM,** of Palos Verdes Estates, Calif. (Oregon Chapter), **Alan Gorton,** Marietta, Ga., (Atlanta Chapter), and **Marshall L. Severson** of Sherman Oaks, Calif. (San Fernando Valley Chapter).

ASM INTERNATIONAL | Emerging Professionals

The Impact of Materials Engineers on Economy and Safety

Pankaj Sharma
Buckman International

Materials and corrosion failure analysis is a very specialized field, where engineers use the skills of materials, mechanical, welding, and chemical engineering to devise methods that answer the question of what went wrong with particular components. In addition, materials engineers also use knowledge in various technical areas such as metallurgy, corrosion, welding, nondestructive testing, materials characterization, corrosion inhibition chemistry, and ASME/API/NACE/ASTM codes and standards.

A materials engineer plays a lead role in the failure analysis and determines whether a component or product failed in service or if failure occurred in manufacturing or during production processing. For example, industrial power generation equipment includes gas turbines, heat exchangers, boilers, reactors, and pressure vessels as key plant components. It is prudent to investigate the root cause of the corrosion problems in this equipment as soon as possible to minimize further financial and production losses.

Corrosion failure is one of the largest expenses in the U.S. economy, yet it rarely receives the attention it deserves. Corrosion costs money and lives, resulting in dangerous failures and increased costs for everything from utilities to transportation and more. For example, in 2010, a report commissioned by the U.S. Chemical Safety Board concluded a catastrophic heat exchanger explosion and fire killed seven workers at the Tesoro Refinery in Anacortes, Wash. Metallurgical failure investigations reported that a catastrophic rupture occurred in a nearly 40-year-old carbon steel heat exchanger due to a high temperature hydrogen attack. In conclusion, materials failure analysis is vital to the U.S. economy as it can reveal any number of problems with industrial equipment.

Student News

Inaugural DomesDay a Smashing Success

The ASM Geodesic Dome Design Competition, DomesDay, was held on October 14 in Pittsburgh during MS&T, sponsored by NSL Analytical and MTS. The competition involved eight teams from six universities competing against

one another, with VT Aluminum Dome Team from Virginia Tech taking home the top prize of $1000. Team Dima-Dome from the University of Connecticut came in second, winning $750. Third place, with $500, went to The Iron Lotus team from Arizona State University. Each team built a geodesic dome that was judged based on a sales presentation, aesthetics, and mechanical strength. Compression testing took place in front of an audience on the convention floor. Judges included ASM Trustee John (Chip) Keough, Larry Somrack from NSL Analytical, and former student board members Jesi Booth and Karly Noelle. For more information, visit asminternational.org/students3.

ASM Grant Supports RPI's MA Outreach

Konane Bay, Sarah Boyd, Karly Chester, and Peter Lezzi
Department of Materials Science and Engineering
Rensselaer Polytechnic Institute, Troy, N.Y.

The Material Advantage Chapter of Rensselaer Polytechnic Institute (RPI MA) has a goal of increasing community interest in materials science and engineering (MSE). Acknowledging the need for students to gain educational experiences with MSE, the club launched a community outreach program in fall 2011, supported by an ASM grant, which has since allowed RPI student volunteers to connect with four schools and more than 300 students. To preserve key components of its outreach efforts, RPI MA developed the "IDEA" framework to guide its volunteers through each outreach event, and the "Materials Buddies" project to prepare new volunteers for future events. To read the full article, visit http://bit.ly/1zfFjDf.

Cold spray researcher named 2014 Mines Medal Fellow

M. Reza Rokni, a South Dakota School of Mines & Technology, Rapid City, S.D., doctoral candidate in materials engineering and science, has been named the 2014 Mines Medal Fellow. Rokni's research focuses on advanced characterization of cold spray deposits. He has developed expertise in advanced materials characterization, including scanning electron microscopy, transmission electron microscopy, electron backscatter diffraction, and nanoindentation. Rokni, of Tehran, Iran, earned his master's degree from the University of Tehran and his bachelor's degree from the University of Semnan, both in materials engineering and science. Ultimately, Rokni hopes to join a national laboratory for post-doctoral study and eventually become a faculty member at the university level.

Proud ISU Cyclones Spot Mascot in Micrograph

The Materials Advantage Chapter at Iowa State University has been named a "Chapter of Excellence" for the past nine years. Proud Cyclones include Andrew Meiszberg, Victor Lee, Zhenpei Ding, and Tyler Schlueter, who spotted the school mascot "Cy" in the microstructure of a copper-nickel-tin alloy they were investigating.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Manish Mehta, PhD
National Center for Manufacturing Sciences
Director of Strategic Projects & Principal Investigator
NCMS-NSF Nanotechnology Commercialization Readiness Study

Manish Mehta is a man of devotion—to industrial engineering, ASM, and global sustainability solutions. Speaking to Manish is an education, whether about his systems approach to developing materials, the commercialization of nanotechnology, or his work with Rotary International's "Project Dignity" in the Sundarbans region of India to provide families with improved sanitation while preventing ecosystem damage.

Manish studied mechanical engineering in Bangalore, India, before earning a scholarship to the University of Cincinnati for a master's and PhD in Industrial/Manufacturing Engineering. He worked on stealth composite technology at the U.S. Air Force Materials Lab and joined ASM as a student member, beginning 25 years as an active member. "Everything I do is related to materials," Manish observes, "I've become a steward of materials, striving to not waste materials or harm the environment when we convert materials into functional objects."

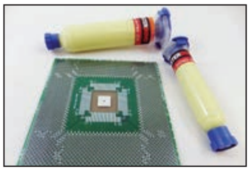
Manish worked with the Environmental Research Institute of Michigan (ERIM) before becoming a Senior Program Manager and Director at the National Center for Manufacturing Science, where he is a principal investigator for one of the largest studies of nanotechnology applications in manufacturing.

Manish chairs ASM Detroit and is excited about programming beyond the technical to include speakers on economic development as well. He says, "Detroit is such a happening place! There's great strength in this chapter. ASM actually has its origins in Detroit, with the 1913 Steel Treaters Club."

Manish serves on the Emerging Technology Awareness Committee, the ASM-IIM Awards Committee, and at Teacher Camps in Ann Arbor, an experience he calls "most gratifying, and the way ASM can make a major societal impact." He is excited to lead the Detroit chapter into the future, saying, "Let's bring in young blood and new faces to ASM...and deal with economic issues and improving our quality of life."

products & literature

Master Bond, Hackensack, N.J., introduces Supreme 3HTND-2DA, a fast curing, high performance **one component epoxy system.** It cures in 5-10 minutes at 150°C and has unlimited working life at room temperature. It is available in syringes and has a shelf life of six months when stored at 40°-50°F. The new epoxy has a die shear strength of 19-21 kg-f as well as good adhesion to metals, ceramics, and silicon dies. It is serviceable over the -100° to +400°F temperature range. As a toughened system, it offers the ability to withstand rigorous thermal cycling and shock. It also features dimensional stability, superior thermal conductivity, electrical insulation properties, and a glass transition temperature of 100°-105°C. masterbond.com.



Innovnano, Portugal, developed nanostructured 3 mol% yttria-stabilized zirconia (3YSZ) as an optimized **ceramic material** for high strength, anti-wear applications. With small grain sizes and exceptional homogeneity, 3YSZ powder has excellent mechanical and physical properties, including improved phase stability, which helps to extend the lifetime of ceramic linings, coatings, and components. The material is produced as a highly pure, uniform nanostructured powder with an even distribution of yttria. This homogeneous composition enables the powder to be sintered at lower temperatures, typically 50°-75°C lower than conventional powders, keeping the grain size to a minimum (<250 nm). Ceramic coatings and components benefit from both excellent hardness (HV10 >1250) and flexural strength (1100-1800 MPa). innovnano-materials.com.

Henkel Corp., Germany, offers the aerospace industry Loctite **benzoxazine resins** for injection processes. With high performance and a weight saving of almost 30% compared to metal alternatives in comparable aerospace engineering applications, benzoxazine resins offer significant savings in aircraft fuel consumption. Thanks to their room temperature stability and low flammability, they also contribute to enhanced health and safety in the aerospace industry. The improved performance characteristics of benzoxazine enable lower material consumption and reduce the hazards of waste products. Loctite benzoxazine resins also have lower shrinkage upon cure, reducing the internal stresses that can affect durability and adhesive bonding. henkel.com/aerospace.

AK Steel, West Chester, Ohio, introduces Chromeshield 22, a new **nickel-free stainless steel** product developed for manufacturers of appliances and food service equipment, tubing, cookware, automotive exhaust components, and heat exchangers. Similar to nickel-bearing stainless steels, Chromeshield 22 is rust and stain resistant with excellent corrosion properties. In numerous applications, its corrosion resistance meets or exceeds the performance of conventional nickel-bearing stainless steels. It is also approved by NSF International as safe for food contact. aksteel.com.

Excelitas Technologies Corp., Waltham, Mass., launched OmniCure AC8 Series **UV LED curing systems.** The series features superior optical uniformity, enhanced process control, and ease of integration to support diverse applications in the curing of inks, adhesives, and coatings. The scalability of AC8 Series allows adjoining of multiple LED heads in order to achieve larger curing areas, supporting customization and flexibility without compromising output uniformity. Precise control of UV irradiance level ensures the correct amount of UV light on every exposure for consistent and reliable results. excelitas.com/omnicureAC8series.

classifieds

To advertise in the classifieds, or to order article reprints, please contact Diane Whitelaw at 440.338.5151 ext. 5240, diane.whitelaw@asminternational.org.

ad index

The ad index is published as a service. Every care is taken to make it accurate, but *Advanced Materials & Processes* assumes no responsibility for errors or omissions.

editorial preview

JANUARY 2015

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- New Forming and Joining Methods
- Integrated Computational Materials Engineering

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Corporate Spotlights

Advertising closes December 4, 2014

FEBRUARY 2015

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International Thermal Spray and Surface Engineering newsletter covering coatings in the aerospace and defense industries.

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M&M 2015 + IMS Annual Meeting
August 2-6, Portland, Ore.

Advertising closes January 5, 2015

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stress RELIEF

3D printed teddy bear made using a new printer developed by CMU and Disney Research.

3D print your kids to bed with these cuddly bears

A new type of printer developed by Carnegie Mellon University (CMU) and Disney Research, both in Pittsburgh, can turn wool and wool blend yarns into fabric objects. The device looks like a cross between a 3D printer and sewing machine and produces 3D objects made of loose felt. Scott Hudson, a professor in CMU's Human-Computer Interaction Institute who developed the felting printer with Disney Research support, says the results are reminiscent of hand-knitted materials.

"I really see this material being used for things that are held close," explains Hudson. "We're really extending the set of materials available for 3D printing and opening up new possibilities for what can be manufactured." That could include apparel, accessories such as scarves and hats, and even teddy bears. It also could be used to produce parts for soft robots—those designed to touch or be near people.

The printer can make objects working directly from computerized designs and is able to rapidly prototype objects and customize products. The machine operates like fused deposition modeling (FDM), the most common process used in low-end 3D printers. In FDM printers, melted plastic is extruded in a thin line into a layer; subsequent layers are added to achieve the object's desired shape, with the layers adhering to each other as the plastic cools. In the felt printer, yarn exits the printer head instead of lines of melted plastic. *For more information: Scott Hudson, scott.hudson@cs.cmu.edu, cmu.edu, disneyresearch.com.*

Dwarf fossil galaxy offers clues to early universe

On the edge of the universe, 75,000 light years away, a galaxy known as Segue 1 is the faintest ever detected. It only contains about 1000 stars and has a rare chemical composition, with vanishingly small amounts of metallic elements present. Scientists, including an astronomer at Massachusetts Institute of Technology (MIT), Cambridge, have analyzed that chemical composition and gathered new insights into the evolution of galaxies in the early stages of our universe.

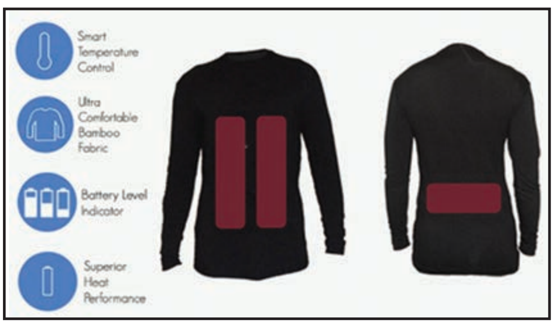
Stars usually form from gas clouds and then burn up as supernova explosions after one billion years, spewing more of the elements that are the basis for a new generation of star formation. However, in contrast to all other galaxies, it appears that Segue 1's process of star formation halted at what would normally be an early stage of development.

Telescopes at Las Campanas Observatory, Chile, where some research on Segue 1 was conducted. Courtesy of Anna Frebel.

"It's chemically quite primitive," says Anna Frebel, an assistant professor of physics at MIT. "This indicates the galaxy never made that many stars in the first place. It tried to become a big galaxy, but failed." Because it remains in the same state, Segue 1 offers valuable information about the conditions of the universe in its early phases. "It tells us how galaxies get started," says Frebel. "It's really adding another dimension to stellar archaeology, where we look back in time to study the era of the first star and first galaxy formation." *For more information: Anna Frebel, 617.254.3917, afrebel@mit.edu, web.mit.edu.*

Heated clothing just in time for winter

Were you slightly freezing last winter? So were Alex Huang and Jason Yakimovich, University of Toronto engineering alumni. Then students slogging through bitter drifts to class, the two decided to take matters into their own hands by inventing the world's first intelligent heated base layer. In just six months, the two founded FuelWear and created a feather-light and washable undershirt called the Flame Base Layer. The garment can add 10°C to body temperature in -20°C weather for three continuous hours. The shirt is made of bamboo fabric for its antimicrobial properties and washability. Heating elements, sewn into patches across the chest and back, are made of carbon fiber and controlled by printed circuit boards. Rechargeable lithium-ion batteries last for up to 12 hours of continuous outdoor use and LEDs indicate battery life. *indiegogo.com/projects/fuelwear-the-first-smart-heated-base-layer.*



Flame Base Layer heated undershirt from FuelWear.

SUCCESS ANALYSIS

Specimen Name: **Polymer Innovation Center**

Class 10,000 clean room for assembly and packaging of life science and semiconductor products.

Vital Statistics:

A new polymer research and development facility is now open in Ravenna, Ohio, in the heart of the state's "Polymer Valley," home to nearly half of Ohio's polymer industries as well as academic resources and a dedicated polymers workforce. The new center is part of Parker Hannifin Corp.'s Parflex division, which designs and manufactures thermoplastic and fluoropolymer hose, tubing, and accessories for applications in the transportation, medical and life sciences, oil and gas, construction, and marine industries. The 24,000-sq-ft facility consolidates the division's R&D activities into one location and is designed to help develop and prototype new products, with roughly 40% of the effort so far going into innovative medical devices such as highly flexible catheters.

Success Factors:

The facility includes a support lab, processing area, and five-story polytetrafluoroethylene (PTFE) paste tower for medical tubing development, as well as offices and meeting space. The center's services are designed to complement its customers' product design, development, testing, and manufacturing capabilities by providing help with everything from design expertise to prototype creation to high-volume production. A wide variety of polymers can be processed at the new facility, including PTFE, melt-processable fluoropolymers, engineered polymers, elastomers, and thermosets. In addition, processing capabilities include multilayer, PTFE, and thermoset extrusion, micro and traditional molding, and twin-screw compounding. In-house material and product testing is supported by an extensive range of analytical, thermal, and rheological test equipment.

Melt flow index machine used to test polymer viscosities at various temperatures.

About the Innovators:

In the past, plant managers within the Parflex facility were frequently asked to make room in their busy production schedules to accommodate test runs for prototypes, as part of the division's R&D efforts. The result was extensive project timelines—a problem solved by the new center. What used to require three or four weeks now takes three or four days due to the dedicated R&D facility. A $2.3 million funding commitment from Ohio's Third Frontier Research and Development Center Program and a $15 million investment from Parker came together to develop the facility. The University of Akron and Cleveland Clinic Foundation are collaborating with Parflex on the project as well.

Tri-layer extrusion line for producing high performance tubes and hose.

What's Next:

The center is now involved in several high profile development projects including high-pressure compressed natural gas hose to leverage America's recent shale gas boom, specialty polymers to enhance existing product performance, and two advanced technology catheter development initiatives with the Cleveland Clinic. The engineering team is also working with customers to develop special tubing consisting of unique polymers in order to improve product performance, reliability, and costs.

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