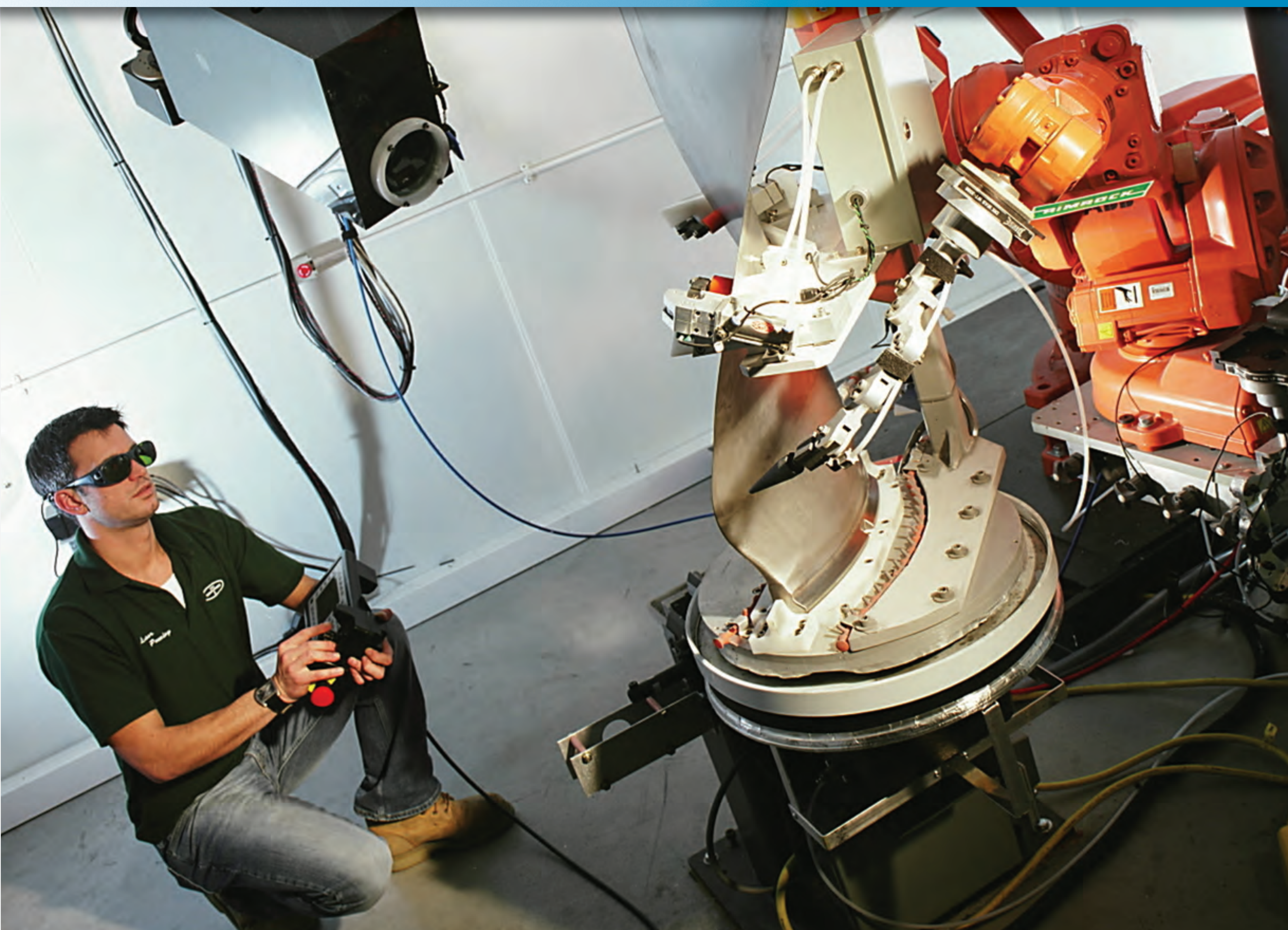
am&p

ADVANCED MATERIALS & PROCESSES®

asminternational.org
MAY 2014 • VOL 172, NO 5



ASM INTERNATIONAL

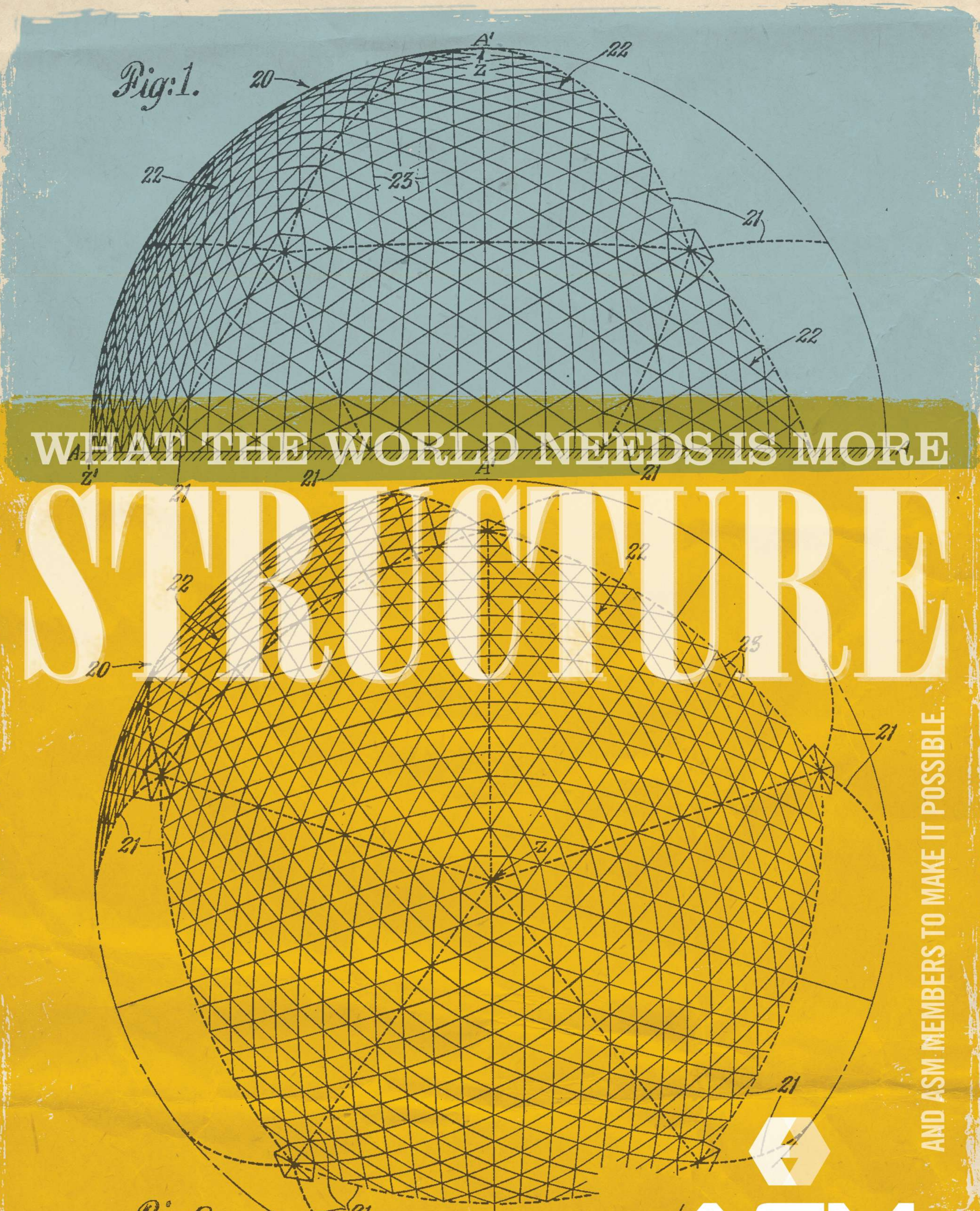


Fig:1.
WHAT THE WORLD NEEDS IS MORE
STRUCTURE
AND ASM MEMBERS TO MAKE IT POSSIBLE.
Fig:2.
ASM
INTERNATIONAL

am&p
ADVANCED MATERIALS & PROCESSES®

asminternational.org
MAY 2014 • VOL 172, NO 5

Aerospace Materials & Applications

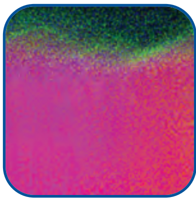
INCLUDED IN THIS ISSUE

AeroMat Conference Preview •
Development of Ti_2AlNb Alloys •
Overcoming Barriers of Magnesium Flammability •

ASM INTERNATIONAL

contents

ON THE COVER:
An engineer checks the placement of laser spots prior to fully automated processing. Laser peening of jet engine fan, compressor, and (potentially) turbine blades enables greater fatigue lifetimes and reduced inspection intervals. Courtesy of Metal Improvement Co., Livermore, Calif. www.cwst.com.



DEPARTMENTS

Check out the Digital Edition online at http://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. 5, May 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.

Change of address: Request for change should include old address of the subscriber. Missing numbers due to "change of address" cannot be replaced. Claims for nondelivery must be made within 60 days of issue. Canada Post Publications Mail Agreement No. 40732105. Return undeliverable Canadian addresses to: 700 Dowd Ave., Elizabeth, NJ 07201. Printed by Publishers Press Inc., Shepherdsville, Ky.

materials witness

Fly the friendly skies

Remember when it was actually fun to fly? Before checked bag fees, invasive pat-downs and x-rays, and the end of meals and peanuts? I'm also old enough to remember people enjoying cigarettes from the comfort of their significantly larger seats. I'm not saying I enjoy breathing secondhand smoke in confined spaces, but there was something enjoyably decadent and *Mad Men*-ish about the idea. When I was a child, my parents' airline of choice was good ole' Braniff International, which seemed glamorous from my limited perspective.

Fast-forward to last fall, flying economy class to Germany on United: People say "never say never," but I will *never* fly economy to Europe again. Trust me, if you've experienced this misery, you will likely agree that "economy plus" is well worth the upcharge for slightly improved leg room. Yes, jet fuel and modern aircraft are expensive, and who can blame the airlines for trying to make a buck? In a roundabout way, our annual aerospace issue addresses these issues in the ongoing quest for lightweighting and related fuel savings.

Because air travel is a global activity, we're proud to present articles from researchers in Canada, China, and the U.S. As Frank Czerwinski of Natural Resources Canada points out, the number of air travelers is projected to increase more than fivefold to reach 16 billion by 2050. In the interest of reducing aircraft weight to save on both fuel and emissions, the FAA and others are taking a fresh look at the existing ban on using magnesium inside commercial aircraft cabins. As the lightest structural metal, this makes a lot of sense if it can be done safely.

On another topic, our Chinese authors present an informative look at Ti_2AlNb alloy development and where this technology stands. Their article looks at both opportunities and challenges, including use of additive manufacturing for aerospace parts. The authors thank Professor Jim Williams for reviewing their findings, who (coincidentally) just spoke at the ASM Cleveland Chapter's annual Zay Jeffries lecture.

In front of a packed house, Prof. Williams, of The University of North Texas and The Ohio State University, talked about additive manufacturing (AM) of metals, with much of the discussion related to aerospace. One of his main points, echoed in the titanium article, is the need to rapidly qualify AM parts. Williams posed the idea that perhaps the right modeling techniques could be developed to help with qualification, in addition to sophisticated sensor technology to closely monitor AM processes.

Our third aerospace article, from Sandia National Labs and The University of North Texas, looks at materials in space, specifically how low earth orbit impacts thin film solid lubricants. Times are changing for space initiatives these days, especially as privatization continues. In mid-April, nearly two-and-a-half-tons of NASA science investigations and cargo made their way to the International Space Station (ISS) aboard SpaceX's Dragon spacecraft, the company's third cargo delivery flight. Dragon's cargo will support more than 150 experiments to be conducted by the crews of ISS Expeditions 39 and 40.

If you have a fond memory from the glory days of airline travel, or an aerospace project you'd like to share, please send a note. We'd love to hear about it.

F. Richards

frances.richards@asminternational.org

am&p
ADVANCED MATERIALS & PROCESSES®

9639 Kinsman Road
Materials Park, OH 44073
Tel: 440/338-5151 • Fax: 440/338-4634

Frances Richards, *Senior Editor*
frances.richards@asminternational.org

Julie Kalista, *Editor*
julie.kalista@asminternational.org

Barbara L. Brody, *Art Director*

Joanne Miller, *Production Manager; Editor, ASM News*
joanne.miller@asminternational.org

Press Release Editor
magazines@asminternational.org

market spotlight

Cobalt market braces for change in 2014 and beyond

According to the new report—*Cobalt: Market Outlook to 2018*—from Roskill Information Services, London, global cobalt consumption increased at a compound annual growth rate of 5.5% between 2008 and 2013. Roskill expects future demand to grow at a similar rate, approximately 6.1% per year to 2018. Demand will be led by Asia, particularly China, South Korea, and Japan, mainly driven by battery cathode production.

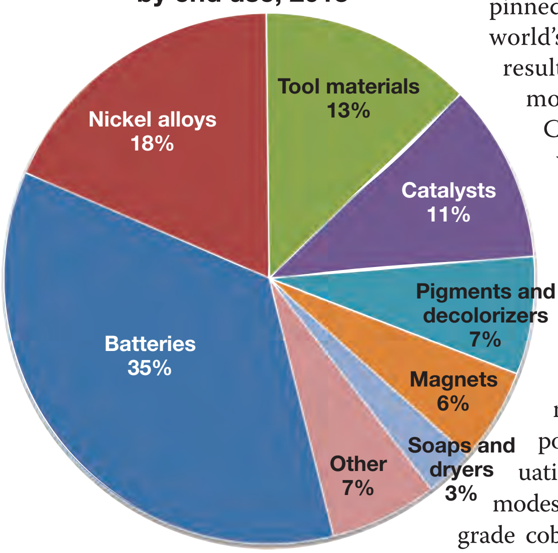
The market went into oversupply in late 2009 and remains in surplus, say analysts, and supply is expected to continue to outstrip demand both this year and next. Beyond 2016, demand is forecast to grow at a faster rate than supply. However, it will take several years for the recent period of oversupply and stockpiling to reconcile, which is likely to keep prices in check over the medium term.

Developments in the Democratic Republic of the Congo (DRC), the world's largest mine producer, have the potential to significantly impact the market this year. The DRC government wants to increase domestic refining of copper and cobalt products and decrease exports of unrefined materials. However, while the proposed export ban on concentrates did not come to fruition in 2013, government rhetoric suggests that such measures could still go ahead this year. While a blanket ban remains unlikely, the 2013 increase in export taxes, from $60 to $100 per ton, could be the first of several changes.

Outside of the DRC, a number of potential mine projects could produce cobalt raw materials, although many are at an early stage of exploration or development. Additional mine supply is likely to come from expansion projects at existing producers through 2018. Future demand is expected to grow at more than 6% annually to 2018, underpinned by strong growth in China, the world's biggest refined producer. As a result, demand is expected to reach more than 110,000 tons annually. Cobalt use in battery applications will drive consumption and is forecast to grow at 9.2% per year, say analysts.

Prices are expected to continue a slight downward trend in 2014 with the ramping up of new projects in Madagascar and the Philippines bringing additional material into the market and compounding the current oversupply situation. Thereafter, Roskill expects a modest year-on-year increase with high-grade cobalt prices increasing at roughly 3.6% per year to 2018. *For more information, visit www.roskill.co.uk/cobalt.*

World Consumption of Cobalt, by end use, 2013



Source: Cobalt Market Outlook to 2018, Roskill Information Services

1967 Corvette Sting Ray

feedback

Dream cars

In our March "Feedback" department, we asked readers about their favorite automotive memories and aspirations. Here are a few of our favorite responses:

1960 Sunbeam Alpine Roadster

My first car was a well-used Sunbeam Alpine Roadster that I bought in Norfolk, Va., when I was in the Navy. It had a convertible top, tonneau cover, and removable plastic hardtop. I tried to drive it to my job interview with Harry Chandler [author of *Metallurgy for the Non-Metallurgist*] in the fall of '69, but it broke down on the New York State Thruway. I made it to Materials Park a couple of days later in my dad's Ford. The rest is history. Now I wish I'd had the wherewithal to have the Sunbeam restored. It was a nice ride, when it ran.

Don Baxter

My first '67 Corvette Sting Ray was a red, big block 427ci/435hp that I bought in late 1967 from a guy who got new ones every fall. I was working for GE in Schenectady, N.Y., in the Large Steam Turbine Dept. My monthly insurance payment was more than my loan and gas costs because the car was considered a high-powered, two-seat sports car and I was under 25. My current '67 Sting Ray is a 327ci/350hp high performance, Goodwood Green convertible with the optional hardtop. 1967 was the last year of the original Sting Rays (1963-67) and this one is very correct and very fast from 0 to 80 mph, one power shift from first to second, and corners well with a stock/original suspension.

Ron Natole

1956 Continental Mark II

My ideal car is the Continental Mark II, the last true classic made in the U.S. It will turn heads anywhere.

Chuck Dohogne

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

Clemex Technologies Inc.

Keeping up with new technology

Technological improvements, such as faster image processing, have always been a concern for Clemex as client satisfaction is a top priority. With the arrival of the latest Super Speed USB 3.0 cameras we deliver systems that provide outstanding image resolution and fastest analysis time available today. www.clemex.com/usb3

A reference when it comes to challenging applications
Image analysis applications are numerous and varied and cannot all be tackled the same way. Over the years Clemex has shown leadership in developing solutions that fit even the most complex cases. New features such as Dual Magnification processing and Conditional Instructions allow labs to further reduce user intervention during analysis and help them fully meet their objectives. www.clemex.com/version7

A trusted supplier of optical imaging hardware and software
A broad range of manufacturing industries, from steel to pharmaceuticals, already benefit from our expertise in choosing the finest microscopes, motorized stages and cameras available on the market and combining them seamlessly with Clemex software for a superior user-experience.

Our fast and reliable application-specific software includes Clemex PSFilter for particle contamination testing (ISO 16232 | ISO 4406-07 | USP 788 | IEST STD CC 1246D), Clemex PSA for particle size and shape measurement, Clemex CIR for inclusion rating (ASTM E-45 | ISO 4967) and Clemex CMT. HD (ASTM-E 384 | ISO 6507) for Vickers and Knoop micro-hardness testing.

As for general purpose applications, our flexible multipurpose software is available in 3 versions and covers a multitude of uses: Clemex Captiva for basic image acquisition, measurements and annotations, Clemex Vision Lite for standard analyses such as particle size & shape, grain size and layer thickness and Clemex Vision PE for atypical or complex applications. www.clemex.com/software

Clemex Technologies Inc.
800 Guimond, Longueuil
Québec, J4G 1T5 Canada
tel: (450) 651-6573
e-mail: info@clemex.com
Website: www.clemex.com

Suede-like material has new Lamborghini covered

The Lamborghini Huracán LP 610-4 offers several customizable interior options jointly conceived by Lamborghini and Alcantara, Italy. The material combines technical and functional performance features including durability, light weight, grip, and breathability. The cockpit can be customized by choosing among seven different options for seats, lower dashboard, door panels, center console, and glove box.

Alcantara is composed of roughly 68% polyester and 32% polyurethane for increased durability and stain resistance. Both the appearance and feel of the material is similar to suede. Alcantara is produced by combining an advanced spinning method with chemical and textile production processes that interact with each other. Since 2009, Alcantara remains certified as carbon neutral, having defined, reduced, and offset all CO_2 emissions derived from its activity. *www.lamborghini.com, www.alcantara.com.*

Eco-friendly rubber bricks

Mohamed A. ElGawady, a researcher at Missouri University of Science and Technology, Rolla, is testing new masonry blocks made from ground tires. "Rubber has a lot of benefits in addition to its sustainability," says ElGawady, associate professor of civil, architectural, and environmental engineering. "It's very durable and provides good insulation. Among their many potential benefits, these new blocks could cut heating bills by 50%."

Mohamed A. ElGawady, associate professor of civil, architectural, and environmental engineering (right) with graduate student Ahmed Gheni.

ElGawady has been working with Midwest Block and Brick, Jefferson City, Mo., to create the blocks, which are made from sand plus scrap tires ground to fine particles. These rubber-added blocks, called rubberized blocks, were constructed with a variety of ratios of sand-to-rubber particles before arriving at the right balance. A compression machine is used to test and compare the strength of prisms built with the rubberized blocks to conventional concrete masonry blocks. Both types of blocks are tested in an environmental chamber where they undergo cycles of extreme temperatures and humidity levels, simulating different weather conditions. The rubberized blocks are also tested under cyclic compression loads, simulating earthquake forces. "Construction with these new blocks could improve a building's resiliency during an earthquake by acting as shock absorbers," says ElGawady. *For more information: Mohamed A. ElGawady, 573/341-6947, elgawadym@mst.edu, www.mst.edu.*

3D-printed bike frame is light and tough

A 3D-printed titanium bicycle frame was created by Renishaw and Empire Cycles, both in the UK. The frame was manufactured in sections from a titanium alloy, using additive manufacturing (AM), and then bonded together. The alloys have a high ultimate tensile strength (UTS) of more than 900 MPa when processed using AM, and achieve near perfect densities of greater than 99.7%, according to Renishaw. The frame was designed using a process called topological optimization—an approach that optimizes material layout within a given design space for a specific set of loads and boundary conditions so that results meet performance targets. The companies eliminated many downward-facing surfaces that would otherwise need wasteful support structures. In partnership with Swansea University, frame testing will continue, both in the laboratory and on the mountainside, using portable sensors. Because no tooling is required, continual design improvements can be made easily and at minimal cost. *www.renishaw.com/en, www.empire-cycle.com.*

Complete bike with 3D-printed titanium alloy frame and seat post bracket.

corporate
spotlight ad

Allied High Tech Products Inc.

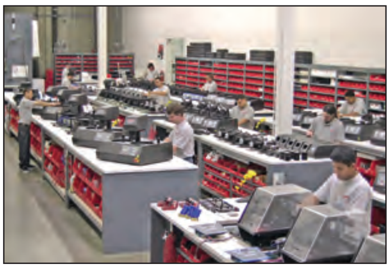
For over 31 years, Allied has been meeting the needs of companies engaged in the materials science, materials manufacturing, aerospace, military, photonics, fiber optics, microelectronics, and research & development industries. We aggressively pursue the advancement of methods and procedures related to each of these industries, and therefore promote close working relationships with several hundred of the world's leading research universities, laboratories and institutions.

Modern, Fully-Equipped Laboratory
Allied High Tech Products, Inc. offers customers and clients year-round, complimentary access to our modern, fully equipped laboratory, and dedicated technical and engineering team. We actively promote the use of our facilities, equipment and consumables in the rapid development of procedures and applications. "Our Lab's For You!"

State-of-the-Art Equipment Design & Manufacturing
Allied designs and manufactures a complete range of state-of-the-art equipment at their California facility. Using the latest design software, a team of dedicated mechanical, electrical and design engineers assure that Allied's equipment is built to specifications that deliver dependable results and durability.

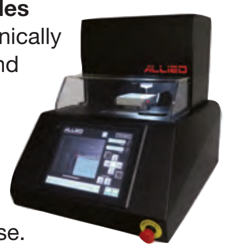

Allied's Fully-Equipped Laboratory


Mechanical & Design Engineering


Equipment Manufacturing Line

Allied's NEW Website

X-Mill™ Precision Mechanical Mill - Now does Contoured Samples
The **X-Mill™** is the most technically advanced instrument of its kind for precision sample preparation. No milling/polishing tool on the market offers similar features and capabilities or produces such accurate results with ease. Now with **3D capability**, the X-Mill™ allows thinning of non-flat/warped silicon and other substrates with unmatched accuracy.



Zeiss Materials Microscopes
Allied is the national distributor for the complete line of Zeiss materials microscopes including inverted, upright and stereomicroscopes for a wide range of optical applications.

Allied also offers the complete line of Zeiss AxioCam cameras, as well as computers, adapters, printers and accessories to build a complete imaging workstation for any application.

Mitutoyo Hardness Testers
Allied is now a national distributor of Mitutoyo Hardness Testers.

From basic Rockwell to advanced Micro Vickers Hardness Testers, Allied has the best to offer from Mitutoyo's top-rated line.


Allied's Consumables Line

ALLIED
HIGH TECH PRODUCTS, INC.

For more information:
Allied High Tech Products, Inc.
2376 East Pacifica Place
Rancho Dominguez, CA 90220 USA
tel: 800/675-1118 (US/Canada) • 310/635-2466 (Worldwide)
fax: 310/762-6808
Web: www.alliedhightech.com

Inform. Connect. Inspire. Evolve.

ASM Members,

As ASM International steps into its second century, there's never been a better time for you to fully realize all the ways membership connects you to professional success. And what better way to celebrate this opportune point in time than with an exciting refresh of our ASM brand!

The design of our new ASM brand mark is just the beginning, symbolizing our organization's core values of connecting people and exchanging knowledge. It points to a rich history as well as a prosperous future. It contains the colors of growth. And it reflects big plans for growing as we embark upon our next 100 years.

Inform. Connect. Inspire. Evolve. These are the actions that ASM has always stood for. Today, our new brand emphasizes that we stand together stronger than ever.

Thom Passek, *Managing Director*

briefs

Steelhead Composites, Denver, purchased and installed a heavy-duty CNC neck forming machine made by **MJC Engineering and Technology,** Huntington Beach, Calif. It is designed to manufacture high-pressure cylinders, including aluminum vessels to 42 cm (16.7 in.) in diameter and to 3 m (10 ft) in length. A seamless aluminum tube is shaped to form a bottle with a domed end and port openings. The bottle is then wrapped with carbon fiber composite using state-of-the-art filament winding capabilities. Composite overwrapped pressure vessels are available as high pressure, light weight gas storage containers for high-pressure compressed natural gas and hydrogen, for example. The machine can also manufacture lightweight hydraulic accumulators. www.steelheadcomposites.com, www.mjcengineering.com.

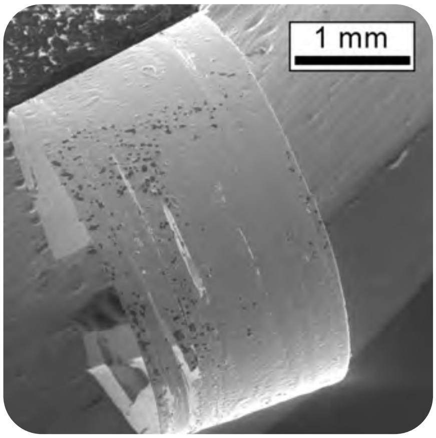
Exelis Inc., Salt Lake City, received a contract worth more than $34 million from **Sikorsky Aircraft Corp.** to produce major structural airframe components for four production-representative CH-53K heavy lift helicopters. Designated as system demonstration test articles, the aircraft will enable the U.S. Marine Corps to evaluate the new helicopter system in 2017. Exelis will fabricate and assemble the composite sponsons, tail rotor pylon, and horizontal stabilizer. www.exelisinc.com, www.sikorsky.com.

The first flight test CH-53K aircraft being delivered for evaluation. Courtesy of Sikorsky Aircraft Corp.

Fore! Glass golf clubs are playing through

What do some high-end golf clubs and a living room window have in common? The answer is glass, but the clubs use metallic glass, which can be bent considerably and spring back to original form. An international team of scientists hopes their discoveries will lead to glass that is both stronger and more ductile.

"We used an experimental technique called nanoindentation to repeatedly sample the initial formation of shear bands," says Seth Imhoff at Los Alamos National Laboratory, N.M. "Essentially it uses a tiny needle to push on the surface of a sample in a very controlled way. Even though the force is small, the tip of the needle concentrates stress in one small region until a single shear band is generated in order to relieve some stress."



A piece of metallic glass was bent around onto itself with a 1-mm radius and glued into place. It would spring back to a flat piece if the glue were removed.

By repeating this process many times, scientists sample many local atomic arrangements and their specific critical stress levels. This evidence challenges the current assumption of only a single type of initiation site, or STZ (shear transformation zone). Identification of multiple types of STZs could lead to new opportunities for controlling the strength and ductility of bulk metallic glasses and, of course, more durable high-performance golf clubs. *www.lanl.gov.*

Manufacturing a solution to planet-clogging plastics

Researchers at Harvard's Wyss Institute, Boston, developed a method to carry out large-scale manufacturing of everyday objects—from cell phones to food containers and toys—using a fully degradable bioplastic isolated from shrimp shells. The objects exhibit many of the same properties as those created with synthetic plastics, without the environmental threat. It also trumps most bioplastics on the market today in posing no threat to trees or competition with the food supply.

The bioplastic was developed from chitosan, a form of chitin, a long-chain polysaccharide responsible for the hardy shells of shrimps and other crustaceans, armor-like insect cuticles, tough fungal cell walls, and flexible butterfly wings. The majority of available chitin in the world comes from discarded shrimp shells, and is either thrown away or used in fertilizers, cosmetics, or dietary supplements.

The Wyss team, led by Javier Fernandez and Don Ingber, developed a new way to process the material so that it can be

A series of chess pieces made of chitosan bioplastic demonstrates a new way to mass-manufacture large, 3D objects with complex shapes made of fully compostable materials. Courtesy of Harvard's Wyss Institute.

used to fabricate large, 3D objects with complex shapes via traditional casting or injection molding techniques. Moreover, the chitosan bioplastic breaks down within about two weeks when returned to the environment, and releases rich nutrients that efficiently support plant growth. *For more information: Javier Fernandez, javier.fernandez@wyss.harvard.edu, www.wyss.harvard.edu.*

Platinum chromium coronary stent system

Boston Scientific, Natick, Mass., received CE Mark approval for its next-generation bare metal stent, the REBEL platinum chromium coronary stent system, designed to treat coronary artery disease. The system offers physicians the same platform as the Promus PREMIER drug-eluting stent, but without the Everolimus drug. The customized platinum chromium alloy stent features high visibility, low recoil, exceptional radial strength, and fracture resistance, while improving axial strength and deliverability. The enhanced low-profile delivery system includes a shorter, more visible tip, unique dual-layer balloon, and a Bi-Segment inner lumen catheter, which provides an appropriate level of pushability and flexibility. The stent system is available on a Monorail platform in 48 sizes, ranging in diameter from 2.25-4.50 mm and lengths of 8-32 mm.
www.bostonscientific.com.

Kaiser Aluminum Corp., Foothill Ranch, Calif., and **The Boeing Co.,** Seattle, formed a closed-loop scrap recycling program that is expected to involve approximately 22 million lb of aluminum in 2014-2015.The program is the largest aluminum recycling program to date and captures 7XXX and 2XXX aluminum alloy recyclables generated at multiple Boeing facilities during production of commercial aircraft. Scrap alloys will be remelted and used to produce aerospace sheet and plate at Kaiser's Trentwood facility in Spokane, Wash. www.kaiseraluminum.com, www.boeing.com.

A new book from **SAE International,** Warrendale, Pa., *Plastics Application Technology for Safe and Lightweight Automobiles,* covers application technology development for various aspects of automotive design—concept design, CAD modeling, predictive engineering methods through CAE, manufacturing method simulation, and prototype and tool making. The book describes the design and manufacturing aspects of energy absorbers, fenders, front-end modules, instrument panels, steering wheels, head lamp assemblies, throttle bodies, polycarbonate glazing, tailgates, and exterior components such as roof racks, wipers, door handles, and rearview mirror assemblies using engineering thermoplastics for safety and reduced weight for next-generation automobiles. http://books.sae.org/r-415.

TESTING CHARACTERIZATION

briefs

Durex Industries, Cary, Ill., expanded its testing and analysis capabilities into a new 2000-sq-ft metrology laboratory and added a scanning electron microscope (SEM). Services at the new lab include microstructural analysis such as grain size measurement, inclusion level, and weld penetration; SEM imaging; EDS elemental composition analysis; thermal imaging (FLIR); x-ray imaging; finite element analysis; and micro-hardness analysis. www.durexindustries.com.

Durex Industries' new metrology lab.

A team of **Harvard University** scientists, Cambridge, Mass., led by physics professor **Amir Yacoby,** developed a magnetic resonance imaging (MRI) system that can produce nanoscale images. Though not yet precise enough to capture atomic-scale images of a single molecule, the system has already captured images of single electron spins. As the system is refined, Yacoby expects it to eventually be precise enough to peer into the structure of individual molecules. www.harvarduniversity.edu.

Physics professor Amir Yacoby and research assistant Yuliya Dovzhenko work in the lab where an MRI system that can produce nanoscale images was developed. Courtesy of Kris Snibbe/Harvard.

Copper-oxide material aids understanding of superconductivity

A new study by scientists at the Max Planck Institute for the Structure and Dynamics of Matter in Germany and the U.S. Dept. of Energy's SLAC and Brookhaven national laboratories pins down a major factor behind the appearance of superconductivity in a promising copper-oxide material. Carefully timed pairs of laser pulses at SLAC National Accelerator Laboratory's Linac Coherent Light Source (LCLS) were used to trigger superconductivity in the material and immediately take x-ray snapshots of its atomic and electronic structure as superconductivity emerged.

The Undulator Hall of SLAC Lab's Linac Coherent Light Source, which "wiggles" electrons to generate high-power coherent x-rays crucial to studying superconductivity.

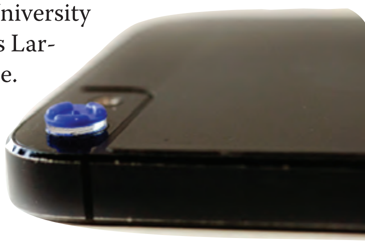
So-called "charge stripes" of increased electrical charge melt away as superconductivity appears. These results help rule out the theory that shifts in the material's atomic lattice hinder the onset of superconductivity. Based on this new understanding, scientists may be able to develop techniques to eliminate charge stripes and help pave the way for room-temperature superconductivity, often considered the holy grail of condensed matter physics. The demonstrated ability to rapidly switch between insulating and superconducting states could also prove useful in advanced electronics and computation.

"The very short timescales and the need for high spatial resolution made this experiment extraordinarily challenging," explains Michael Först, a scientist at the Max Planck Institute. "Using femtosecond x-ray pulses, we captured the quadrillionths-of-a-second dynamics of the charges and the crystal lattice. We've broken new ground in understanding light-induced superconductivity."

The compound used in this study was a layered material consisting of lanthanum, barium, copper, and oxygen grown at Brookhaven Lab by physicist Genda Gu. Each copper oxide layer contained the crucial charge stripes. *www.bnl.gov.*

Adhesive-free lens turns smartphones into microscopes

A new device called the Micro Phone Lens, developed by University of Washington (UW) mechanical engineering alumnus Thomas Larson, turns any smartphone or tablet into a handheld microscope. The pliable lens sticks to a device's camera without any adhesive and makes it possible to see things magnified dozens of times on the screen. Larson graduated in 2013 and formed his own company in Olympia, Wash.



A new lens that sticks to a device's camera without using adhesive can turn any smartphone or tablet into a handheld microscope.

The lens is about the size of a button and comes in its own carrying case. It sticks flat onto smartphone camera lenses, then an external light source such as a lamp is turned on, and the device is run in camera mode. Moving the device closer or farther from the object brings it into focus. Several other products exist that can adapt a smartphone to be used as a microscope, but they are significantly more expensive and the attachments are heavy or require permanent adhesives.

Larson developed his lens while working in the lab of Nathan Sniadecki, UW associate professor of mechanical engineering. Larson's lens is now as powerful as the research microscopes used in the lab, says Sniadecki. After graduation, Larson ran a Kickstarter campaign for the 15X microscope lens, and more than 5000 people signed up. He shipped orders to people around the world who need microscopes they can use in the field or in classrooms where expensive microscopes are in short supply. Now, he is creating the 150X lens, which will be available this summer. He manufactures the lenses at his lab and is working with an optical mold-making company to design more sophisticated optics for the new model. *For more information: Thomas Larson, 360/250-6894, thomas@microphonelens.com.*

The **Ronald E. McNair Center for Aerospace Innovation and Research,** at the **University of South Carolina,** Columbia, will partner with **Fokker Aerostructures,** a subsidiary of Dutch-based Fokker Technologies, to support and inspire next-generation aircraft technology development. Project details will likely involve development of advanced manufacturing technology for thermoplastic composites, use of digital image correlation to better understand failure mechanisms, and certification strategies for new advanced composite structures. McNair Center has 27 researchers working in a wide range of aerospace-related research fields. www.sc.edu/mcnair.

Characterizing bulk metallic glass at lightning speed

Scientists at Yale University, New Haven, Conn., developed a significantly faster way to identify and characterize complex alloys known as bulk metallic glasses (BMGs). Using traditional methods, it usually takes a full day to identify a single metal alloy appropriate for making BMGs. The new method lets researchers screen roughly 3000 alloys per day while identifying certain properties, such as melting temperature and malleability.

BMGs are metal alloys typically composed of three or more elements, for example, magnesium, copper, and yttrium. They can be used for producing hard, durable, and seamless complex shapes that no other metal processing method can achieve. Already used in watches, golf clubs, and other sporting goods, BMGs also have likely applications in biomedical technology, such as implants and stents, mobile phones, and other consumer electronics, explains Jan Schroers, professor of mechanical engineering and materials science. He says there are an estimated 20 million possible BMG alloys with about 120,000 metallic glasses produced and characterized so far.

Using standard methods, it would take approximately 4000 years to process all possible combinations, Schroers calculates. The new method could reduce the time to about four years. The technique combines a process called parallel blow forming with combinatorial sputtering. Blow forming generates bubble gum-like bubbles from the alloys and indicates their pliability. Co-sputtering is used to fabricate thousands of alloys simultaneously; alloy elements are mixed at various controlled ratios, yielding thousands of millimeter size and micron thick samples. Since 2010, his research team has tested about 50,000 alloys using the novel method and identified three specific new BMG alloys. *For more information: Jan Schroers, 203/432-4346, jan.schroers@yale.edu, www.yale.edu.*

briefs

Vladimir Gevorgyan, a chemistry professor at **University of Illinois at Chicago,** will lead the U.S. effort in a three-nation project to develop efficient catalytic methods that replace rare metals with abundant and inexpensive ones such as iron and copper. The project is the result of a competition sponsored by the **International Union of Pure and Applied Chemists**. With funding from the **National Science Foundation,** Gevorgyan's lab will focus on copper, while the German lab will concentrate on iron. The Chinese facility will develop heterogeneous versions of these catalysts. www.iaf.fraunhofer.de, www.uic.edu.

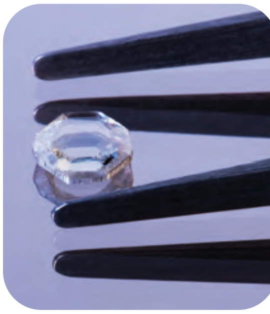
Vladimir Gevorgyan, University of Illinois at Chicago chemistry professor. Courtesy of Joshua Clark.

The **Lockheed Martin Space Systems Advanced Technology Center** (ATC) opened a new state-of-the-art laboratories building in Palo Alto, Calif. The 82,000-sq-ft **Advanced Materials & Thermal Sciences Center** will house 130 engineers, scientists, and staff. The new labs will host advanced research and development in emerging technologies such as 3D printing, energetics, thermal sciences, nanotechnology, synthesis, high-temperature materials, and advanced devices. www.lockheedmartin.com.

Lockheed Martin Space Systems ATC's new labs building.

New process holds promise for synthetic diamond crystals

Synthetic diamond crystals have unique properties that make them well suited for applications such as lenses for high-energy laser optics, x-ray radiation detectors, and ophthalmological scalpels. Scientists at the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg, Germany, are now manufacturing high-quality artificial diamonds in all shapes and sizes.



A high-purity single-crystal diamond made at Fraunhofer IAF.

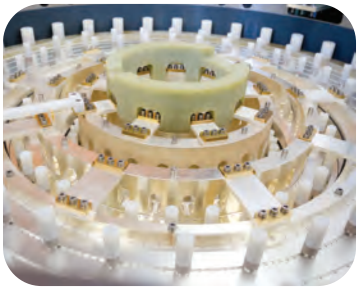
Researchers are able to produce 3D geometries and discs of different diameters and thicknesses by using plasma-enhanced chemical vapor deposition (CVD), a process by which diamond is chemically deposited on a substrate from the gas phase. A specially pretreated silicon or silicon dioxide (silica) substrate is coated with diamond by means of microwave plasma in an ellipsoidal reactor. Fraunhofer IAF's diamond lab contains eight such plasma reactors for growing diamonds in both polycrystalline and single-crystal form. Scientists can determine the orientation of polycrystalline diamond growth by applying small diamond seed crystals to the substrate before plasma deposition occurs. Single-crystalline diamonds with a continuous homogenous crystal lattice structure, however, must be grown on a single-crystal diamond substrate.

"We use CVD because it allows us to coat larger substrates, unlike other manufacturing processes such as the high pressure, high temperature method. What's more, this method will enable us to produce diamonds of high enough quality for use in electronic applications, and means we can homogeneously deposit diamonds with diameters to 10 cm on silicon substrates," explains group manager Nicola Heidrich.

Because diamond is chemically resistant, biocompatible, and able to withstand extreme temperatures, scientists are using it to develop electrochemical sensors that will in the future enable them to monitor water quality over long periods of time. Diamond is also an electrical insulator that can be turned into a conductor by adding boron and phosphorous to it. Researchers are working on ways to exploit its outstanding electronic properties for use in the high-performance transistors and components based on quantum effects of the future. *www.iaf.fraunhofer.de.*

38-tesla magnet debuts

The High Field Magnet Laboratory (HFML) at Radboud University Nijmegen, the Netherlands, set a world record by generating a 38-tesla continuous magnetic field in a resistive (non-superconducting) magnet. The HFML design proves that expensive superconducting coils are not required to achieve 38 tesla, lowering purchasing costs tenfold.



Magnet coils. Courtesy of Radboud University Nijmegen.

Materials research demands stronger magnets because higher magnetic fields allow more properties of important materials to be uncovered and investigated. In a magnetic field of 38 tesla, certain quantum effects are 100 times stronger than in a field of 33 tesla, which, until now, was the maximum magnetic field available in the Radboud lab. In 2011, the HFML began an ambitious project of designing a resistive magnet that would surpass the current world record of 36 tesla.

"The step from 33 to 38 tesla is significant. We will be able to clarify the properties of materials faster and more efficiently, and this will provide a major boost to materials innovation and development. Experiments in such high magnetic fields are currently only possible in the 45 tesla hybrid magnet, a partially superconducting magnet in Tallahassee, Florida, which is hugely overbooked and cannot satisfy all the demand. With the new magnet, we will make magnetic fields of this level available to a larger group of scientists," says researcher Uli Zeitler. *www.ru.nl.*

Ulbrich Stainless Steels and Special Metals Inc.

Ulbrich marks a 90th year milestone

Founded in 1924 by Frederick Christian Ulbrich Sr., Ulbrich Stainless Steels & Special Metals, Inc. was a small metal scrap processing center in Wallingford, Connecticut. Ulbrich is now marking its 90th anniversary this year with 700 employees, and 12 locations around the world, including its headquarters in North Haven, Conn. Today, the company remains family-owned, led by the founder, Fred Sr.'s son, Fred Jr., Chairman of the Board, and grandson, Chris, Chief Executive Officer.

Ulbrich serves stainless steel and special metal markets with strip, flat wire, shaped wire, foil and ultra-lite foil, and sheet product forms. It has evolved into a worldwide, high quality precision metals manufacturing and distribution network.

"We have achieved this milestone as a result of the commitment, loyalty, knowledge and hard work of each employee through the years," said Chris Ulbrich, CEO. "We also extend sincere appreciation to all customers who have supported Ulbrich with orders and feedback. Our dedicated customer base has always been key to the company's success."

When Fred Sr. founded Ulbrich in 1924, he could not have known that the company would endure through the Great Depression, diversify amidst two world wars, thrive during lunar exploration, and develop into an international business. Ulbrich supplies precision products at the international level for numerous critical applications in the medical, power generation, energy, automotive, aircraft, aerospace, petro chemical, oil and gas, industrial and consumer markets.

To celebrate its 90th year anniversary, Ulbrich is planning a series of commemorative events at all of its locations.

Ulbrich Stainless Steels & Special Metals, Inc.
153 Washington Avenue
North Haven, CT 06473
Tel: 800-243-1676
e-mail: information@ulbrich.com
Web: www.ulbrich.com

industry news

Energy Trends

briefs

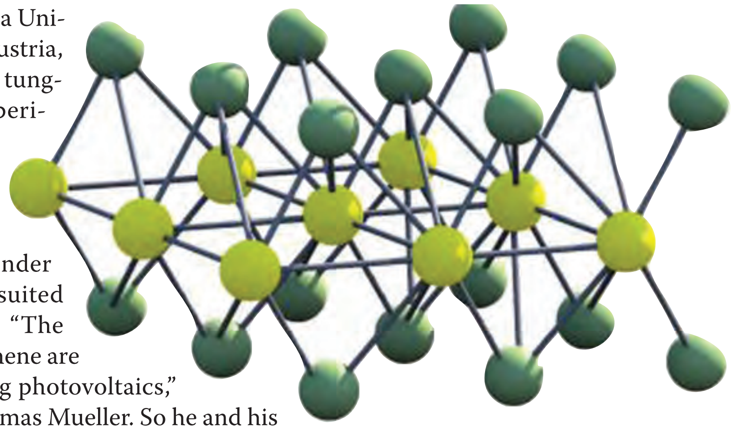
ASTM International, West Conshohocken, Pa., introduced a new standard—ASTM E2956 – 14—Standard Guide for Monitoring the Neutron Exposure of LWR Reactor Pressure Vessels. The USA Code of Federal Regulations requires a surveillance program for all operating LWRs to monitor changes in the fracture toughness properties of ferritic materials in the reactor vessel beltline, which result from exposure to neutron irradiation and the thermal environment. This data is then used to determine the appropriate safety conditions used throughout the vessel's life. www.astm.org.

Researchers from **North Carolina State University,** Raleigh, developed a new processing technique that makes LEDs brighter and more resilient by coating the semiconductor material gallium nitride (GaN) with a layer of phosphorus-derived acid. Researchers started with polar GaN, composed of alternating layers of gallium and nitrogen. To increase luminescence, the material's surface was etched with phosphoric acid. Phosphonic groups that self-assemble into a monolayer on the surface were also added. This layer further increases luminescence and improves the stability of GaN by making it less likely to react chemically with its environment. www.ncsu.edu.

A key patent from **3M,** St. Paul, Minn., for lithium-ion battery nickel-manganese-cobalt (NMC) cathode technology emerged from reexamination at the **U.S. Patent and Trademark Office (USPTO)** with all original claims being confirmed as patentable and with no amendments (U.S. Patent 7,078,128). NMC cathode technology is widely used in lithium-ion batteries for consumer electronics and electric vehicles. The patented technology enables lithium-ion battery makers to design electrodes for specific applications for optimum balance of power, energy, stability, and cost. www.3M.com.

Making the thinnest solar cells

Researchers at Vienna University of Technology, Austria, created a diode made of tungsten diselenide and experiments show it could be used to create ultrathin flexible solar cells. Although graphene is often considered a wonder material, it is not well suited for building solar cells. "The electronic states in graphene are not practical for creating photovoltaics," says research leader Thomas Mueller. So he and his team looked for other materials that can be arranged in ultrathin layers but have better electronic properties.



Tungsten diselenide. Courtesy of TU Vienna.

They used tungsten diselenide, which consists of one layer of tungsten atoms connected by selenium atoms above and below the tungsten plane. The material absorbs light, much like graphene, but can be used to create electricity. The layer is so thin that 95% of the light just passes through—but a tenth of the remaining 5%, which is absorbed by the material, is converted into electrical power. A larger portion of the incident light can be used if several of the ultrathin layers are stacked on top of each other—but sometimes high transparency is a useful side effect. "We envision solar cell layers on glass facades, which let part of the light into the building while at the same time creating electricity," says Mueller. *For more information: Thomas Mueller, thomas.mueller@tuwien.ac.at, 43 1/58801-38739, www.graphenelabs.at.*

Discovery could lead to better electric vehicle batteries

An international research team led by Western University, Ontario, investigated electric batteries and battery materials to reveal an underlying mechanical interaction that occurs during the carbon coating process. The coating not only affects the conductivity and performance of battery materials, but also alters the chemistry of the battery material's interactive surface. Using advanced measuring techniques, including scanning electron microscope (SEM) imaging, researchers discovered that the surface of the $LiFePO_4$ battery materials may actually melt during the heating process (at 600°-900°C), and that this phase change is size-dependent.

"By carbon coating at a relatively high temperature, the surface of $LiFePO_4$ battery materials basically becomes a liquid, creating island-shaped phases or pockets on the top of the battery materials, which breaks its conductivity," explains Xueliang (Andy) Sun. He also notes the discovery has yet to solve the problem of building better electric car batteries, but understanding the surface chemistry greatly enhances the possibility to do so. *For more information: Xueliang (Andy) Sun, 519/661-2111 ext. 87759, xsun@eng.uwo.ca, www.eng.uwo.ca.*

Californium could be used to safely store radioactive waste

Californium is "wicked stuff," according to Florida State University, Tallahassee, professor Thomas Albrecht-Schmitt. In carefully choreographed experiments, researchers found that californium had amazing abilities to bond and separate other materials. It was also found to be extremely resistant to radiation damage. The discoveries could help scientists build new storage containers for radioactive waste, plus help separate radioactive fuel, which means the fuel could be recycled. *For more information: Thomas Albrecht-Schmitt, 850/645-0477, albrecht-schmitt@chem.fsu.edu, www.fsu.edu.*

Self-mending paint immobilizes military vehicle rust

Developed by The Johns Hopkins University Applied Physics Laboratory, Laurel, Md., in partnership with the Office of Naval Research (ONR), Arlington, Va., polyfibroblast allows scratches forming in vehicle paint to scar and heal before corrosive effects reach the metal beneath. Polyfibroblast is a powder that can be added to commercial-off-the-shelf (COTS) paint primers. It is made up of microscopic polymer spheres filled with an oily liquid. When scratched, resin from the broken capsules forms a waxy, water-repellant coating across the exposed steel that protects against corrosion. While many self-healing paints are designed solely for cosmetic purposes, polyfibroblast is being engineered specifically for tactical vehicles used in harsh environments.

Adding polyfibroblast powder to COTS paint primers allows scratches forming in vehicle paint to scar and heal before the effects reach the metal beneath.

From rainstorms to sunlight, tactical vehicles face constant corrosion threats from the elements, costing the Navy alone roughly $7 billion each year. About $500 million of that is the result of corrosion to Marine Corps ground vehicles, according to the most recent Department of Defense reports. Vehicles transported and stored on ships also are subject to salt spray from the ocean, a leading cause of problems for military hardware. In one laboratory experiment, polyfibroblast showed it could prevent rusting for six weeks inside a chamber filled with salt fog. *www.onr.navy.mil, www.jhuapl.edu.*

Nanocoating increases aircraft engine service life

Researchers at University West, Sweden, are using nanoparticles in the heat-insulating surface layer that protects aircraft engines from heat. In tests, this increased the coating's service life by 300%. A heat-insulating surface layer is sprayed on top of metal components, shielding the engine from excessive heat. The temperature can be increased, leading to increased efficiency, reduced emissions, and decreased fuel consumption. The group hopes to control the structure of the surface layer in order to increase its service life and insulating capability.

"The base is a ceramic powder, but we have also tested adding plastic to generate pores that make the material more elastic," says Nicholas Curry. The ceramic layer is subjected to great stress when the enormous changes in temperature make the material expand and contract. It is important to make the layer elastic. Over the past few years, research has focused on further refining the microstructure for industry use. *www.hv.se/en.*

New technique binds organic compounds to metal surfaces

Queen's University (Ontario, Canada) researchers developed a new process that allows organic compounds to bind to metal surfaces. "Imagine pouring vegetable oil onto a metal surface and expecting it to stay," says Hugh Horton. "We have created a bond through a chemical absorption process that allows that to happen." In the new process, the bond between the metal and organic coating occurs through carbon instead of sulfur, which gives much greater strength and resistance to oxidation. The technology is being patented and commercialized by PARTEQ and Green Centre Canada. *For more information: Hugh Horton, 613/533-2470, hortonj@chem.queensu.ca, www.queensu.ca.*

briefs

PPG Industries, Pittsburgh, completed its acquisition of **Hi-Temp Coatings Technology Co. Inc.,** Boxborough, Mass., a privately-owned supplier of high-temperature-resistant and insulative coatings. The acquisition enhances the product portfolio of PPG's protective and marine coatings business, adding coatings that withstand extreme temperatures to protect both carbon steel and stainless steel substrates. The coatings are used in refineries, petrochemical plants, pulp and paper mills, and power plants. www.corporate.ppg.com.

Research and Markets added a new study, *Markets in Wear Coatings: Hard Chrome and its Alternatives.* This comprehensive report discusses the various technologies, industries in which they are used, and forecasts to 2020. A number of alternatives to hard chrome are discussed, dominated by thermal spray, in particular high-velocity oxy-fuel (HVOF), which is often favored due to its high strength and wear resistance, relatively low cost, and fast turnaround time. However, other emerging processes that are capturing the chrome and HVOF markets are explored as well. www.researchandmarkets.com.

Scientists report that rough zinc oxide coatings can prevent tiny silicon parts from adhering to each other. **Xinchun Lu** and colleagues explain that adhesion is a big concern when designing very small microelectromechanical systems (MEMS). Silicon is widely used in MEMS devices, but is sticky. The traditional solution is to either coat silicon with a water-repellent coating or roughen the surface. The group combined the two—using a water-repellent zinc oxide film with a rough surface. Thicker films were rougher and had a lower adhesion force than thin ones. Low humidity also helps, according to researchers. www.acs.org.

industry news

PROCESS TECHNOLOGY

briefs

After 23 years of service, **Vari-Form,** Troy, Mich., announced the retirement of the first machine to ever hydroform an automotive structural part. Production of instrument panel beams for Chrysler S body minivans such as Dodge Caravan began in July 1990. Over time, the press was used to produce structural parts for several generations of these vehicles. Dubbed **"Old Faithful"** by Vari-Form engineers, production peaked at more than 700,000 units per year in 1996. www.vari-form.com.

During two decades of active use, Old Faithful output nearly 10 million units.

Jean-Paul Herteman, CEO of **Safran,** France, and Joseph Morone, CEO of **Albany International Corp.,** Rochester, N.H., inaugurated a new plant in Rochester that will produce 3D woven RTM (resin transfer molded) composite parts for aircraft engines. The 300,000-sq-ft facility will make fan cases and blades for CFM International's LEAP engine, dedicated to the next-generation single-aisle aircraft. Particularly strong and lightweight, the 3D parts will help achieve 15% percent better fuel consumption than today's best CFM engine. www.safran-group.com, www.albint.com.

Cold spray technology restores aging bombers

South Dakota School of Mines and Technology, Rapid City, and Ellsworth Air Force Base, Piedmont, S.D., signed an agreement formalizing a relationship for collaborative projects such as using what they call a "revolutionary research technology" to refurbish aging bombers. The new partnership has already helped return four B-1s to service and could save the military millions of dollars.

Using innovative cold spray technology, aging B-1 bombers are being restored to full service at Ellsworth Air Force Base. Courtesy of U.S. Air Force.

School of Mines faculty researchers in connection with the Army Research Lab developed a patent-pending process using cold spray technology to deposit aluminum powder in worn and damaged areas of aircraft panels, machining them back to their original dimensions, thus returning bombers to full service. Panels were nearly impossible to replace without significant cost and time because OEMs no longer produce these 30-year-old aircraft components.

With proper approvals, $2.5 million could be saved this year alone on the B-1s at Ellsworth. An emerging technology, cold spray is capable of depositing a wide range of metal powders to create high-performance coatings on diverse materials without overheating them. This technology could be used for similar repairs on other weapon systems, and also has broad commercial applications. *www.sdsmt.edu.*

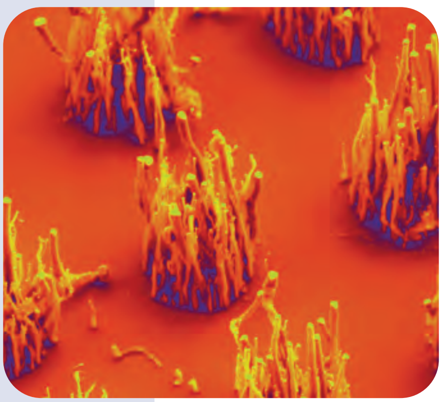
Scientists build carbon nanofibers with ambient air

Researchers from North Carolina State University, Raleigh, demonstrate that vertically aligned carbon nanofibers (VACNFs) can be produced using ambient air, making the manufacturing process safer and less expensive. VACNFs hold promise for use in gene-delivery tools, sensors, batteries, and other technologies, but conventional techniques for creating them rely on toxic ammonia gas.

"This discovery makes VACNF manufacture safer and less expensive, because there is no need to account for the risks and costs associated with ammonia gas," explains Anatoli Melechko, adjunct associate professor of materials science and engineering. "This also raises the possibility of growing VACNFs on a much larger scale."

In the most traditional method to manufacture VACNFs, a substrate coated with nickel nanoparticles is placed in a vacuum chamber and heated to 700°C. The chamber is filled with ammonia gas and either acetylene or acetone gas, which contains carbon. When a voltage is applied to the substrate and a corresponding anode in the chamber, the gas is ionized. This creates plasma that directs nanofiber growth. Nickel nanoparticles free the carbon atoms, which begin forming VACNFs beneath the nickel catalyst nanoparticles. However, if too much carbon forms on the nanoparticles, it can clog the passage of carbon atoms to the growing nanofibers. Ammonia's role in this process is to keep carbon from forming a "crust" on the nanoparticles, which would prevent formation of VACNFs.

"We didn't think we could grow VACNFs without ammonia or a hydrogen gas," Melechko admits. His team tried the conventional vacuum technique, using acetone gas. However, they replaced the ammonia gas with ambient air and it worked. The size, shape, and alignment of the VACNFs are consistent with those produced using conventional techniques. *For more information: Anatoli Melechko, 865/566-2713, anatoli_melechko@ncsu.edu, www.ncsu.edu.*



Researchers grow vertically-aligned carbon nanofibers using ambient air, rather than ammonia gas. Courtesy of Anatoli Melechko.

corporate spotlight ad

Inductotherm Group

Inductotherm Group develops advanced technologies — products, equipment and systems — for the melting, heating, coating, and other thermal treatment of metals. With 40 companies around the world, Inductotherm Group is recognized as the technology pacesetter in the thermal processing industry, able to innovate on a global scale, while delivering products efficiently at the local level through our 38 engineering/manufacturing facilities.

Here are some of our companies/brands:

CONSARC

Consarc designs and manufactures furnaces and related systems for vacuum induction melting (VIM), vacuum arc remelting (VAR), electroslag remelting (ESR), vacuum precision investment casting (VPIC), induction skull melting (ISM), and solar silicon melting furnaces.

INDUCTOHEAT

Inductoheat manufactures advanced induction heating equipment, offering general purpose to fully customized heat treating and annealing machines, pipe end heaters, crankshaft and camshaft heating machines and copper tube annealing plants.

THERMATOOL

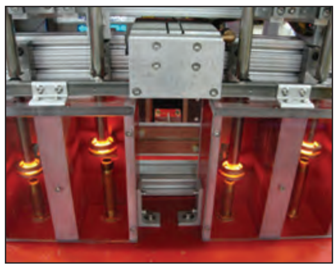
Thermatool delivers the pipe and tube industry quality HF welding and heat treating equipment, power supplies for inductively coupled plasmas, high speed cutting machines and the most technologically advanced engineered structural lines available today.

INDUCTOTHERM

Inductotherm is the leading manufacturer in induction technology and designs advanced induction melting, heating, holding and pouring systems for virtually all metals. Inductotherm's product line also encompasses a complete line of induction equipment for melting, heating, coating, galvanizing, and galvannealing on a continuous basis, primarily for the steel industry.

RADYNE

Radyne brings to the forefront the newest technology in medium and high frequency induction power sources to build systems for brazing and soldering in a controlled atmosphere or in air, heat treating processes such as annealing, hardening and tempering, wire and pipe heating, shrinkfit, crystal growing, curing and lab applications.



INDUCTOTHERM GROUP

For all of our companies and brands, please visit:
www.INDUCTOTHERM**GROUP**.com

Nanotechnology

briefs

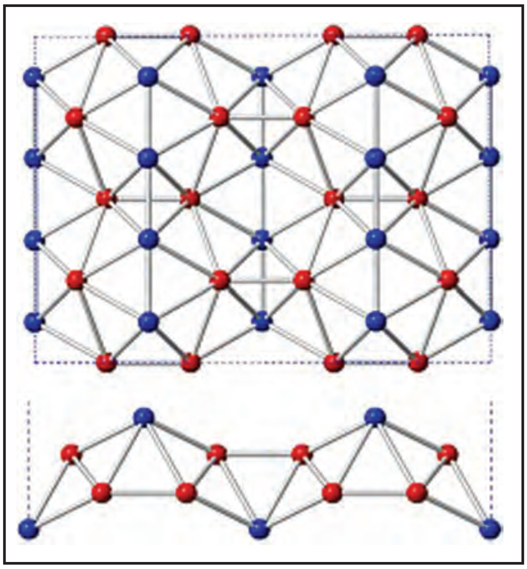
The **National Science and Technology Council,** Washington, released the **2014 National Nanotechnology Initiative (NNI) Strategic Plan,** which aims to ensure that nanotechnology advances and applications continue. It also addresses potential concerns about future and existing applications. The plan is a guide for agency leaders, program managers, and the research community regarding design and implementation of nanotechnology R&D investments and activities. http://nano.gov/node/1089.

Applied Nanotech Holdings Inc., Austin, and **NanoHolding Inc.,** the parent company of **Nanofilm Ltd.,** will merge to create a new company named **PEN Inc.** The new entity will build a platform for a higher rate of expected revenue growth, based on increased capabilities in intellectual property, personnel, development facilities, operating facilities, and customer relations to pursue product commercialization. www.appliednanotech.net.

The **V-SMMART Nano** (volumetric scanning microwave microscope analytical and research tool for nanotechnology) project aims to develop a new tool for subsurface analysis that will push the measurement of subsurface structures at the nanoscale to new limits. The consortium is developing and will commercialize a 3D hybrid scanning probe microscope platform able to probe the local reflection and transmission of microwaves from samples. It will then reconstruct the subsurface 3D structure of the materials from these signals, with nanoscale resolution in the three spatial dimensions. www.vsmmartnano.com.

Discovery of 2D structures with unique properties

Researchers at Stony Brook University, N.Y., discovered the structure of 2D boron crystals, which is relevant to electronic applications and to understanding boron nanostructures. "Boron is in many ways an analog of carbon," says Xiang-Feng Zhou. "Its nanostructures—nanoparticles, nanotubes, and two-dimensional structures—have attracted a lot of interest in the hopes of replicating, or even surpassing, the unique properties and diversity of carbon nanostructures. Our findings overturn the assumptions and predictions of numerous previous studies." Flat monolayer structures of boron were found to be extremely unstable, and the actual structures have finite thickness. These findings will likely lead to a revision of structural models of boron nanoparticles and nanotubes. In particular, it is possible that hollow, fullerene-like structures will be unstable for boron. *www.stonybrook.edu.*



Projections of 2 × 2 × 1 supercell of Pmmn-boron structure along [001] and [100] directions.

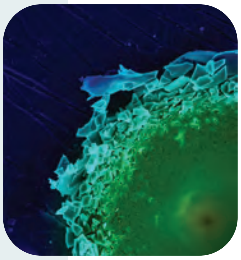
Electrochemical nanoceramic production line debuts

Cambridge Nanotherm, UK, installed the first of many fully automated lines to produce Nanotherm ceramic, which is grown on the surface of aluminum to create a dielectric layer directly on the surface of an aluminum substrate. The nanoceramic dielectric layer is reportedly between two and 10 times thinner than the competition and achieves thermal resistance of 0.014 °Ccm²/W. The dielectric has a thermal conductivity of 7 W/mK, which is two to three times more effective at heat dissipation than conventional MB PCB (metal back printed circuit board) dielectric materials. The first application of this technology is effective heat dissipation for LED lighting, which reduces operating temperatures by 20% to extend LED life or make it more energy efficient. *www.camnano.com.*

Sea creatures inspire ceramic-based armor

Researchers at Massachusetts Institute of Technology, Cambridge, analyzed the shells of a sea creature, mollusk Placuna placenta, to determine exactly why they are so resistant to penetration and damage—even though they are 99% calcite, a weak, brittle mineral. The shells' unique properties emerge from a specialized nanostructure that allows optical clarity, as well as efficient energy dissipation and the ability to localize deformation.

Engineered ceramic-based armor, while designed to resist penetration, often lacks the ability to withstand multiple blows, due to large-scale deformation and fracture that can compromise its structural integrity, says professor Christine Ortiz. The properties of this natural armor make it a promising template for the development of bio-inspired synthetic materials for both commercial and military applications—such as eye and face protection for soldiers, windows and windshields, and blast shields, Ortiz explains. *For more information: Christine Ortiz, 617/452-3084, cortiz@mit.edu, www.dmse.mit.edu.*



Transmission electron microscope image shows the region surrounding an indentation researchers made in a piece of shell from Placuna placenta. The image shows the localization of damage to the area immediately surrounding the stress. Courtesy of Ling Li/MIT.

About Instron®

Instron is a leading global manufacturer of testing equipment for the material and structural testing markets used to evaluate materials ranging from native tissue to advanced high-strength alloys. Instron systems perform a variety of tests such as tension, compression, cyclic, fatigue, impact, melt flow, multi-axis, rheology, and torsion. Providing single-source convenience through a comprehensive range of solutions and localized service & support, Instron's broad range of service capabilities include assistance with performance verification & calibration, standards compliance, testing system relocation, staff training, and preventative maintenance.

The Instron Centers of Excellence around the world ensure that behind every Instron system is an unprecedented commitment and dedication to quality and customer satisfaction. Instron remains involved with multiple ASTM and ISO committees, gaining first-hand knowledge of recent and upcoming changes to standards that affect our customers.

Instron
825 University Ave
Norwood, MA 02062, USA
tel: 800/564-8378
fax: 781/575-5725
e-mail: info_news@instron.com
Web: www.instron.com

corporate
spotlight ad

Tinius Olsen Inc.

Time tested

The first universal testing machine was the inspiration of Tinius Olsen, an inventor passionate about finding new ways to test the limits of materials. By 1880, he had proven and patented enough of his revolutionary ideas and designs to create an entire line of testing machines and launch his own company.

Today, Tinius Olsen is managed by the fifth generation of the Olsen family and has long since emerged as a global leader in the manufacture of materials testing equipment. With the emergence and growth of new materials, from engineering plastics to advanced composites, the company's product line has expanded exponentially. Likewise, its third-party accredited technical team supports an ever-growing worldwide customer base. Tinius Olsen is an essential resource for anyone with materials to test.

Tinius Olsen products

The company designs and manufactures one of the world's most comprehensive families of machines for determining the mechanical properties of materials. Its major product line include hydraulic and electro-mechanical floor model universal testing machines and bench-top units, all of which can be provided with a wide variety of tooling, control, and software options.

Metal components testing

Advanced Super "L" hydraulic universal testing machines, available with closed-loop servo control, today offer frame capacities from 150 kN to 2.7 MN (30,000 to 600,000 lbf).

The Super "L" console has been totally redesigned to provide simple operational controls from a handheld terminal and an extremely quiet hydraulic power package, all contained in a single enclosure with a significantly smaller footprint. Additionally, this console can be adapted to provide a simple, cost-effective scheme converting pumping units from manual to servo control capabilities.

Six entirely new models of the cost efficient "T" series of bench-top testing machines have been added as well.

Tinius Olsen

Tinius Olsen Inc.
1065 Easton Road, Horsham, PA 19044
tel: 215/675-7100; fax: 215/441-0899
e-mail: sales@tiniusolsen.com
Web: www.tiniusolsen.com

Development of Ti_2AlNb Alloys: Opportunities and Challenges

W. Chen and J.W. Li
*Beijing Aeronautical Manufacturing Technology Research Institute
Beijing, China*

L. Xu and B. Lu
*Institute of Metal Research, Chinese Academy of Sciences
Shenyang, China*

Ti_2AlNb offers a well-balanced property profile for application in aerospace engines to significantly reduce weight.

During the past 30 years, enormous research has been devoted to developing Ti-base intermetallics for use in gas turbine engines. The driving force was to replace Ni-base superalloys (density 8-8.5 g/cm^3) with lower-density materials (4-7 g/cm^3) that have adequate temperature capability to reduce weight. Alloys based on the composition Ti_2AlNb, often called *orthorhombic alloys,* offer higher specific strength and better stability (Fig. 1) than conventional Ti-base intermetallics such as TiAl and Ti_3Al[1-2]. (All alloy compositions based on Ti_2AlNb will be called Ti_2AlNb as a common class of alloy.)

Although the database for Ti_2AlNb alloys has been significantly expanded, few applications exist in aerospace engine production. Factors are both material and process related. This article presents a brief history of Ti_2AlNb and efforts to mature this material for commercial component production. The assessment is validated using processing experience gained from a current R&D program at Beijing Aeronautical Manufacturing Technology Research Institute (BAMTRI) and Institute of Metal Research (IMR) in China.

Alloy design

In the late 1970s, Nb was found to improve the ductility of Ti_3Al (α_2) alloys by stabilizing a relatively ductile, ordered B2 phase[3]. A large range of alloy compositions has since been examined and alloys with higher room temperature ductility and enhanced temperature capabilities were discovered. One of the most attractive alloys was Ti-25Al-10Nb-3V-1Mo (at.%), which was referred to as "super-α_2." (All compositions are reported in atomic percent in this article.) Vanadium was added to replace some niobium for cost and density reduction, while molybdenum improves high-temperature strength, creep resistance, and Young's modulus[4].

In 1988, Banerjee[5] first identified the orthorhombic (O) phase based on the stoichiometric composition Ti_2AlNb in the alloy Ti-25Al-12.5Nb, which also contained the α_2 and B2 phases. Because of the attractive properties associated with alloys containing the O phase, many Ti_2AlNb alloys were investigated over the years. Figure 2 shows the phase diagram of the Ti-22Al-Nb system. Typical Ti_2AlNb alloys have compositions ranging from 20-30 Al and 12.5-30 Nb. Ti-22Al-23Nb, Ti-22Al-25Nb, and Ti-22Al-27Nb are among the ternary alloys that have been mostly investigated.

The processing-microstructure relationship of Ti_2AlNb alloys is similar to conventional α/β Ti alloys. A super-transus processing results in acicular morphology of the α_2/O phase while a sub-transus processing results in equiaxed

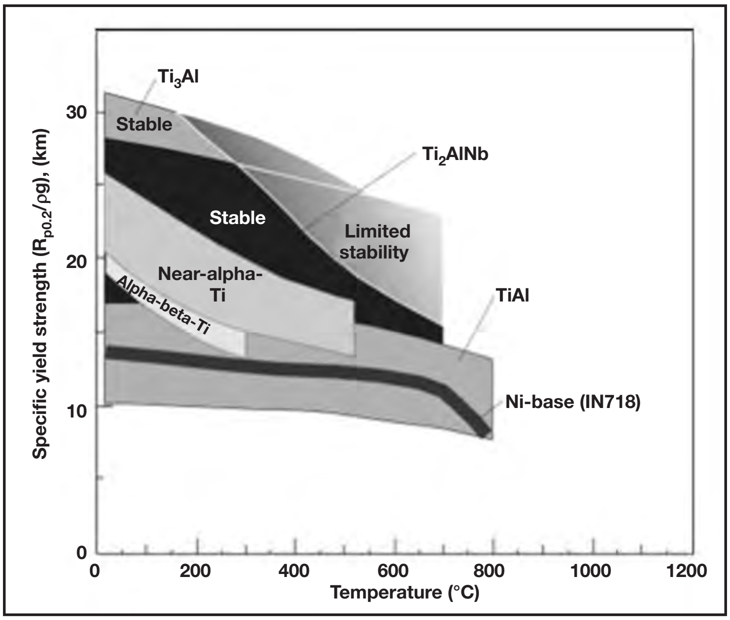


Fig. 1 — *Specific yield strength ranges as a function of temperature for Ti_2AlNb alloys in comparison to near-α Ti alloys, Ti_3Al-base alloys, nickel-base alloys, and TiAl-base alloys[2].*

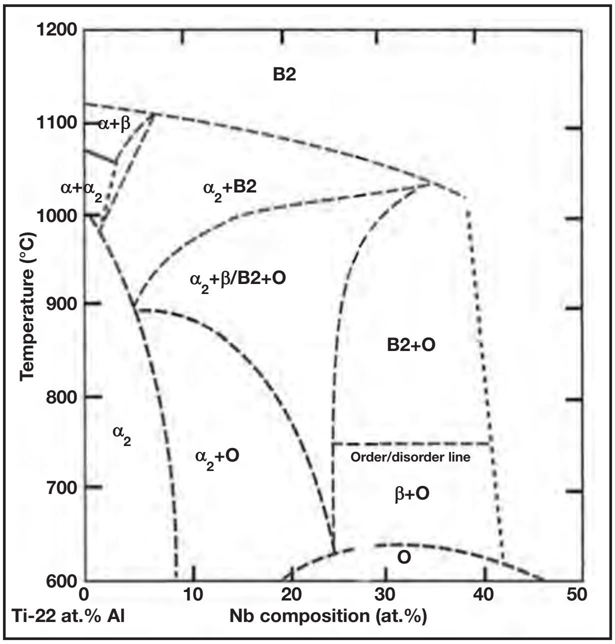


Fig. 2 — *An isopleths of the Ti-Al-Nb phase diagram at a constant 22Al[6].*

TABLE 1 — EFFECT OF ALLOYING ELEMENTS ON MECHANICAL PROPERTIES OF Ti_2AlNb ALLOYS

Element	Type	Effect on Mechanical Property	Reference
Al	α stabilizer	Oxidation and creep resistance improve, ductility and toughness decrease	10
Nb	β stabilizer	Density, high temperature strength, elevated temperature oxidation resistance, and room temperature toughness increase	10
Mo	β stabilizer	Density, tensile strength, elevated temperature creep resistance, and toughness increase	11, 12
V	β stabilizer	Density decreases and room temperature ductility, toughness, elevated temperature strength, and creep properties increase	9
Zr	—	Creep strength improves, yield stress and room temperature ductility are not effected	17
Si	β stabilizer	Creep property and oxidation resistance improve	8
Fe	β stabilizer	Yield strength, ultimate tensile strength, creep resistance improve	13
W	—	High temperature strength and creep resistance improve	9
Ta	β stabilizer	Yield strength and B2/β transus temperature improve	14
Y	—	Hardness improves	15
B	—	Room temperature ductility, hardness, elevated temperature creep property improve	16

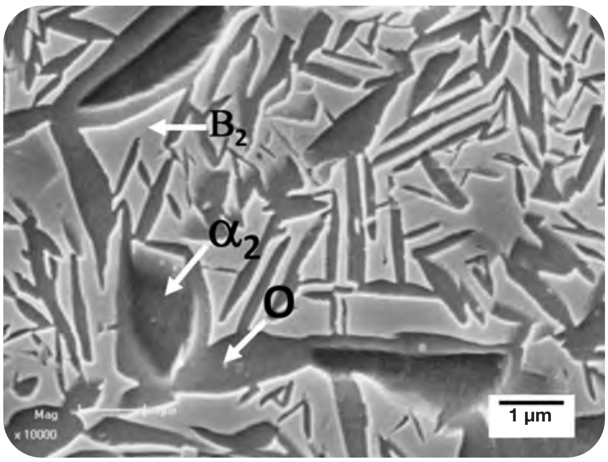


Fig. 3 — *Microstructure of a Ti-22Al-24Nb-0.5Mo alloy showing α_2, O, and B2 phases.*

morphology. However, much more complex microstructures can be generated in these alloys. Depending on the Nb content and thermo-mechanical processing condition, Ti_2AlNb alloys exhibit different combinations of α_2, O, and B2 phases. The B2 phase can be retained on quenching and subsequently decompose to α_2 and O laths via aging. The α_2 phase can also transform to O phase under certain conditions. A detailed study of the microstructure evolution of several Ti_2AlNb alloys can be found in Ref. 6. Figure 3 shows the microstructure of the Ti-22Al-24Nb base alloy with 0.5% addition of Mo. The dark, gray, and bright regions correspond to the α_2, O, and B2 phases.

In the literature, Gogia summarizes the correlation between microstructure and mechanical properties of the ternary Ti_2AlNb alloy system[7]. First, in equiaxed α_2+B2 or O+B2 microstructure, a higher volume fraction of the B2 phase results in an increase of strength, ductility, and fracture toughness. The B2 phase can decompose into α_2 and O by aging, with the higher aging temperature causing a decrease in strength and increase in ductility. For the B2 phase, higher Al content and larger grain size leads to increased ductility and toughness. Secondly, increasing the cooling rate in the beta heat-treated microstructure produces a finer microstructure and hence a higher strength, which is similar to conventional α/β Ti alloys. Lath microstructure of the α_2+O phase is preferred in creep-driven applications. Quaternary additions such as Mo, V, Si, Fe, and Zr were also explored. The effect of alloying elements on microstructure and mechanical properties is summarized in Table 1[8-17].

There is no universal alloy composition suitable for all applications. Rather, alloy composition must be tailored together with processing to achieve the required properties for specific components.

Processing and applications

Wrought Processing: For relatively low-ductility materials such as Ti_2AlNb alloys, wrought processing is particularly useful to achieve the full potential of materials due to the need to optimize mechanical properties through microstructure manipulation. Standard processing practices such as melting, forging, and hot rolling can be used for making Ti_2AlNb products. The effect of alternative processing methods such as extrusion and isothermal forging are also under investigation.

Properties of Ti-base intermetallics are more composition-sensitive than conventional Ti alloys. Ti_2AlNb alloys require additional precautions during processing because their alloying elements have large differences in melting points and densities (Ti: 1668°C, 4.5 g/cm^3; Al: 660°C, 2.7 g/cm^3; Nb: 2468°C, 8.6 g/cm^3). Ti_2AlNb ingot material usually suffers from pronounced segregation of alloying elements, shrinkage porosity, coarse microstructures, and

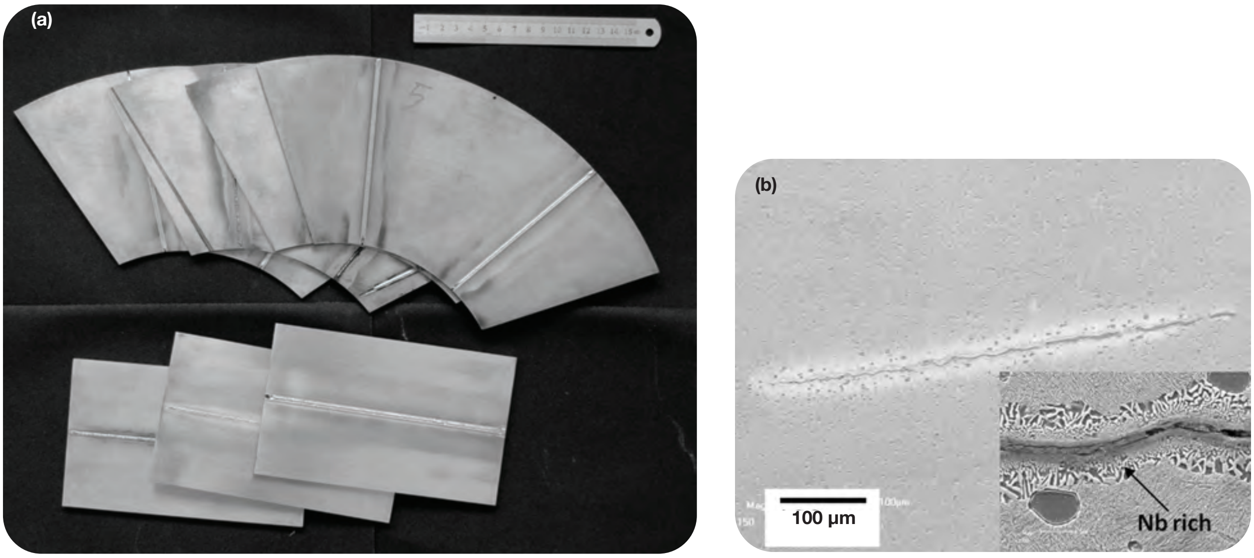


Fig. 4 — *(a) Hot rolled Ti-22Al-24Nb-0.5Mo sheets after welding test, and (b) a crack in the weld HAZ caused by Nb segregation.*

texture. Direct casting of Ti_2AlNb components has not yet succeeded, likely due to these problems.

For the casting process, minimizing segregation is extremely important. Ingot inhomogeneities in both composition and microstructure are difficult to remove by subsequent wrought processing. These inhomogeneities can easily cause machining cracks during aerospace component manufacturing. Figure 4a shows several hot rolled Ti-22Al-24Nb-0.5Mo sheets after a welding test. This material has fairly good weldability, but chemical analysis indicates that the heat affected zone (HAZ) of welds is prone to crack if Nb segregation happens in this area. As can be seen in Figure 4b, the embedded picture illustrates a large crack caused by Nb segregation. The yield stress, ultimate tensile stress, and elongation of hot rolled Ti-22Al-24Nb-0.5Mo sheets are 1130 MPa, 1233 MPa, and 7.3% at room temperature; and 845 MPa, 1002 MPa, and 12.5% at 650°C, respectively.

Hindustan Aeronautics Ltd. (Bangalore, India) manufactured compressor blades from a Ti-24Al-15Nb alloy for an experimental gas turbine GTX engine produced by conventional close-die forging[7]. In addition, the Central Iron and Steel Research Institute (Beijing, China) reports component blanks made of Ti-22Al-25Nb alloy, including rings, die-forged blades, and spin-formed components[18]. However, no other public information about testing and application of Ti_2AlNb engine components has been found.

Powder Metallurgy: Powder metallurgy (PM) is a long-standing method of producing Ni-base alloy components used in turbine engines. The weakness of cast-and-wrought processing motivated the exploration of PM technology to produce Ti_2AlNb products. The advantage of the PM technique is that high quality, near-net-shape, and homogeneous parts can be made with substantially reduced machining and scrap. For high-alloyed materials such as Ti_2AlNb, PM methods are far superior to cast-and-wrought processing for various reasons. These include element segregation, texture, and residual stress upon cooling from processing conditions.

Ti_2AlNb powders are generally too strong to be cold compacted. They are therefore usually processed by hot isostatic pressing (HIP) followed by heat treatment. IMR developed a net-shape PM method for making various Ti components with complex shapes using pre-alloyed, gas-atomized powders. Dimensions of the final components are calculated based on finite element modeling of powder shrinkage during HIP. This technique has matured to a state of designing and making aerospace components with high precision. Figure 5 shows a PM net-shape Ti-22Al-24Nb-0.5Mo aerospace engine component.

Fig. 5 — *A PM net-shape Ti-22Al-24Nb-0.5Mo aerospace engine component.*

However, PM is no panacea either. Small volume fractions of residual pores (less than several microns in diameter) do not seem to affect tensile properties because Ti_2AlNb alloys have adequate ductility to withstand small internal stress risers, but these same pores can act as fatigue crack initiation sites during cyclic loading. In addition, weldability is also expected to be degraded by residual porosity. Investigation of this issue is currently underway.

Opportunities and challenges

The potential for Ti_2AlNb alloys to reach the engine components market critically depends on understanding and tailoring composition, and on subsequent processing to achieve the required microstructure and mechanical properties. A few challenges related to Ti_2AlNb processing were already described. The following discussion iden-

TABLE 2 — PROPERTIES OF Ti_2AlNb VS. Ti ALLOYS AND Ni-BASE ALLOYS[2]

Properties	Near-αTi	Ti_2AlNb	γ-TiAl	Ni-base
Density	+	+/-	++	-
HT spec. Young's modulus	+/-	+	++	+
Coefficient of thermal expansion	+/-	+	-	-
RT ductility	++	++	-	+
Formability	+	+	-	+
Specific HT tensile strength	-	+	+/-	-
Creep resistance	-	+	+	++
Specific RT-HCF strength	+	+	-	+/-
RT crack growth	+	+/-	-	+
RT crack growth threshold	+	+/-	+/-	+/-
RT fracture toughness	+	+/-	-	++
Oxidation resistance	-	+	+	++
HT embrittlement	-	+/-	+	
Embrittlement & RT fatigue	-	+/-	+	+

HT: High temperature, RT: Room temperature, HCF: High cycle fatigue

TABLE 3 — EFFECTS OF ENVIRONMENT AND STRAIN RATE ON TENSILE DUCTILITY OF A Ti-25Al-10Nb-3V-1Mo ALLOY TESTED AT 650°C

Environment	Strain rate	Fracture strain, ε_f	Elongation (%)	R of A (%)
Vacuum	2×10^{-3}	1.24	24.5	70.9
Air	2×10^{-1}	0.94	29.1	60.9
Air	2×10^{-3}	0.18	14.8	16.2

tifies some materials-related issues and introduces an emerging technology that may affect the future of Ti_2AlNb.

Materials Development: In the past 30 years, composition design has played a significant role in improving the mechanical properties of Ti_2AlNb alloys and current materials offer a balanced set of properties. However, even with all their attractive properties, Ti_2AlNb alloys still present significant challenges.

Mechanical properties such as high-cycle fatigue (HCF), low-cycle fatigue (LCF), crack growth, fracture toughness, and creep behavior of Ti_2AlNb alloys have been studied extensively. Table 2 provides an overview of the pros and cons of Ti_2AlNb alloys vs. other alloys.

One additional consideration regarding Ti_2AlNb alloys is the apparent environmental sensitivity at temperatures above roughly 550°C. Ward, et al.[19], showed that a Ti-25Al-10Nb-3V-1Mo alloy exhibits significant, but not total, ductility loss during tensile testing in air at temperatures of 550° and 650°C. This ductility loss is most severe when testing at lower strain rates such as 2×10^{-4}. Testing at higher strain rates such as 2×10^{-1} minimized ductility loss, which is consistent with an environmental effect. It suggests that at high temperatures, oxygen and nitrogen can dissolve interstitially or form brittle phases in the subsurface zone[20, 21], causing early failure of Ti_2AlNb. This point was further confirmed by testing in vacuum where the alloy showed excellent ductility with no significant strain rate sensitivity. Examples of Ward's data for tests run at 650°C are provided in Table 3.

While these ductility reductions are not catastrophic, they are significant enough to require consideration during design of any component used under these operating conditions. Environmental protective coatings might mitigate this effect, but the component design still must be robust enough to function even if the coating is breached during service. Such a practice is commonly used in cases where similar environmental sensitivity is encountered.

New Technology: Additive manufacturing (AM) has gained increasing attention since 2010 and its advantages are widely recognized[22]. The ability to directly produce intricate shapes is remarkable. Complex shapes have been made from spherical powder using both laser and electron beam AM methods[23]. These parts are essentially in-situ castings with high solidification rates. Therefore, the tensile properties—particularly yield strength—of these parts are expected to be somewhere between those of forging and larger investment casting.

Avio S.p.A (Turin, Italy) demonstrated the ability to make γ-TiAl low-pressure turbine blades (Fig. 6) using electron beam melting (EBM) technology. Theoretically, any metal powder, including Ti_2AlNb, can be used given that the particle size falls in the specified range and segregation is expected to be minimal. Two major concerns regarding AM parts are columnar grains in the build direction and residual stress due to high solidification rates. For aerospace, complex AM processes must be developed to meet stringent property requirements established by traditional manufacturing methods such as casting and forging. One major challenge is to devise a means of rapidly qualifying AM parts in order to take full advantage of the compression of production cycle time. Another challenge is to develop a comprehensive cost model for this manufacturing process[24]. These factors are just as important to the acceptance of new production methods as the AM technology itself.

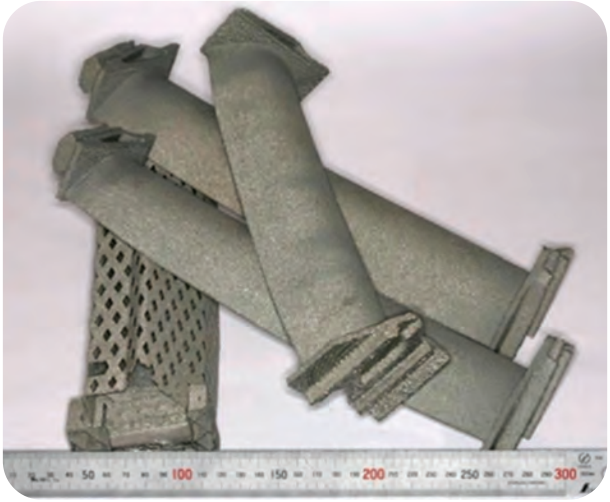


***Fig. 6** — γ-TiAl LPT blades made by EBM additive manufacturing. Courtesy of Avio S.p.A.*

Summary

Introducing any new material is an enormous undertaking. It is important to realize that it took more than 50 years of research for γ-TiAl to mature before GE Aircraft Engines introduced it into the low-pressure turbine (LPT) of GEnx engines, specified in the Boeing 787 in 2005. Despite the immaturity of current Ti_2AlNb alloys compared to γ-TiAl, they offer a well-balanced property profile as well as good formability. Over time, further improvements can be expected with the development of more complex compositions and processing. ❍

Acknowledgment
The authors are grateful to Prof. Jim Williams for reviewing this article.

For more information: Wei Chen is a senior research scientist at the Science and Technology on Power Beam Processes Laboratory, Beijing Aeronautical Manufacturing Technology Research Institute, Beijing 100024, China, werner_nju@163.com.

References

1. G. Lutjering, J.C. Williams, Titanium, 2nd ed., Springer-Verlag, Berlin, 2007.
2. C. Leyens, M. Peters, Titanium and Titanium Alloys: Fundamentals and Applications, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, 2003.
3. M.J. Blackburn, D.L. Ruckle, and C.E. Bevan. Research to Conduct an Exploratory Experimental and Analytical Investigation of Alloys, AFWAL, Wright-Patterson, OH, 1978.
4. J. Kumpfert and C.H. Ward, Titanium Aluminides in Advanced Aerospace Materials, H. Buhl (ed.), Springer Verlag, Berlin, p 73-83, 1992.
5. D. Banerjee, et al., A New Ordered Orthorhombic Phase in a Ti_3Al-Nb Alloy. *Acta Metall. Mater.*, Vol 36, p 871-882, 1988.
6. C.J. Boehlert, et al., The Microstructural Evolution in Ti-Al-Nb O+Bcc Orthorhombic Alloys, *Met. Trans. A*, Vol 30, p 2305-2323, 1999.
7. A.K. Gogia, High Temperature Titanium Alloys, *Defense Sci. J.*, Vol 55, No. 2, p 143-173, 2005.
8. D. Banerjee, Deformation of the O and α2 Phases in the Ti-Al-Nb System. *Phil. Mag. A.*, Vol 72, p 1559-1587, 1995.
9. K. Muraleedharan, et al., Transformations in a Ti-24Al-15Nb Alloy: Part II, A Composition invariant β/O transformation. *Met. Trans. A.*, Vol 23, p 417-431, 1992.
10. S.C. Gill and J.A. Peters, Production of Low Oxygen Contamination Orthorhombic Ti-Al-Nb Intermetallic Foil, *Scripta Mater.*, Vol 35, p 175-180, 1996.
11. D. Banerjee, R.G. Baligidad, and A.K. Gogia, Engineering Multiphase Intermetallics, Structural Intermetallics, H.J. Hemker, et al., (ed.), TMS, Warrendale, PA, 2001.
12. H.T. Kestner-Weykamp, C.H. Ward, et al., Microstructures and Phase Relationships in the Ti_3Al+Nb System, *Scripta Met. Mater.*, Vol 23, p 1697-1702, 1989.
13. C.G. Rhodes, Order/Disorder Temperature of the BCC Phase in Ti-21Al-26Nb, *Scripta Mater.*, Vol 38, p 681-685, 1998.
14. Y. Mao, S.Q. Li, et al., Microstructure and Tensile Properties of Orthorhombic Ti-Al-Nb-Ta Alloys, *Intermetallics*, Vol 8, p 659-662, 2000.
15. Y.B. Ke, H.P. Duan, and Y.R. Sun, Effect of Yttrium and Erbium on the Microstructure and Mechanical Properties of Ti-Al-Nb Alloys, *Mater. Sci. Eng. A*, Vol 528, p 220-225, 2010.
16. F. Tang, S. Nakazawa, and M. Hagiwara. Effect of Boron Microalloying on Microstructure, Tensile Properties and Creep Behavior of Ti-22Al-20Nb-2W Alloy. *Mater. Sci. Eng. A*, Vol 315, p 147-152, 2001.
17. L. Germann, et al., Effect of Composition on the Mechanical Properties of Newly Developed Ti_2AlNb-based Titanium Aluminide, *Intermetallics*, Vol 13, p 920-924, 2005.
18. J.W. Zhang, et al., Research and Application of Ti_3Al and Ti_2AlNb Based Alloys, *The Chinese Journal of Nonferrous Metals*, Vol 20, p 336-341, 2010.
19. C.H. Ward, J.C. Williams, and A.W. Thompson, Microstructural Instability in the Alloy Ti-25Al-10Nb-3V-1Mo, *Scripta Met.*, Vol 24, p 617-622, 1990.
20. C. Leyens, Environmental Effects on Orthorhombic Alloy Ti-22Al-25Nb in Air Between 650° and 1000°C, *Oxid. Met.*, Vol 52, p 475-503, 1999.
21. S.G. Warrier, S. Krishnamurthy, and P.R. Smith. Oxidation Protection of Ti-aluminide Orthorhombic Alloys: An Engineered Multilayer Approach. *Met. Trans. A*, Vol 29, p 1279-1288, 1998.
22. I. Gibson, D.W. Rosen, and B. Stucker. Additive Manufacturing Technology. Springer Science and Business Media, LLC, New York, NY, 2010.
23. L.E. Murr, et al., Metal Fabrication by Additive Manufacturing Using Laser and Electron Beam Melting Technologies, *J. Mater. Sci. Tech.*, Vol 28, p 1-14, 2012.
24. W. Peter, et al., Current Status of Ti PM: Progress, Opportunities and Challenges. *Key Eng. Mat.*, Vol 520, p 1-7, 2012.

Overcoming Barriers of Magnesium Ignition and Flammability

Frank Czerwinski
CanmetMATERIALS
Natural Resources Canada
Hamilton, Ontario

The use of magnesium in commercial aircraft cabins is being reevaluated to save weight, as it is the lightest structural metal.

Although weight reduction is a worthy goal for all forms of transportation, it is of particular importance to aerospace applications. Today, the global aviation industry produces roughly 2% of all human-induced emissions and 12% of carbon dioxide generated by all transport sources. As the number of passengers traveling by air is projected to increase more than fivefold to reach 16 billion in 2050, the detrimental effects of emissions from burning jet fuel pose ever greater environmental concerns. In the interest of reducing aircraft weight, Federal Aviation Administration (FAA) and various aerospace specification committees are reevaluating the existing ban on magnesium use inside commercial aircraft cabins[1].

Considering magnesium for commercial aviation

In modern aircraft design, a variety of lightweighting options are explored. For example, significant improvements in weight savings and durability within airframe structures may be achieved through composite materials and fiber-metal laminates. The latter are advanced hybrid material systems consisting of metal layers bonded with fiber-reinforced polymer layers. Case in point: Composites and carbo-fibers represent approximately 50% of the Boeing 787's primary structure, including its fuselage and wings. This substantial increase from 12% composites implemented in a Boeing 777 to 50% in the 787 emphasizes the growing importance of these materials. In addition to fiber composites and polymers, there is a need for structural metals, and magnesium—with its specific density of 1.8 g/cm^3—is the primary candidate. Potential weight savings are substantial when compared to another light-metal option—aluminum—with its specific density of 2.7 g/cm^3.

Although magnesium has been widely applied in a variety of aerospace applications since the 1930s, after reaching its peak in the 1950s, it was gradually diminished to only residual quantities. Now, there is renewed interest in magnesium for components inside the aircraft cabin, such as overhead compartments, folding tables, and food trolleys. Passenger seats are at the top of the list because they offer significant opportunities for weight reduction. As an example, an Airbus aircraft with individual seat weights from 11 kg for certified economy class to about 20 kg for a wide body plane, and seat quantities from 117 in the A318 to 700 in the A380; total aircraft seat mass ranges from 1200-14,000 kg[2]. Considering that roughly 43% of the seat weight is comprised of aluminum alloys, replacing them with magnesium offers a weight reduction of 28-30%.

The high strength-to-weight ratio, along with other unique properties exhibited by magnesium alloys are, however, overshadowed by their high surface reactivity. In particular, a lack of stability at increased temperatures is often seen through ignition and burning when in contact with an open flame or another heat source (Fig. 1). For aerospace applications, where in-flight and post-crash fires are a concern, easy ignition is detrimental to safety. To reduce the risk of magnesium ignition, a number of design-related options are being explored to prevent a temperature increase during possible contact with a flame. The dominant factor affecting ignition resistance, however, is controlled by the very nature of magnesium.

Fig. 1 — *Flames of burning Mg-3%Al alloy with extensive fumes and temperature exceeding 3000°C.*

Ignition vs. flammability

The easy ignition of magnesium is typically associated with powder-like forms, comminuted fine chips, or magnesium dust, which ignite instantly after contact with a flame or electric spark. These characteristics are widely explored in pyrotechnics. By contrast, bulk forms of magnesium do not ignite easily and to start the reaction, a metal region or its entire volume must reach a certain temperature.

However, under certain conditions experienced during manufacturing or service, magnesium may ignite and burn. For engineering applications, behaviors of bulk forms are of concern. Susceptibility of magnesium and its alloys to burning is described by the *ignition temperature,* which is defined in several different ways throughout the literature. As an example, a 1960s study authorized by the FAA defined ignition as "the point where the white flame appears and starts to propagate"[3]. When test conditions are well defined, ignition temperature can be measured with reasonable reproducibility. It is clear, however, that the ignition temperature does not represent the intrinsic parameter and in addition to differences in definition, its value is affected by numerous testing conditions. The absence of both a suitable definition of ignition and well standardized methods of determining the ignition temperature of combustible metals is the reason why literature data are often difficult to compare.

On the other hand, the term *flammability* characterizes the susceptibility of an alloy to ignite and burn after contact with a flame or another heat source. Quite often, no distinction is made between ignition and flammability and both terms are used interchangeably in the literature. However, flammability should be seen as a different quantity. Although the reaction of magnesium with oxygen is exothermic in nature, and releases substantial heat, ignition may not lead to burning if sufficient heat is removed. Alloys developed specifically for high-temperature service may resist ignition or may self-extinguish if ignited.

Different measures exist for characterizing ignition and flammability. During ignition testing, an emphasis is placed on temperature, whereas flammability testing focuses on time. In practice, it involves a set of time periods during contact with a flame of well-defined characteristics: At first, the flame does not lead to ignition, then ignition occurs but is self-extinguished after flame removal, and finally the magnesium ignites and burns despite flame removal. Both temperature and time are interdependent. During ignition testing, the longer heating time, i.e., lower heating rate, reduces the ignition temperature. Then, during flammability testing, the lower flame temperature delays the onset of magnesium burning for a longer period.

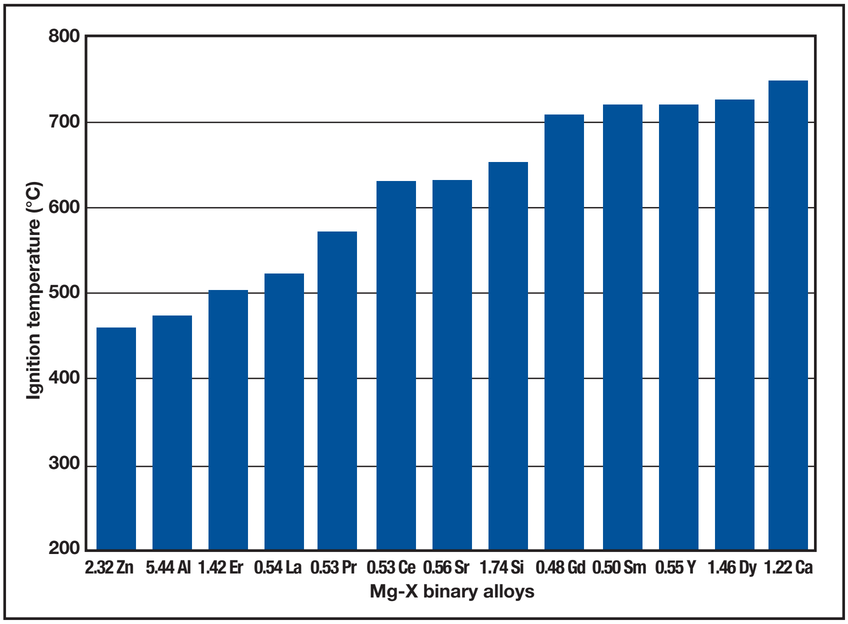


Fig. 2 — *Ignition temperature of binary Mg alloys tested during continuous heating. Based on data from [9].*

Suppressing surface reactivity via alloy chemistry

The surface reactivity of magnesium is affected by alloying additions, a key requirement of structural materials. The ignition temperature of pure Mg, typically in the range of 630°-640°C, is reduced by alloying elements such as Al, Zn, Cd, Mn, and Si, which is explained through lowering the liquidus temperature. By contrast, rare earths and other elements with high affinity to oxygen, together referred to as reactive elements, show the opposite effect. Although the liquidus temperature is reduced through alloying with reactive elements, the ignition temperature increases.

Examples of changes in the ignition temperature as a result of alloying are shown in Fig. 2. A common conclusion based on the available literature is that minor additions of rare earths such as Y, Ce, Nd, Dy, Gd, Er, or La cause a sharp increase in the ignition temperature of magnesium. The minimum effective amount, often as low as 0.1%, depends on the particular reactive element and the base alloy chemistry. In some cases, an optimum content exists, beyond which the opposite effect occurs, thereby reducing the ignition temperature. Of reactive elements beyond the rare earths list, Ca is proven to be very effective in raising the ignition temperature of magnesium alloys. To suppress ignition, Ca also may be added as a CaO oxide dispersion, widely available.

Understanding the role of small amounts of reactive elements is of strategic importance due to their high cost and limited availability. Therefore, similarity to the reactive element effect in high-temperature materials that form chromia, alumina, or NiO protective scales

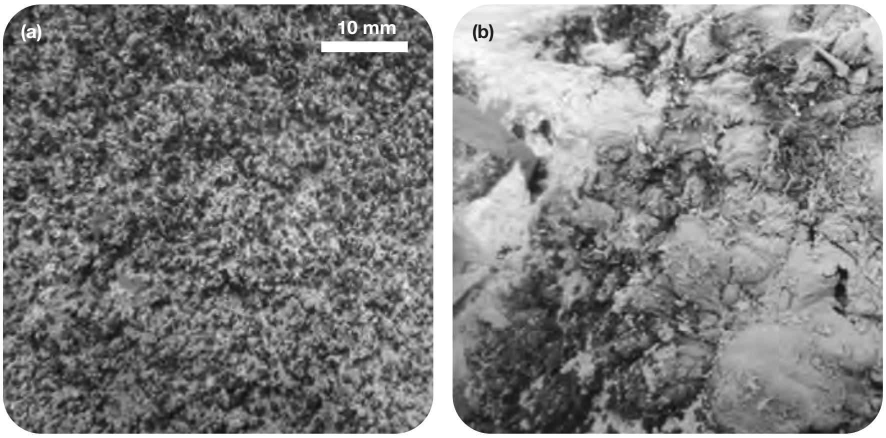


Fig. 3 — *Morphological development during magnesium oxidation and combustion: (a) MgO oxide nodules formed on Mg-6%Al alloy prior to ignition, and (b) morphology of combustion product.*

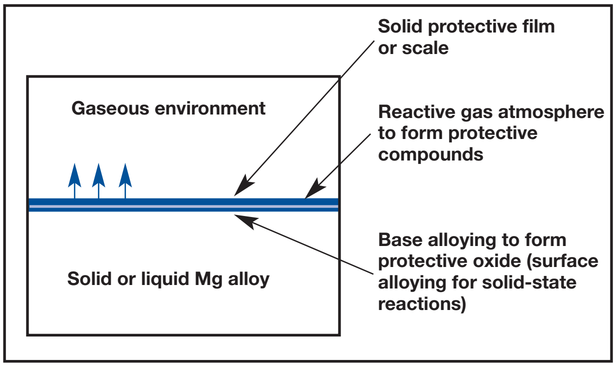


Fig. 4 — *Schematics explaining suppression of magnesium ignition and flammability through base alloying and protective atmospheres of a reactive nature.*

should be explored. It is well documented that minor additions of reactive elements cause a drastic improvement in the high-temperature oxidation resistance of these alloys[4]. Because the effectiveness of reactive elements depends on base alloy chemistry, it is likely that some alloys may contain substantial amounts of reactive elements, but only a fraction of it is effective in inhibiting oxidation, ignition, or other forms of surface reactivity. It is reported that a combination of two or more reactive elements causes a synergistic effect, substantially increasing their effectiveness in suppressing ignition. For binary Mg-Y alloys, a substantial increase in ignition temperature to 900°C was achieved for Y concentrations exceeding 10%[5]. That amount of Y was reduced significantly with Ce additions to form a Mg-Y-Ce system, which was attributed to a higher contribution of Y_2O_3 oxide within the scale. Combining Ca with Y, and Ag or Be with rare earths, also yields benefits.

Developing nonflammable alloys

The need for nonflammable magnesium alloys, supported by application opportunities in aerospace, fuels activities aimed at developing next-generation alloys. Present commercial grades with improved ignition resistance, such as WE43, ZE41, ZE10, or Elektron 21, were primarily designed to retain certain mechanical properties at elevated temperatures. Because they contain rare earths, ignition and flammability resistance is improved.

A new Mg alloy development direction contains—in addition to α-Mg—a novel phase with a long period stacking order (LPSO) structure[6]. The LPSO structure is formed in the Mg-M-RE system where *M* is represented by Co, Ni, Cu, Zn, or Al, and *RE* are rare earths limited to Y, Gd, Tb, Dy, Ho, Er, or Tm. The alloy with chemistry of Mg96.75Zn0.75Al0.5, produced by powder metallurgy and rapid solidification, reached an ignition temperature of 780°-940°C. As further progress, Kumadai nonflammable magnesium alloys were developed, which consist of C36 type intermetallic compounds, produced by extrusion with a yield point of 410-460 MPa and an ignition temperature exceeding 1107°C, the boiling point of pure magnesium.

Vital role of surface oxide

Magnesium alloys are not used in typical high-temperature applications and are mostly exposed to high temperatures during primary melting and at different stages of the component manufacturing cycle such as casting, hot forming, or welding[7]. The essence of magnesium ignition prevention in these processes is to create a protective barrier layer on the solid or liquid surface, thus supressing reaction with oxygen. Because conventional magnesium alloys do not generate protective oxides, they require protective atmospheres that react with the molten alloy to form such a barrier.

The phenomena of ignition and flammability are inherently related to high-temperature oxidation. In a sense, onset of ignition is understood as a failure of the protective oxidation, when surface oxide or other compounds lose their protective properties. The competing effect of temperature and time during testing of ignition and flammability indicates that both phenomena are controlled by the progress in oxide growth during high-temperature exposures, but before reaching the growth stage when oxide loses its protective properties due to its morphological characteristics. As shown in Fig. 3, the morphology of oxide nodules does not act as a barrier layer, resulting in magnesium ignition and combustion.

Ignition temperature is not generally correlated with a presence of the liquid fraction. Although ignition of pure magnesium may take place in solid state, for the majority of alloys, it occurs in liquid state. Especially for magnesium alloys containing reactive elements, the ignition temperature may be well above the liquidus line. A concern of aerospace applications is that during in-flight or post-crash fire scenarios, an aircraft component may experience partial or complete melting. Because the surface oxide, composed of pure MgO, does not offer sufficient protection, current research focuses on modifying its chemistry and microstructure to suppress oxide diffusivity characteristics[8]. By modifying substrate composition, the integrity and structure of oxide layers is changed to form a dense and protective surface scale after exposure to an open flame or other heat source (Fig. 4). There are similarities between the effect of rare earth elements on magnesium oxidation and oxidation of high-temperature alloys, forming protective oxides. The reactive element additions positively affect ignition and flammability resistance and improve the protective properties of surface oxide layers at the same time.

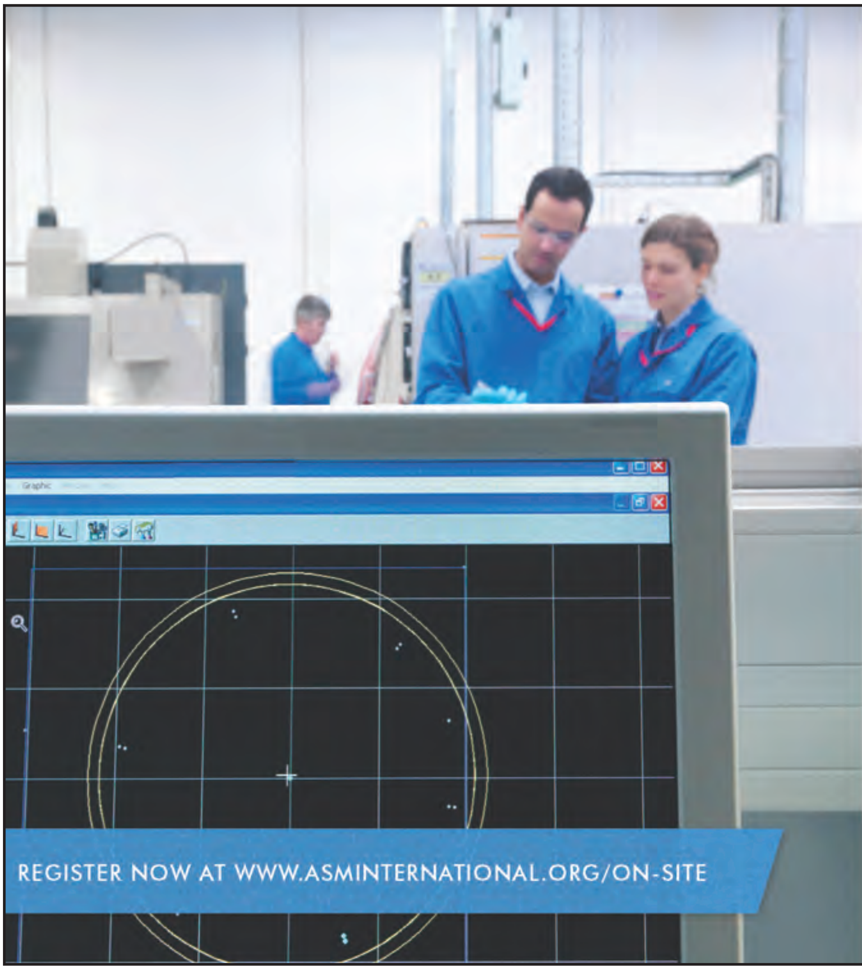
Summary

The application potential of magnesium alloys as lightweight structural materials in aerospace and especially inside the aircraft cabin are hindered by their high surface reactivity at increased temperatures with particular concerns of ignition and flammability during a potential contact with a flame or other heat source. Global efforts to develop ignition-resistant and non-flammable magnesium alloys widely explore micro-alloying with rare earth metals and other elements having a high affinity to oxygen. As demonstrated by experimental alloys, this approach allows shifting the ignition temperature well above the liquidus, not only easing requirements on protective atmospheres during liquid-state processing, but also increasing the safety margin for possible aerospace applications. ❍

For more information: Frank Czerwinski is group leader, senior research scientist, CanmetMATERIALS, Natural Resources Canada, 183 Longwood Rd. S., Hamilton, Ontario, L8P 0A5, 905/645 0887, frank.czerwinski@nrcan.gc.ca, www.nrcan.gc.ca/mining-materials/materials.

References

1. T. Marker, Evaluating the Flammability of Various Magnesium Alloys During Laboratory- and Full-scale Aircraft Fire Test, DOT/FAA/AR-11/3, U.S. Dept. of Transportation, Federal Aviation Administration, Atlantic City, N.J., 2013.
2. A. Stachel, Light Weight Alloys in Seat Design, Influence of Magnesium in Seats, Keiper Recaro Group, www. recaro.com, 2013.
3. P. Boris, A Study of the Flammability of Magnesium, Federal Aviation Agency, Washington, 1964.
4. F. Czerwinski and W. Smeltzer, The Growth and Structure of Thin Oxide Films on Ceria-Sol-Coated Nickel, *Oxidation of Metals,* Vol 40, No. 5-6, p 503-527, 1993.
5. J. Fan, et al., Oxidation Behavior of Ignition Proof Magnesium Alloys with Rare Earth Addition, *J. Alloys Compd.,* Vol. 509, p 2137-2142, 2011.
6. Y. Kawamura and T. Marker, Flame Resistant Magnesium Alloys with High Strength, www.fire.tc.faa.gov, 2013.
7. F. Czerwinski, Magnesium Injection Molding, New York: Springer Verlag, 2008.
8. F. Czerwinski, Oxidation Characteristics of Magnesium Alloys, *J. of The Minerals, Metals and Materials Society,* Vol 54, No. 12, p 1477-1483, 2012.
9. Y. Kim, et al., Key Factor Influencing the Ignition Resistance of Magnesium Alloys at Elevated Tempeartures, *Scripta Mater.,* Vol 65, p 958-961, 2011.



Materials in Space:
Exploring the Effect of Low Earth Orbit on Thin Film Solid Lubricants

M.T. Dugger*
T.W. Scharf*
S.V. Prasad, FASM*
Materials Science and Engineering Center,
Sandia National Laboratories
Albuquerque, N.M.

Challenges facing materials used in space have not changed significantly over the past few decades, but today's requirements have a different focus than those used in the heyday of space exploration. This article considers the effect of atomic oxygen exposure on thin film solid lubricants.

From the 1960s through the early 1990s, large government investments in space exploration by both the U.S. and the former Soviet Union emphasized performance, while factors such as cost and aging requirements were secondary. Spacecraft were launched soon after they were completed and tested, and traveled for relatively short missions. With today's increased commercial and military use of space, performance is still the primary factor, but satellites may spend significant time awaiting launch opportunities. Missions often require longer time periods than early exploration, so lubricants are expected to perform in space for years rather than days or weeks, and must do so after operating and being stored in terrestrial environments for months or years. While there have been several notable missions within the solar system, many space missions remain near Earth. Among these missions are those associated with the International Space Station (ISS), and polar-orbiting satellites for Earth observation, in an environment known as low earth orbit (LEO).

LEO corresponds to altitudes of roughly 200 to 1000 km. Objects in orbit experience thermal cycles associated with cyclic sun exposure and radiative heat transfer to space as well as solar UV exposure, which can degrade polymeric materials. However, the primary element present in LEO is atomic oxygen (AO)[1]. AO is created by photodissociation of oxygen molecules in the upper atmosphere by UV radiation from the sun[2]. At orbital velocities near 8 km/s, AO has energy of approximately 5 eV/atom and flux density of 10^{13}-10^{15} atoms/cm^2.s, depending on altitude[3]. At this energy, AO can break bonds and induce chemical reactions with many materials, posing a concern for long-term degradation of materials in LEO.

Satellite components—specifically those designed for mechanical hold and release functions—rely on solid lubricant coatings to mitigate adhesion, friction, wear, and debris generation. Thin film solid lubricants have been investigated for use in space for almost 30 years. Some of their advantages include lack of migration, which eliminates extra mass associated with lubricant delivery and containment systems, consistent frictional behavior from cryogenic temperatures to hundreds of degrees centigrade, and lack of velocity dependence on friction coefficient over a wide range of sliding speeds. Even with these advantages, space systems designers are hesitant to employ new materials without some flight history and an understanding of how the space environment impacts these materials.

**Member of ASM International*

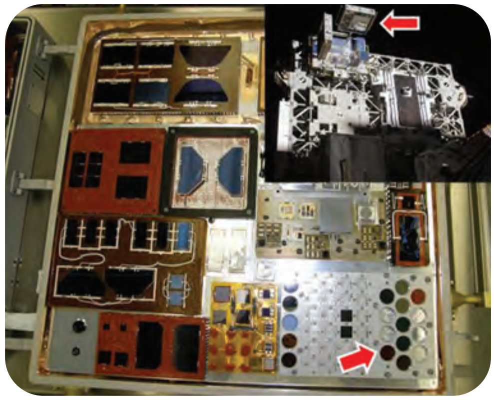


Fig. 1 — *MISSE-7 solid lubricant films (denoted by red arrow) placed in a "suitcase-style" passive experiment container (PEC) mounted externally on the ISS (shown in inset with red arrow pointing to the PEC). Courtesy of NASA.*

This article considers the effect of AO exposure on thin film solid lubricants of molybdenum disulphide (MoS_2) and diamond-like carbon nanocomposites (DLN), a silica-containing diamond-like carbon film. Advances in deposition methods over the past few decades enable dense films to be created that are more resistant to oxidative degradation and the effects of adsorbed moisture than their predecessors. Further, incorporating additional phases improves the films' tribological performance in a range of atmospheres.

MoS_2 films

Sputtered thin films of MoS_2 were first exposed to atomic oxygen in LEO as part of the NASA Evaluation of Oxygen Interactions with Materials-3 (EOIM-3) experiment during the STS-46 mission aboard the shuttle Atlantis, launched July 31, 1992[4]. The total AO fluence for EOIM-3 was estimated to be 2.2 to 2.5×10^{20} atoms/cm^2 over a period of 42.25 hours. The specimens also experienced an estimated 22±4 equivalent solar hours of UV exposure. The tray reached a temperature of

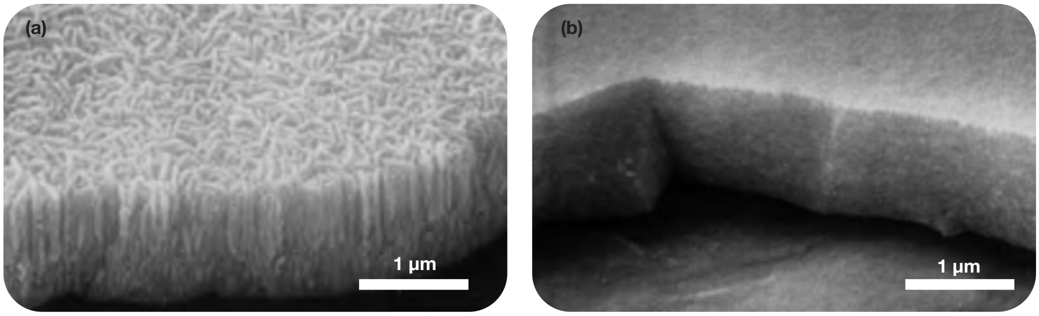


Fig. 2 — *Fracture surface morphology of pure MoS_2 exhibits a columnar growth morphology (a), and dense MoS_2/Sb_2O_3 films (b) exposed to LEO on EOIM-3.*

55°C for about 12 hours, and then cycled between roughly 5° and 20°C during the EOIM-3 exposure period. Sputtered films of pure MoS_2[5] representing the historical, columnar growth morphology typical of undoped films were evaluated alongside structurally modified films that were co-sputtered with antimony oxide (MoS_2/Sb_2O_3)[6], or deposited in multilayers with nickel (MoS_2/Ni)[7]. In addition to LEO exposure, films were also exposed in a terrestrial facility[8] using AO energy per atom and UV exposures designed to emulate the LEO environment. In this case, films experienced an AO fluence of 1.97×10^{20} atoms/cm^2 (about 15% less than in the space flight) during an exposure of 25.28 hours. Several identical sets of samples were produced for EOIM-3 so that samples could be examined after LEO exposure, after AO exposure in the laboratory, and after desiccated storage on earth for the same time period.

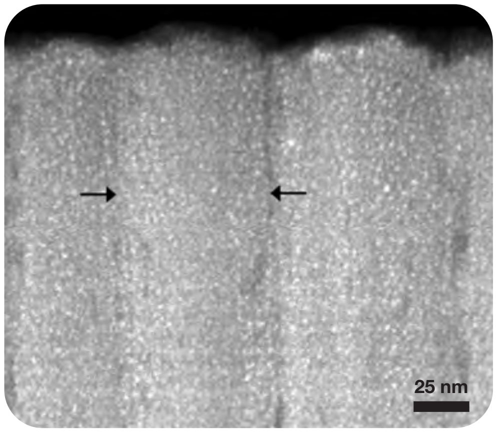


Fig. 3 — *Cross-sectional HAADF-STEM image of the MoS_2/Sb_2O_3/Au film. Brighter Au nanoparticles are distributed throughout the film. Arrows show intercolumnar boundary.*

More recently, a composite MoS_2 film was exposed to LEO during the Materials on the International Space Station-7 (MISSE-7) experiment. Samples were installed on the ISS on November 23, 2009, during STS-129 (another Atlantis mission), and recovered on March 1, 2011, during STS-133 (shuttle Discovery), accumulating 463 days of exposure. MISSE-7 samples were exposed to 3.60×10^{21} atoms/cm^2, roughly 14.4 times the total fluence of the earlier EOIM-3 experiment. Composite MoS_2 films were co-sputtered with antimony oxide and gold (MoS_2/Sb_2O_3/Au)[9], and were enclosed in "suitcase style" passive experiment containers (PECs), shown in Fig. 1, as part of Sandia's Passive ISS Research Experiment (SPIRE) on MISSE-7. These LEO exposure experiments were considered passive, while active experiments were led by B. Krick and W.G. Sawyer at the University of Florida, where data from sliding wear tests was collected on orbit and downloaded directly from space.

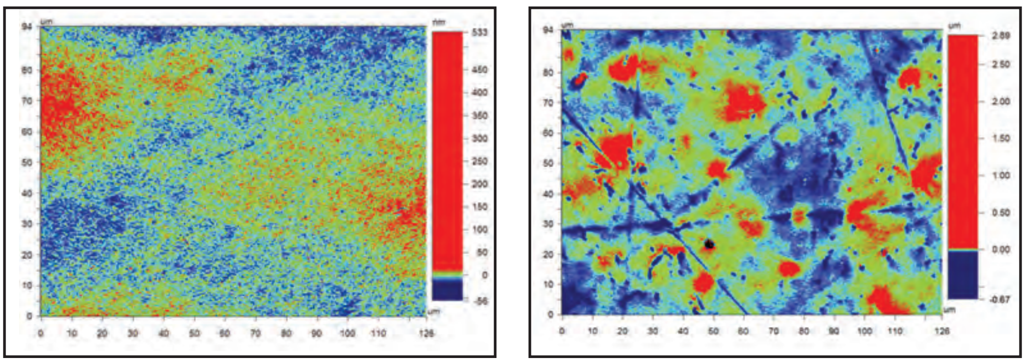


Fig. 4 — *Contour maps from optical interference profilometry of the MoS_2/Sb_2O_3/Au film in as-deposited condition (left) with RMS roughness of 8.0±0.3 nm and after exposure to LEO during MISSE-7 (right) with RMS roughness of 34.0±7.9 nm.*

Figure 2 shows the morphology of MoS_2 films at fractured edges created intentionally by plastically deforming the substrate through indentation with a hardened steel ball. The columnar morphology of the pure MoS_2 film is contrasted with the smooth fracture morphology of the MoS_2/Sb_2O_3 film. Doping of MoS_2 films interrupts the columnar growth of pure MoS_2, and tends to create films with more equiaxed grains, and hence reduced porosity.

Figure 3 shows a cross-sectional HAADF-STEM image of the MoS_2/Sb_2O_3/Au film. This film is a composite with nanoscale Au particles distributed throughout the amorphous MoS_2/Sb_2O_3 matrix. Surface roughness changes accompanying exposure of MoS_2/Sb_2O_3/Au films to LEO during the MISSE-7 mission are illustrated in Fig. 4. RMS roughness increased significantly from as-deposited films changing from 8.0±0.3 to 34.0±7.9 nm after LEO exposure. This increase in roughness is likely due to the effects of heterogeneous erosion of the film by AO, as well as potential impacts of micrometeoroids or other space debris.

Typical friction coefficient behavior for MoS_2 films is shown in Fig. 5(a). Friction traces for the MoS_2/Sb_2O_3/Au films show that sliding begins with a friction coefficient that is elevated with respect to the steady-state value established after several cycles of sliding contact. This initial friction coefficient is attributed to various chemical and

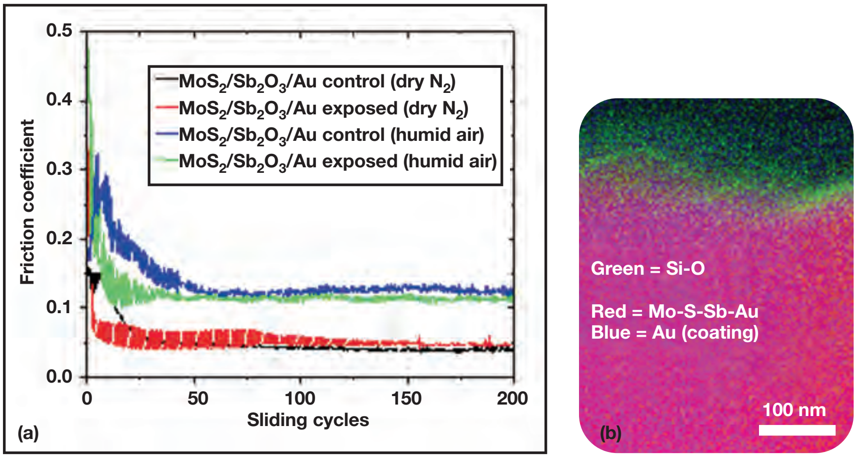


Fig. 5 — *Friction traces for $MoS_2/Sb_2O_3/Au$ film sliding before and after exposure to LEO during MISSE-7 (a) and an EDS elemental map of the coating after space flight (b).*

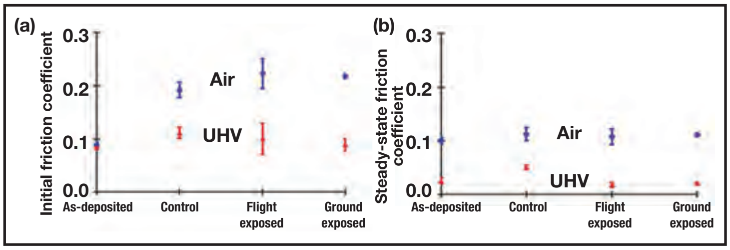


Fig. 6 — *Initial (a) and steady-state (b) friction coefficient values for MoS_2/Sb_2O_3 films as a function of exposure conditions during EOIM-3. The solid symbols correspond to mean, and error bars represent one standard deviation from at least three tests.*

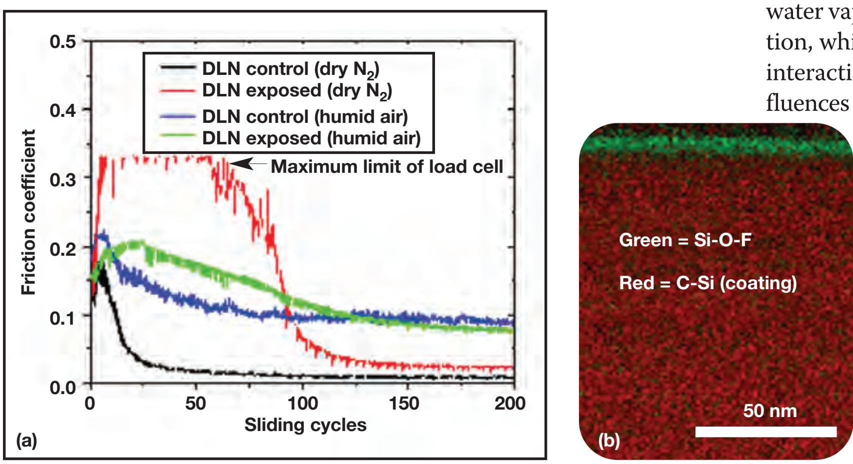


Fig. 7 — *Friction traces for the DLN film before and after exposure to LEO during MISSE-7 (a) and an EDS elemental map of the coating after space flight (b).*

structural factors, including wearing through any oxidized surface layers and adsorbed species, reorientation of randomly oriented lamellae of MoS_2 so that the easily sheared basal planes are parallel to the sliding direction, and establishing a transfer film of MoS_2 on the mating surface. This figure also illustrates that the steady-state friction coefficient exhibited by MoS_2 films is higher in environments containing water vapor compared to that in inert atmospheres. This is due to dynamic oxidation and water vapor effects on the MoS_2 during sliding, which disrupts the easy shear between sulfur-terminated basal planes. A cross-sectional energy dispersive x-ray spectroscopy (EDS) map of this film acquired using a transmission electron microscope is shown in Fig. 5(b), and displays a surface layer of oxidation and silicon contamination a few nm thick. It is believed that silicon was deposited on the surfaces at some point during sample installation or orbit, because it was not observed on control samples. X-ray photoelectron spectroscopy of these samples confirms accumulation of oxidized silicon on the surfaces. Silicon contamination was also found on the EOIM-3 flight-exposed samples due to proximity to a thermal control blanket during flight, but was not present on control or ground exposed samples.

To further illustrate the effect of AO exposure in LEO on tribological behavior of these films, a large amount of friction coefficient data for the MoS_2/Sb_2O_3 films tested as part of the EOIM-3 experiment is summarized in Fig. 6. As-deposited films exhibit essentially no run-in behavior when tested in air, because the dynamic oxidation effects outweigh those caused by adsorbed surface species and any thin initial surface oxidized layer due to exposure to desiccated air. When tested in ultrahigh vacuum, however, run-in behavior is evident in all exposure conditions. The figure also shows that the initial friction coefficient is elevated for control as well as exposed samples. Surface oxide in control samples is produced by exposure to oxygen and low concentrations of water vapor during desiccated storage for the mission duration, while exposed samples develop a surface oxide due to interaction with AO. However, none of these exposures influences the steady-state friction coefficient because the surface oxidized layer is easily worn away, exposing the non-oxidized material beneath.

Surface analysis of EOIM-3 samples using Auger electron spectroscopy reveals that AO exposure causes surface depletion of sulfur, presumably through the creation of volatile sulfate species. This depletion occurs over a depth of less than 10 nm. All samples exposed to AO also exhibit oxidation of the near surface layer to MoO_3 and MoO_2.

DLN films

In addition to MoS_2 films, DLN films also were exposed to LEO during MISSE-7. These films were deposited using plasma-assisted chemical vapor deposition, and contain amorphous carbon and an interpenetrating network of oxidized silicon[10].

Friction behavior of DLN films is shown in Fig. 7(a). Tests in dry nitrogen demonstrate that while the control sample also exhibits a short run-in period, the initial run-in period for the DLN film was increased substantially to about 80 cycles by the flight exposure environment. After the surface layer is worn away, the film exhibits a steady-state friction coefficient of $\mu < 0.03$ in dry nitrogen. The friction coefficient is higher in 50% relative humidity air, exhibiting a steady-state value of roughly 0.08, while also exhibiting elevated friction during a run-in period.

Surface chemical analysis in Fig. 7(b) reveals the cause of the increased run-in period of the AO-exposed DLN sample. The EDS map of the film acquired in the transmission electron microscope shows a layer of silicon, oxygen, and fluorine a few nm thick on this sample, similar to the $MoS_2/Sb_2O_3/Au$ film. Because carbon erosion by AO results in formation of volatile CO and CO_2, the surface layer on the DLN film is probably the result of both surface contamination and the oxidized silicon that is naturally part of the film remaining behind after erosion of the carbon phase.

Summary and outlook

Frictional behavior of solid lubricant films is highly influenced by phenomena that occur at the nanoscale. Surface oxidation of just a few nanometers creates a significantly higher initial friction coefficient for all MoS_2 films compared to the steady-state value, but lasts only a few cycles until the oxidized layer is worn away. When sliding in environments containing water vapor and oxygen, dynamic oxidation and water vapor effects result in a higher steady-state friction coefficient for MoS_2 films compared to that exhibited in inert atmospheres or vacuum. DLN films exhibit similar behavior to composite MoS_2 films, including a run-in period associated with removal of surface contaminants and layers created by AO exposure, as well as the development of a transfer film on the mating surface.

Composite MoS_2 and DLN coatings have now been flown in space to determine changes in surface composition and frictional behavior that accompany exposure to AO in Low Earth Orbit. Samples exposed during MISSE-7 experienced a fluence of AO about 14 times greater than that during EOIM-3, but effects of LEO exposure on surface chemistry and tribological behavior were very similar for both missions. Given that oxide layers a few nm thick are easily worn away exposing virgin lubricant underneath, an intriguing possibility for protecting thin film solid lubricants after deposition, but before use, may be to intentionally cap the solid lubricant film with a layer of oxide or metal to act as a barrier to the diffusion of water and oxygen into the film. ❍

For more information: Michael T. Dugger and Somuri V. Prasad, Materials Science and Engineering Center, Sandia National Laboratories, Albuquerque, NM 87185-0889, mtdugge@sandia.gov and svprasa@sandia.gov. T.W. Scharf is on sabbatical from the Dept. of Materials Science and Engineering, The University of North Texas, Denton, TX 76203-5310.

Acknowledgments

The authors thank Paul Kotula for TEM analysis and Andre Claudet for supporting the MISSE-7 tribological analysis. $MoS_2/Sb_2O_3/Au$ and DLN coatings were provided by Andy Korenyi-Both (Tribologix Inc.) and Chandra Venkatraman (Bekeart Advanced Coatings Technologies), respectively. The MISSE-7 project for Sandia National Laboratories was led by Gayle Thayer. Sandia National Laboratories (SNL) is a multiprogram laboratory managed and operated by Sandia Corp., a wholly owned subsidiary of Lockheed Martin Corp., for the U.S. DOE's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

References

1. L. Leger, J. Visentine, and B. Santos-Mason, Selected Materials Issues Associated with Space Station, 18th International SAMPE Technical Conference 18, Oct. 7-9, 1986, Seattle.
2. M. Nicolet and P. Mange, The Dissociation of Oxygen in the High Atmosphere, *J. Geophys. Res.,* Vol 59, p 15-45, 1954.
3. L. Leger and K. Dufrane, Space Station Lubrication Considerations, Proc. 21st AMS, NASA Conf. Publ. 2470, 1987.
4. M.T. Dugger, Protective Coatings and Thin Films: Synthesis, Characterization and Applications, Y. Pauleau and P.B. Barna, eds., NATO Advanced Research Workshop, May 30-June 5, 1996, Alvor, Portugal, Klewer Academic Publishers, p 157-168, London, 1997.
5. M.R. Hilton and P.D. Fleischauer, Structural Studies of Sputter-Deposited MoS_2 Solid Lubricant Films, Mat. Res. Soc. Symp. Proc. 140, p 227-238, 1990.
6. B.C. Stupp, Synergistic Effects of Metal Co-Sputtered with MoS_2, *Thin Solid Films,* Vol 84, p 257-266, 1981.
7. M.R. Hilton., et al., Structural and Tribological Studies of MoS_2Solid Lubricant Films Having Tailored Metal-Multilayer Nanostructures, *Surf. Coat. Technol.,* Vol 53, p 13-23, 1992.
8. S.Y. Chung, et al., Flight- and Ground- Test Correlation Study of BMDO SDS Materials: Phase I Report, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (JPL Pub. 93-31), p 1-64, 1993.
9. T.W. Scharf, P.G. Kotula, and S.V. Prasad, Friction and Wear Mechanisms in $MoS_2/Sb_2O_3/Au$ Nanocomposite Coatings, *Acta Mater.,* Vol 58, p 4100-4109, 2010.
10. T.W. Scharf, et al., Mechanisms of Friction in Diamondlike Nanocomposite Coatings, *J. Appl. Phys.,* Vol 101, 063521-1, 2007.

Additive Manufacturing Produces Polymeric Cranial Implants

With regard to modern medical applications, additive manufacturing is making headway—literally—when it comes to building cranial implants. One company finding success in this area is Oxford Performance Materials (OPM), South Windsor, Conn., who received the first FDA 510(k) clearance for its polymer laser-sintered OsteoFab Patient-Specific Cranial Device (OPSCD). The customizable implant restores voids in the skull caused by trauma or disease. Manufactured in a matter of hours with additive manufacturing (AM) technology from EOS, Munich, Germany, the device was successfully implanted in a patient missing a significant portion of cranial bone a few days later. "It was very large, measuring nearly six inches across," says OPM president Scott DeFelice. "It fit perfectly."

OsteoFab technology, OPM's brand for additively manufactured medical and implant parts produced from PEKK material contributed to the success. PEKK (Poly-Ether-Ketone-Ketone) is a high-performance thermoplastic with many exceptional properties (see sidebar). It has mechanical and thermal qualities that make it highly suitable for cranial reconstruction. For example, PEKK has a density and stiffness similar to bone, is lighter than traditional implant materials such as titanium and stainless steel, and is chemically inert and radiolucent so it will not interfere with diagnostic imaging equipment. Most importantly, PEKK is also osteoconductive, meaning bone cells will grow onto it.

In some implants, the surrounding bone pulls away over time. And with most implants, fasteners are very important because if bone does not grow into the implant, they hold everything in place. Because PEKK has osteoconductive properties, long-term implant stability may be easier to achieve.

Laser sintering

Because low-volume parts with complex shapes were needed, AM was the logical choice. PEKK was already being sold as a raw material in pellet, film, and extruded bar stock for orthopedic and spine applications, but occasionally OPM had requests for a one-off product with a complex organic shape. It was already being molded and machined, but because these processes have substantial limitations in terms of tolerance and geometry, other options were explored.

Laser sintering lifts manufacturability restrictions that traditional processes impose—for instance, draft angles in molding and corner design for CNC tooling. It also does not require upfront costs such as tooling and molding, so it is well suited for creating one-off, patient-specific parts (Figs. 1 and 2). Laser sintering does not generate the level of waste that subtractive cutting and milling do.

PEKK, unlike its cousin PEEK, has a high melting point relative to other polymers, so all current commercial AM processes were immediately removed from consideration until OPM discovered EOS, makers of the high-temperature EOSINT P 800 laser-sintering system (Fig. 3). "EOS is a clear leader for high-temperature industrial 3D printers," says DeFelice. "We found their technology to be the only laser-sintering system in the world that can run high-temperature materials such as PEKK."

Path to FDA approval

The path to commercialization of patient-specific implants was arduous. Aside from the not-so-trivial prerequisite of the right molecule and the right process, DeFelice says climbing the mountain of regulatory requirements was a daunting task. "For starters, you need an ISO 13485 compliant facility that has design controls and an appropriate clean manufacturing environment. You also need to be compliant with CFR 21 cGMP (current Good Manufacturing Practices). Add to that a completely validated process and ISO 10993

A Peek at PEKK: Thermoplastic Shape Shifting

While PEKK shares some of the qualities of its better-known cousin PEEK—high mechanical strength, heat resistance, and biocompatibility, to name a few—it is no ordinary thermoplastic. The difference is structural: PEEK is a homopolymer, made up of identical monomer units. By contrast, PEKK is polymorphous, which means it has lots of molecular "knobs." By adjusting the polymer's manufacturing process, or incorporating different additives, melting points, crystallization levels, and mechanical properties, PEKK is capable of supporting many different applications and a variety of customized materials from the same base molecule.

OPM is a participating member of America Makes, the National Additive Manufacturing Innovation Institute (NAMII), a White House initiative to advance additive manufacturing as a critical process in the U.S. "In the context of NAMII, we're establishing what are called B-Basis allowables, which are structural design parameters for aerospace use, for PEKK," says DeFelice. "We are very active in that market."

In the broader market, in addition to its recently FDA-cleared OsteoFab cranial implant, OPM is providing OXFAB materials and critical parts for other demanding sectors such as the nuclear, aerospace, chemical processing, and semiconductor industries. As DeFelice says, "After fourteen years of mixing, blending, and modifying this molecule, we're just getting started."

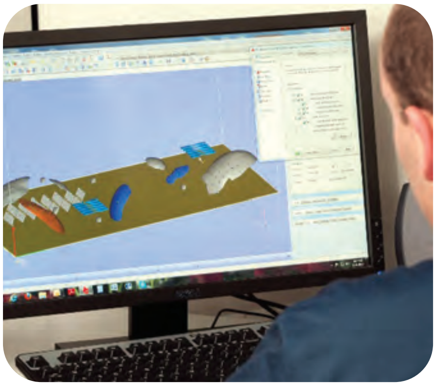


Fig. 1 — *A batch of implants are set up for production. The EOSINT P 800 system can run multiple, different designs in a single build. All images are courtesy of Fred Smith Associates.*

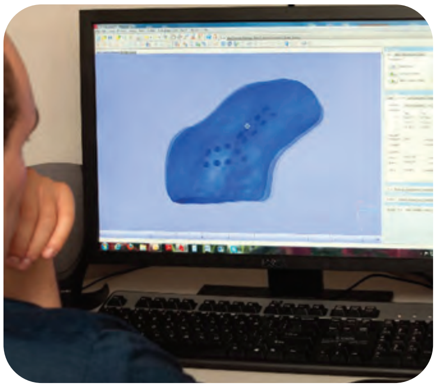


Fig. 2 — *3D digital model of a cranial implant.*

Fig. 3 — *Using patient-specific 3D digital data, the cranial implant is additively manufactured with an EOSINT P 800 high-temperature plastic laser-sintering system.*

biocompatibility data on your finished parts."

Once all that "stuff" is out of the way, the lifecycle of a patient-specific cranial implant starts with the patient. If someone comes to the hospital with a skull injury, a CT or MRI scan is performed and produces a slice file similar to data used to build parts via laser sintering.

That slice file is then sent to OPM where 3D design software is used to create an implant that precisely fits the patient's anatomy. The implant is then printed or "grown." This "growing" phase is entirely automatic—the laser-sintering system lays down a thin layer of powder on its build platform. Guided by the lowest slice of the implant design file, a high-temperature laser melts a cross section of the implant. When that layer is done, the build platform lowers, and a new powder layer is distributed on top of the old one, and the laser melts the next cross section. The process repeats until the entire implant is built. Laser sintering is capable of producing practically any shape geometry to match the precise needs of individual patients.

When the implant is removed from the leftover powder (Fig. 4), it must be inspected for quality. In addition to mechanical and analytical testing, a structured light scanner is used to do 100% line-of-sight metrology inspection to certify its dimensional accuracy. Finally, the implant is shipped to the hospital. "The total process from receiving the data to shipping the implant takes less than two weeks," according to DeFelice. (Figs. 5 and 6).

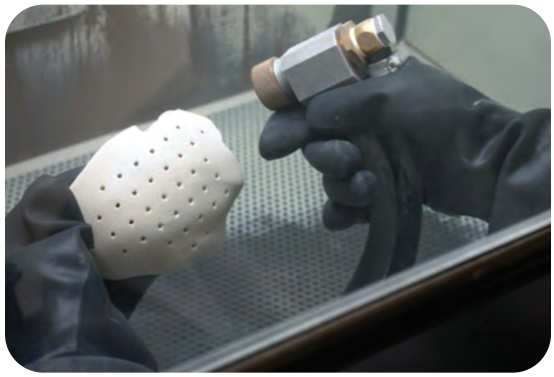


Fig. 4 — *The completed part is cleaned of any residue powder.*

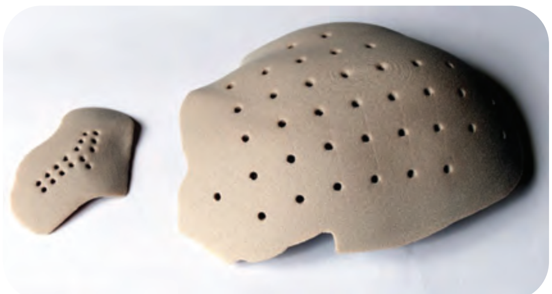


Fig. 5 — *Cleaned implants.*

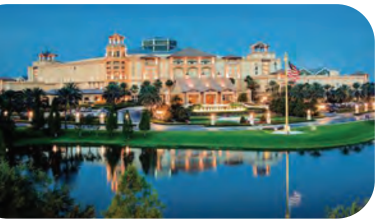
Fig. 6 — *Skull model demonstrates how an implant is customized to fit the cranial hole.*

More implant types possible

Having successfully created and obtained clearance for their cranial product, OPM is making plans to move throughout the body to use the technology. OPM will only operate in highly regulated, high-risk markets such as medical. "We are after critical parts, and biomedical is the pinnacle of that," DeFelice says. "That means you need the right material, the right process, the right quality system, and the right metrology. When the patient is on the operating table and the part shows up and doesn't fit, you are putting someone's life at risk. With the first implant case, where the implant was very large, extensive areas of critical tissues were exposed during surgery. Every second is critical in that situation."❍

For more information: Scott DeFelice is president and CEO of Oxford Performance Materials (OPM), 30 South Satellite Rd., South Windsor, CT 06074, 860/698-9300, www.oxfordpm.com.

AeroMat 25
CONFERENCE AND EXPOSITION



With its stunning Spanish Renaissance architecture, the Gaylord Palms Convention Center embraces the historic old-world charm of St. Augustine, the island spirit of Key West, and the mysterious waters of the Everglades in one place.

Industry partner: ATI

Corporate sponsor: BOEING

Sponsors: AMERICAN ELEMENTS, ASM INTERNATIONAL, Bodycote, GEO, INDUCTOHEAT An Inductotherm Group Company

AeroMat 25

The Latest Word in Aerospace Materials

June 16-19, 2014
Gaylord Palms Resort & Convention Center, Orlando

While the aerospace industry is heading toward an era of new designs based on new material capabilities, cost remains a concern. Expenses related to both manufacturing and operating aerospace products, including the impact on fuel efficiency, are of vital importance to the future of aerospace. It is necessary to develop efficient processing techniques, as well as components that are lightweight, able to withstand higher temperatures, and offer longer lifespans than previous designs. These next-generation components may require radically different configurations in addition to novel system architectures that demand new materials and processes to enable these configurations to function as efficiently as conceived.

PLENARY PROGRAM

Monday, June 16, 2014
3:30 – 5:00 p.m.
Commercial Aerostructure Supply Chain
Dawne Hickton, RTI International Metals Inc.

It is an exciting time for titanium manufacturers and suppliers as the ramp up begins producing historical numbers of commercial aircraft. Orders have reached record levels, with the largest production backlog in history. Hickton will discuss the effects of the production ramp up on the supply chain, highlighting the risks and problem-solving strategies related to the multifaceted, global production of today's aircraft. She will focus on how to transform a company from a Tier 4 producer of base material to a vertically integrated Tier 1 producer in the competitive aerospace industry.

Status and Plans for the NASA Commercial Crew Program - Putting Space Travel within Reach of Anyone
Jon N. Cowart, NASA

The NASA Commercial Crew Program is working with private industry to create and develop rockets and spaceships capable of taking non-NASA trained astronauts into Earth orbit. Once these private companies demonstrate this capability, NASA may contract them to transport NASA astronauts to the International Space Station. This program is key to a future where average people may someday travel to space as routinely as they get on planes today.

Tuesday, June 17, 2014
10:30 a.m. – 12:00 p.m.
The Transformative Potential of Additive Manufacturing
William E. Frazier, FASM, NAVAIR

Additive manufacturing (AM), also known as 3D printing and direct digital manufacturing (DDM), is a layer-by-layer component fabrication and repair technology that is transforming product design, business practices, and logistics frameworks around the globe. In a 2010 Navy workshop, DDM was identified as a means to reduce costs and increase throughput, both by 30%. The potential of AM to produce components on demand, where and when they are needed, makes AM processes extremely attractive. This presentation delves into the Navy's efforts to advance this disruptive technology and overcome myriad challenges associated with its implementation.

EXHIBIT DATES AND TIMES*

AeroMat is the premier exposition for networking with and selling to experts in the areas of structural properties, materials characterization, environmental effects, design, synthesis, processing, and manufacturing technology.

Monday, June 16,
3:00 – 6:30 p.m.
Refreshment Break
3:00 – 3:30 p.m.
AeroMat Plenary Session on Exhibit Floor
3:30 – 5:00 p.m.
Networking Reception
5:00 – 6:30 p.m.

Tuesday, June 17,
10:00 a.m. – 3:45 p.m.
Refreshment Break
10:00 — 10:30 a.m.
AeroMat Plenary on Exhibit Floor
10:30 a.m. – 12:00 p.m.
Lunch 12:00 – 1:00 p.m.
HT Plenary Sessions on Exhibit Floor
1:00 – 3:00 p.m.
Refreshment Break
3:00 – 3:30 p.m.

Additive Manufacturing at GE – Revolutionizing the Way We Think

David H. Abbott, GE Aviation

Additive manufacturing (AM) has recently exploded onto the scene, challenging preconceived notions about designing, producing, and even using complex 3D geometry. Compared to the previous two or three industrial revolutions, change is happening at an ever accelerating rate due to recent technological advances. GE is also experiencing sweeping changes. AM is not only changing how engineers design and build, but also how they think. It is evolving into more than just another design or manufacturing tool. It is becoming a way of life.

EDUCATION SHORT COURSES

Make the most of your AeroMat experience and take an education short course. The 2014 courses are conveniently scheduled post conference, June 19, at the Gaylord Palms Resort and Convention Center.

Titanium and Its Alloys

Instructor: Rodney Boyer, FASM

Date: Thursday, June 19

Time: 8:30 a.m. – 4:30 p.m.

Titanium and its alloys are a versatile family of metals with applications in many industries. They have high strength-to-weight ratios, excellent corrosion resistance, high and low temperature capabilities, and compatibility with graphite fibers, which are gaining importance with the increased use of composites in aircraft structure. This unique combination of physical, mechanical, and chemical properties makes them attractive for aerospace, marine, industrial, biomedical, and other applications. This course provides an overview of titanium alloy processing, from refining ore to machining hardware, and discusses how the unique properties of titanium drive applications in various industries.

Additive Manufacturing

Instructor: Frank Medina

Date: Thursday, June 19

Time: 8:30 a.m. – 4:30 p.m.

This course covers various aspects of additive, subtractive, and joining processes to form 3D parts with applications ranging from prototyping to production. Additive manufacturing (AM) technologies fabricate 3D parts using layer-based manufacturing processes directly from computer-aided-design (CAD) models. Direct digital manufacturing (DDM) or rapid manufacturing (RM) involves the use of AM technologies in direct manufacturing of end-use parts. Learn about a variety of AM and other manufacturing technologies, their advantages and disadvantages for producing both prototypes and functional production quality parts, and some of the important research challenges associated with using these technologies.

Modeling of Heat Treatment Processes for Steel Parts

Instructors: B. Lynn Ferguson, Ph.D., Zhichao (Charlie) Li, Ph.D., Andrew Freborg, PE, MS

Date: Thursday, June 19

Time: 8:30 a.m. - 4:30 p.m.

This course is designed to introduce analytical modeling to the heat treating industry. The focus is on the usefulness of modeling results in terms of understanding and improving heat treatment processes for steel parts, including carburization methods and hardening using a variety of quenching media. The material data and process variables requirements for accurate analytical models will also be presented. Case studies that demonstrate the dependence of distortion and residual stress state on the heat treat process parameters and steel alloy hardenability will be presented. ❍

Wednesday, June 18, 10:00 a.m. – 1:00 p.m.

Refreshment Break
10:00 – 10:30 a.m.

Exhibitor Thank You
10:30 – 11:45 a.m.

Lunch
12:00 – 1:00 p.m.

*Dates and times are tentative and subject to change.

AeroMat 25 – The Latest Word in Aerospace Materials takes place from June 16-19, in Orlando.

Metallurgy Lane

The Toolmakers: Part I

Man is a toolmaker. In fact, the entire progress of mankind has been marked by the ability to develop better tools.

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.

Simple tools were first devised for hunting purposes, followed by more complex ones for agriculture and construction, and always included efforts to make better weapons for war. Finally, with the Industrial Revolution, humans began to invent mass-produced machine tools.

During the middle of the 18th century, British clockmaker Benjamin Huntsman rediscovered the ancient Wootz method of melting small quantities of wrought iron in clay pots, with wood chips to supply the carbon, as part of his quest for more uniform steel to make clock springs. His method was further refined years later by the British steelmaker Robert Mushet who simply added pig iron to crude sponge iron. For more than 175 years (1740 to 1920), this process was used for making steels for tools. The crucible process, as it was called, was well suited for making small batches of high-quality, controlled-chemistry steel.

The tool steels made in the first 100 years after crucible melting became widely used were simple iron-carbon alloys. During the 1860s, Mushet was doing practical processing work that involved adding other metals to tool steel. His studies led him to the 1868 discovery that adding tungsten and manganese in sufficient amounts caused steel to be extremely hard on cooling in air from a red heat. At the time, conventional wisdom said hardening could only be done by rapidly quenching in water. Mushet's "Special Steel," as it was known, contained 2% carbon, 2.5% manganese, and 7% tungsten. It is considered the ancestor of all modern tool steels because it could withstand difficult service conditions and required less resharpening due to its greater wear resistance.

Circa 1829, the crucible furnace at Abbeydale, England, is the oldest example of the type developed by Benjamin Huntsman. Courtesy of www.steelguru.com.

Taylor and White revolutionize tool steel industry

Frederick Taylor, an efficiency expert working on machining studies at Bethlehem Steel Co. with the help of experienced metallurgist Maunsel White, studied the heat treating variables that affected alloy tool steel performance. In the course of their study, Taylor and White found that the higher the heating temperature before the steel was cooled, the greater the usefulness and life of the tool. "Metals men" had known for years that if steel was heated at too high a temperature, it would be ruined, or "burnt" as they described it. Taylor and White simply followed the clues provided by their own experimental data.

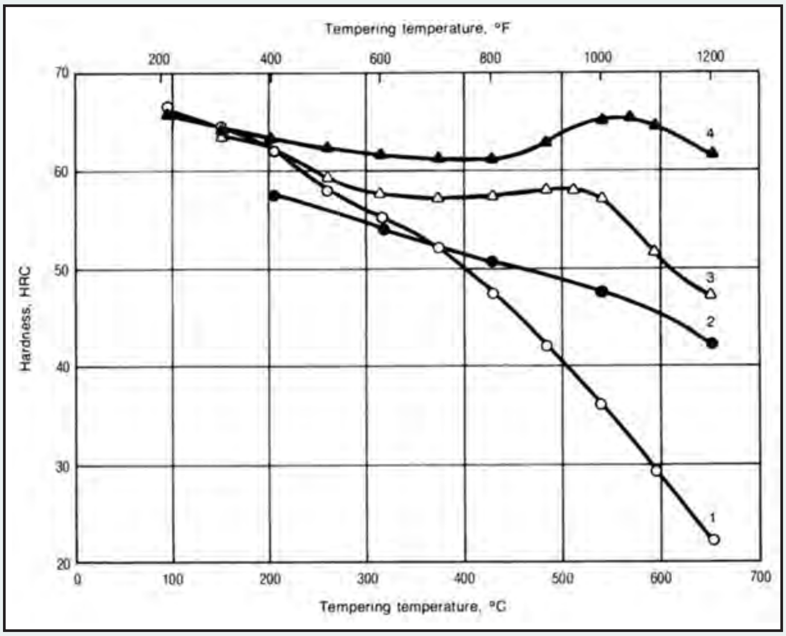
Frederick Taylor (pictured) and Maunsel White discovered that heat treatment produces secondary hardening in tungsten tool steels. Courtesy of Library of Congress/U.S. public domain.

This led them to temperatures in the 2200° to 2400°F range, almost to the melting point of their steels. Alloy steel tools containing tungsten were so greatly improved when heated to these excessively high temperatures before cooling that they could be operated under conditions so severe that the cutting point would glow to a dull red. Later, with some refinement in alloy content, these would be called high-speed steels, and would be said to possess "red hardness." The use of high-speed steels revolutionized the machining industry. Heavier machine bases were needed to support the stresses and vibration of the heavier cuts that could now be used to remove metal.

Alloy development continues

In the meantime, improved alloys that would provide maximum response to the Taylor and White heat treatment were being tested in many advanced industrial countries. J.A. Mathews of the Crucible Steel Co. reported the results of a survey he conducted in 1901 on the common tool steels in use, "Modern high-speed steels seem to have sprung fairly fully developed from a variety of sources at almost the same time." The change from the old type to the new that Mathews is referring to was a rather drastic change in chemistry from the Mushet steels containing 1.5-2.0% carbon, 2.5-4% manganese and 7-9% tungsten to the new steels with 0.6-0.8% carbon, 4-6% chromium (manganese was no longer used), and 10-20% tungsten.

Mathews was granted a patent in 1905 for the addition of vanadium to high-speed steel. With the addition of about 1% vanadium to the 18% tungsten, 4% chromium, and 0.60-0.80% carbon steel, the first truly universal high-speed steel was born. By 1905, the "18-4-1 high-speed steel" was in commercial production and would remain the major tool steel for metal machining during the next 35 to 40 years.



Variation of hardness with tempering temperature for four typical tool steels. Courtesy of Wrought Tool Steels, Properties and Selection: Irons, Steels, and High-Performance Alloys, Vol 1, ASM Handbook, ASM International, 1990.

Metallurgical research moves forward

One of the first research studies on high-speed steels was by H.C. Carpenter of England, who believed that the high-temperature phase (austenite) was the source of red hardness. He was led into this error due to the large amount of austenite he found in samples after cooling from the hardening temperatures.

Another British metallurgical research study undertaken by C.A. Edwards and H. Kikkawa provided the first comprehensive understanding of the major metallurgical phenomena in high-speed steel. They concluded that chromium imparts the self-hardening, and that the extremely high hardening temperature was needed to dissolve the tungsten. Maximum resistance to tempering can only be obtained by getting the tungsten into solution. They also concluded that careful tempering studies with hardness measurements could provide valuable information on the relative merits of cutting tools.


Edgar Bain, a research metallurgist who worked with Marcus Grossman to publish research studies and a book on high-speed tool steels. Courtesy of Library of Congress/U.S. public domain.

Shortly after Edgar Bain's early work using x-rays to determine the crystal structure of austenite (fcc), ferrite (bcc), and martensite (bcc), he and Zay Jeffries, while working at the GE Lamp Division, published their famous paper in *Iron Age* in 1923 on the "Cause of Red Hardness of High Speed Steel."

This paper is considered a classic in the field of metals technology, not because it changed industrial practices, but because it combined the latest research tool (x-ray diffraction) with the most recent theory of hardening—slip interference by precipitated particles. This paper showed, as concluded earlier by Edwards and Kikkawa, that the high hardening temperatures are needed to dissolve the particles of tungsten-containing carbide in the austenite. Bain and Jeffries then concluded that the softening of hardened steel during tempering, which occurs in ordinary steel at low temperatures (300° to 900°F), is caused by grain growth and carbide particle growth beyond the critical size. They reasoned that the greater stability of the tungsten carbide forces its formation at 1000° to 1200°F, where it increased the hardness to a peak called "secondary hardening." It is only at these temperatures that the larger tungsten atoms can move within the iron space lattice to form the alloy carbides. Later studies would confirm the thrust of their theories, although the details of alloy carbide formation would be more complex in detail.


Zay Jeffries (pictured) published on the theory of red hardness in high-speed tool steels with Edgar Bain and served as ASM president in 1929. Courtesy of ASM International.

The following year, 1924, Edgar Bain moved from General Electric Co. to Atlas Steel Co. in Dunkirk, N.Y., where he worked with one of America's most interesting and prolific metallurgists, Marcus A. Grossmann. The publications of Bain and Grossmann in 1924 included high-carbon, chromium steels, chromium in high-speed steel, and their major work, "On the Nature of High Speed Steel," which they published in Great Britain in the *Journal of The Iron and Steel Institute.* This paper was a compilation of the arts on the manufacturing and metallurgy of high-speed steel. In some ways, it appears to be a combination of Grossmann's practical knowledge with the metallurgy and theory reported earlier by Bain and Jeffries. Grossmann and Bain expanded this effort in their collaboration in 1931 with the publication of a textbook entitled "High Speed Steel."

For more information:
Charles R. Simcoe can be reached at crsimcoe@yahoo.com. For more metallurgical history, visit www.metals-history.blogspot.com.

corporate
spotlight ad

Carpenter Technology Corporation

Engineered Materials for a Changing World

Carpenter Technology Corporation (NYSE:CRS) is a leading manufacturer and distributor of specialty alloys, including superalloys, stainless steels and titanium alloys for customers around the world. Their experts have been solving customers' design and production challenges within the aerospace, transportation, medical, consumer, energy, and industrial markets.

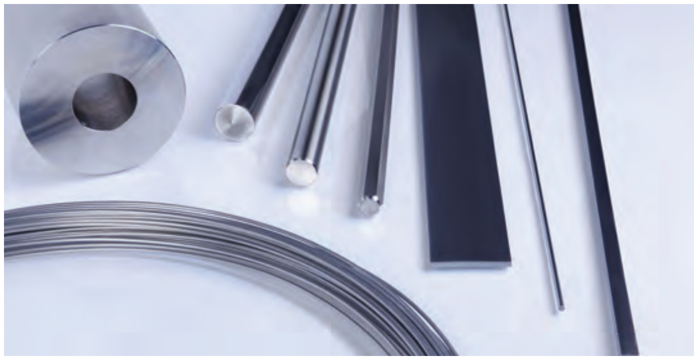
Carpenter's manufacturing and sales facilities can be found in the United States, Europe, Asia, Mexico and Canada.

Specialty Alloys
Carpenter develops and manufactures a full catalog of specialty alloys, including stainless steels, high-strength alloys, superalloys, magnetic and controlled expansion alloys, medical alloys and superior corrosion resistant alloys. Product forms include billet, solid and hollow bar, wire, fine wire, precision strip, plate, loose powder, and custom shaped bar and wire.

Carpenter's growth initiatives have led to the 2012 acquisition of Latrobe Specialty Metals, Latrobe, Pa. In January 2014, Carpenter began production at a newly constructed facility in Limestone County, Alabama, for the manufacture of approximately 27,000 tons of premium products annually. To further support increased demand for premium products, their main manufacturing facility in Reading, Pa., expanded melting, forge finishing and annealing capacity.

Titanium
Dynamet Inc., a Carpenter subsidiary, is a leading domestic and international supplier of titanium alloy products for the aerospace, medical, consumer products, motor sports and recreation equipment industries. Its wire, bar, fine wire, strip and shaped products have been used for applications requiring superior corrosion resistance, light weight, strength and biocompatibility.

Powder Products
Carpenter Powder Products (CPP) is one of the world's most versatile producers of specialty alloys in the form of gas atomized spherical loose powders and consolidated powder metallurgy products. With a state-of-the-art powder metallurgy research and development facility, Carpenter Powder Products leads the way as a powder supplier for metal injection molding and hot isostatic pressing processes.



Precision Machined Components and Repair
Amega West Services, a Carpenter subsidiary based in Houston, Tex., is a manufacturer and service provider of complex machined components for drilling, exploration, completions and production equipment. The acquisition has expanded Carpenter's portfolio of target applications in a fast-growing oil and gas market.

Research and Development
Carpenter's strong commitment to product innovation is evidenced by its modern research and development center, where teams work in such areas as physical metallurgy, analytical chemistry, materials characterization, and process and systems development. Over the years, Carpenter has been issued more than 200 patents and published many technical papers. Technical articles are available in Carpenter's Alloy TechZone™ at www.cartech.com.

Technical Expertise
Carpenter's experienced and knowledgeable metallurgists, process engineers and other product specialists help customers solve their most difficult materials challenges. Much of that technical knowledge is available online in Carpenter's free Alloy TechZone and in product literature at www.cartech.com. In addition, designers, OEMs, and purchasers are downloading MetalMass™, Carpenter's iPhone®/iPad® app that estimates the total weight and cost of a variety of metallic materials. Together, these offerings have greatly assisted customers in the field.

CARPENTER®

Carpenter Technology Corporation
tel: 1-800/654-6543
e-mail: service@cartech.com; Web: www.cartech.com

MAY 2014 • VOL 9 • ISSUE 2

TSS[SM]
ASM Thermal Spray Society
An Affiliate Society of ASM International®

iTSSe™

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

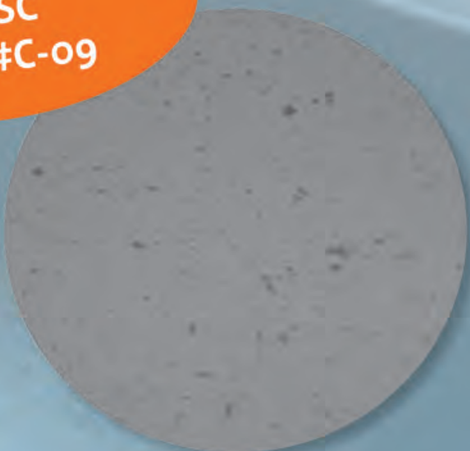
Thermal Spray Coatings in the Energy/Power Generation Industries

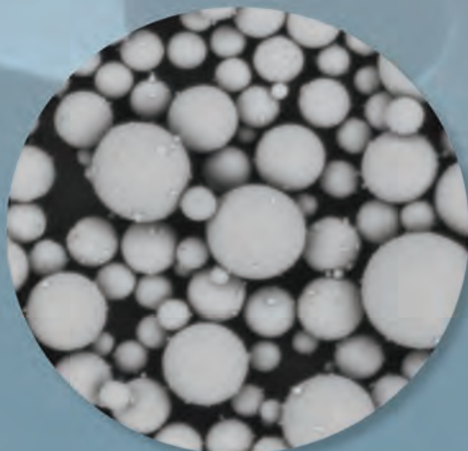
***JTST* Highlights**

Society News

ASM INTERNATIONAL

tss.asminternational.org





TSS ASM Thermal Spray Society
An Affiliate Society of ASM International®

MAY 2014 • VOL 9 • ISSUE 2

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

Departments

About the cover
The ProPlasma gun is capable of high deposition rates and is designed to improve plasma stability. Courtesy of Saint Gobain. www.saint-gobain.com.

Editors Robert Gansert
Rajan Bamola
Managing Editor Julie Kalista
Art Director Barbara L. Brody
Production Manager Joanne Miller

National Account Manager
Kelly Thomas, CEM.CMP
Materials Park, Ohio
tel: 440/338-1733
e-mail: kelly.thomas@asminternational.org

International Thermal Spray & Surface Engineering™ is published quarterly by ASM International®, 9639 Kinsman Road, Materials Park, OH 44073; tel: 440/338-5151; www.asminternational.org.

Thermal spray plays major role in power generation

The power generation industry comprises a complex array of technologies based on the energy source: fossil fuels, diesel, nuclear, biomass, solar, wind, and hydro. It is this complexity that has led to, perhaps, the most comprehensive integration of thermal spray technology found in any industry. By integrating thermal spray, we are referring to combining specially formulated material with the appropriate spray device to deposit coatings with desired surface characteristics for the particular application. The most common example might be depositing thermal barrier coatings on gas turbine buckets and vanes to enhance inlet temperatures to improve power efficiencies.

Estimates of the total dollar value of this market based on new orders accepted by major OEMs for power generation equipment are not an accurate indicator of the growth or contraction of thermal spray applications for this industry. A very robust and substantial aftermarket exists for repairs and spare parts. Numbers are further complicated by new concepts such as solar farms and alternate energy systems that are not included in OEM turbine data. Suffice it to say that as these alternate sources grow, thermal spray applications will also expand. Growth for thermal spray materials, equipment, and services will likely continue in the aftermarket arena as new power plants near completion and transition to spare parts and repairs.

This issue is illustrated in the development of two newer technologies: A modified plasma torch and cold spray. In the first article, a case study of improved deposition efficiency of yttria stabilized zirconia using a modified commercially available plasma torch is presented. The authors claim a 40% savings in labor, materials, and energy costs compared with a conventional plasma gun. In the other article, a low-pressure cold spray system is described, which can be used for 3D manufacturing. In terms of its application to power generation equipment, one can visualize use of these devices for localized repairs, for example, stellite wear shields for LP steam turbine blading for water droplet erosion.

Learn about these and other exciting new thermal spray technologies at this year's International Thermal Spray Conference being held in Barcelona, Spain, on May 21-23. It offers many opportunities to interact and learn about advanced materials and techniques for improvements in current and future applications in the power generation and other industries. We hope those attending and presenting will offer insights in upcoming issues. To contribute an article, please email me at rajanb@surfacemodificationsystems.com.

Rajan Bamola
iTSSe co-editor
Surface Modification Systems Inc.

CONFERENCES • EXPOSITIONS • SYMPOSIUMS

North American Cold Spray 2014
September 16-17
Bromont, Quebec, Canada

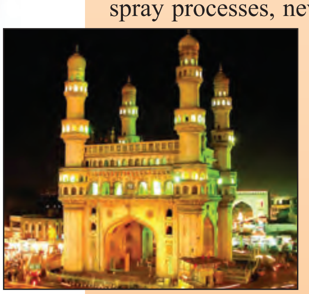
The North American Cold Spray Conference and Exposition offers attendees a basic understanding of cold spray, information on global R&D cold spray technology programs, firsthand information on industrial applications, and networking opportunities with international experts. A student poster presentation and prize competition will be an exciting highlight of the 2014 North American Cold Spray Conference. The competition includes a review by expert judges and prizes for students with the best posters. For more information, visit asminternational.org/conferences.

Aerospace Coatings: Development and Manufacturing Trends for the 21st Century
October 8-9
Hartford, Conn.

This symposium brings together thermal spray professionals involved in a wide range of responsibilities. Gain key perspectives with presentations from invited speakers including Rolls Royce, PWA, Curtiss-Wright Surface Technologies, LLC Surface Technologies, Delta Airlines Inc., Lufthansa Technik AG, Naval Aviation Department, Pratt and Whitney, KLM Engineering and Maintenance, and other leading organizations. Visit asminternational.org/events to learn more.

6th Asian Thermal Spray Conference
Hyderabad, India
November 24-26

This is the first time the event will be held in India and is organized by the International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) and the Asian Thermal Spray Society (ATSS). ATSC provides an ideal platform to exchange information, share technology advances, and gather new ideas for further research. Technical sessions address thermal spray processes, new application areas, novel material systems, simulation and modeling, emerging characterization and diagnostic techniques, and much more. Abstracts are now being accepted for consideration for both oral and poster presentations. **Abstract submission deadline is June 15.**



A two-day thermal spray course taught by Christopher Berndt precedes the event on November 22-23. The exhibition offers an opportunity to showcase products and equipment. For more information, visit www.atsc2014.in.

Thermal Spray Community Mourns Joachim Heberlein (1939-2014)

Emeritus Professor Joachim (Jockel) V.R. Heberlein passed away on February 17 after a long battle with ALS. Professor Heberlein was born in Berlin in 1939. He received his diploma in physics in 1966 from the University of Stuttgart. In 1967 he came to the University of Minnesota, where he received his Ph.D. in mechanical engineering in 1975. After working for 14 years at Westinghouse R&D Center in Pittsburgh where he served as manager of applied plasma research, lamp research and nuclear and radiation technology, he rejoined the mechanical engineering department at the University of Minnesota in 1989 as associate professor. He was promoted to professor in 1994, was appointed Ernst Eckert Professor of Mechanical Engineering in 2000, and retired at the end of 2012.

Professor Heberlein published more than 140 journal papers, received 13 patents, and coauthored with Pierre Fauchais and Maher Boulos the recently published textbook *Thermal Spray Fundamentals* (Springer, 2013). He advised or co-advised nearly 30 Ph.D. students, an equal number of M.S. students, and advised seven students through completion of their diploma theses at several European universities. He was an internationally recognized authority on the subject of thermal plasmas of the type used for industrial applications such as thermal spray coatings, plasma cutting, electrical circuit breakers, and materials synthesis. He was particularly known for his pioneering studies of arc-electrode interactions. Jockel had many interactions with industry, including research collaborations with Hypertherm on plasma cutting, Eaton Corp. on electrical circuit breakers, and Nitto Denko Technical Corp. on nanomaterials synthesis.

Jockel's students were famously devoted to him, and he was beloved among the faculty and staff of the M.E. department at the University of Minnesota. He and his wife Yuko often hosted dinner parties at their house. He loved music, telling stories about adventures past, and sharing good wine.

Jockel contributed greatly to the ASM Thermal Spray Society, having served as chair of the JTST Editorial Committee for 10 years (1996–2006) and chair of the TSS Awards Committee for seven years (2004-2001). He was also a past member of the Program Committee, Nominating Committee, Academic Advisory Council, and ITSC 2003 organizing committee. He was named ASM Fellow in 2001, inducted into the TSS Hall of Fame in 2004, and received a number of other awards, including the ASM Allan Ray Putnam Service Award in 2009 and the TSS President's Award in 2013. Jockel's lively spirit and amazing energy will be missed by all.

Dorfman Inducted into Thermal Spray Hall of Fame

Mitchell R. Dorfman, FASM, Sulzer Metco Fellow, will be inducted into the Thermal Spray Hall of Fame on May 21 during the ITSC Plenary Session in Barcelona, Spain. Dorfman is being recognized "for innovations in thermal spray turbine engine coatings, and for exceptional contributions to the thermal spray industry and technical community, and for dedicated mentoring of next-generation thermal sprayers." He received his B.S. in Mechanical Engineering in 1978 and M.S. in Materials Science in 1979 from State University of New York at Stony Brook. He is internationally known for his development of materials for thermal spray, particularly carbides for wear resistance, zirconias for thermal barriers, and various materials for abradables. He holds 16 patents and more than 60 publications or presentations. Dorfman served on a number of TSS committees, is a past president of TSS, and currently serves on the ASM Board. He was named ASM Fellow in 2010.

Kay Receives TSS President's Award

Charles M. Kay, Vice President, Marketing, ASB Industries, is the 2014 recipient of the TSS President's Award for Meritorious Service. The award will be presented to him during ITSC 2014 in Barcelona, Spain.

EDUCATION

Introduction to Thermal Spray
July 7- 8
Materials Park, Ohio

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. To learn more, visit asminternational.org/learning/courses.

Thermal Spray Safety Management
July 10
Materials Park, Ohio

This course focuses on key elements of a comprehensive health and safety system using the U.S. Occupational Safety and Health Standard 29 CFR 1910 as a basis. The course provides necessary and up-to-date information to support businesses complying with this mandatory standard. Numerous examples showing the practical application of the standard to the real world workplace in a typical thermal spray operating environment will be given. To learn more, visit asminternational.org/learning/courses.

CASE STUDY

Improving Deposition Rate Efficiency

Thermal spray applications in the gas turbine-power generation industry are among the most established uses for this technology, in addition to widespread applications in the petroleum industry. However, several challenges exist with regard to conventional gas turbines. These include the need for higher temperature thermal barrier coatings (TBCs), CMAS-resistant overlays, and cost reduction.

The first two challenges are related to new material and coating development, which increases per component cost. The competitive nature of the thermal spray industry does not offer much variation in feedstock prices. Therefore, thermal spray applicators must concentrate on efficiency improvements to reduce costs. One strategy—increasing deposition efficiency—lowers both powder and labor costs. However, although this approach offers some savings, higher spray rates at higher efficiencies are most beneficial.

Recognizing the need for a cost-efficient plasma gun capable of high deposition rates, Saint-Gobain, France, worked to develop a commercially available solution called the ProPlasma gun. Engineers analyzed both gun components and gas flow dynamics to design a gun that improves plasma stability. The gun was developed based on a pre-existing design, so that the new torch can be implemented on available controllers and power supplies. ProPlasma also increases electrode life per kilogram of deposited material.

Considerable effort was spent on characterization of ProPlasma sprayed, yttria-stabilized zirconia (YSZ) for thermal barrier applications. The coating was sprayed at 150 g/min at 57% efficiency versus 40-60 g/min for the F4 system. This translates to roughly 25% savings in powder and 40% savings in combined labor, energy, and powder costs. The increased efficiency and cost savings is critical due to a gradual change to TBCs based on zirconia and doped with more expensive rare earth elements such as gadolinium.

Similar trends regarding improved deposition efficiencies are noted for materials in non-power related industries as well. Of particular interest is plasma sprayed yttria. This material is widely used to protect chamber components from erosion in the reactive ion etching process in semiconductor fabrication. For this application, critical factors include coating quality (very high density, lower probability of particle release) and related costs. Yttria is an expensive material, and therefore deposition efficiency is critical.

Combining the ProPlasma gun with a specially developed yttria powder is highly efficient. Traditional yttria powders available for this application are made using agglomeration and sintering. As another option, Saint-Gobain's newly patented DEnsitY yttria powder is narrow sized, plasma densified, and exhibits very high purity (>99.98%). This powder melts more easily in the plasma, enabling higher coating densities. Deposition efficiency improvements between 10-15% were achieved using the new powder in conjunction with an F4 torch, and up to 30% when combined with the ProPlasma gun, which allows even higher spray rates. For example, a 100% increase can be achieved for optimized coatings: 25 g/min for the F4 versus 50 g/min for the ProPlasma. A microstructure of the optimized coating is shown in Fig. 2.

Fig. 1 — *The ProPlasma gun is capable of high deposition rates and is designed to improve plasma stability.*

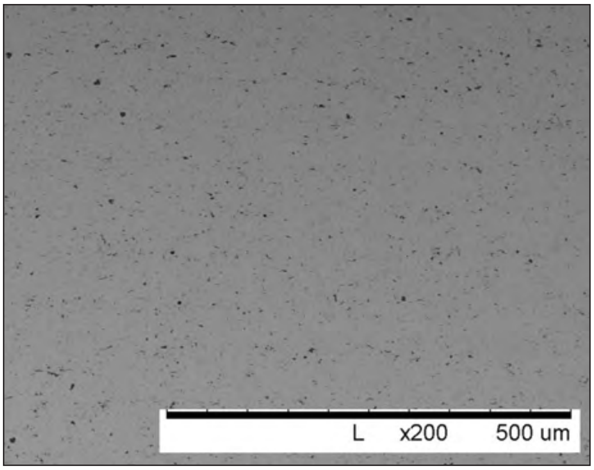


Fig. 2 — *Microstructure of the optimized coating.*

As the thermal spray industry grows, particularly in the power generation field, solutions that deposit coatings with torches capable of high deposition efficiencies and specially engineered powder morphologies enhancing deposition rates will have a competitive advantage. **iTSSe**

For more information: Shari Fowler-Hutchinson is product sales development manager, Saint Gobain, 1 New Bond St., M/S 525-203, Worcester, MA 01615, 508/795-5908, shari.fowler-hutchinson@saint-gobain.com, www.saint-gobain.com.

Considering Cold Spray for Additive Manufacturing

Julio Villafuerte*
CenterLine (Windsor) Ltd.
Windsor, Ontario

Thermal spray encompasses a variety of coating processes that apply metals, polymers, ceramics, cermets, and other materials onto metallic, polymeric, composite, and ceramic substrates. One of these processes is cold spray, which propels feedstock material against a substrate with enough kinetic energy to produce a dense coating or freeform at relatively low temperatures.

Cold spray is beneficial in applications that use heat-sensitive substrate materials or those with difficult-to-reach spray areas. One example involves spraying inside small-diameter, heat-sensitive tubes or bores to provide corrosion resistance. Cold spray produces deposits that are oxide-free and fully dense with acceptable mechanical properties. The process requires heating of a pressurized carrier gas (typically nitrogen or air) that is passed through a "DeLaval" convergent-divergent nozzle. The divergent section of the nozzle creates a supersonic gas jet as the carrier gas expands toward the nozzle exit. The spray material (in powder form) is injected into the gas jet either upstream or downstream of the nozzle throat.

Depending on the process temperature, each material requires a specific minimum particle velocity in order to successfully form a well bonded and dense deposit. The latter depends on the material's ability to plastically deform upon impact. Therefore, the less ductile the spray material, the more particle velocity required to produce bonding. In practice, a cold-spray-grade powder mix must contain, at least, one material that can easily deform upon impact with the substrate surface.

Commercial cold spray systems, including upstream and downstream injection systems, have been available for more than a decade. Cold spray was primarily designed for use in applications that are extremely sensitive to high process temperatures. Examples include:

- Dimensional restoration of bearing surfaces of cast aluminum and cast iron for automotive, marine, locomotive, and earthmoving equipment
- Manufacturing of electrically conductive buses on the delicate surface of coated conductive glass for heated glass applications
- Deposition of pure aluminum inside semiconductor processing chambers to reduce contamination
- Repair of corroded surfaces in magnesium components for commercial and military aircraft
- Restoration of corrosion damage in nuclear reactor vessels

In downstream injection cold spray, the spray powder is injected into the nozzle tube downstream of the throat. The major benefits of this approach include the ability to design and build smaller guns for greater accessibility and maneuverability and the ability to manufacture practical, low cost, durable engineered consumables that experience minimal erosion from the spray materials (Fig. 1).

In order to spray inside hard-to-access constrained spaces, some manufacturers developed special nozzle assemblies as seen in Fig. 2. Given the required short standoff distance (8-15 mm) and the low temperature of the process, cold spray is considered superior to other thermal processes with regard to surgically depositing material onto hard-to-reach heat-sensitive surfaces, and without the need for masking.

As manufacturing processes move forward, cold spray is becoming more attractive as an enabling technology for 3D printing or additive manufacturing. Traditional manufacturing relies on subtractive manufacturing techniques,

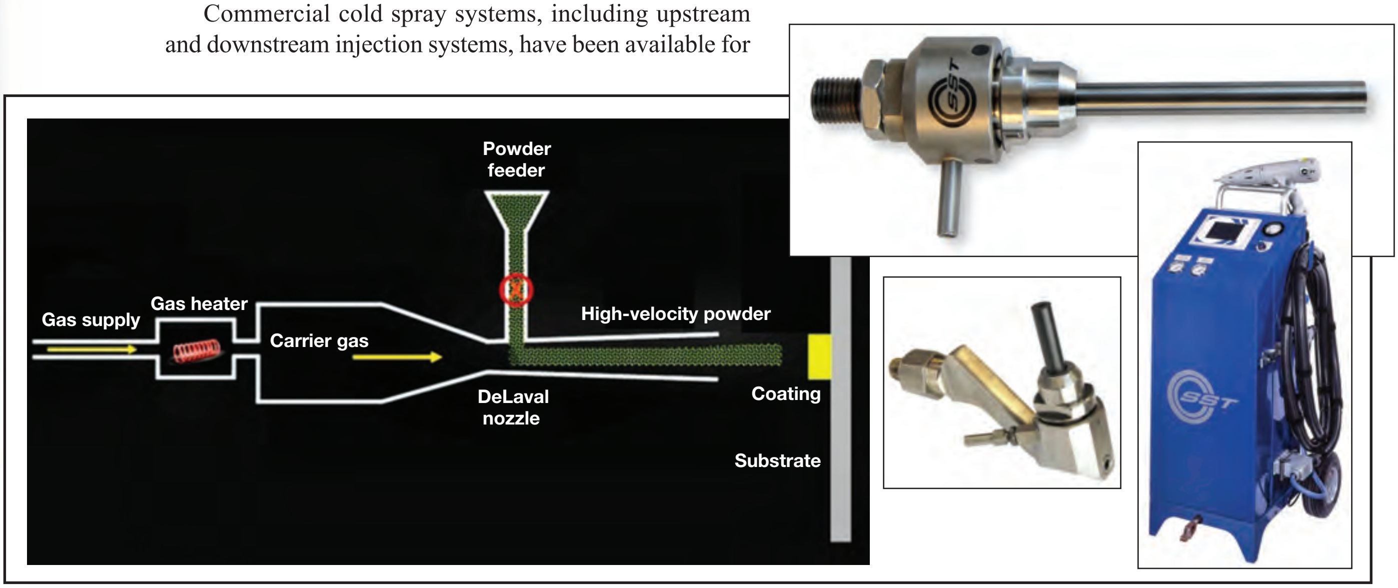


Fig. 1 — *Downstream injection system SST Series P with manual gun, showing modular easy-access nozzles. All images courtesy of CenterLine (Windsor) Ltd.*

**Member of ASM International and ASM Thermal Spray Society* and involves systematic removal of material from bulk shapes by cutting or drilling to arrive at a final shape. Additive manufacturing, on the other hand, builds shapes by precisely adding and consolidating layers of materials following a 3D digital model[1]. Depending on the nature of the materials involved (e.g., polymers vs. metals) as well as the application, a wide range of consolidation techniques may be used including photopolymerization, material jetting, binder jetting, extrusion, powder bed fusion (laser processing[3-5]), direct energy deposition (welding[2] and laser processing[3-5]).

Currently, additive manufacturing is mostly used to create functional prototypes or components made of polymeric materials because consolidation techniques for polymers are economical and readily available. At the other end of the spectrum, additive manufacturing of functional metallic parts has been limited by the metallurgical challenges associated with consolidating metals and other elevated temperature engineering materials of interest. Today, selected metals, such as titanium, cobalt, chromium, and nickel-base alloys, can be used to create high-value custom engineered components for aviation[6] and medical uses.

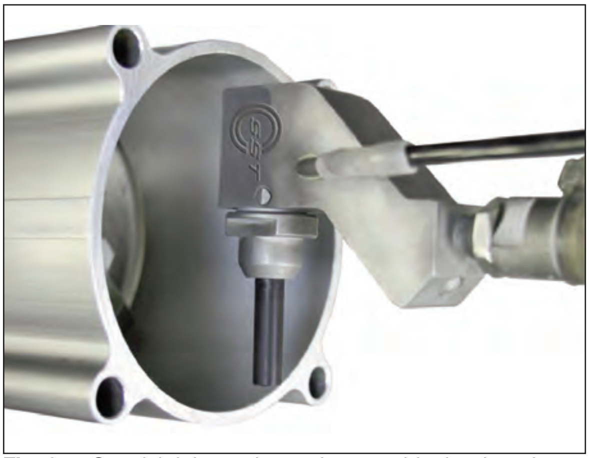


Fig. 2 — *Special right-angle nozzle assembly developed to access hard-to-reach surfaces.*

The geometrical quality of a complex 3D shape is dictated by spot size resolution (the smaller the better), which is why laser beams on powder beads are the preferred method for producing intricate geometries made of special alloys. Currently, the smallest spot size for cold spray deposition is about 4.0 mm, which is sufficient for 3D dimensional restoration of an assortment of metallic components in the world of remanufacturing or rapid prototyping (Fig. 3). However, a much smaller cold spray footprint would be required to produce a highly finished shape. Manufacturers are already work-

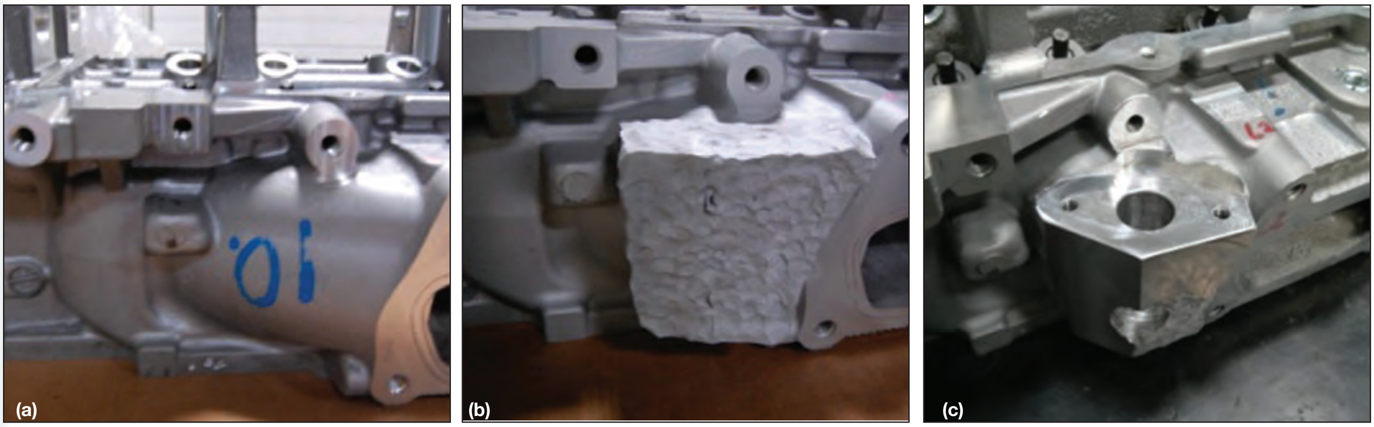


Fig. 3 — *Freeform feature added to a prototype machine component by cold spraying. (a) Prior to spraying, (b) as sprayed, (c) finished.*

ing on such developments and, in the near future, cold spray may become a reliable and practical technology that will enable 3D printing of engineering components at low temperatures. **iTSSe**

For more information: Julio Villafuerte is corporate technology strategist, CenterLine (Windsor) Ltd., 595 Morton Dr., Windsor, ON, Canada, 519/734-8868 ext. 4474, julio.villafuerte@cntrline.com, www.supersonicspray.com.

References

1. ASTM Standard F2792-12a, Standard Terminology for Additive Manufacturing Technologies. DOI: 10.1520/F2792-12A.

2. N.Kapustka and I. Harris, Exploring Arc Welding for Additive Manufacturing of Titanium Parts, *Weld. J.*, (3), p 32-35, 2014.

3. L. Xue, Laser Consolidation Methodology and Apparatus for Manufacturing Precise Structures, U.S. Patent 6,504,127, Jan. 7, 2003.

4. L. Xue and M.U. Islam, Free-Form Laser Consolidation for Producing Metallurgically Sound and Functional Components, *J. of Laser Applications,* Vol 12, Issue 4, p 160-165, 2000.

5. L. Xue, Y. Li, and S. Wang, Direct Manufacturing of Net-Shape Functional Components/Test-Pieces for Aerospace, Automotive, and Other Applications, *J. of Laser Applications,* Vol 23, Issue 4, 2011.

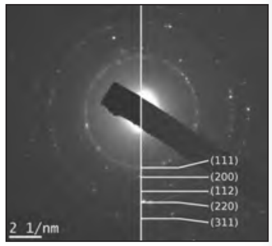
6. http://www.geaviation.com/company/additive-manufacturing.html

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. In addition to the print publication, *JTST* is available online through www.springerlink.com. For more information, visit asminternational.org/tss. Articles from the February and April issues, as selected by *JTST* Editor-in-Chief Christian Moreau, are highlighted here.

Lu_2O_3-SiO_2-ZrO_2 Coatings for Environmental Barrier Application by Solution Precursor Plasma Spraying and Influence of Precursor Chemistry

Émilien Darthout, Aurélie Quet, Nadi Braidy, and François Gitzhofer

Environmental barrier coatings are subjected to thermal stress in gas turbine engines introducing a secondary phase as zircon ($ZrSiO_4$). This is likely to increase the stress resistance of Lu_2Si2O_7 coatings made by induction plasma spray using liquid precursors. Precursor chemistry effect is investigated synthesizing ZrO_2-SiO_2 nanopowders using an induction plasma nanopowder synthesis technique. Tetraethyl orthosilicate (TEOS) as silicon precursor and zirconium oxynitrate and zirconium ethoxide as zirconium precursors are mixed in ethanol and produce a mixture of tetragonal zirconia and amorphous silica nanoparticles. Zirconium ethoxide uses precursor results in zirconia particles with diameters below 50 nm because of exothermic thermal decomposition of the ethoxide and its high boiling point with respect to solvent, while larger particles are formed when zirconium oxynitrate is employed. Coatings are synthesized in the Lu_2O_3-ZrO_2-SiO_2 system. After heat treatment, the doping effect of lutetium on zirconia grains inhibits zircon formation. Dense coatings are obtained using zirconium ethoxide because denser particles with a homogeneous diameter distribution create the coatings.

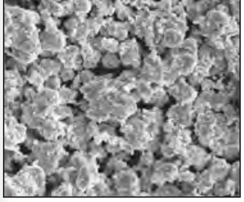


Selected area electron diffraction pattern of nanopowders produced from Zr oxynitrate +TEOS mixture (left) and Zr ethoxide +TEOS mixture (right). The Miller index of tetragonal zirconia is marked for the corresponding rings of the Debye Scherrer pattern.

Microstructures and Dielectric Properties of PZT Coatings Prepared by Supersonic Plasma Spraying

Guolu Li, Linsong Gu, Haidou Wang, Zhiguo Xing, and Lina Zhu

The microstructures and dielectric properties of PZT coatings prepared by supersonic plasma spraying were studied. Samples



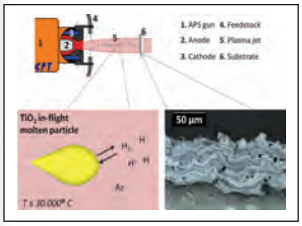
SEM micrograph of PZT powder prepared by solid-state reaction.

of PZT coatings were evaluated by various techniques, while the phases and microstructures of coatings were investigated by XRD, SEM, and TEM, respectively. Results show that coatings deposited on steel substrates have a dense microstructure, and there was no phase transformation during spraying. Additionally, the Curie temperature of PZT coatings was roughly 370°C by the investigation of dielectric constant.

Milestones in Functional Titanium Dioxide Thermal Spray Coatings: A Review

M. Gardon and J.M. Guilemany

The relationship between titanium dioxide and TS technologies is explored with a goal to provide detailed information related to the most significant achievements, lack of knowhow, and performance of thermal spray TiO_2 functional coatings in photocatalytic, biomedical, and other applications. The influence of thermally activated techniques such as atmospheric plasma spray and high-velocity oxygen fuel spray on TiO_2 feedstock based on powders and suspensions is revised; the influence of spraying parameters on the microstructural and compositional changes and the final active behavior of the coating were analyzed. Recent findings on titanium dioxide coatings deposited by cold gas spray and the capacity of this technology to prevent loss of the nanostructured anatase metastable phase are also reviewed.

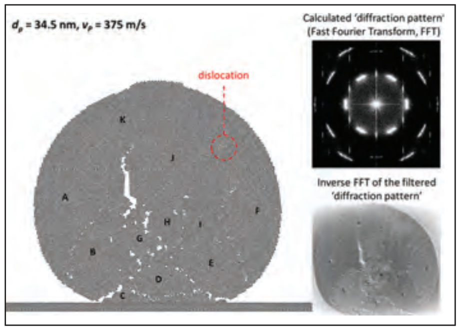


Schematic of an APS gun, interaction between TiO_2 particles and the plasma jet, and a representative obtained coating.

Impact Behavior of Intrinsically Brittle Nanoparticles: A Molecular Dynamics Perspective

B. Daneshian and H. Assadi

Impact behavior of intrinsically brittle materials at the nanoscale is a topic of growing interest in aerosol deposition and cold spraying of ceramic materials, for instance. The behavior of single-crystalline brittle nanoparticles upon impact on a rigid substrate, within the framework of a molecular dynamics model was examined. The model is based on the Lennard-Jones formulation, where brittleness is brought about by using a relatively small cut-off interaction distance. Simulations were carried out for different values of particle size and velocity. Results show that despite induced brittleness, particles start to deform without breaking into fragments, as particle size falls below a critical value. Deformation of particles can be accompanied by poly-crystallization and bonding to the substrate. Results are summarized into a parameter selection map, providing an overview of the conditions for successful deposition of intrinsically brittle materials.

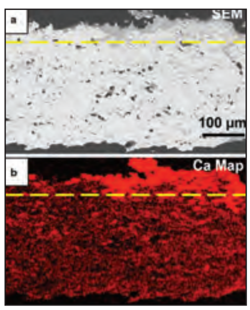


Snapshot of the atomic positions and its respective Fourier transform (calculated diffraction pattern) for a 34.5-nm brittle particle impacting a rigid substrate at a velocity of 375 m/s. Formation of sub-grains, labeled by letters, and dislocations are evident. Grain structure is clearer in the inset showing the inverse Fourier transform of the filtered diffraction pattern.

CMAS-Resistant Plasma Sprayed Thermal Barrier Coatings Based on Y_2O_3-Stabilized ZrO_2 with Al_3+ and Ti4+ Solute Additions

Bilge S. Senturk, Hector F. Garces, Angel L. Ortiz, Gopal Dwivedi, Sanjay Sampath, and Nitin P. Padture

Higher operating temperatures in gas-turbine engines made possible by thermal barrier coatings (TBCs) have a new problem: Environmentally ingested airborne silicate particles (sand, ash) melt on hot TBC surfaces, forming calcium-magnesium-alumino-silicate (CMAS) glass deposits. Molten CMAS glass degrades TBCs, leading to premature failure. Use of a commercially manufactured feedstock powder, in conjunction with the air plasma spray process, deposits CMAS-resistant yttria-stabilized zirconia-based TBCs containing Al_3+ and Ti_4+ in solid solution. Results from the characterization of these new TBCs and CMAS/TBCs interaction experiments are presented. The ubiquity of airborne sand/ash particles and demand for higher operating temperatures in future high efficiency gas-turbine engines necessitates CMAS resistance in all hot-section components. The versatility, ease of processing, and low cost offered by the process could benefit the development of these new CMAS-resistant TBCs.



(a) Cross-sectional SEM image of APS 7YSZ TBC heat treated with CMAS (1200°C, 24 h, in air) and (b) corresponding EDS Ca elemental map. Horizontal dashed lines indicate position of the TBC top surface before CMAS interaction.

ASMnews®

Nominations Sought for 2015 ASM/TMS Distinguished Lectureship in Materials & Society

Nominations are now being accepted for the ASM/TMS Distinguished Lectureship in Materials & Society. The Lecture was established in 1971 and is jointly sponsored by The Minerals, Metals & Materials Society (TMS) and ASM International. The topic of the lecture shall fall within these objectives:

- To clarify the role of materials science and engineering in technology and in society in its broadest sense.
- To present an evaluation of progress made in developing new technology for the ever changing needs of technology and society.
- To define new frontiers for materials science and engineering.

Qualifications of the lecturer include:

- A person experienced in national or industrial policy-making in the field of materials science and engineering.
- An eminent individual who has an overall understanding of technology and society, and how both are affected by developments in materials science and engineering.
- A person associated with government, industry, research, or education.

Nominations may be proposed by any member of either society. Submit nominations by September 1 for consideration. Recommendations should be submitted to the headquarters of either society.

For a complete listing of the rules and nomination form, visit www.asminternational.org/awards or contact Christine Hoover at 440/338-5151 ext. 5509, christine.hoover@asminternational.org, or Deb Price of TMS at awards@tms.org.

ASM INTERNATIONAL

Your "Brand New" ASM

Introducing the new ASM International. We are moving into the next century with a revamped brand platform, updated look, and exciting initiatives planned for the future. Read more about ASM's new logo and plans for the future on pages 8-9 in this issue.

Microscopy & Microanalysis 2014

The Microscopy & Microanalysis 2014 Conference and the 47th International Metallographic Society Annual Meeting will take place August 3-7 at the Connecticut Convention Center in downtown Hartford. Plan to attend the diverse technical program, educational short courses, excellent vendor exhibits, and fun social activities. Topics of particular interest to IMS members are listed below and the full list of events can be found through the IMS website at www.metallography.net.

Register for this event **by June 23** to receive an early bird discount. Learn more at www.metallography.net.

M&M 2014 MICROSCOPY & MICROANALYSIS AUGUST 3–7 • HARTFORD, CT

Short Course: Sunday, August 3

X17 – Metallography for Failure Analysis, instructor Frauke Hogue, FASM

Conference Symposia:
Monday – Thursday, August 4-7

A13 – Practical Applications and Analytical Trends of Metallography and Microstructure

P03 – Mineral Analyses from Laboratory to Spacecraft

P06 – Failure Analysis of Structural Materials: Microscopy, Metallurgy and Fractography

P07 – Microscopy and Characterization of Ceramics, Polymers, and Composites

P08 – Imaging and Analysis of Cultural Heritage Materials

...in this issue

ASM INTERNATIONAL

Submit news of ASM and its members, chapters, and affiliate societies to
Joanne Miller, editor, *ASM News* • ASM International, 9639 Kinsman Road, Materials Park, OH 44073
tel: 440/338-5151, ext. 5662 **fax:** 440/338-4634 **e-mail:** joanne.miller@asminternational.org

Contact ASM International at 9639 Kinsman Road, Materials Park, OH 44073 **tel:** 440/338-5151, ext. 0, or 800/336-5152, ext. 0 *(toll free in U.S. and Canada)* **fax:** 440/338-4634 **e-mail:** MemberServiceCenter@asminternational.org
website: www.asminternational.org

From the President's Desk

ASM's New Look, Invigorating the Chapters

Moving into the new centennial, ASM decided to align its brand with its vision and strategic positioning. With much excitement, the Board of Trustees approved a new logo at the winter meeting in Cleveland.

Why did we embark on a new logo? I simply see it as another *Red Queen Effect*—a clear and effective demonstration of our leadership to stay ahead of trends in both the materials world and business environment. Indeed, ASM has continuously evolved. The 100th Anniversary provided us a springboard for looking ahead with a visionary gleam. We have grown to serve materials professionals in the United States and the world beyond. Our roots are in the metals industry, and we have seen significant growth in metals-based materials, as well as nonmetallic and hybrid ones. The focus of our members and customers varies from chapter to chapter in continental North America, and even more vividly in other regions of the world. Further, ASM has demonstrated phenomenal resilience in the face of economic uncertainties. We have the tenacity to innovate and advance membership and chapter development, quality of content and delivery, student engagement, professional excellence, and societal partnerships. Our partnerships now extend to new initiatives such as NIST Manufacturing Programs and the National Network for Manufacturing. We remain the cynosure of all eyes in the global materials community.

Chapters are the pillars of ASM. Chapter visits are the most pleasant aspect of the ASM Presidency, to inform and to listen. Recently, I visited the Montreal and Ontario chapters as well as the Notre Dame and North Texas chapters. A common thread among them is their student activity and awards for posters and symposium presentations. In addition, these chapters are thinking out of the box with vibrant programming aimed at retention and growth. One chapter invited five incubator materials enterprises to present their strategies, with adjudication and awards by the audience! I also had a unique opportunity regarding friendships—to renew old ones and forge new ones.

ASM is indeed looking forward to the new century with a new look. Vice President Collins will soon lead a team effort in aligning our vision with the Strategic Plan. We need your ideas as we advance together.

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

Student News

Announcing: ASM Dome Design Competition!

ASM International Student Board Members are pleased to announce a new design competition open to all Material Advantage students at MS&T 2014! In an effort to bring "our home at the dome" to chapters and students across the country, student teams will design and build miniature geodesic domes. The competition will take place during MS&T and focus on the following areas: mechanical strength, aesthetics, and a design presentation. Top prizes are $1000, $750, and $500!

General Guidelines:

- Competition is open to graduate and undergraduate Material Advantage students.
- Each team of two to five students will design and build a geodesic dome out of their material of choice.
- A maximum of three domes may be submitted from each Material Advantage Chapter.
- Total project costs must not exceed $300.
- Dome must comply with geometric restrictions.
- Project teams are responsible for transporting their dome to MS&T14 in Pittsburgh. Teams may apply for shipping reimbursement up to $100 from ASM.

Register your team and find complete details on the new ASM website at www.asminternational.org/students3.

STUDENT POSTER COMPETITION

2014 North American Cold Spray Conference

North American Cold Spray
CONFERENCE AND EXPOSITION

A student poster presentation and prize competition is an exciting highlight of the 2014 North American Cold Spray Conference. The competition includes a review by expert judges and prizes awarded to students with the best posters. The competition will take place on September 16 at Domaine Château-Bromont in Bromont, Québec, Canada. Contact Dr. André McDonald at andre.mcdonald@ualberta.ca for more information.

Visit www.asminternational.org then click on Conferences & Expositions then Cold Spray 2014.

For more news about students winning awards and scholarships or serving as leaders in their Material Advantage chapters, turn to pages 4-7 of this issue.

Kishor M. Kulkarni Distinguished High School Teacher Award

The ASM Materials Education Foundation is pleased to accept nominations for the **Kishor M. Kulkarni Distinguished High School Teacher Award.** This award was established through a generous donation by Dr. Kishor M. Kulkarni and his family to honor and recognize the accomplishments of one U.S. high school science teacher each year who has demonstrated a significant and sustained impact on pre-college age students.

Caryn Jackson (right) of Tolles Career & Technical Center in Columbus, Ohio, accepted the 2013 Kishor M. Kulkarni Distinguished High School Teacher Award from Dr. Kulkarni at MS&T 2013.

Award Eligibility:

- Candidate must be a full or part-time actively employed U.S. high school teacher.

Suggested Candidates:

- Past recipients of ASM Foundation K-12 Teacher Grants
- Graduates of the ASM Materials Camp-Teachers program

Award:

- Cash Grant: $2000 + recipient's travel cost up to $500 to receive the award at MS&T14.

Nomination Details:

- Any ASM member may forward a qualified application/nomination for consideration.
- Current and past ASM & ASM Foundation Trustees may nominate a U.S. teacher candidate who does not belong to these two categories.

Nomination deadline is June 30. For more information and to access the form, visit www.asmfoundation.org. Submit nomination along with supporting documents to jeane.deatherage@asminternational.org.

Attention STEM Teachers!

2014 ASM Materials Camp-Teachers Schedule

Attend a one-week professional development session this summer – at no cost to you! Learn some exciting, simple, low-cost experiments to engage your students. Here is your opportunity to participate in a hands-on lab experience that shows you how to use applied engineering techniques in the classroom. Review the schedule to find a convenient location near you.

To apply, visit www.asmfoundation.org. For more information, contact Jeane Deatherage at jeane.deatherage@asminternational.org.

Dates	Locations
June 2-6	Meridian, Miss.
June 9-13	Kansas City, Mo.; Oak Ridge, Tenn.; Tuscaloosa, Ala.
June 16-20	Calgary, Canada; Cleveland; Columbus, Ohio (Year 2); Dayton, Ohio; Houghton, Mich; Houston
June 23-27	Greenville, S.C.; Hammond, Ind.; New Orleans; Newark, Del.; Pittsburgh; Salt Lake City; Urbana, Ill.
July 6-11	Albuquerque, N.M.
July 7-11	Albany, N.Y.; Chicago; Indianapolis; Long Beach, Calif.; Newark, N.J., and Ottawa, Canada; Vancouver, Wash.; Youngstown, Ohio
July 14-18	Ann Arbor, Mich.; Boston; Hattiesburg, Miss.; Lehigh Valley, Pa.; Montgomery County, Md.; Virginia Beach, Va.
July 21-25	Akron, Ohio; Butte, Mont.; Cincinnati; Columbus, Ohio (Year 1); DeKalb, Ill.; Oxford, Miss.
July 28-August 1	Columbus, Ohio (MSP); Fort Wayne, Ind.; Millersville, Pa.; Naperville, Ill.; San Antonio
August 4-8	Madison, Wis.; Ogden, Utah; Richmond, Va.

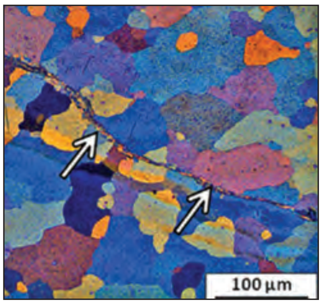
IMC: Revised Rules, Fewer Classes, Larger Prize Money

The International Metallographic Contest (IMC), an annual event cosponsored by IMS and ASM International to advance the science of microstructural analysis, just got more enticing. Updates to the rules recently approved by the IMS Board are designed to encourage participation and to simplify the process for participants to submit entries. There are now five different classes of competition—down from 11 classes—covering all fields of optical and electron microscopy:

Class 1: Optical Microscopy—All Materials
Class 2: Electron Microscopy—All Materials
Class 3: Student Entries—All Materials (Undergraduate or Graduate Students Only)
Class 4: Artistic Microscopy (Color)—All Materials
Class 5: Artistic Microscopy (Black & White)—All Materials

All of the classes have increased prize money! Best-In-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of $3000.

For a complete description of the new rules, tips for creating a winning entry, and judging guidelines, visit www.metallography.net. Deadline for entries is **July 19.**



The weld interface in an extrusion-welded magnesium alloy. From the 2013 IMC Jacquet-Lucas Award winning entry.

Chapter News

Notre Dame Hosts President Ravindran

ASM president Ravi Ravindran visited the Notre Dame Chapter on March 10. It was déjà vu for Ravi, as he visited the Chapter as ASM trustee in 1999 when Walter Hornberger was the chair. Ravi congratulated the executive for his visionary approach in partnering with sister societies. It was a joint ASM-AFS meeting with 50 attendees and a collegial environment.

Left to right: Nassos Lazaridis, ASM president Ravindran, David Guisbert (chair), Sarah Leach, Mike Stanage (vice chair), Robert Merryfield, Jeffery Allen, and Walter Hornberger (past chair).

Rocky Mountain Honors Williams and Awards Scholarships

The ASM Rocky Mountain Chapter recently honored Prof. David B. Williams, FASM, with its 2014 Charles S. Barrett Silver Medal and Lectureship. A world-renowned electron microscopist, now serving as the dean of engineering at The Ohio State University, Williams presented a lecture entitled "Reflections on the Structure of Metals: From Viewing the Small World to Leading on a Larger Stage."

The Chapter also awarded scholarships to four undergraduates in the Metallurgical and Materials Engineering Department at Colorado School of Mines. Recipients of the $250 awards include Madeline Hatlen, Brittany Bofenkamp, Tyrel Jacobsen, and Ryan Peck. The scholarships are awarded annually to students who excel academically and/or provide strong support to ASM or Material Advantage.

David Williams, FASM, accepts the Charles S. Barrett Silver Medal from ASM Rocky Mountain Chapter chair Jim Fekete.

From left: Prof. Kip Findley (Material Advantage Chapter advisor); Brittany Bofenkamp, Prof. John Speer (Scholarship Committee chair); Madeline Hatlen, Jim Fekete (Chapter chair), and Ryan Peck. Not pictured is Tyrel Jacobsen.

Boston MAdvantage

Boston University's Material Advantage Chapter leaders met with ASM trustee Jackie Earle for lunch. The BU MAdvantage Chapter works with the Boston ASM Chapter on "Materials Experience" events to educate local high school students about materials engineering. They also organize a successful Career Panel Discussion to inform members and students about local companies and opportunities. Pictured are Ph.D. students Yang Yu, Zenan Qi, Shizhao Su, Deniz Cetin, Ryan Eriksen, ASM trustee Jackie Earle, and BU MA faculty advisor Soumendra Basu.

Pittsburgh Young Member Night

On February 20, the ASM Pittsburgh Golden Triangle Chapter hosted the 28th annual Young Members Night (YMN) at the University Club in Pittsburgh. Young Members Night included a poster competition for graduate and undergraduate students, a presentation by student speaker Brian DeCost from Carnegie Mellon University, a presentation from ASM trustee Jacqueline Earle on making the most of an engineering career, and an awards ceremony for Outstanding College Seniors and the PCEAS junior and sophomore. The well-attended event was organized by the YMN Committee.

Poster prize winners (left to right): Sudipto Mandal, Rachel Ferebee, Tugce Ozturk, Jann Grovogui, Natasha Gorski, Holly Fitzgibbon, Elise Hall, Tejank Shah, and Tim Hosch (YMN chair).

Detroit Rewards Student Achievement in Materials

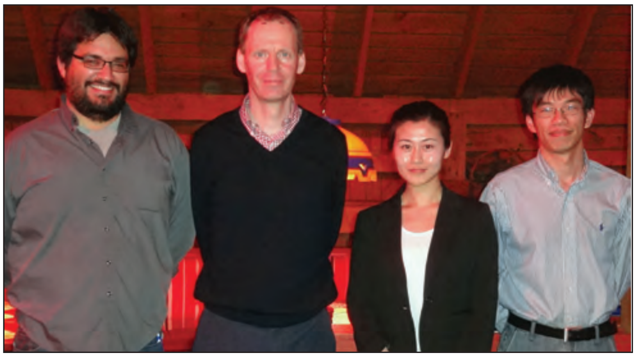
As part of its Student Outreach Program, the ASM Detroit Chapter judged a "Best Use of Materials Award" at the 2014 Michigan Regional Future Cities Competition. The nationwide competition challenges middle school students to design and create a futuristic city. First-time entrant, Priest Elementary/Middle School from Detroit, won for their city, "New Huron." Set in southeastern Michigan 500 years in the

For a list of upcoming ASM Training Courses, see our ad on page 64 of this issue.

The winning team, shown accepting the award from James Boileau (back row) of the ASM Detroit Chapter includes (left to right): Quiana Long-McCrory (mentor), Adriana Ayala, Adan Tostado, Nadia Zavala, and Linda Keteyian (teacher). Congratulations to Priest Elementary/Middle School!

future, their city offers healthy beachfront living. Cities were judged on the students' vision of what kinds of advanced materials would be used, as well as the variety and use of materials in their models.

Hartford's Students Shine



Three students presented their research on April 8 during the ASM Hartford Chapter's Student Night. Shown, from left, are Mauricio Andres Gordillo, Rainer Hebert (vice chair), Chechen C. Wang (who gave the first-place talk "Accelerating Materials Property Predictions Using Machine Learning"), and Zheng Ren.

Chapter Volunteer Honor Roll Nominations

The ASM Volunteerism Committee is looking for your chapter champion volunteers. The Chapter Volunteer Honor Roll will recognize chapter volunteers whose performance is considered exemplary to the success of ASM. We invite all chapters to nominate one volunteer from their Chapter for the Honor Roll. Chapter Executive Committees should select a member who is currently serving the chapter as a volunteer in an ongoing capacity. These names will appear in an "ASM Volunteer Honor Roll" article in this section of the August issue and each volunteer will receive an ASM MVP tie or scarf in recognition of their contributions.

Please submit your volunteer's name **by June 15** by visiting www.asminternational.org. The nomination form link can be found on the **About Local Chapters** page. This is a unique way to celebrate your most valued volunteers. We look forward to your submissions.

Alpha Sigma Mu, CT Alpha Chapter 2014 Inductees were also recognized during the ASM Hartford Chapter's Student Night. From left to right: Harold Brody (Chapter advisor), Jordan Parley, Pamela Dyer, Alexandra Merkouriou, Alexander Reardon, Benjamin Bedard, Shannon Gagne, and Timothy James. Not shown is Douglas Hendrix.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Steven Ashlock
Ceramic Engineering Senior
Missouri University of Science & Technology

One minute can change a life. That's what happened to Steven Ashlock his first day on the campus at Missouri University of Science and Technology. "I enjoyed chemistry in high school and thought I wanted to be a chemical engineer," Ashlock recalls. But he spoke with a professor in Ceramic Engineering and changed his major that day. "I like working more with my hands in the lab—seeing what you can pull out of the earth and making it useful."

Now a senior, Ashlock is giving his own time to "change a life." He is president of the Keramos ceramic engineering society, a delegate for MS&T, and vice president of his university's ASM Material Advantage Chapter. "Older students helped me with homework and introduced me to professors," he explains. "Now I want to be a mentor to younger students." He regularly gives demos to high school students and promotes STEM education. "Getting them excited about science is very rewarding," says Ashlock. He's pleased to say that several students joined the Ceramics Department after these visits.

Ashlock finds ASM helpful in a changing industry and says, "I love keeping up on newer technologies and using the journals for help with papers." He also learned collaboration and leadership skills in the student professional societies. "Being involved helped me come out of my shell and prepared me as a future leader in the industry. It makes me a better engineer—because that's the ultimate goal."

As he prepares to join the workforce, Ashlock plans to stay involved in ASM and serve as a contact for MS&T students. "It doesn't take that long to volunteer or even just talk about ASM in daily life. You may mention something that inspires someone to say 'I want to do that for a living.' Never underestimate the power of your words."

Members in the News

Singhal Elected President of Washington State Academy

Subhash C. Singhal, FASM, Battelle Fellow Emeritus at the Pacific Northwest National Laboratory, was recently named President of the Washington State Academy of Sciences. He became a founding member of the academy in 2008. He is also a member of the National Academy of Engineering. The Washington State Academy of Sciences is patterned after the National Academies, and provides expert scientific and engineering analysis to inform public policy-making, and works to increase the role and visibility of science in the State of Washington.

Asphahani Receives NACE Founders Award

Dr. Aziz Asphahani, FASM, was selected as the recipient of the 2014 NACE Founders Award for his influence on corrosion science and education, as well as his longstanding commitment to the mission and goals of the NACE Foundation. He was one of the inaugural members of its Board of Directors, helping to shape its direction. As chairman of the ASM Educational Foundation in 2004, he championed the partnership between the ASM Materials Camps for Teachers and the NACE Foundation and paved the way for the success of the cKit program. He also played a key role in the curriculum development of the corrosion engineering program at the University of Akron, involving the NACE Foundation. Asphahani is president and CEO of QuesTek Innovations LLC., Evanston, Ill. The award was presented on March 12 at the NACE 2014 meeting in San Antonio.

Suárez's Phase II Proposal Funded

The National Science Foundation (NSF) announced that it is funding the second phase of a new Nanotechnology Center for Biomedical, Environmental and Sustainability Applications hosted by the University of Puerto Rico-Mayagüez (UPRM). **Prof. O. Marcelo Suárez** of UPRM explains that a strong point of their proposal was the impact on local public schools, many serving low-income households. More than 340 students from these schools are affiliated with the Center through their Materials Science & Engineering clubs. The Phase II funding provides $5 million for five years. The NSF program CREST (Centers for Research Excellence for Science & Technology) in 2008 granted the initial funding to establish the Nanotech Center.

Diversity Summit

The First TMS Diversity Summit on Creating and Sustaining Diversity in the Minerals, Metals, and Materials Professions will be held July 29-31 in Washington. Beyond keynotes from industry leaders, the summit will include interactive working sessions focusing on practical applications for sowing seeds of diversity and leadership and harvesting improvement in oneself and one's organization. Among the organizers are these ASM leaders: **Elizabeth Holm, FASM** (Carnegie Mellon University), **Diran Apelian, FASM,** (Worcester Polytechnic Institute), **Julie Christodoulou, FASM,** (Office of Naval Research), **Tresa Pollock, FASM** (University of California, Santa Barbara), and ASM trustee **Linda Schadler, FASM** (Rensselaer Polytechnic Institute). Christodoulou and Schadler will also be Summit speakers, as will ASM's first female president (2008), **Dianne Chong, FASM** (Boeing).

TMS Materials Bowl

University of Florida 2014 Materials Bowl winning team

For the eighth year in a row, a popular game-show-styled knowledge contest pitted students from 12 universities against each other to determine the championship contenders. Students answered individual and team questions based on diverse areas of materials science and engineering.

The University of Florida team – **Steven Chiu, Hunter Henderson, Glenn Bean,** and **Peter Feldtmann** – took home the championship trophy, $250 for each team member, and $500 for their school's Material Advantage chapter.

Runner-up was the team from University of Illinois Champaign-Urbana, who received $500 for its Material Advantage chapter. Team members include **Meher Bharucha, Kaitlin Tyler, Liv Dedon,** and **Maxwell Li.**

Preciado Awarded Fellowship

Edwin Sabas Preciado was among 18 graduate students at the University of California, Riverside, to receive a Graduate Research Fellowship (GRF) from the National Science Foundation (NSF) this year. The NSF GRF Program provides three years of financial support within a five-year fellowship period. Preciado, a second-year materials science and engineering Ph.D. student, works with Ludwig Bartels, a professor of chemistry. He is developing single layer transition metal dichalcogenide films—a semiconductor material said to have ultimate thinness as well as improved optical properties over silicon—that will be used in the next generation of microchips.

Material Advantage Grad Honored as Young Scientist

David Kisailus, the Winston Chung Endowed Chair of Energy Innovation at the University of California, Riverside's Bourns College of Engineering, has been named a Kavli Fellow. The Kavli Foundation selects young scientists as Fellows to support scientific research, honor scientific achievement, and promote public understanding of scientists and their work. Kisailus, a former Material Advantage member, is now an associate professor in the Dept. of Chemical and Environmental Engineering—part of the Materials Science and Engineering Program—and works in the field of biomimetics.

CMU's Real World Engineering Program

Fourteen Carnegie Mellon University (CMU) engineering students were selected to network with industry leaders and receive valuable job advice March 12-14 during the annual Real World Engineering (RWE) Program in Washington. Students shadowed engineering professionals, attended a networking reception with alumni and D.C. industry professionals, and toured Lockheed Martin's Energy Solutions and Space Experience Center. **Benjamin Paren,** a sophomore majoring in materials science and engineering, and engineering and public policy, from Naperville, Ill., praised the RWE program, "Many doors were opened for me in terms of understanding what kinds of jobs I could have in the future."

PM Champion Awarded for Advancing Technology Applications

Robert J. Dowding, research manager for materials and manufacturing science, U.S. Army Research Laboratory (ARL), was selected to receive the first-ever Vanguard Award from the Metal Powder Industries Federation (MPIF). The award recognizes powder metallurgy (PM) industry champions from the end-user community whose long-time promotion of the technology has contributed to the expansion of powder metal applications. The award presentation will take place at the PM2014 World Congress, May 18-22, in Orlando.

TMS Student Poster Contest Winners

Sixty posters were entered by individuals or teams of students in this year's TMS Technical Division Student Poster Contest held in San Diego in February. Congratulations to these ASM joint student members who were among this year's winners:

Best of Show

Undergraduate (Structural Materials Division): "Honeycomb Materials for Improved Automobile Crashworthiness," **Connor Slone, Kit James, You Li,** and **Peter Anderson** (professional ASM member), The Ohio State University; *Graduate* (Materials Processing & Manufacturing Division): **Tara Power**, McMaster University.

Undergraduate Winners

Electronic, Magnetic & Photonic Materials Division: **Marc Doran,** The Ohio State University; Extraction & Processing Division: **Brian Jamieson**, McMaster University; Light Metals Division: **Raul Marrero** and **Oscar Marcelo Suarez,** University of Puerto Rico, Mayagüez Campus; Materials Processing & Manufacturing Division: **Mary Gallerneault**, McMaster University.

Graduate Winners

Extraction & Processing Division: **Sean Dudley** and **Grant Wallace,** Montana Tech of the University of Montana; Light Metals Division: **Abu Syed Humaun Kabir, Mehdi Sanjari, Jing Su,** and **Stephen Yue** (professional ASM member), McGill University; Structural Materials Division: **Zhiqian Sun, Jan Ilavsky** (professional ASM member), The University of Tennessee, Argonne National Laboratory.

Medical Materials Database— New Neurological Module!

This summer, ASM and Granta will launch a new Neurological Module in the **Medical Materials Database,** providing a peer-reviewed and reliable source of materials-related data for neurological device design. Current database users have FREE access to a preview version of this new module.

The Neurological Module preview is fully integrated with the existing Medical Materials Database, which includes Orthopaedic and Cardiovascular Modules. The preview contains records describing a representative and diverse sample of neurological devices and the materials (with specific grades, coatings, and more) used in those devices. The full release in June will include nearly five times more device records than are included in the preview, plus additional materials, drugs, and coatings.

For more information, contact Scott Flowers, Account Manager, at scott.flowers@asminternational.org, 800/336-5152 ext. 5230, or 440/338-5151 ext. 5230.

IN MEMORIAM

Prof. Emeritus Joachim (Jockel) V.R. Heberlein, FASM, TS–HoF, a pillar of the thermal spray community, died on February 17. From Minneapolis, he was beloved among the faculty and staff of the M.E. department at the University of Minnesota. Heberlein contributed greatly to the ASM Thermal Spray Society, having served as chair of the JTST Editorial Committee for 10 years (1996-2006) and chair of the TSS Awards Committee for seven years (2004-2001). He was also a past member of the Program Committee, Nominating Committee, Academic Advisory Council, and ITSC 2003 organizing committee. He was named ASM Fellow in 2001, inducted into the TSS Hall of Fame in 2004, and received a number of other awards, including the ASM Allan Ray Putnam Service Award in 2009 and the TSS President's Award in 2013. See full obituary on page 3 of *iTSSe* in this issue.

Discover what's possible through ASM Education.

Advance your skills, learn from our respected international experts, and earn CEUs. ASM's accredited courses offer a variety of learning options that fit your career goals, schedule, and budget. Stay current in your career or stand out with an ASM certificate program.

Course	Date	Location
Introduction to Thermal Spray	7/7-8	ASM World Headquarters
Welding Inspection and Quality Control	7/7-10	ASM World Headquarters
Thermal Spray for Gas and Oil Industries	7/9	ASM World Headquarters
Thermal Spray Safety Management	7/10	ASM World Headquarters
Introduction to Metallurgical Lab Practices	7/15-17	ASM World Headquarters
Heat Treating for the Non-Heat Treater	8/4-6	ASM World Headquarters
Metallography for Failure Analysis	8/11-14	ASM World Headquarters
Fractography	8/11-14	ASM World Headquarters
Mechanical Testing of Metals	8/18-21	ASM World Headquarters
Nitinol for Medical Devices	8/19-21	ASM World Headquarters
Introduction to Polymers and Polymer Testing	8/25-28	IMR Test Labs Lansing, NY, USA
Steel Metallography	8/25-28	ASM World Headquarters

FOR MORE UPCOMING COURSES OR TO REGISTER, VISIT: asminternational.org/learning

ASM INTERNATIONAL

AUTHORIZED IACET PROVIDER

products & literature

Carl Zeiss X-ray Microscopy, formerly Xradia Inc., Thornwood, N.Y., announced that Toshiba Nanoanalysis Corp., Kawasaki, Japan, selected the ZEISS Xradia 520 Versa **3D x-ray microscope** (XRM) to expand its analysis lab's capabilities. The microscope was designed for studying hard-to-image materials and the evolution of their microstructures within industrial and scientific laboratory environments. It extends the boundaries of nondestructive 3D imaging in situ and in 4D (over time) with advanced contrast tuning capabilities, extensive filtering options, and enhancements delivering greater accuracy and workflow efficiency. www.zeiss.com/microscopy.

For production environments that require quality and repeatability, AbrasiMatic 450 from Buehler, Lake Bluff, Ill., is a fully automated 18-in. (455 mm) **abrasive cutter** that delivers consistent results. It comes fully equipped with 3-axis motion and a full suite of advanced cutting features that save time and protect the integrity of the cut surface. With both *X* and *Z* wheel motion and *Y* table motion, larger samples can be easily sectioned, while serial cutting can be programmed and recalled for repeated use. New capabilities allow users to secure methods with a PIN, preventing accidental changes or deletion. www.buehler.com.

EOS of North America, Novi, Mich., expanded its **powder metal materials** portfolio with EOS Titanium Ti64ELI and EOS StainlessSteel 316L to open up new fields of application for components fabricated by laser sintering of powder metals. Ti64ELI provides high-detail resolution while StainlessSteel 316L features high ductility for medical applications such as surgical instruments and orthopedics. Parts built in EOS Titanium Ti64 have a chemical composition and mechanical properties corresponding to ASTM F136, and parts built from EOS StainlessSteel 316L have a chemical composition corresponding to ASTM F138. www.eos.info.

ad index

classifieds

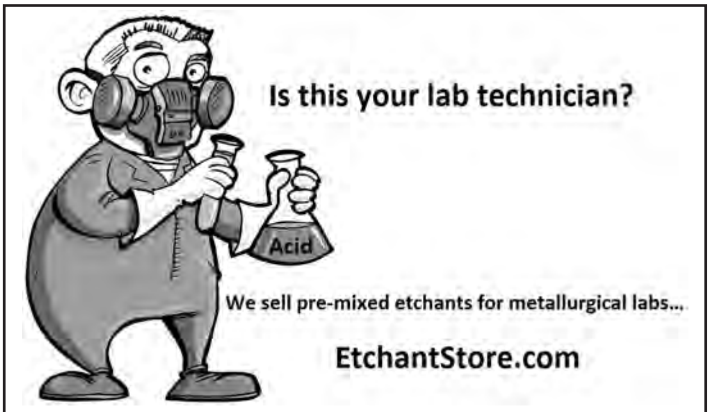
FACULTY POSITION IN METALLURGICAL & MATERIALS ENGINEERING

The Department of Metallurgical & Materials Engineering (MTE) at The University of Alabama (UA) seeks outstanding applicants at the Assistant/Associate or Full Professor level. We are looking for a strong candidate in the areas of transport phenomena in materials processing, chemical-metallurgy, and ferrous and nonferrous process metallurgy. Applicants must hold a Ph.D. degree in Metallurgical Engineering or Materials Science and Engineering. The successful candidate will be expected to develop a strong externally funded research program and to excel in teaching.

The University of Alabama has experienced unprecedented growth and prosperity over the last decade including significant increases in undergraduate and graduate enrollment within the College of Engineering and the completion of the new North Engineering Research Center which has more than 100,000 square feet dedicated to materials research. The MTE department is currently comprised of nine full-time faculty members with active funded research grants and enrolls more than 130 undergraduate and graduate students. The Department has a strong history of research and teaching in the areas of solidification science and molten metal processing, materials characterization, mechanical behavior, thin film deposition, magnetic materials and devices, and computational materials science. More information about the Department of Metallurgical & Materials Engineering can be found at http://mte.eng.ua.edu/.

Review of applications will begin on June 30, 2014 and will continue until the position is filled. Applicants must submit a cover letter, complete curriculum vitae, a research statement, a teaching statement, and a list of at least three references with contact information. Applicants are required to apply electronically at http://facultyjobs.ua.edu/postings/35001. Inquiries can be addressed to the Search Committee Chair via email (mtefacsearch@eng.ua.edu) or via surface mail (Department of Metallurgical & Materials Engineering, Box 870202, The University of Alabama, Tuscaloosa, AL 35487-0202).

The Department is committed to building a diverse educational environment and encourages applications from underrepresented groups including minorities, women, and people with disabilities. The University of Alabama is an equal opportunity, affirmative action, Title IX, Section 504, ADA employer. Salary is competitive and commensurate with experience level.



To advertise in the classifieds, or to order article reprints, please contact Diane Whitelaw at 440/338-5151, ext. 5240; diane.whitelaw@asminternational.org.

Visit the new www.asminternational.org today.

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

JUNE 2014
Composites Testing & Characterization

Highlighting:
- Automotive Composites Testing
- Resonant Ultrasound Spectroscopy
- Dynamic Testing of Composites

Special Supplement:
HTPro newsletter covering heat treating technology, processes, materials, and equipment, along with Heat Treating Society news and initiatives.

Advertising Bonus:
- Signet Ad Study

Advertising closes May 5, 2014

JULY 2014
Thermal Processing/ Surface Engineering

Highlighting:
- Surface Modification Techniques
- Advances in Cold Spray
- Powder Compaction Manufacturing

Advertising closes June 4, 2014

Contact us:
9639 Kinsman Road
Materials Park, OH 44073-0002
440/338-5151
Fax: 440/338-4634
www.asminternational.org/AMP

Subscriptions/Customer Service:
800/336-5152, ext. 0
MemberServiceCenter@asminternational.org

Sales Staff:
Skip Wolfe, *Director, Sales and Marketing*
440/338-5151 (ext. 5226)
Fax: 440/338-8542
skip.wolfe@asminternational.org

***AM&P*/ASM Web Media**
Erik Klingerman,
National Sales Manager
440/338-5151 (ext. 5574)
Fax: 440/338-8542
erik.klingerman@asminternational.org

***iTSSe*/Affiliate Sponsorships**
Kelly Thomas, CEM.CMP
National Account Manager
440/338-1733
Fax: 614/948-3090
kelly.thomas@asminternational.org

STRESS RELIEF

Snore-no-more pillow

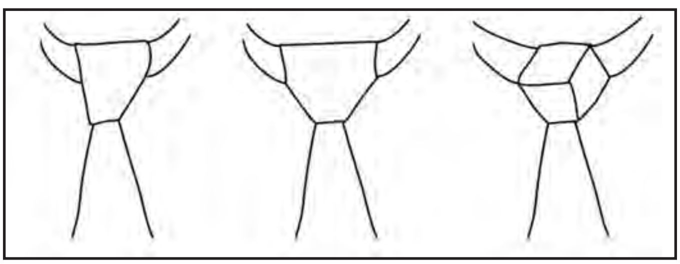
Available from Hammacher Schlemmer, New York, the Snore Activated Nudging Pillow features a built-in microphone that listens for snoring. Once detected, the sleeper is gently nudged to change positions. The pillow inflates an internal air bladder that causes the nudging, without a painful jab from someone being kept awake. The elevation alone could open a person's airways to stop the snoring.

The pillow allows the user, or sleepless companion, to adjust the microphone for light or heavy snoring, while the air bladder can be manually inflated to a desired thickness between 4 and 7 in. It automatically deflates back to its original thickness. The device also has a 30-minute delay setting that allows one to fall asleep without triggering inflation. Researchers used the pillow in a study a few years ago and found that the longest snoring episodes were reduced by 43.8%. *www.hammacher.com/ Product/83483.*

How many ways to tie a tie?

Most men do not consider more than one, two, or maybe three ways to tie their tie, if they tie one at all—but the fact is, there are far more ways to do it than most would ever imagine. In 1999, researchers at the University of Cambridge, UK, came up with a mathematical language to describe all the actions that can be performed in tying a tie and used it to calculate that the total number of possible outcomes was a reasonable 85. However, researchers at KTH Royal Institute of Technology, Stockholm, now say that number is far too small because it leaves out many possibilities. They extended the mathematical language and used it to create a new upper limit—177,147.

Researchers adjusted the 1999 parameters and added terminology for describing tie movements. After putting it all together, they used the revised math language to calculate the new total number of possible tie knots. This may not be the last word, however, as some of the parameter assignments, such as maximum winds, could be adjusted for longer ties or those made of thinner material. *www.kth.se/en.*

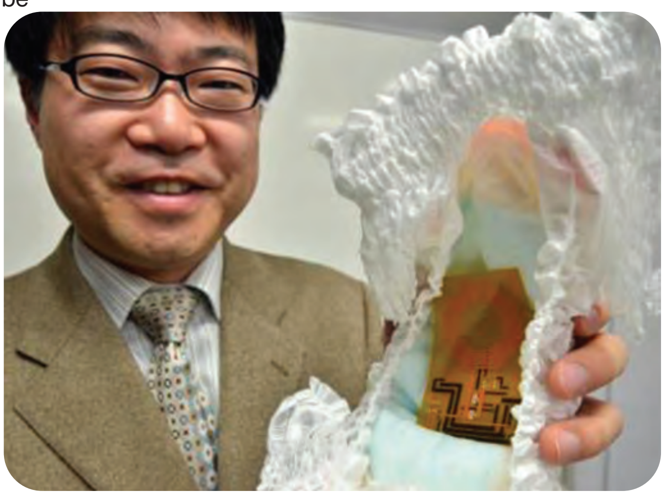


Different examples of tie knots. Left, a Four-in-Hand; middle, a Double Windsor; right a Trinity. The Four-in-Hand and Double Windsor share the flat facade, but have different bodies that produce different shapes. The Trinity has a completely different facade, produced by a different wind and tuck pattern. Courtesy of arXiv:1401.8242 [cs.FL].

Dirty diaper? New sensor knows for sure

A disposable organic sensor that can be embedded in a diaper to wirelessly alert caregivers was developed by researchers at the University of Tokyo. The flexible integrated circuit printed on a single plastic film transmits information and receives its power wirelessly. According to researchers, it could potentially be manufactured very inexpensively.

Sensors could be put directly on the skin like a plaster, in place of the ring-shaped devices currently used in hospitals to monitor pulse and blood oxygen levels, say researchers. The flexibility of a single sheet of plastic film reduces discomfort and can be applied to a larger number of places than other options—offering greater potential to monitor well-being. The prototype system is capable of monitoring wetness, pressure, temperature, and other phenomena that cause a change in electrical resistance, but the team would like to refine it to reduce power consumption before it goes into widespread use. *www.u-tokyo.ac.jp/en.*



SUCCESS ANALYSIS

Former LLNL researchers Lloyd Hackel (left) and Brent Dane with a robot used to laser peen parts for aviation and other industries at MIC's Livermore R&D Center. Courtesy of Julie Russell/LLNL.

Specimen Name: Laser Peening for Aerospace Parts

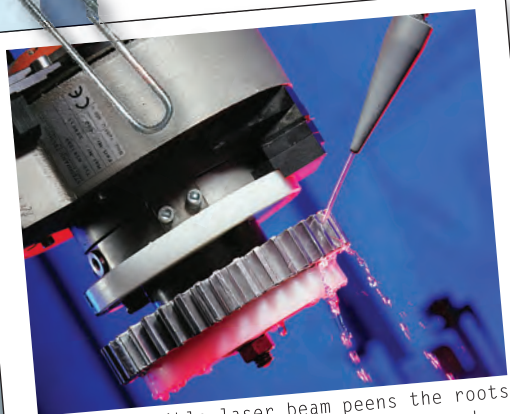
Vital Statistics:

One method widely used to strengthen metal is peening, which involves bombarding it with tiny metal balls known as shot to induce a layer of compressive stress at the surface to prevent fatigue and reduce corrosion. Taking it up a notch from traditional shot peening is laser peening, a process that induces deep compressive stress to significantly extend the service life of components.

Laser peening, invented in the 1970s, uses short bursts of intense laser light to create pressure pulses on metal surfaces, which generate shock waves that travel into the metal and compress it. In the early days, the technology was not suitable for commercial parts due to high costs and slow lasers. Now, one version of modern laser peening employs a unique, high-energy laser developed at Lawrence Livermore National Laboratory (LLNL) fired at the surface of a metal part to generate pressure pulses of one million psi. These pulses propagate through the part to plastically compress the metal and generate an area of residual compressive stress. Peening helps components last longer and resist cracking. Applications include aerospace engine blades and wings, as well as turbine blades used in gas and nuclear reactors for power generation.

Success Factors:

Lloyd Hackel and Brent Dane—former LLNL researchers with nearly 40 years of combined experience—began developing commercial laser peening technology while working on a project funded by DARPA (Defense Advanced Research Projects Agency) and the U.S. Navy and Air Force. Their project, within LLNL's Science and Technology Program, aimed to develop laser technology for x-ray lithography and satellite imaging research. This technology, a spinoff from the DOE's Inertial Confinement Program, was eventually used to develop laser peening for commercial use.

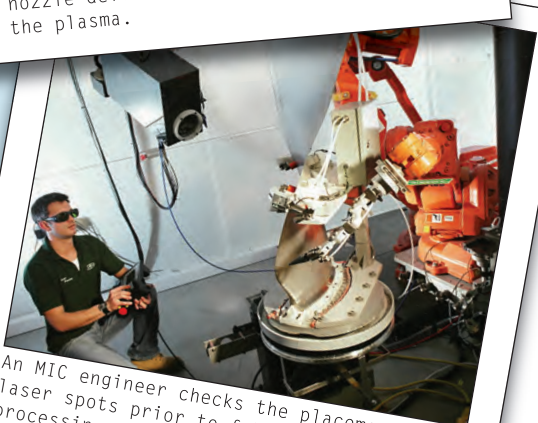


As an invisible laser beam peens the roots of gear teeth, a robotically positioned nozzle delivers a flow of water that tamps the plasma.

Hackel and Dane's research caught the eye of Metal Improvement Co. (MIC), Paramus, N.J., a business unit of Curtiss-Wright that performs both traditional shot peening and now laser peening for the majority of aircraft engine and airframe builders around the world. MIC executives wondered if the men could use their expertise to develop disruptive laser peening technology for manufacturing purposes. Hackel and Dane set out to develop a neodymium-doped glass laser that produces one billion watts of peak power in 20-billionth-of-a-second pulses—roughly the same output as a large commercial power plant. In 1997, LLNL's Industrial Partnerships Office worked with the researchers and MIC to develop a formal agreement to commercialize the technology.

About the Innovators:

In 2003, Hackel and Dane left the Lab for MIC because they saw industry as an opportunity to push their technology further. Working out of an MIC regional R&D center in Livermore, the men expanded their laser peening technology, enabling MIC to win large contracts to peen more than 40,000 jet engine fan blades and 1000 discs. MIC's laser peening work is estimated to have saved the aviation industry hundreds of millions of dollars in parts and service due to longer lasting components.



An MIC engineer checks the placement of laser spots prior to fully automated processing.

What's Next:

Potential applications include preventing metal erosion and corrosion on ship propellers, rudders, and thrusters, and fortifying metals used in high-performance automotive engines, deep-water oil drilling rigs, welds in nuclear power plants and for nuclear waste storage containers, and medical devices such as hip implants.

Contact Details:

C. Brent Dane, Director of Laser Technology
Curtiss-Wright Surface Technologies
Metal Improvement Company
7655 Longard Rd., Livermore, CA 94551
925/960-1090, cbrent.dane@cwst.com, www.cwst.com