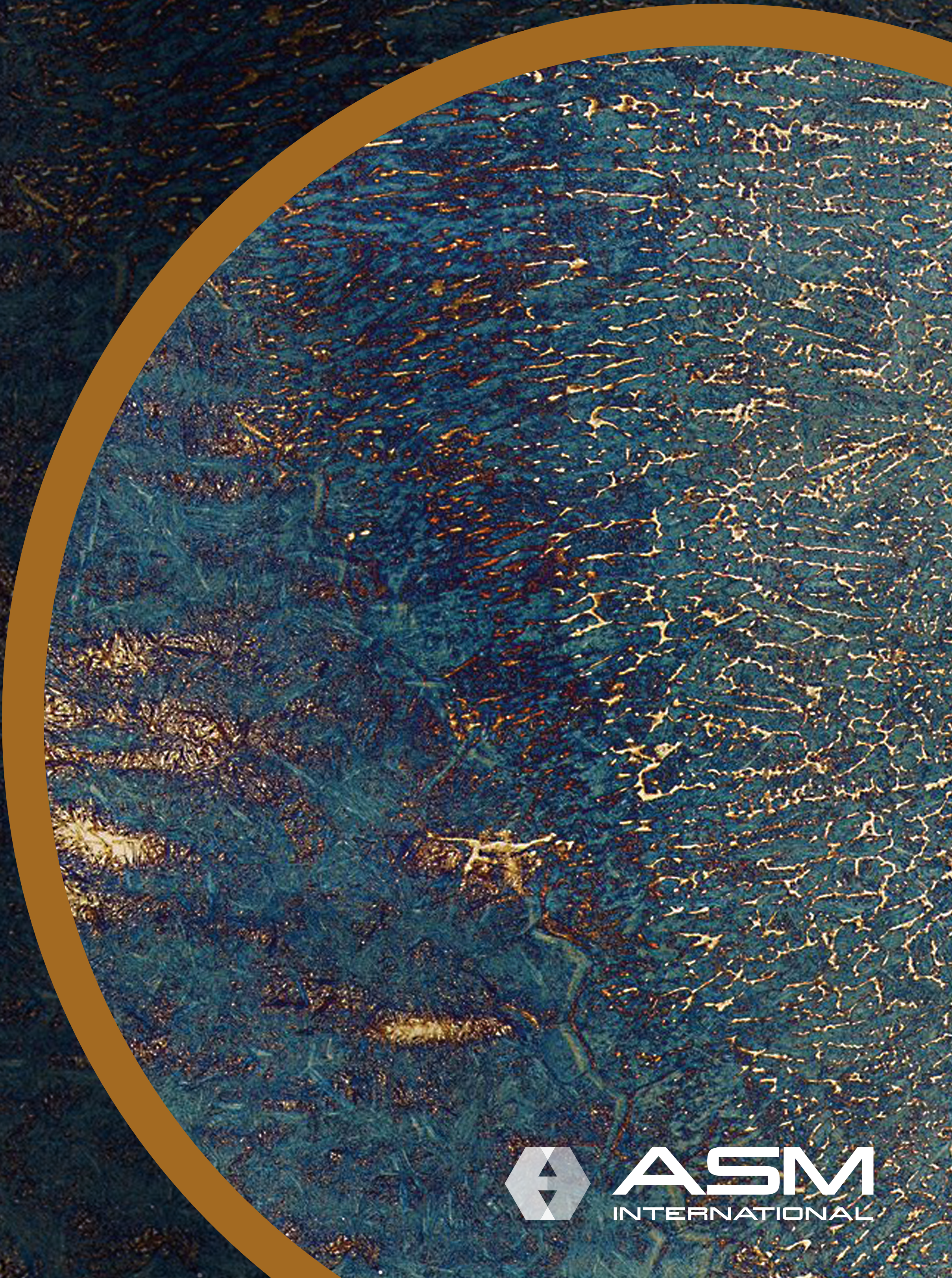
FEBRUARY 2016 | VOL 174 | NO 2

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION



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MICROSCOPY & METALLOGRAPHY

KINETICALLY ACTIVATED BAINITE WELDS

P.12

ASM INTERNATIONAL


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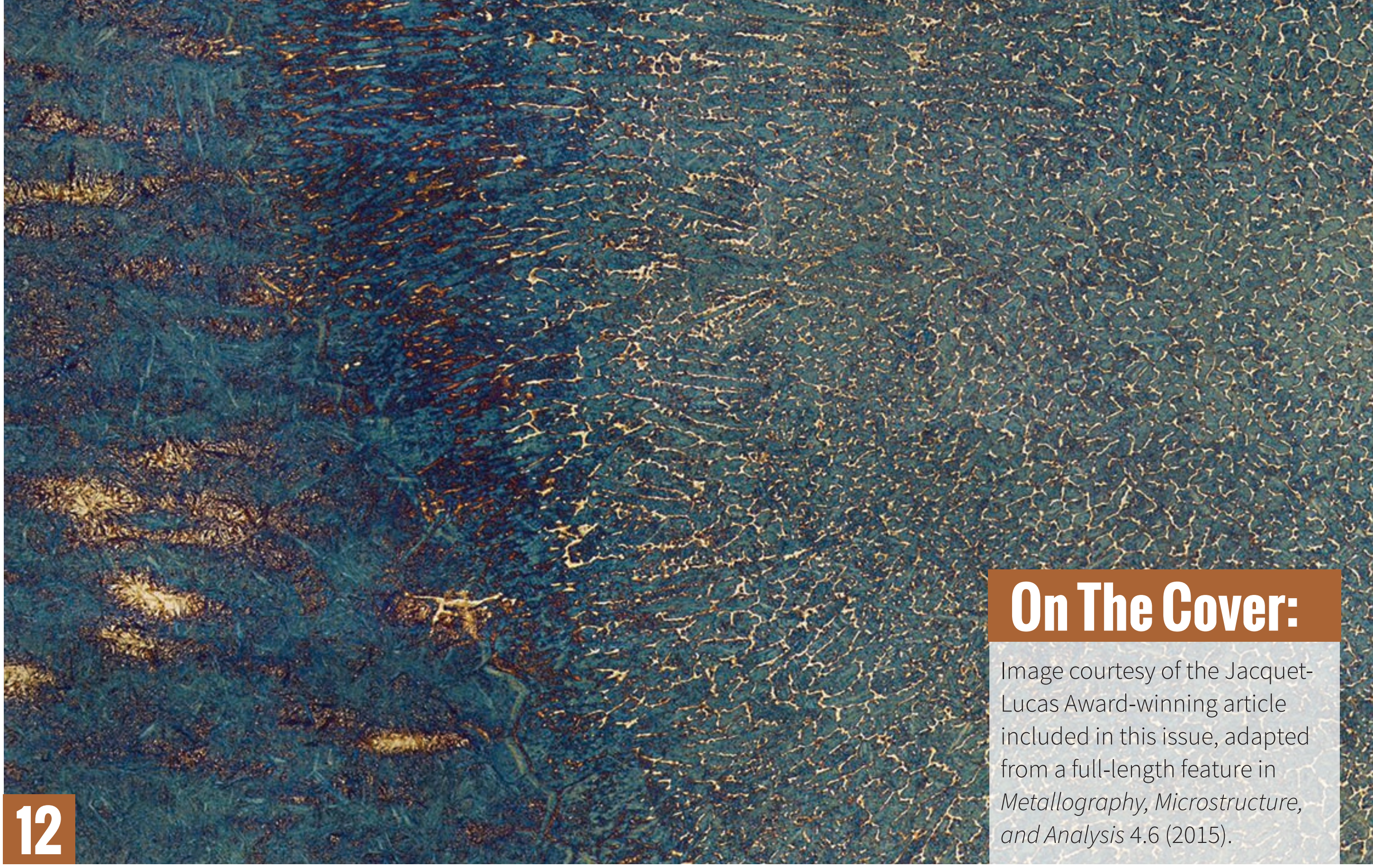
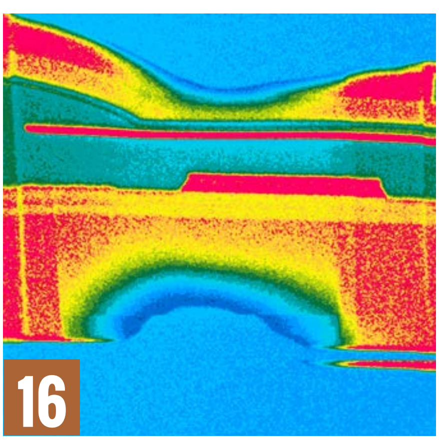


On The Cover:

Image courtesy of the Jacquet-Lucas Award-winning article included in this issue, adapted from a full-length feature in *Metallography, Microstructure, and Analysis* 4.6 (2015).



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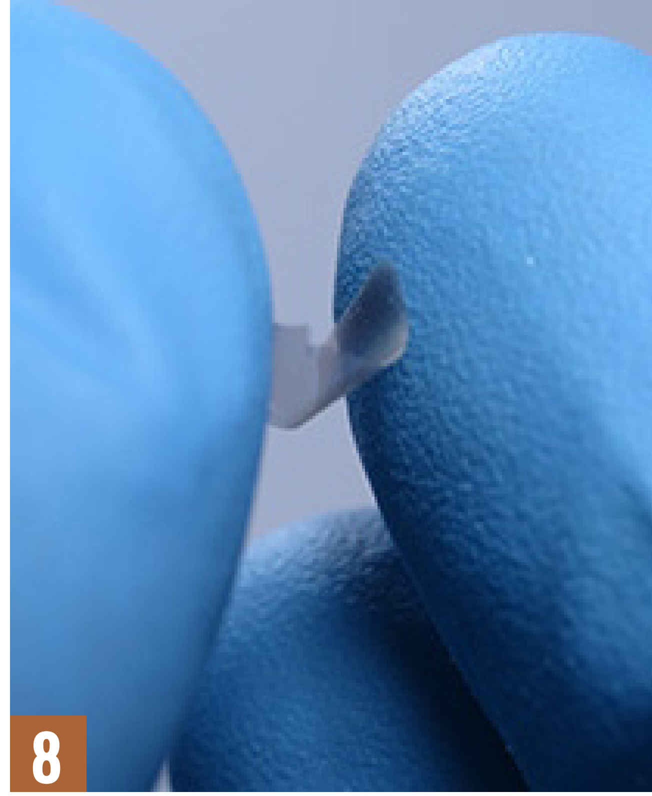
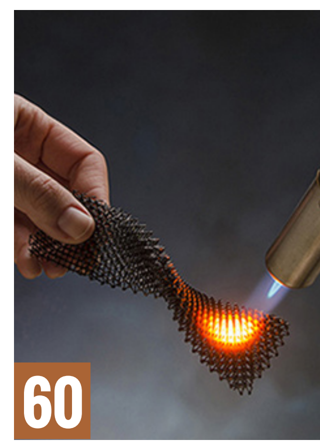
FEATURES





TRENDS

INDUSTRY NEWS

DEPARTMENTS

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MAKING THE MOST OF OLD MAN WINTER

During February—the heart of Old Man Winter—things can seem somewhat dull and dreary, especially when ground and sky reflect each other using only a palette of grays. The holidays are long forgotten and spring feels far away. Groundhog Day and Valentine's Day try to inject some levity, but they can only do so much. In times like these, we can all use some cheerful news. Perhaps most exciting is the birth of Matthew Kalista Lucko on January 4 to our very own editor, Julie Lucko. Everyone is doing well!

ASM welcomes Matthew Kalista Lucko!

In other news, the scientific world is celebrating a different sort of growing family. As you have no doubt heard by now, the periodic table is getting four new elements, the first additions since 2011. And, as with any baby, one of the joys for the "parents" is the honor of picking out names: The research teams who discovered the elements will have the privilege of choosing their permanent names and symbols. Elements may be named after a mythological concept, mineral, place, property, or scientist. (See story on p. 6.) Another exciting development included in this issue is the announcement by Puris that they have produced what they believe to be the largest 3D-printed complex titanium part to date—a 31-lb aerospace component made using binder jetting technology. (See story on p. 10.) As additive manufacturing continues to make strides at a breakneck pace, it is announcements like these that serve to keep the industry moving forward in a positive and exciting way.

Another bright spot we are thrilled to share is the widespread media attention gained by one of our January feature articles, which discusses metallic glue for ambient environments. The article came about from working with ASM's Emerging Technologies Awareness Committee (ETAC), specifically Dave Furrer, FASM, of Pratt & Whitney, and Hanchen Huang of Northeastern University. Huang is one of the article's authors and he reports coverage of the *AM&P* article in numerous news outlets, including the front page of the U.S. DOE Office of Science website, front page of the Northeastern University website, coverage on the science.energy.gov website under University Research, news stories on fortune.com and gizmag.com, and a video segment on Discovery Channel Canada. This type of news coverage happens from time to time with technology advancements, and we were happy to break this story. If any of you are working on revolutionary technologies, we hope you will consider *AM&P* a useful vehicle to share your stories.

Speaking of ASM committees, it's people like you who make them shine. Please take a look at our annual Call for Volunteers on p. 51. As the saying goes, "Many hands make light work." ASM is only as strong as the fabric of its individual volunteers woven together. Besides that, the committees can be a lot of fun and you never know how the connections made might change your life or your career path.

F. Richards

frances.richards@asminternational.org

MARKET SPOTLIGHT

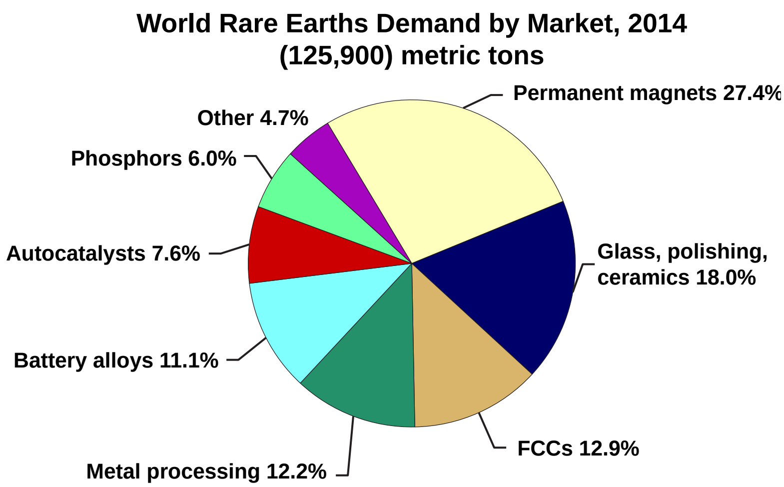
WORLD RARE EARTHS DEMAND TO REACH $4.5 BILLION BY 2019

World Rare Earths, a new study from The Freedonia Group Inc., Cleveland, reports that global demand for rare earths is expected to increase 3.5% per year to 149,500 metric tons in 2019, valued at $4.5 billion. The largest increases are forecast for the permanent magnet segment, boosted by expanding production of advanced neodymium magnets for applications such as wind turbines and hybrid and electric vehicles. Rising output of nickel-metal hydride batteries is also expected to fuel demand. In addition, upgrades to oil refining sectors in emerging countries are projected to boost global catalytic cracking capacity, supporting production of fluid cracking catalysts and an associated demand for lanthanum and cerium. Increased production of steel, motor vehicles, and electronics is expected to drive rare earths consumption as well.

Extreme pricing volatility (particularly during 2010-2012 when China cut export quotas for the metals) has prompted the use of substitute materials and spurred development of catalysts and other products designed with low rare earth requirements. While depressed rare earth prices will promote a shift back to rare earth-based products, ongoing wariness of severe price shifts continues to restrain overall market advances, say analysts.

China will remain the leading consumer of rare earths, accounting for over two-thirds of the global demand in 2019. Japan will remain the second biggest global market, benefiting from a large domestic electronics manufacturing sector and robust demand for rare earths in battery, magnet, and polishing powder production. India is projected to hold the fastest gains of any major market worldwide due to rising domestic production of motor vehicles and metal alloys, as well as expanding catalytic cracking capacity, which are expected to boost rare earths consumption. India is also developing local production of rare earth magnets, although this market will remain small in the near term.

China will continue to account for the majority of rare earths mining output through 2019, although its share of total production is expected to drop as a number of new projects in Canada, Tanzania, South Africa, and other countries begin commercial production. Major output increases are also expected in Australia as Lynas continues to ramp up production following capacity expansions. *For more information, visit freedoniagroup.com.*



Source: The Freedonia Group Inc.

FEEDBACK

KUDOS TO ABKOWITZ

The September article "Did Al Gore Invent the Titanium Six Four?" was a most interesting history about titanium alloy development. I found the Al Gore title spoof provocative and gutsy. I am also very pleased that Stan Abkowitz is around to tell the metallurgical side of the story.

William R. Jones, FASM

CRIME AND PUNISHMENT

The October editorial column on "Welcoming Failure" was well taken, as we should all learn from past errors. You might have mentioned the case of people who know of a defect in their product and fail to fix it. The GM ignition switch problem comes to mind as a recent example. The company knew people were being killed and maimed but did nothing. This is where the court expert comes in, to help punish the bad actors in some way—money, not jail time.

Charles Dohogne

WISH COMES TRUE

Thank you for all the "Metallurgy Lane" articles about our materials technology history. I trust that the author or ASM will eventually publish a compilation. When you do, I will be interested in obtaining a copy.

Roger Austin

[The ASM Technical Books Committee recently approved a proposal for a historical volume based on Charles Simcoe's popular "Metallurgy Lane" series. Publication is expected in late 2016. *—Eds.]*

CORRECTION

The November/December article "Materials Sustainablility App Serves as Teaching Tool" failed to recognize one of the authors, Brittany Palac. We apologize for the omission. *—Eds.*

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS

Japanese team leader Kosuke Morita at the Riken Institute.

PERIODIC TABLE GAINS FOUR NEW ELEMENTS

On Dec. 30, 2015, The International Union of Pure and Applied Chemistry (IUPAC) formally verified the addition of four new chemical elements to the periodic table. These are the first additions to the table since 2011, when elements 114 and 116 were included. "The chemistry community is eager to see its most cherished table finally being completed down to the seventh row," says Jan Reedijk, president of the Inorganic Chemistry Division of IUPAC.

Japanese researchers at the Riken Institute were awarded credit for discovery of element 113 (temporary name and symbol: ununtrium, Uut). A collaborative team from the Joint Institute for Nuclear Research in Russia, Lawrence Livermore National Laboratory (LLNL), and Oak Ridge National Laboratory has met the criteria for discovery of elements 115 and 117 (ununpentium, Uup; ununseptium, Uus), while the Russian and LLNL researchers together were granted discovery of element 118 (ununoctium, Uuo).

The teams have been invited to provide permanent names and two-letter symbols for the elements they discovered. Elements can be named after a mythological concept, mineral, place or country, property, or scientist. Following initial acceptance by the IUPAC Inorganic Chemistry Division and a five-month public review, the organization's highest body—the Council—will make a final decision on the new names and symbols. *iupac.org.*

ANTI-STAB MATERIAL GETS LIGHTER AND THINNER

DSM Dyneema, the Netherlands, recently announced Dyneema Anti Stab Technology, a patented material for soft armor applications. Compared to traditional materials, the new technology enables designers to create protective vests that are up to 25% lighter and thinner. "We developed the Anti Stab Technology to deliver maximum protection against knife stabs, meeting the specific needs of law enforcement officers in hostile confrontations, as well as military personnel engaged in urban warfare," says Marcio Manique, global business director of the company's life protection unit. The anti-stab technology can be combined with Dyneema soft ballistic materials to develop multi-threat protective gear. DSM Dyneema is collaborating with Aegis Engineering Ltd., UK, a global manufacturer of personal protective apparel, on a multi-threat prototype vest to assess the new material for compliance with international standards. *dyneema.com.*

Protective vest made with Dyneema Anti Stab Technology.

Twenty carats of gold foam is lighter than milk foam. Courtesy of Gustav Nyström and Raffaele Mezzenga/ETH Zurich.

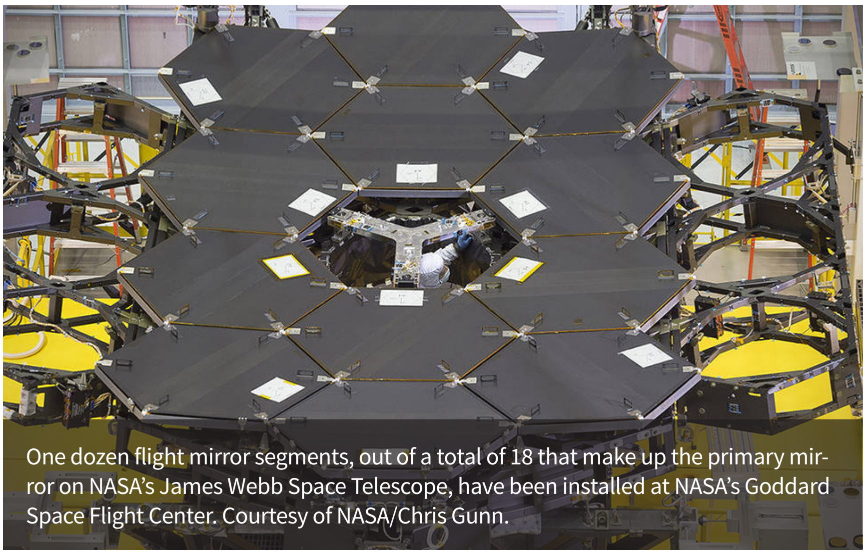
FEATHERWEIGHT GOLD FOAM

Researchers at ETH Zurich, Switzerland, led by Raffaele Mezzenga, professor of food and soft materials, created a lightweight foam made of gold. This 3D mesh is the lightest form of the metal ever produced. "The so-called aerogel is a thousand times lighter than conventional gold alloys. It is lighter than water and almost as light as air," says Mezzenga.

The foam is 98 parts air. Of the two parts solid material, more than four-fifths are gold and less than one-fifth is milk protein fibrils. This corresponds to around 20 carat gold. Though the aerogel primarily consists of pores, it is nearly impossible to differentiate it from conventional gold with the naked eye, and unlike its conventional form, it is malleable by hand. The new material could be specified in many applications where gold is currently used, including jewelry, chemical catalysis, and applications involving light absorption and reflection. The aerogel could also find use in pressure sensors. When pressure increases, the material compresses. This allows the gold particles, which do not touch at normal atmospheric pressures, to contact one another and make the material conductive. *www.ethz.ch/en.*

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

METALS | POLYMERS | CERAMICS



One dozen flight mirror segments, out of a total of 18 that make up the primary mirror on NASA's James Webb Space Telescope, have been installed at NASA's Goddard Space Flight Center. Courtesy of NASA/Chris Gunn.

CENTRAL MIRRORS INSTALLED ON JAMES WEBB SPACE TELESCOPE

One dozen flight mirrors are now installed on NASA's James Webb Space Telescope, out of the 18 segments that make up the primary mirror. "This milestone signifies that all of the hexagonal shaped mirrors on the fixed central section of the telescope structure are installed, and only the three mirrors on each wing are left for installation," says Lee Feinberg, optical telescope element manager at NASA's Goddard Space Flight Center, Greenbelt, Md., where the structure is being constructed.

Each hexagonal mirror segment measures just over four feet and weighs 88 pounds. After assembly, the 18 segments will work together as one 21.3-ft mirror, unfolding and adjusting to shape after launch. The mirrors are made of ultra-lightweight beryllium and are placed on the telescope's backplane using a robotic arm, guided by engineers. Completion of the primary mirror is expected in spring 2016, and the telescope's launch is planned for 2018. *nasa.gov/webb*.

NANOSCALE PLATES ARE BOTH THIN AND STRONG

Researchers at the University of Pennsylvania, Philadelphia, successfully manufactured nanoscale plates that are 1000 times thinner than a sheet of paper but strong enough to spring back into shape after being manipulated by hand. Typically, a nanoscale film needs to be stretched across a frame or put on a rigid backing to prevent it from curling. "The problem is that frames are heavy, making it impossible to use the intrinsically low weight of these ultra-thin films," says professor Igor Bargatin. "Our idea was to use corrugation instead of a frame. That means the structures we make are no longer completely planar. Instead they have a 3D shape that looks like a honeycomb, but they are flat and contiguous and completely freestanding."

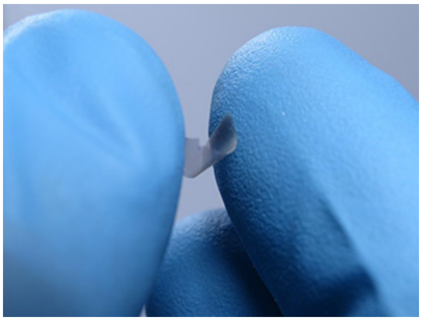
The team deposited aluminum oxide in precisely controlled atomic layers, producing 25-100 nm thick plates with hexagonal divots. "It's like an egg carton, but on the nanoscale," explains professor Prashant Purohit. In addition

BRIEFS

Pexco LLC, Atlanta, a specialty plastics manufacturer serving medical, defense, and industrial markets, acquired **Scientific Plastics Corp.** (SPC), St. Paul, Minn. SPC manufactures injection molded plastics and has experience with materials such as PEEK, Ultem, polysulfone, and polycarbonate. Pexco also acquired **Precision Extrusion Inc.,** Glens Falls, N.Y., a medical extruder, in December 2015. *pexco.com*.

Ducommun Inc., Carson, Calif., received a contract from **Airbus,** Herndon, Va., to produce titanium formed parts for the windshield assembly for both the A320 and A330 families. Parts will be manufactured at Ducommun's facility in Parsons, Kan., which specializes in titanium thermal forming technology. *ducommun.com.*

Reliance Steel & Aluminum Co., Los Angeles, acquired **Tubular Steel Inc.** (TSI), St. Louis, a distributor and processor of carbon, alloy, and stainless steel pipe, tubing, and bar products. TSI stocks over 60,000 tons and ships over two million custom lengths of pipe, tubing, and bar products annually from its seven U.S. locations. The company also operates a fabrication business. *rsac.com*.



The researchers' aluminum oxide plates are 1000× thinner than a sheet of paper, but can be squeezed and bent without breaking. Courtesy of Bargatin Group.

Alcoa will supply titanium seat track assemblies for the entire 787 Dreamliner family, including the 787-9 shown here. Courtesy of Boeing.

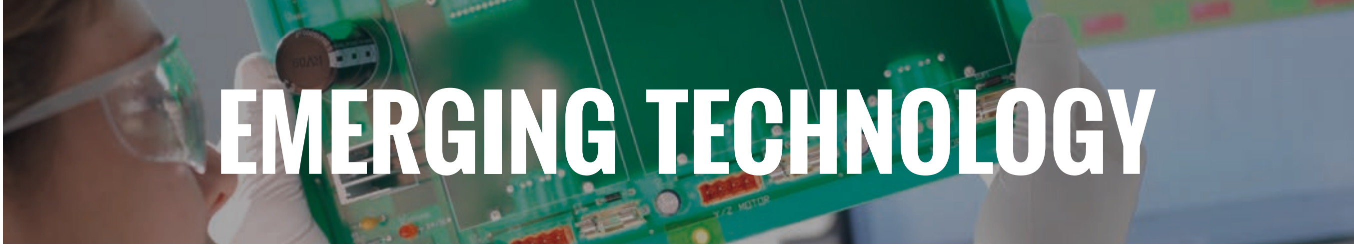
to preventing curling, the corrugation resists tearing by stopping cracks at an internal wall. *upenn.edu.*

AEROSPACE COMPOSITE EARNS SAE-AMS SPECIFICATION

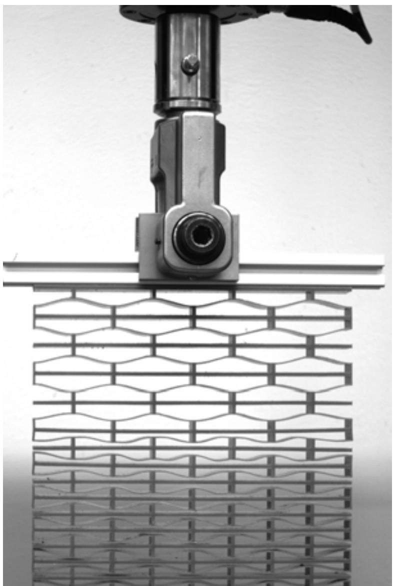
The Society of Automotive Engineers—Aerospace Material Specification Nonferrous Alloys Committee (SAE-AMS) published aerospace specification AMS4355 for SupremEX 225XE, a particle-reinforced, aerospace-grade aluminum metal matrix composite produced by Materion Corp., Mayfield Heights, Ohio. SupremEX 225XE is made by reinforcing a high-quality aerospace aluminum alloy with 25 vol% ultrafine silicon carbide particles, resulting in a lightweight, strong, and stiff composite that can replace aluminum, titanium, steel, and other structural alloys and composites. The AMS4355 specification covers the material in reinforced, hot isostatically pressed shaped billets. Materion is working to obtain specifications for forged and extruded forms, and other grades of the SupremEX product line. *materion.com.*

ALCOA AND BOEING FORGE SUPPLY DEALS

Alcoa Inc., Pittsburgh, recently signed two long-term supply contracts with The Boeing Co., Chicago, valued at over $2.5 billion. Under the agreements, Alcoa Fastening Systems & Rings will supply advanced titanium, stainless steel, alloy steel, aluminum, and nickel-base superalloy fastening systems for every Boeing platform, and Alcoa will serve as the sole supplier of ready-to-install titanium seat track assemblies for all three 787 Dreamliner variants. Titanium seat tracks are stronger, weigh less, and offer superior corrosion resistance compared with traditional materials. Alcoa will supply tracks using production capabilities gained through the acquisition of RTI International Metals. RTI is now known as Alcoa Titanium & Engineered Products. *alcoa.com.*



EMERGING TECHNOLOGY



Honeycomb architecture of new phase transforming cellular materials being developed by Purdue University and General Motors.

REUSABLE, 3D-PRINTED MATERIALS ABSORB ENERGY

Purdue University, West Lafayette, Ind., is collaborating with General Motors, Detroit, to develop a new type of energy-absorbing material that could be 3D printed and have an impact on everything from earthquake engineering to football helmets. The honeycomb architecture of the *phase transforming cellular materials* (PXCMs) could be scaled to a range of sizes tailored for various applications. One size could be integrated into helmets to reduce head impacts, while another would be suitable for use in buildings to dampen earthquake forces. Being able to 3D print the PXCMs would make them less expensive and more practical than other technologies, explains associate professor Pablo Zavattieri. "The main advantage is that not only can it be used as an energy absorbing material, but unlike many other materials designed for this purpose, the PXCMs are reusable because there is no irreversible deformation," he says. The structures can be made of metals, polymers, or "anything that behaves elastically."

Energy dissipation due to the mechanical behavior of the unit cells adds to the intrinsic energy dissipation of the base material. "Many emerging materials like aluminum, magnesium, and fiber-reinforced composites suffer from low intrinsic energy dissipation. The energy absorption capability of structures that are made of such base materials can be increased by incorporating PXCMs into the structures," says Nilesh Mankame of General Motors' Smart Materials & Structures Group. Like other phase-transforming materials such as shape-memory alloys, PXCMs could be controlled using heat or other external stimuli. *For more information: Pablo Zavattieri, 765.496.9644, zavattie@purdue.edu, www.purdue.edu.*

LIQUID CRYSTAL RESEARCH FOCUSES ON ARTIFICIAL LENSES

Devesh Mistry, a researcher at the University of Leeds, UK, is developing a new eye lens made of the same material found in smartphones and TV screens, which could restore long-sightedness in older people. As people age, their lenses lose elasticity and they develop presbyopia, which often leads to the need for reading glasses. Mistry is now working with liquid crystals to create a truly adjustable artificial lens. "Using liquid crystals, lenses would adjust and focus automatically, depending on eye muscle movement," he explains. Mistry's research focuses on developing synthetic replacements for the diseased lens, with the goal of having a prototype ready in 2018. Within a decade, the research could lead to the new lens being implanted into eyes in a quick surgical procedure under local anesthetic. Eye surgeons would make an incision in the cornea and use ultrasound to break down the old lens. The liquid crystal lens would then be inserted, restoring clear vision. *www.leeds.ac.uk.*

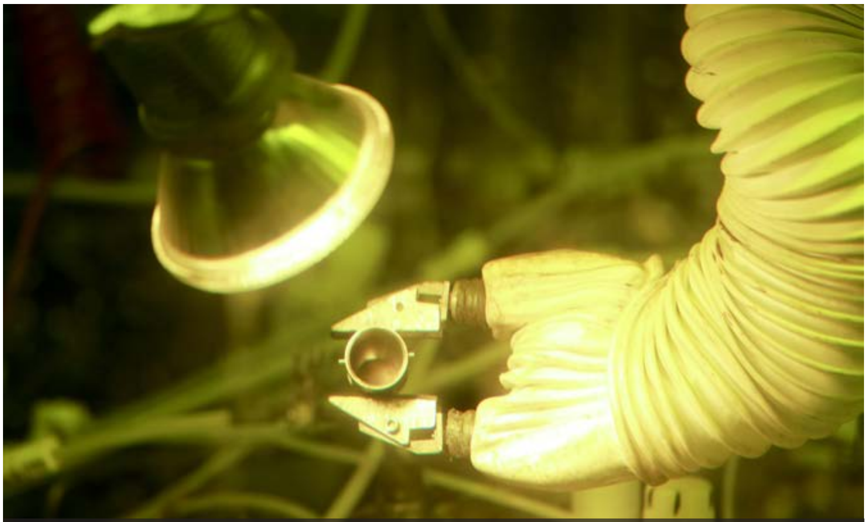
Prototype of an electrically switchable contact lens made of liquid crystals.

BRIEF

Researchers at **New York University,** New York, received a three-year, $2 million grant from the **Gordon and Betty Moore Foundation** to explore new ways to create advanced materials atom-by-atom for use in next-generation electronic devices. The work is part of the foundation's Emergent Phenomena in Quantum Systems initiative to stimulate breakthroughs in understanding the principles of complex quantum matter. *nyu.edu.*

NYU

PROCESS TECHNOLOGY



ORNL researchers recently produced 50 grams of plutonium-238.

PLUTONIUM-238 MAKES A COMEBACK

Researchers at the DOE's Oak Ridge National Laboratory (ORNL), Tenn., recently produced 50 grams of plutonium-238—restoring a U.S. capability on hold for nearly 30 years. The goal is to provide power for NASA and other missions. The new sample, which is in the same oxide powder form used to manufacture heat sources for power systems, represents the first end-to-end demonstration of a plutonium-238 production capability in the U.S. since the Savannah River Plant in South Carolina ceased production in the 1980s. Researchers will analyze the sample for chemical purity and plutonium-238 content, verify production efficiency models, and determine whether adjustments need to be made before scaling up the process.

"Once we automate and scale up the process, the nation will have a long-range capability to produce radioisotope power systems such as those used by NASA for deep space exploration," says project leader Bob Wham. The success of Wham and a team of engineers and technicians at ORNL comes two years after NASA began funding the DOE Office of Nuclear Energy through a $15 million per year effort to revive the department's capability to make plutonium-238. Initially, 300-400 grams of the material will be produced annually. After automation and scale-up are complete, roughly 1.5 kg per year will be made. *ornl.gov*.

PURIS PRINTS LARGEST TITANIUM PART TO DATE

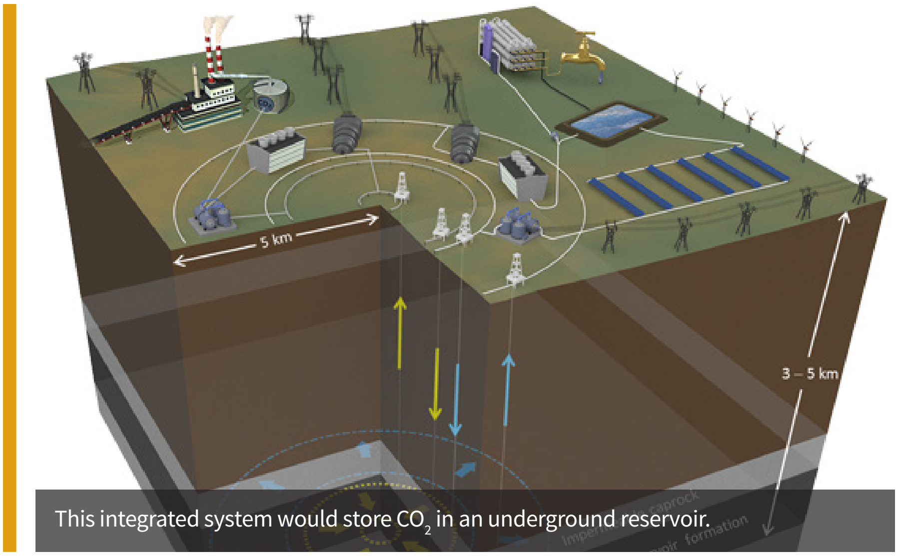
Puris LLC, Bruceton Mills, W.V., reports that it recently achieved an important 3D printer milestone by printing the largest complex titanium part for commercial use to date. The part was 3D-printed using binder jetting technology and processed to 100% density. It measures approximately 19 × 19 × 11 in. with a cross-section thickness of 0.375-in. and weighs roughly 31 lb. The part was produced on an ExOne M-Print 3D printer for an aerospace customer. The use of binder jetting technology allowed Puris to print the part at room temperature, eliminating the residual stress buildup inherent in other 3D printing technologies. Puris defines a "large part" as one weighing 10 to 1000 pounds. The company has previously printed large parts using Inconel powder and is able to print other high performance alloys as well. *purisllc.com.*

BRIEFS

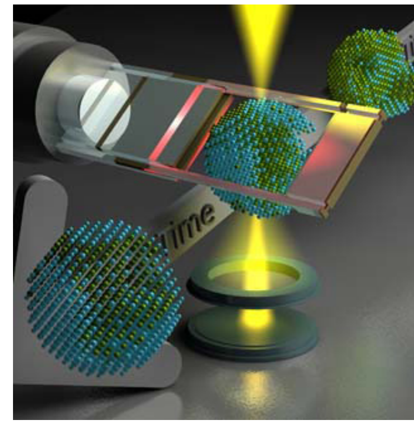
Bodycote, UK, will open two new heat treatment plants this year. In Covington, Ga., a new plant will open in spring to replace the nearby Conyers facility. The new facility will primarily serve automotive and general industrial customers in Georgia and Florida. In South Carolina, a new Nadcap-accredited facility will be established at Greenville to serve the region's aerospace manufacturing industry with heat treating and brazing processes. *bodycote.com.*

Oerlikon, Switzerland, acquired **Laser Cladding Services LLC,** Houston, a company specialized in laser cladding applications for the energy industry. The process uses a laser beam to deposit materials and layers onto a substrate or fabricate near-net shape parts. The method enables a full metallurgical bond to the base material, improving corrosion resistance and wear properties. *oerlikon.com.*

ENERGY TRENDS



This integrated system would store CO_2 in an underground reservoir.



A Titan 80-300 Cubed microscope was used for the catalyst research. Courtesy of Stephen MacIntyre.

UNDERGROUND BATTERY COULD CLEAN UP ENERGY

A team of researchers from Lawrence Livermore National Laboratory (LLNL), Ohio State University, University of Minnesota, and TerraCOH Inc. developed a subsurface system that stores energy from renewable sources and dispatches it to the grid throughout the year like a massive underground battery, all while storing CO_2 from fossil fuel power plants.

The intermittency of wind and sunshine is one of the biggest challenges to widespread integration of renewable energy into electric grids, while the cost of capturing CO_2 and storing it permanently underground is a major challenge for decarbonizing fossil energy. This large-scale system could overcome both obstacles.

The process involves injecting liquid-like CO_2 into underground reservoirs in sedimentary rock, creating a pressurized plume that pushes brine up production wells to the surface. The brine would then be heated and reinjected into the reservoir, storing thermal energy. The resulting pressurized CO_2 would enable the system to be charged or discharged depending on supply and demand. When there is insufficient renewable energy, the pressurized CO_2 and brine could be released and converted to power. According to computer models, the amount of CO_2 that could be stored underground by the system would be at least four million tons per year over 30 years, the equivalent of the CO_2 impact of a 600 MW coal plant. *energy.gov.*

INDIVIDUAL NANOPARTICLES TRACKED AT ATOMIC LEVEL

Researchers at McMaster University, Canada, in conjunction with scientists at National Research Council Canada and Shanghai Jiao Tong University, have taken atomic-level images of individual nanoparticles during heating. Using advanced electron microscopic techniques, the team was able to track the atomic rearrangement of an individual platinum-iron nanoparticle as it was annealed inside the microscope.

The work could have significant impact in the automotive industry, where there has been a surge of interest in developing alternative energy sources, particularly fuel cell technology. Fuel cell devices are far more efficient and environmentally friendly than conventional combustion technologies. However, they have typically relied on pricey platinum nanoparticles as catalysts, making them too expensive for widespread commercialization. The new process could enable development of less expensive catalysts, such as platinum-iron nanoparticles. *www.eng.mcmaster.ca.*

BRIEF

Florida State University, Tallahassee, researchers are working to make solar cells more effective. Through a soaking procedure, researchers assembled two molecules, an acceptor and sensitizer, on a surface. The molecules work together to perform photon upconversion, combining two low energy, green photons to generate a higher energy, blue photon, which is used generate electricity. Using this process in optimized solar cells can increase maximum efficiency from 33% to more than 45%. *fsu.edu*.

JACQUET-LUCAS AWARD

METALLOGRAPHIC ANALYSIS OF KINETICALLY ACTIVATED BAINITE WELDS

This entry won the prestigious Jacquet-Lucas Award for Best in Show at the 2015 International Metallographic Contest held in conjunction with the M&M 2015 conference in Portland, Oregon.

Peter Kirbiš, Tomaž Vuherer, Tomaž Irgolič, and Ivan Anžel, University of Maribor, Slovenia*

**Member of ASM International*

Low temperature, carbide free bainitic steels are capable of achieving tensile strengths to 2500 MPa while maintaining reasonable values of ductility and fracture toughness[1,2]. Their mechanical properties are derived from a very fine scale of bainitic ferrite plates with thicknesses of 20-50 nm. Plates are formed at low temperatures between 200°C to 300°C within steels where the precipitation of cementite is inhibited by alloying additions of roughly 1.5% Si or Al, thus enriching the retained austenite with carbon. This provides sufficient stability for it to undergo a stress/strain induced transformation into martensite, which retains the work hardening capacity and is known as the transformation induced plasticity (TRIP) effect[3,4].

To ensure low transformation temperatures, these alloys contain concentrations of carbon close to 0.8%. When such steels are welded, they are susceptible to cold cracking, due to formation of brittle martensite within the weld and reaustenitized heat affected zones (HAZ)[6]. Therefore, these steels must be preheated before welding, after which prolonged isothermal holding treatments are applied to regenerate the bainitic microstructure within the weld and reaustenitized regions. These treatments can last from several hours to a few days. The endeavor of welding such steels is nevertheless encouraging, as it has been shown that the welds can achieve tensile strengths comparable to those of the base materials[7].

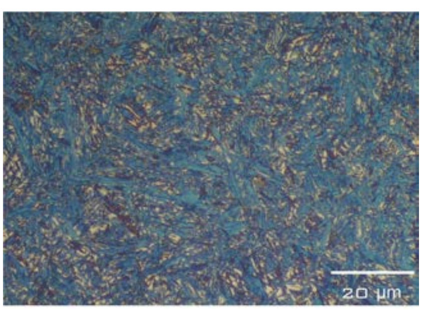


Fig. 1 — Polarized LOM of initial bainitic microstructure before welding shows fine sheaves of bainitic ferrite separated by regions of retained austenite. Etched with 7% aqueous $Na_2S_2O_5$, mag. 1000×.

The authors' research has led to development of a new grade of low temperature bainitic steels—named Kinetically Activated Bainite (KAB) steels—with exceptionally rapid transformation kinetics at temperatures below 200°C. This is achieved by creating kinetically suitable conditions at a higher temperature via a precipitation reaction. If such a rapid formation of bainite can be obtained during welding, determining how welding parameters influence the microstructure and mechanical properties of the weld is of great interest.

MATERIALS AND METHODS

The alloy's chemical composition, along with the critical temperatures of the bainite start (Bs) and martensite start (Ms), are shown in Table 1. Upon air cooling to room temperature after a hot rolling treatment, the newly developed steel forms a microstructure of carbide-free lower bainite (Fig. 1). Microstructures were investigated by etching with 7% aqueous $Na_2S_2O_5$, which is known to respond by coloring bainitic regions blue and martensite brown, whereas retained austenite etches white or in a slight purple[8]. In this condition, the steel has a Vickers hardness of 660 HV, coinciding with a yield strength of 1800 MPa and tensile strength of 2800 MPa. Because no suitable fillers for welding this steel are commercially available, welds were produced using the activated tungsten inert gas (A-TIG) process with variable heat inputs. The region of interest is the one that experiences the highest heat input and is indicated with a square in Fig. 2.

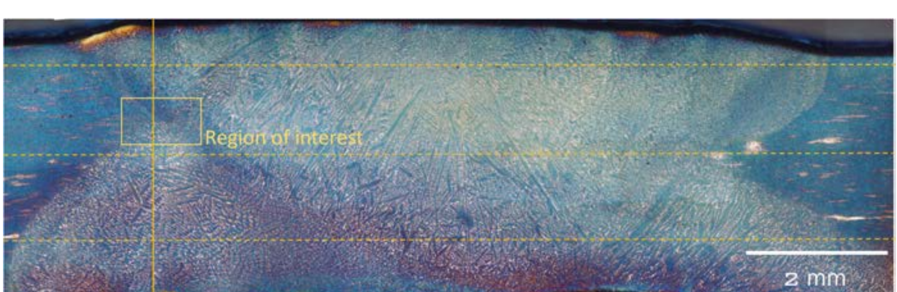


Fig. 2 — Polarized LOM mosaic image of a weld with investigated region marked by a square. Dotted lines represent points where hardness measurements were performed. A marked segregation appears at the edge of the fusion zone boundary, indicated by color change.

TABLE 1–STEEL COMPOSITION (WT%)

C	Si	Mn	Mo	Cr	V	Al	Ni	Bs	Ms
0.82	1.2	2.5	0.6	1.8	0.22	1.5	1	240°C	51°C

RESULTS

The initial trial involved a relatively high heat input. Weld 1 develops a high hardness and exhibits a coarse microstructure (Fig. 4), while the microstructural features of interest are shown in greater detail in Fig. 5. The presence of coarse austenite and solidification porosity is thought to be the main cause of the modest 850 MPa tensile strength. Heat input was then reduced during formation of Weld 2, in which a more refined microstructure develops (Fig. 6). A more detailed view is provided in Fig. 7(a), where appreciable segregations within the HAZ are still visible, but to a lesser extent than Weld 1. The grain boundary enriched region was additionally etched with Vilella's reagent, as shown in Fig. 7(b). This etchant delineates a thinner austenite layer with additional bainitic sheaves growing into the enriched region. Figure 8 presents a mosaic image of Detail (b) of Weld 2, showing coarse retained austenite regions.

The tensile properties of Weld 2 are appreciably higher, reaching values up to 1200 MPa. Heat input was further decreased during the third welding test. The microstructure of Weld 3 indicates that films of austenite at the grain boundaries no longer occur. However, some martensite is present within the segregated region in the HAZ. The parameters used for the production of

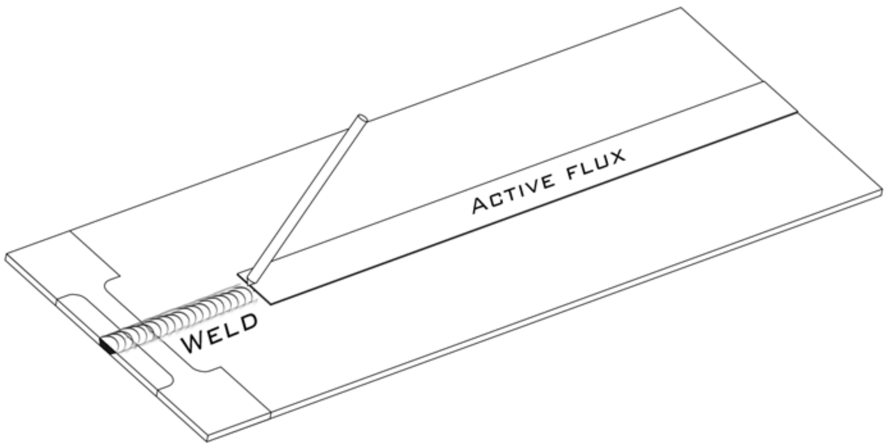


Fig. 3 — Weld diagram shows the welding procedure and location of the tensile samples taken.

Weld 3 resulted in the greatest tensile strength of 1578 MPa.

DISCUSSION

Four kinds of retained austenite appear in the weld microstructures, which vary in scale as well as chemical composition: thin films in between the bainitic ferrite subunits; micron-size blocks in between the bainitic sheaves; coarse austenite within the interdendritic regions of the weld bead, which is up to tens of microns in thickness; and coarse austenite blocks formed within the reaustenitized zone, which are up to 10 μm thick. It is widely known that the properties of carbide-free bainitic steel strongly depend on the mechanical stability of retained austenite[9]. This stability is profoundly influenced by its size[10], whereby coarse regions transform into brittle high carbon martensite under lower stresses than their fine counterparts[11].

Very coarse austenite regions within the HAZ must be prevented, as their presence is unacceptable. This can be accomplished by controlling heat input and optimizing the hot rolling treatment. Whereas retained austenite within the interdendritic regions cannot be entirely avoided, it should be distributed as finely as possible and its volume fraction kept low. As shown in Table 2, the average amount of interdendritic retained austenite changes proportionally with heat input. However, the relation is not linear, and it can be expected that the total amount cannot be reduced below a certain value. This is due to the high alloy content of the new steel, where rapidly occurring segregation of Mn and C[12] suppresses the formation of bainite within the interdendritic regions.

Even though the interdendritic space is substantially enriched with alloying elements, this is thought to be insufficient to promote an adequately high mechanical stability of the austenite for achieving tensile properties comparable to the initial material. This is evident from the results summarized in Table 2, where Weld 3 with the lowest hardness and retained austenite fraction achieves the greatest tensile strength. The lower strength of the weld enables small strains to be accommodated through the deformation of interdendritic retained austenite.

CONCLUSIONS

The initial bainitic microstructure regenerated successfully within the fusion and reaustenitized zones during A-TIG welding. Therefore, no regeneration heat treatment or preheating of the KAB steel are deemed necessary. Welds achieved nearly 60% of the base material's tensile strength, mainly due to significant segregations. These result in formation of martensite and coarse

TABLE 2–PROPERTIES OF DIFFERENT WELDS

Weld	Normalized Heat input *[J/mm²]*	Retained austenite fraction *[V%]*	Average hardness *[HV1]*	Tensile strength *[MPa]*
1	261	16.5	720	850
2	130	12.5	680	1200
3	90	10.3	530	1578

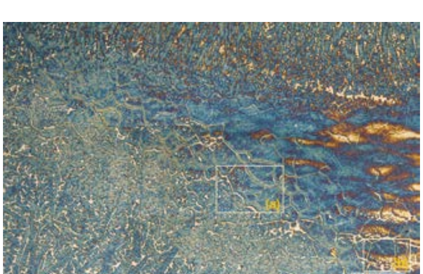


Fig. 4 — Polarized LOM of Weld 1 shows the weld and reaustenitized regions. Etched with 7% aqueous $Na_2S_2O_5$.

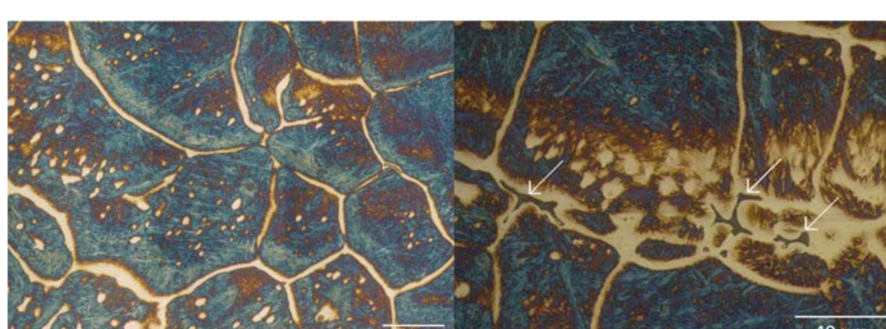


Fig. 5 — From left to right, detail (a) of Weld 1 as marked in Fig. 4 shows grain growth and segregations within the reaustenitized region of Weld 1; Detail (b) of Weld 1 as marked in Fig. 4 shows porosity at the fusion zone boundary. Etched with 7% aqueous $Na_2S_2O_5$.

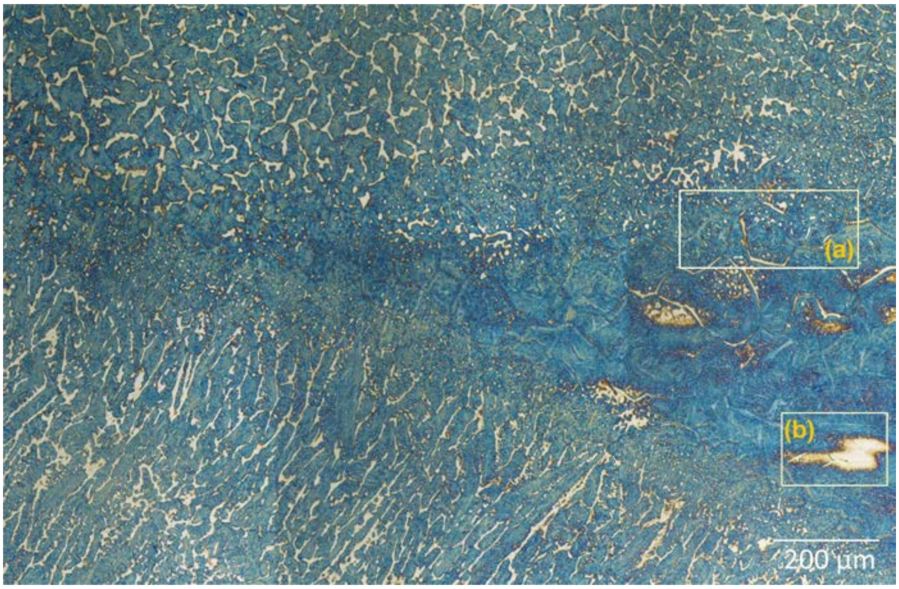


Fig. 6 — Weld intersection of Weld 2 shows the dendritic structure of the weld and the reaustenitized region. Etched with 7% aqueous $Na_2S_2O_5$.

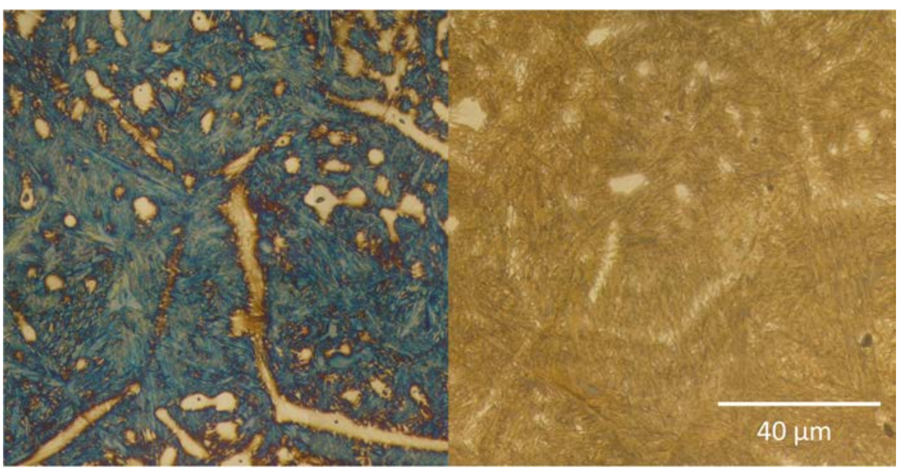


Fig. 7 — LOM mosaic image of Detail (a) in Fig. 6 shows segregations and grain growth within the reaustenitized region of Weld 2. Left side is etched with 7% aqueous $Na_2S_2O_5$; right side is etched with Vilella's reagent.

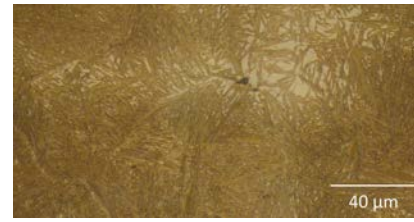


Fig. 8 — LOM mosaic image of Detail (b) in Fig. 6 shows coarse retained austenite regions. Etched with Vilella's reagent.

retained austenite regions within the HAZ at high heat inputs. In the absence of coarse retained austenite, the weld exhibits tensile properties that correlate well with its hardness. A more complete solution for welding these steels would involve the use of specially designed fillers, which will be discussed in future work. Detailed studies should also be conducted concerning the influence of welding on the precipitates. **~AM&P**

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USING HIGH RESOLUTION S/TEM TO ANALYZE SMARTPHONE DISPLAYS

The rapidly increasing complexity of microelectronic devices is necessitating the use of sophisticated imaging tools to analyze and correct defects.

With more than 60 research institutions, Fraunhofer is Europe's largest application-oriented research organization. Among these units is the Fraunhofer Institute for Microstructure of Materials and Systems IMWS, which includes the Fraunhofer Center for Applied Microstructure Diagnostics (CAM). Its specialized "microstructure of materials and systems" approach identifies weaknesses and defects in materials and components, determines their causes, and then develops safer components, new materials, and better manufacturing processes.

Researchers analyze nano and microstructures, determine material and component properties, and simulate application behavior using material models. Activities focus on detecting, analyzing, and preventing electrical, electronic, and mechanical defects and failures during development, design, and field application. Together with equipment suppliers, the CAM unit also develops tools for diagnostics and testing that enable improved detection and control of defects and faults via industrial failure analysis and quality monitoring.

Fraunhofer CAM specializes in process and material assessment and physical failure analysis for semiconductor technologies, packaging, assembly, system integration, and MEMS components. Its research includes preparation techniques based on focused ion beams and lasers that improve throughput and capability in industrial failure diagnostics and nanoanalytics. The center offers a wide array of analytical capabilities, including nondestructive defect localization, FIB and electron microscopy, surface and trace analysis, crystallography and optical spectrometry, surface topography and deformation, polymer characterization, mechanical and reliability testing and modeling, and electrochemical characterization and corrosion testing.

TEM SAMPLE PREPARATION

Among the most challenging tasks in today's microelectronics industry is preparation of ultra-thin, site-specific samples for examination in a TEM instrument. TEM, and its close relative STEM, offer sub-angstrom (sub 0.1 nm) resolution, good enough to resolve individual atoms in many electronic materials. Their use in semiconductor manufacturing has grown rapidly in recent years as the size of critical features has shrunk beyond the resolving power of SEMs (~1.0 nm), which have long been the mainstay of the industry for failure analysis and defect characterization. Samples for S/TEM must be thin enough to transmit electrons—generally less than 100 nm, and thinner is almost always better. For many purposes, they also need to be thinner than the structure being examined. A transistor gate that is 22 nm long requires a lamella that is 22 nm or less in thickness to provide an unambiguous cross-sectional view.

Finally, as modern devices have moved away from conventional planar designs to complex 3D architectures (e.g., FinFETs), the cross section must also be accurately oriented to the device. Accurate sample preparation is essential because these defects are relatively rare but contain important information about the manufacturing process. They are expensive to obtain and if they are destroyed in the preparation process the information is lost forever. Dual beam instruments, which in a single instrument combine a SEM for high-resolution imaging and a FIB for removing (and occasionally adding) material to the sample with nanometer scale precision, are the only reliable and efficient way to meet these sample requirements.

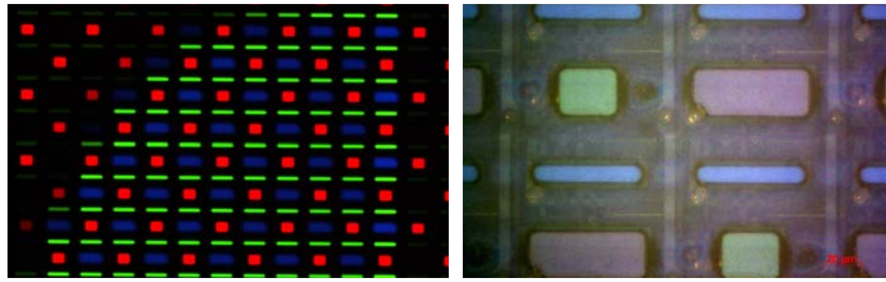
In dual beam based sample preparation, the targeted defect is first located using information provided by defect inspection or electronic test procedures. This may involve navigating to the physical location of a device identified by its logical location using coordinates provided by the CAD design layout. At the target location, packaging material and overlaying circuit layers must be removed. The FIB is then used to mill away material on either side of a thin lamella containing the target. The lamella is cut free from the wafer, then extracted and attached to a TEM sample grid. Next, the FIB is used again to thin the lamella to the desired final thickness, ready for examination in the TEM. One company that has made great progress in automating the sample preparation process is

Fig. 1 — FEI Titan G2 60-300.

FEI Co., Hillsboro, Ore., by improving the speed and reliability of its DualBeam instrument. Fraunhofer CAM has been closely involved in many of those developments.

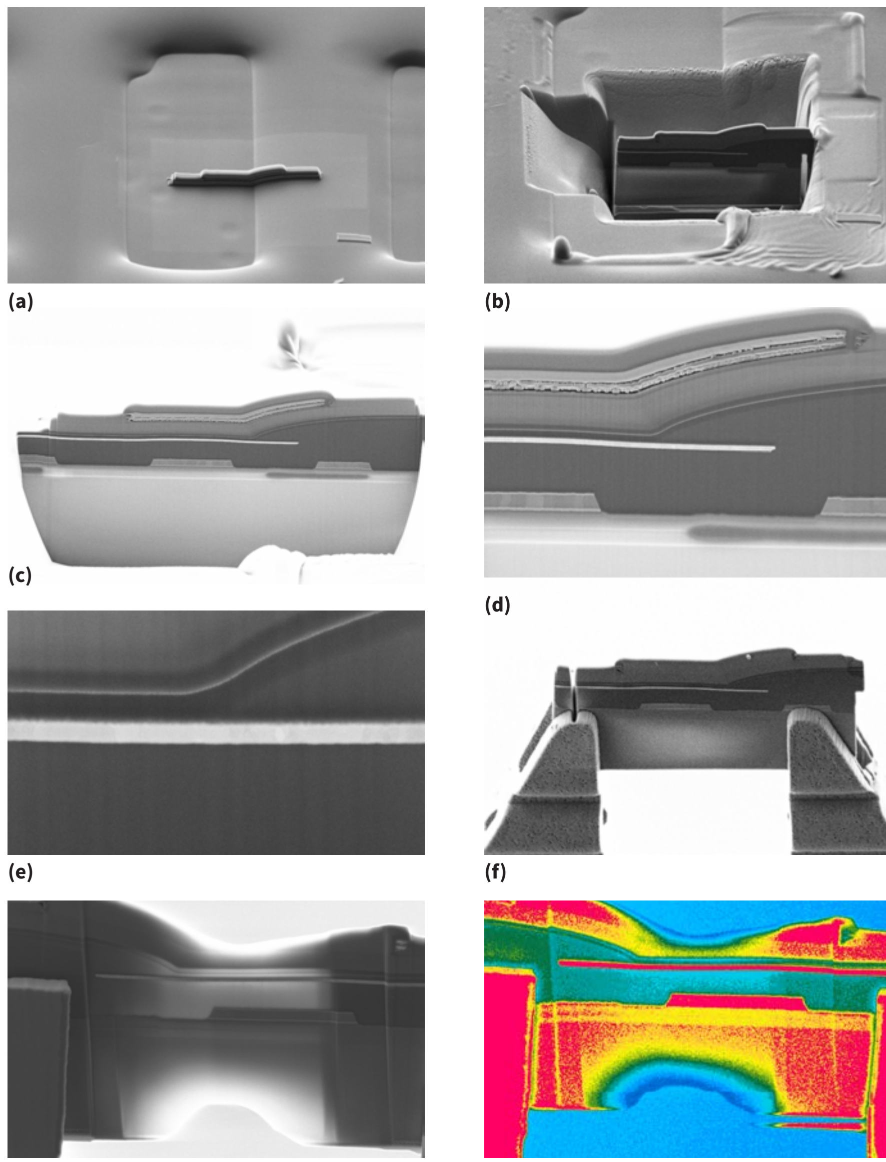
S/TEM IMAGING AND ANALYSIS

Recent developments in S/TEM have greatly increased its utility in semiconductor applications. The advent of practical image correctors has greatly simplified interpretation of high-resolution TEM images. Similarly, probe correctors have improved the lateral resolution of imaging and compositional analysis by reducing the size of the scanned STEM “spot.” Improvements in electron source technology and incorporation of monochromators have improved both TEM imaging and STEM probe diameter by reducing the adverse effects of chromatic aberration. This is particularly important at lower beam energies used to image light materials and reduce knock-on damage. Using a highly efficient multi-detector energy dispersive x-ray spectrometer, a monochromated, probe-corrected STEM can deliver maps of elemental distribution with atomic scale resolution.



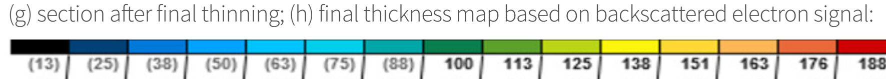
(a) (b)

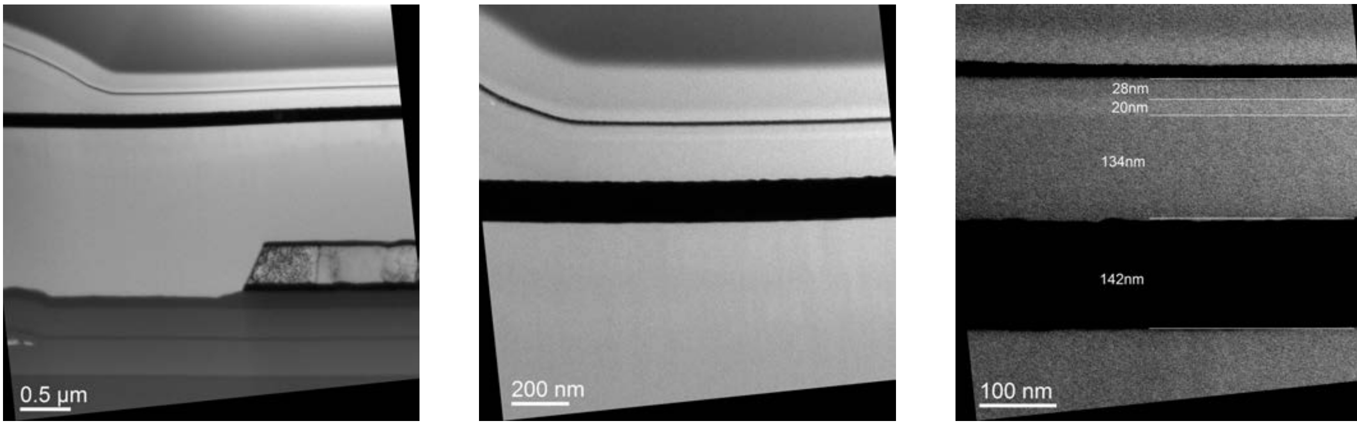
Fig. 2 — (a) Magnified view of an operating Super AMOLED display from a Samsung Galaxy III smart phone; (b) higher magnification view of powered down display acquired with a light microscope.



(a) (b) (c) (d) (e) (f) (g) (h)

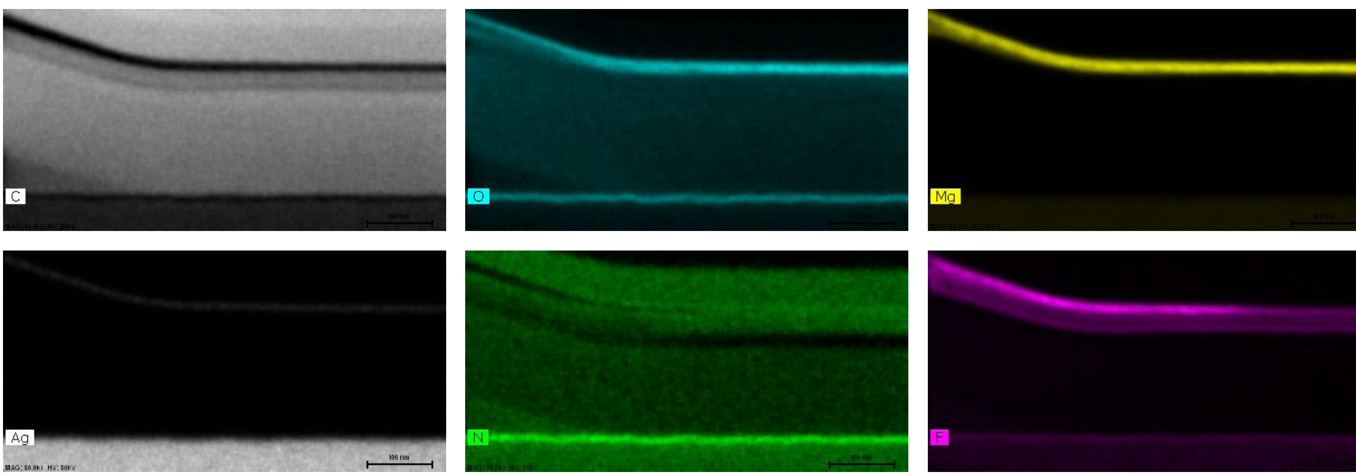
Fig. 3 — DualBeam TEM sample preparation workflow: (a) Protective layers deposited at location of section to protect upper layers from erosion; (b) FIB milling leaves thick section ready for extraction; (c) section surface; (d) higher magnification of section surface; (e) still higher magnification of region of interest at edge of blue pixel; (f) extracted section transferred to TEM holder; (g) section after final thinning; (h) final thickness map based on backscattered electron signal:





(a) (b) (c)

Fig. 4 — TEM images: (a) Bright field overview of blue pixel cross section; (b) higher magnification bright field image of OLED stack; (c) measurements of layer thicknesses from bright field image.



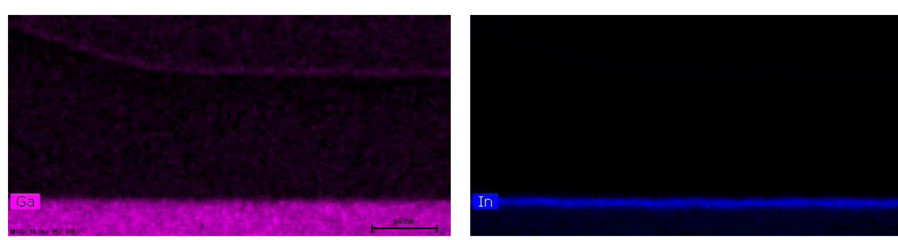


Fig. 5 — STEM EDS element distribution maps for selected elements (normalized raw intensity plots). Note layer separation in C and N maps; O enrichment at metal surfaces; F enrichment in the top metal, ETL layer, ETL/EML interface, and at bottom electrode surface (in layer on top surface of bottom metal).

One of Fraunhofer CAM's most significant recent acquisitions is the Titan G2 60-300 S/TEM from FEI. This system provides the widest commercially available range of beam energies, maximizing penetration of heavier samples at higher energies while improving contrast in lighter samples and reducing knock-on damage in beam-sensitive samples at lower energies.

AMOLED TOUCHSCREEN APPLICATION

Touchscreen displays have become ubiquitous on mobile phones, tablets, and laptop computers. Typically they are created by integrating a capacitive sensor array with an active matrix organic light emitting diode (AMOLED) array. Manufacturers use various names for their proprietary technologies. Samsung, for instance, calls their technology Super AMOLED. Recently, a touchscreen manufacturer asked Fraunhofer CAM whether it was possible to image the structure and analyze the composition of a touchscreen AMOLED stack. For the purpose of the demonstration, a commercially available Samsung Galaxy III mobile phone was purchased. No information from the manufacturer was solicited or used in the investigation.

The display consists of a pattern of red, green, and blue (RGB) diodes. Each diode consists of multiple layers of material with thicknesses ranging up to a few tens of nanometers. Layer thickness and composition determines the color and efficiency of the diode. The blue diode is the most sensitive to process variations, aging, and is also the most difficult to produce. The planned analysis workflow involved the following steps:

1. Separate the Super AMOLED display from the smartphone.
2. Prepare TEM cross sections by FIB, including low-voltage polishing and transfer into a special TEM clip holder.
3. Perform TEM investigations at 80 kV. Visualize and measure the different active layers (thickness and structure).
4. Analyze the elemental distribution within the layers.

DISCUSSION AND SUMMARY

In describing this work, Andreas Graff of Fraunhofer CAM explains, "To our knowledge, no one has previously established a routine to prepare OLED samples for S/TEM by FIB, and no one has seen the composition in the critical layers in a real device before and confirmed their dimensions by S/TEM. Descriptions in the literature led us to expect layer dimensions greater than 30 nm, yet we measured thicknesses in the 20 nm range. We were able not only to prepare the samples and measure the layer thicknesses, but also to measure elemental distributions within the layers. The fluorine distribution is notably different than we expected, perhaps due to an aging effect that occurred during the observations. Our client was quite pleased with the results and fully expects to incorporate this type of analysis in future development work."

In a recent interview, Frank Altman, Fraunhofer CAM's group leader for semiconductor diagnostics, emphasized the challenges posed by the rapidly increasing complexity of microelectronic devices. "Our main challenge is complexity, especially with the advent of 3D integration and advanced packaging technologies. Typically, we look at electrically defective samples and are tasked with discovering the physical root cause. Often we have only one chance to analyze a defect, so it is very important to make the right choices in preparing the sample and executing the analysis," says Altman.

"First, we have to locate the defect and expose it, then perform the structural and material analysis. It can be very challenging just to get access to structures buried deeply in a chip, or in multichip packages with through-silicon vias, or TSVs. We have to remove lots of material to gain access, then find a specific TSV, microbump, memory cell, or transistor. The challenge is further increased by the range of materials and scales we have to cover, from centimeters to nanometers. We have access to numerous preparation tools for grinding, broad beam ion milling, FIB, and delayering, but we first have to decide which tools to use. For site specific preparation, FIB is always our first choice. The availability of gas chemistries for selective milling is very powerful in deprocessing a circuit. From the electron microscopy point of view, polymers, organics, and other soft materials are a big challenge, and they are becoming more common in microelectronic devices. They are easily damaged and they do not generate much contrast. The OLED display analysis is an excellent example. We had to analyze a stack of different amorphous layers that are very difficult to differentiate, with minimal contrast, and very easy to damage or destroy. In this case, the Titan TEM's low voltage performance and the SuperX EDS detector were absolutely essential to our success," he adds. **~AM&P**

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FIELD ASSISTED SINTERING TECHNOLOGY UPDATE–PART I

Field assisted sintering technology (FAST) enables cost-effective manufacturing of metal, ceramic, and composite components with sub-micron grain microstructures and tailored properties.

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Making net-shape components with sub-micron grain microstructures presents significant challenges. Typical steps involved in making these components using powder materials include green compaction, sintering at elevated temperatures, and hot pressing to improve density. During these conventional sintering and hot pressing processes, significant grain growth occurs due to long thermal exposure, thereby destroying the effective functionality of sub-micron grain materials in the final component. To maintain sub-micron grain microstructures in the compacted and sintered product, sintering time and temperature must be significantly reduced. These challenges have been addressed with the introduction of field assisted sintering technology (FAST). FAST is known by different names as applied by other laboratories, including plasma assisted sintering (PAS), pulsed electric current sintering (PECS), and electric pulse assisted consolidation (EPAC). FAST components are produced in a very short time, i.e., a few minutes compared with hours or days using conventional methods. Also, power consumption for FAST is about 20% to 30% less than what is required by traditional techniques such as pressureless sintering, hot pressing, and hot isostatic pressing. FAST is ready to be transferred to private industry for production of net-shape components.

FIELD ASSISTED SINTERING TECHNOLOGY

Figure 1 shows a schematic diagram of a field assisted sintering system. The powder material to be sintered is contained in a graphite or metal die, and pressure is applied via an upper and lower punch. Pulsed or continuous mode dc current flowing through the punch and die provides radiant heating to the powder, while current flowing through the powder produces instant Joule heating. The combined effects of pressure, temperature, high current density, and localized heating at the grain boundaries result in a high sintering rate. Sintering is carried out in a controlled environment including vacuum, backfilled argon, and nitrogen gas.

The Applied Research Laboratory at Penn State is the only U.S. university facility featuring three operational FAST units (Fig. 2). These include an R&D unit (FCT HP D 25) with a load capacity of 25 tons, an industrial prototype unit (FCT HP D 250) with 250 ton capacity, and a hybrid unit (FCT HB HPD 320) with 320 ton capacity. The hybrid unit can manufacture components up to 350 mm in diameter and 100-150 mm long. Units have a 2400°C maximum operating temperature and provide up to 10,000 A of dc power. The system includes a digital radiation thermometer (600°-3000°C range), specimen displacement measuring equipment, pressure control unit, and gas flow controller. The mold assembly is placed in a water-cooled vacuum system to eliminate oxidation and contamination.

Technological benefits of FAST compared with conventional processes include high flexibility; 100 to 1000 times faster processing cycle; retention

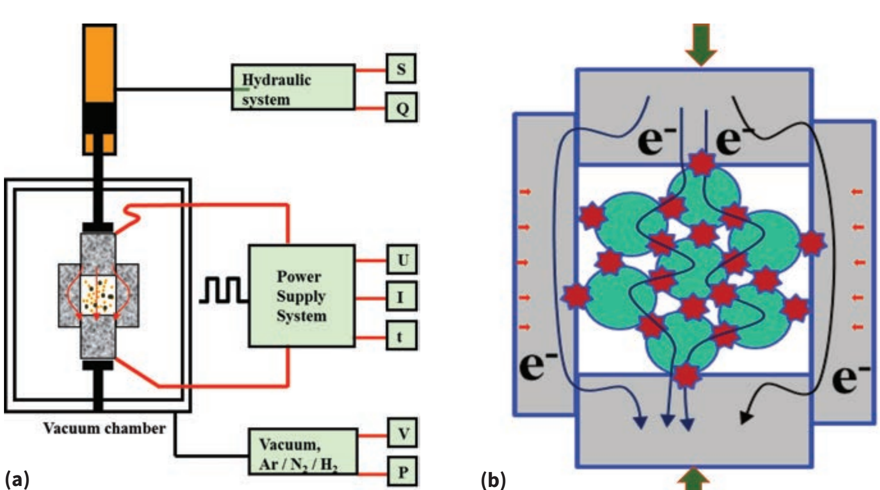


Fig. 1 — (a) Schematic diagram of field assisted sintering technology/spark plasma sintering technology and (b) materials interaction within mold.

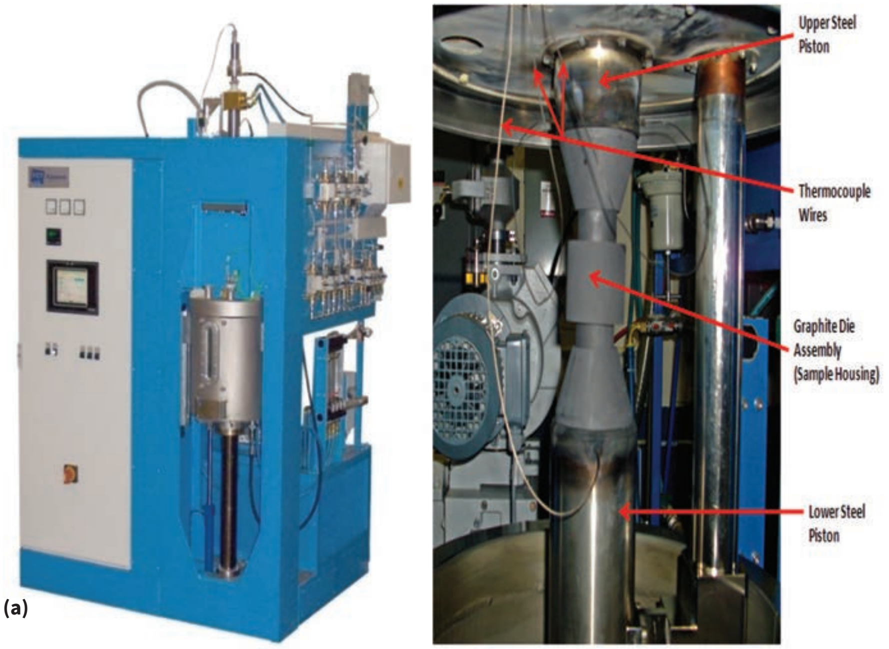


Fig. 2 — Field-assisted sintering units: (a) 25 ton, (b) 250 ton, (c) hybrid 320 ton.

of a sub-micron grain microstructure; achieving 100% density; and energy savings of 60-70%. Applications range from hypersonic vehicles and optical mirrors to cutting tools and aerospace components. The technology enables engineering of new materials and design and development of prototype components with features not economically feasible using conventional manufacturing methods.

THERMALLY MANAGED COMPONENTS

Space exploration is one endeavor where thermal management is of critical importance. For example, NASA is seeking thrusters with double the thrust-to-weight ratio using advanced propulsion techniques such as the Nuclear Thermal Propulsion (NTP) system shown in Fig. 3. Requirements for the NTP rocket nozzle include high thermal conductivity, good mechanical properties, and light weight.

The thermal conductivity of diamond is three to six times higher than that of copper, whereas thermally grown pyrolitic (TGP) graphite is four times higher (in plane). Similarly, thermal conductivities of multiwall carbon nanotubes (MWCNT) and single wall carbon nanotubes (SWCNT) are about 10 times and 20 times higher than copper, respectively (Fig. 4). Therefore, blending copper powder with diamond, MWCNT, or SWCNT significantly enhances the thermal conductivity of thermally managed components.

It is equally important that the interface between the Cu matrix and secondary phase (e.g., diamond, MWCNT, or SWCNT) is adequate for heat transfer. Electrons dominate heat conduction in copper, whereas phonons dominate in second-phase materials including diamond. Therefore, for good heat conductivity in metal matrix composites (MMCs), the energy heat transfer must coordinate between electrons and phonons.

Other challenges in dealing with copper and diamond are the large mismatch in their coefficient of thermal expansion (CTE) and no chemical bonding, which results in a poor interface and

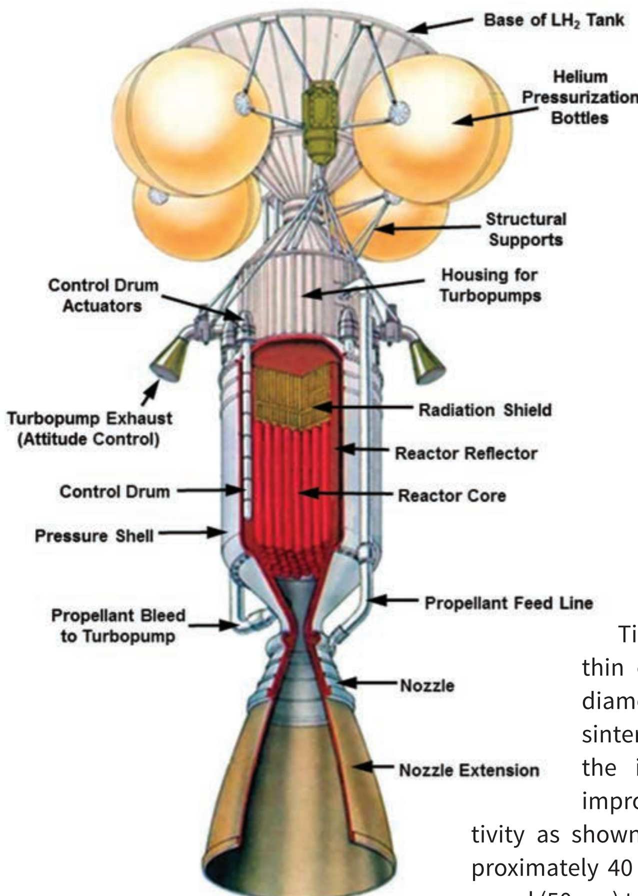


Fig. 3 — Schematic diagram of advanced nuclear thermal propulsion (NTP) system.

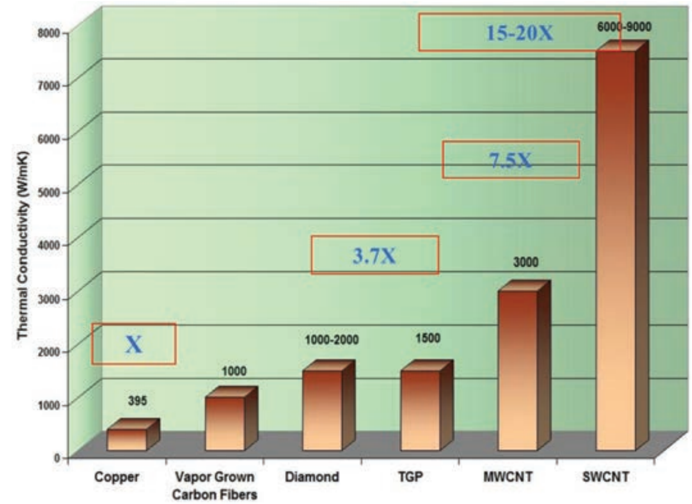


Fig. 4 — Comparative thermal conductivities of Cu, diamond, MWCNT, and SWCNT.

reduced thermal conductivity. Figure 5 shows that the thermal conductivity of Cu decreases as the volume fraction of diamond increases. This led to the development of a copper alloy with small volume fraction additions of carbide-forming elements such as Zr, Ti, and Cr, which form a thin carbide layer between diamond and copper during sintering. This enhances the interface, resulting in improved thermal conductivity as shown in Fig. 6. Adding approximately 40 vol% of industrial diamond (50 µm) to copper alloy NARloy-Z (Cu-4%Ag-0.5%Zr) used in space rocket-engine applications increases thermal conductivity by roughly 70% over base line. The composite structure is about 30% lighter than the NARloy-Z material and, therefore, the density-normalized thermal conductivity is 140% better. High thermal conductivity enables increased turbopump power and higher chamber pressure, resulting in improved thrust and specific impulse (Isp).

The manufacture of a near-net-shape space rocket nozzle made of NARloy-Z with 40-60 vol% diamond composite is under development. Figure 7 shows a composite ring made of this material, which indicates the uniform distribution of diamond in the NARloy matrix.

NET-SHAPE TITANIUM ALLOY COMPONENTS

Increasing application of titanium and its alloys versus aluminum and steel in the aerospace industry is due to titanium's lower density and higher strength. In addition, the superior corrosion resistance of titanium and its alloys

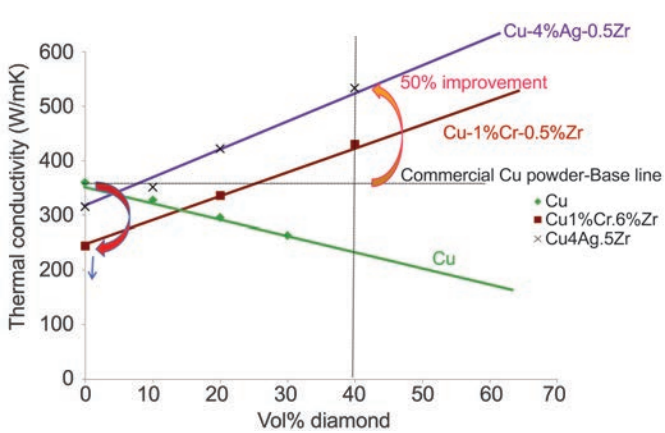


Fig. 5 — Thermal conductivity enhancement in Cu-Ag-Zr-D (NARloy-Z-D) composite.

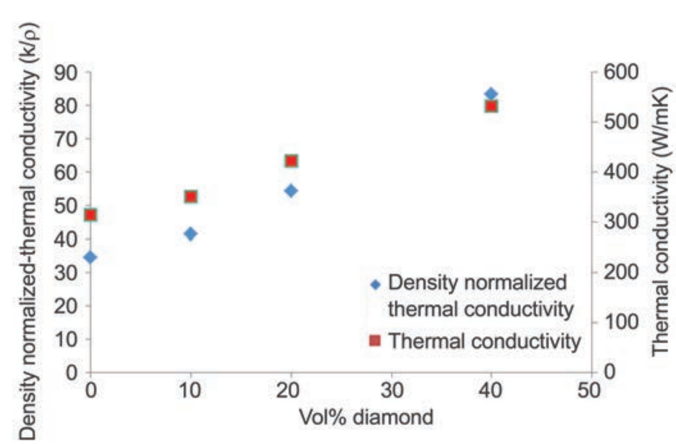
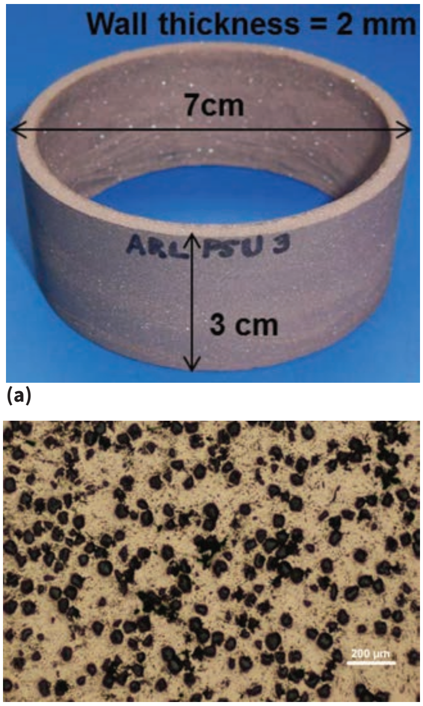


Fig. 6 — Thermal conductivity of NARloy-Z-D composites at room temperature. Both thermal conductivity (λ) and density normalized (λ/ρ) are also shown.



(a)

(b)

Fig. 7 — (a) Fabrication of NARaloy-Z with 40 vol% diamond composite ring by FAST; (b) microstructure of composite cross section.

makes them suitable for use in both terrestrial and marine environments. Four categories of titanium alloys include near alpha, alpha + beta, beta, and titanium-aluminide intermetallics. Alpha alloys are characterized by relatively low strength (≤550 MPa UTS), with some alloys used in high temperature applications (up to 600°C). Beta alloys feature 1100 MPa UTS with significantly higher ductility. Alpha-beta alloys offer higher strength in combination with reasonable levels of ductility. For example, Ti-6Al-4V alloy exhibits 900 MPa UTS and 12% elongation.

Net-shape components are made cost effectively using powder metallurgy techniques (Fig. 8). Blending Ti 6-4 powder with a small volume fraction of B enables producing sintered products by FAST that exhibit a uniform fine-grain microstructure and better mechanical properties including hardness and strength as shown in Figs. 9 and 10.

Benefits of manufacturing Ti 6-4 alloy by FAST include:

- 5% higher UTS of FAST Ti 6-4 than commercially available rolled Ti 6-4 sheet

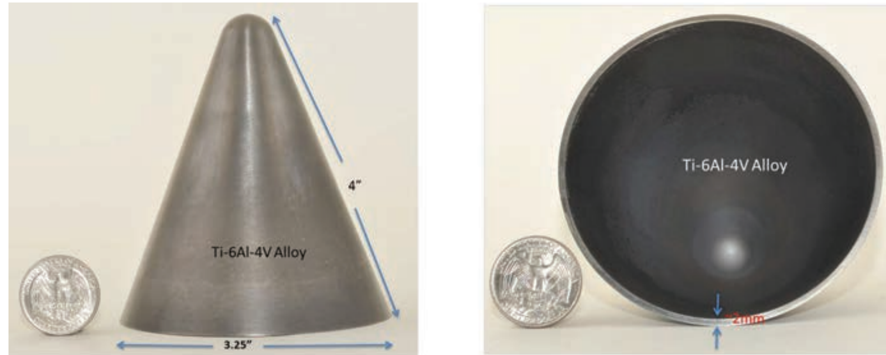
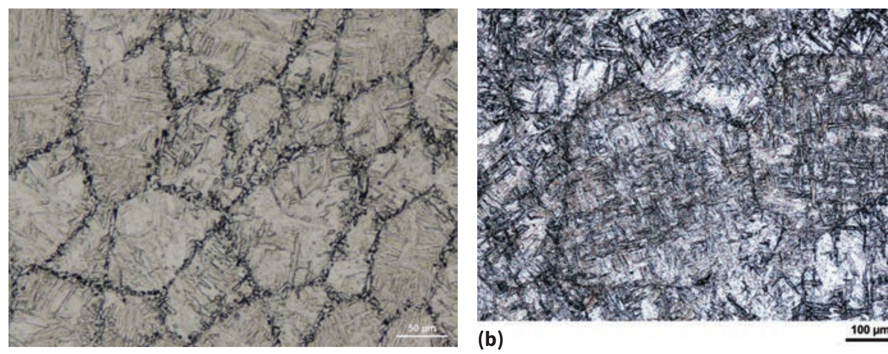


Fig. 8 — Fabrication of net-shape hollow cone made of Ti alloy produced by FAST (1200°C, 25 MPa, 5 min hold time).



(a)

(b)

Fig. 9 — Optical micrograph of Ti-6Al-4V powder (a) with 1.6% B and (b) without B, sintered by FAST at 1250°C, 45 MPa, 20 min.

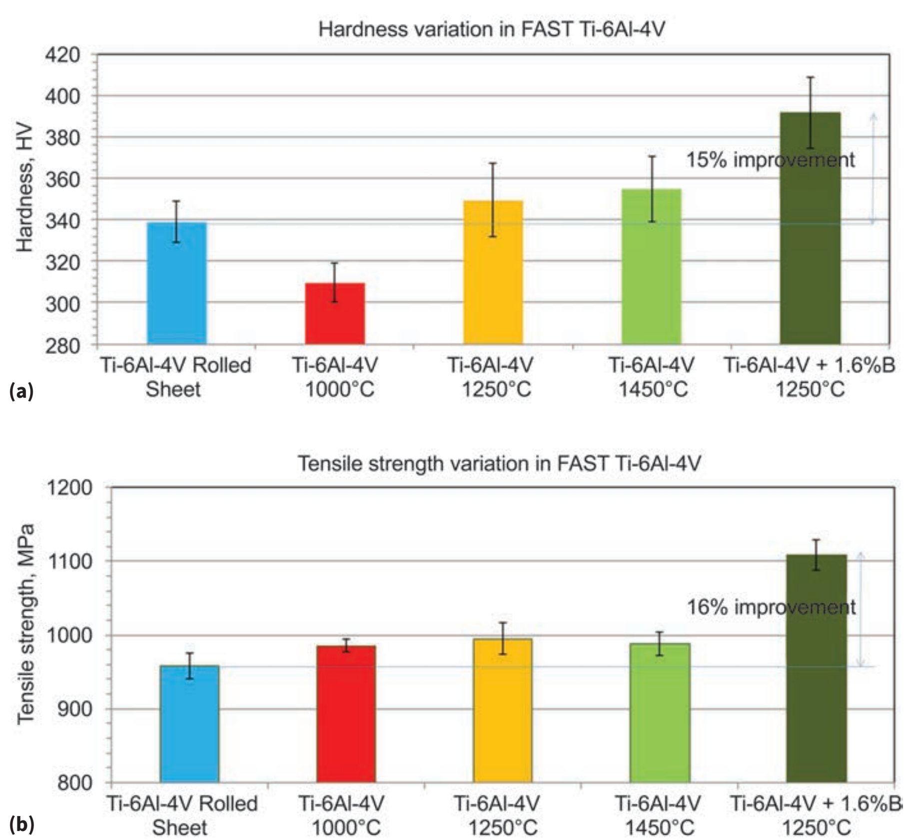


Fig. 10 — Variations in (a) hardness and (b) UTS for Ti-6Al-4V with and without B addition manufactured using FAST at different sintering temperatures.

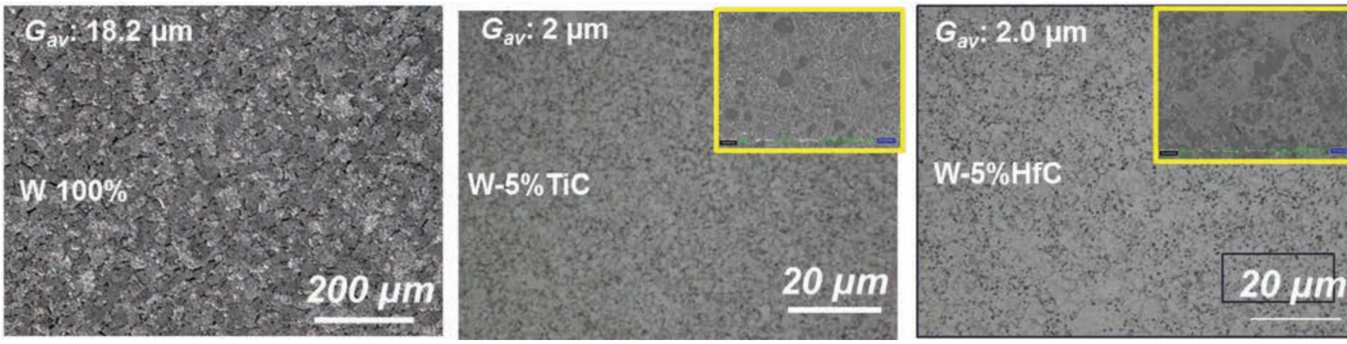


Fig. 11 — Cross-section optical micrographs show reduction in sintering temperature and grain size, and improvement in density with increasing volume fraction of inhibitor (TiC).

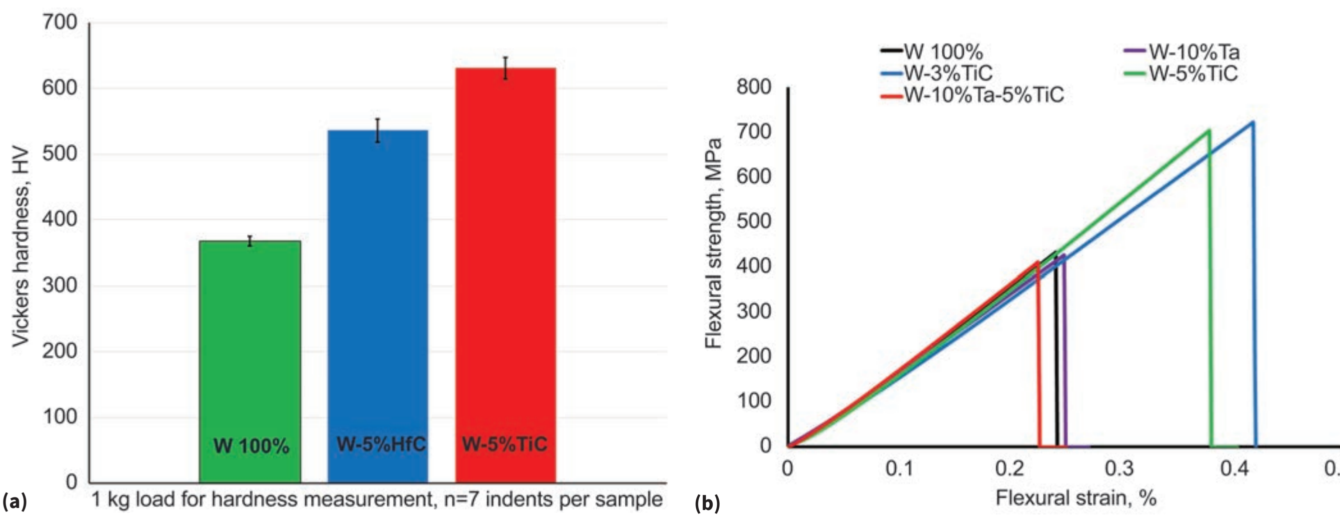


Fig. 12 — Influence of TiC and HfC inhibitors on (a) hardness and (b) flexural strength of W and W-Ta alloy materials, respectively.

- Adding 1.6 wt% B to Ti 6-4 reduces grain size from 600 to 100 μm, and the material is 16% stronger than rolled Ti 6-4 sheet
- 15% increase in hardness
- Faster processing cycle (less than 20 minutes compared with conventional methods)

Further, significant weight savings can be achieved by replacing conventional Ti 6-4 alloy with Ti-6Al-4V-B alloy.

NET-SHAPE REFRACTORY MATERIAL COMPONENTS

Rocket nozzles used in space applications are often made of W and Ta-base refractory alloy materials. Components are manufactured using hot pressing followed by wire electrical discharge machining (EDM). During hot pressing, there is significant grain growth, which is undesirable for high temperature structural applications. The vacuum plasma spray process is also being explored to make net-shape rocket nozzles using a graphite mandrel followed by hot isostatic pressing (HIP). Problems associated with HIP include porosity at grain boundaries that cannot be removed completely by the process, which has a detrimental effect on performance. In addition, vacuum plasma spray plus HIP results in a long process cycle, large grain size, and a high rejection rate associated with dimensional changes. Approaches to overcome these problems include development of W and Ta alloys with minimum grain growth during sintering, and manufacturing net-shape components using FAST.

Significant progress has been made in reducing grain growth during sintering of W and Ta alloys by using grain growth inhibitors including TiC, ZrC, WC, and HfC. Figure 11 shows that grain size is significantly reduced from 22 to <2 μm. Sintering temperature was also reduced for W from 2200° to 1800°C by adding up to 10 vol% TiC with improved density (Fig. 11 insets). In this study, TiC served as an inhibitor and contributed to improved mechanical properties (hardness and flexural strength of W and Ta) associated with uniform distribution of fine secondary phases in the matrix and solid solution strengthening (Fig. 12). **~AM&P**

For more information: Jogender Singh is director, FAST-Center of Excellence, Department of Materials Science and Engineering, Pennsylvania State University, University Park, PA 16801, 814.863.9898, jxs46@psu.edu, www.psu.edu.

METALLURGY LANE

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

PIONEERS IN METALS RESEARCH—PART V

SAMUEL LESLIE HOYT WAS ONE OF THE EARLIEST METALLURGISTS TO RECEIVE HIS ADVANCED TRAINING IN EUROPE.

Samuel Leslie Hoyt was a native of Minnesota and graduated from the University of Minnesota in 1909. His main interest at that time was in geology, so he enrolled at Columbia School of Mines to earn his graduate degree. Here he was advised to take Henry Marion Howe's course in metallurgy and metallography taught by William Campbell under Howe. As with several other students exposed to metallography, Hoyt dropped geology in favor of a degree in metallurgy. After two years at Columbia, he enrolled in the Royal Institute of Technology at Charlottenburg, Germany, to pursue advanced studies under some of the best metallurgy professors in Europe. His classmates included Paul Dyer Merica and several other Americans. He took a field trip to visit steel mills with Merica and a new acquaintance, Guillaume (William) Kroll, the inventor of a process for making titanium.

EARLY CAREER

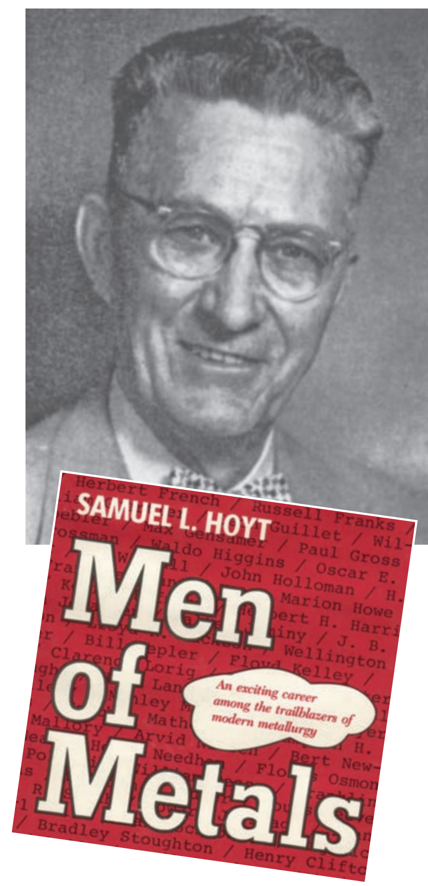
Hoyt returned to Columbia in 1913 where he received his doctorate in metallurgy. He then began his career as an instructor at his old school, the University of Minnesota, teaching metallography and the new field of phase diagrams. After six years, Zay Jeffries recruited Hoyt to come to the GE Lamp Division in Cleveland where he worked with Edgar Bain who had joined GE at the same time. During the next two years, Hoyt conducted research on problems related to manufacturing tungsten wire for lamps. In 1921, he transferred to the GE Central Research Laboratories at Schenectady, N.Y., where he worked under Willis Whitney, the lab's first research director. Here he had contact with Arthur Compton of atomic bomb fame, who had married a classmate of Hoyt's. Compton won the Nobel Prize in Physics in 1927. Hoyt also worked with Irving Langmuir, who graduated from Columbia School of Mines with a metallurgical engineering degree and later won a Nobel Prize in Chemistry.

EUROPEAN TRAVELS

In 1925, GE sent Hoyt to visit Europe to study developments in tungsten and lamp bulb manufacturing. He used the opportunity to visit teachers and classmates from his time at the Royal Institute a decade earlier. He discussed advances in precipitation hardened aluminum with his favorite teacher, Professor Guerther, who was working on alloys in the aluminum-zinc system with remarkable success at high strength. Alloys in this system would become the major high strength alloys in the U.S. after WWII.

Hoyt also visited a classmate who had been working on tungsten carbide cemented with cobalt, which was used in Germany as a cutting tool superior to high-speed steel. Hoyt brought samples back to GE and along with Zay Jeffries helped convince GE to go into production of tungsten carbide tools in a division called Carboloy.

After a decade of working in the most advanced research laboratory in the U.S., Hoyt accepted a position at A.O. Smith, a manufacturer of steel pipelines, oil field equipment, and chemical pressure vessels. Working with steel vendors, he became acquainted with metallurgists throughout the industry. He was visited by some of his classmates from Europe and by men he had visited in England. Kroll also came to see him on his trip to interest U.S. companies in his process for making titanium.

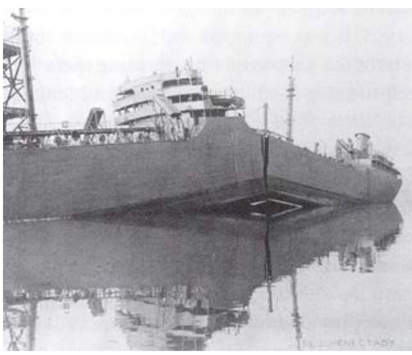


Samuel Leslie Hoyt and his book, "Men of Metals."

BATTELLE YEARS

In 1939, Hoyt accepted a position as consultant to the president of Battelle Memorial Institute in Columbus, Ohio, the largest metals research laboratory in the U.S. As a nonprofit organization, Battelle did contract research for industry and the government. At that time, many companies lacked the facilities and staff to conduct their own research. Hoyt broadened Battelle's activities by using his experience in welding, steel quality, and brittle fracture. This was especially important when all-welded ships began to rupture at

Battelle headquarters viewed from the Olentangy River, Columbus, Ohio. Courtesy of Wikimedia Commons/Columbus Free Press.



SS Schenectady, a welded tanker ship that broke in half while docked in 1943.

low temperatures during WWII. Through his contacts at Battelle, Hoyt became acquainted with many industrial metallurgists, corporate executives, and government agencies.

At the end of WWII, army officials asked Hoyt to help explore the metals developments in Germany and occupied areas of Europe. With his knowledge of German, university contacts, and his trip for GE in 1925, he was well suited for the job. He saw the devastation of European cities and learned that many laboratories he had visited were moved to temporary sites after their original locations were destroyed during bombing raids.

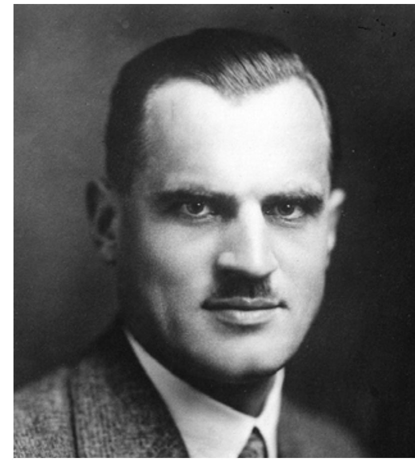
Upon returning to Battelle, he worked on the institute's plans for expanding into Europe. Two sites were selected for building laboratories, Frankfurt, Germany, and Geneva, Switzerland. Hoyt traveled to Europe again in 1952 to survey the market in steel research where he discovered many companies had problems and programs beyond the capacity of their own staff. He found enough potential research needs that Battelle went forward with its European plans.

Hoyt worked with Zay Jeffries in 1951 on the World Metallurgical Congress organized by ASM. He frequently saw Jeffries during his time at Battelle, as Jeffries was a trustee on the Board of Directors. It had been 30 years since they worked together at GE's tungsten wire plant in Cleveland.

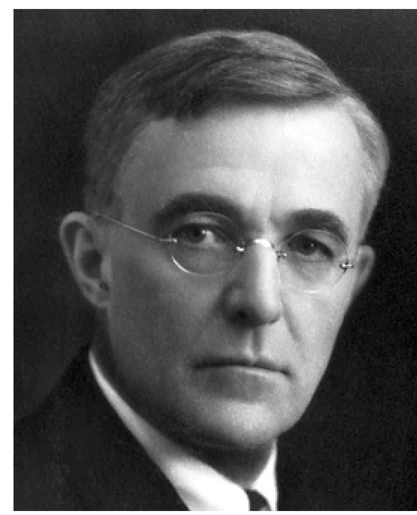
CONSULTING WORK

Hoyt retired in 1953 and started a consulting practice. The country was just becoming aware of the serious problem of brittle fractures, which destroyed many structures, especially ones constructed by welding. Once a crack started, it could run to destruction as it did with all-welded ships. Adding to the problem was the knowledge that hydrogen in steel and in welds could produce cracks large enough to cause brittle failures. Most of his work involved large structures, such as dam gates and penstocks in hydroelectric power plants, where welding of heavy plate was both a steel quality issue and a welding problem. Hoyt later became involved in brittle failures in rocket motor cases. These failures and the resulting destruction of intercontinental ballistic missiles upon launching set back the U.S. defense effort by several years. It was brought under control after research on steel cleanliness, improved welding techniques, new tools for nondestructive testing to locate defects in the interior of metals, and a new approach to fracture toughness technology.

In 1959, Hoyt was again recruited to travel to Europe for his fourth visit since college. He represented NATO in studying the European metals industry.



Arthur Compton of atomic bomb fame worked with Samuel Hoyt at the GE Central Research Labs.



Irving Langmuir of GE Labs won the Nobel Prize in Chemistry in 1932.

By this time, Hoyt was well acquainted with Europeans and was very conversant in German. He continued consulting throughout the 1960s and finished with his autobiography, "Men of Metals," published by ASM in 1979. He described his career and all the men he knew, from European pioneers such as Le Chatelier, Guerther, and Adolf Martens to those he knew from teaching, working at GE, the steel industry, research advising, and consulting. His book contains more than 300 metals men he knew during his career. As he describes them, they were the leading metallurgists of the first half of the 20th century, the time period when the science of physical metallurgy blossomed.

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

TSS
Thermal Spray Society
ASM INTERNATIONAL

FEBRUARY 2016 | VOL. 11 | ISSUE 1

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

THERMAL SPRAY COATINGS IN AEROSPACE AND MARINE APPLICATIONS

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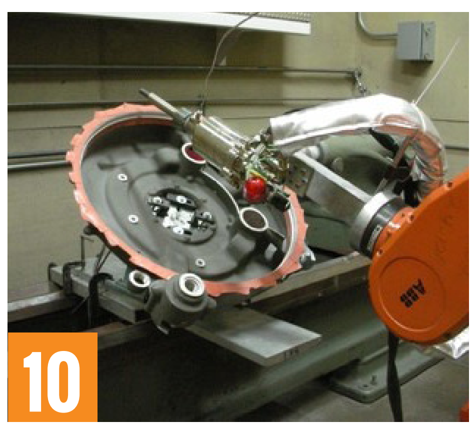


DEPARTMENTS

ABOUT THE COVER

Thermal spray aluminum coatings are applied on the splash zone of various offshore oil and gas platforms. The splash zone requires special protective care by exotic painting techniques because cathodic protection is ineffective against corrosion. Courtesy of L&T Hydrocarbon Engineering Ltd., Mumbai, India. lnthydrocarbon.com.

EDITORIAL OPPORTUNITIES FOR *iTSSe* IN 2016

The editorial focus for *iTSSe* in 2016 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

April: Energy & Power Generation

August: Automotive & Industrial Applications

November: Emerging Technologies/ Applications & Case Studies

To contribute an article to one of these issues, contact the editors c/o Frances Richards at frances.richards@asminternational.org.

To advertise, contact Kelly Thomas, at kelly.thomas@asminternational.org.

CREATING A VIBRANT THERMAL SPRAY COMMUNITY

Attending the International Thermal Spray Conference & Exposition (ITSC) involves much more than simply arriving at the destination and going to lectures. We must think about our time and justify expenses, but we also need to consider how our efforts might positively influence the thermal spray community. As Thermal Spray Society members work with various partners for ITSC planning, we discuss past efforts, new programming ideas, interesting seminars, and associated activities. We also talk about students, different industries that use thermal spray, papers that will interest a diverse audience, and creating an exhibit floor that will provide an effective venue for suppliers.

Kay

Over the past several years, the Programming Committee members of ASM and DVS have seen an increase in paper contributions from Asia. Unfortunately, this trend is lower in the U.S. For those individuals serving in leadership positions with regard to surfacing technologies, it is important to recognize the contributions of many. Leaders can serve as ambassadors for the thermal spray community and encourage others to submit papers and become involved in industry activities.

Coming this May is the Far East ITSC tri-rotation in Shanghai. In addition to reading this issue of *iTSSe,* you can also go online to learn further details about ITSC and do your due diligence before heading east! For those preparing papers, think of how important your contribution is and about the possibility of reaching newcomers to the industry. Many of us involved in volunteering for the Thermal Spray Society cannot help mentioning the passion and hard work of both committee members and the leadership team. Many ASM staff members also work diligently to support the Society, which is the backbone that makes it possible to do what we do.

In this issue, you will see a focus on marine and aerospace applications. In the 1960s, the U.S. government gave substantial support to engineers to reach higher into the sky with R&D funding for new designs and materials. John F. Kennedy's inspiring "moon speech" in September 1962 is a prime example of this era. It is this kind of support that laid the foundation for many of the technology advancements bearing fruit today.

Sincerely,
Charles Kay
Vice president, Marketing, ASB Industries Inc.

TSS COMMITTEE CHAIRS NAMED FOR 2015-2016 TERM

The ASM Thermal Spray Society Board appointed chairs to each of its committees for the 2015-2016 term. **Christian Moreau, FASM,** Concordia University, Montreal, continues as president of TSS. **Luc Pouliot,** Tecnar Automation Ltd., Quebec, Canada, still serves TSS as immediate past president and chair of the Nominating Committee. **Robert C. Tucker, Jr., FASM,** The Tucker Group, continues as chair of the Journal of Thermal Spray Technology Committee. **Atin Sharma,** Siemens Energy Inc., Charlotte, N.C., serves as chair of the Membership, Marketing and Outreach Committee. **Douglas Puerta,** Element Materials Technology, Portland, Ore., continues to serve as vice president of TSS and chair of the TSS Program Committee. **Fardad Azarmi,** North Dakota State University, Fargo, N.D., was named chair of the TSS Training Committee. **Timothy N. McKechnie, FASM,** Plasma Processes LLC, Huntsville, Ala., continues to serve as chair of the TSS Awards Committee. **Shari Fowler-Hutchinson,** Saint-Gobain, Worcester, Mass., serves as chair of the Exposition Committee and **Richard Chromik,** McGill University, Montreal, was named chair of the Accepted Practices Committee. If you are interested in serving on an affiliate society committee, contact the respective committee chair or email joanne.miller@asminternational.org.


Moreau


Pouliot


Tucker


Sharma


Puerta


Azarmi


McKechnie


Fowler-Hutchinson


Chromik

SEEKING APPLICANTS FOR TSS STUDENT BOARD MEMBERS

The ASM Thermal Spray Society is seeking applicants for its two student board member positions. Nominations are due by **April 1, 2016.** Students must be a registered undergraduate or graduate during the 2015-2016 academic year and must be studying or involved in research in an area closely related to thermal spray technology. For more information on eligibility and benefits, visit tss.asminternational.org.

JOURNAL OF THERMAL SPRAY TECHNOLOGY ANNOUNCES EDITORIAL TRANSITION

After 12 years of serving as editor-in-chief of the *Journal of Thermal Spray Technology* (JTST), Dr. Christian Moreau, FASM, TS HoF, has transferred his responsibilities to Dr. Armelle Vardelle, FASM, according to Dr. Robert C. Tucker, Jr., FASM, TS HoF, chair of the Journal of Thermal Spray Technology Committee. Vardelle has been Lead Editor of JTST since 2013 and prior to that was an associate editor of the journal from 2006 through 2012. She will be succeeded as Lead Editor by Dr. André McDonald.

Moreau became JTST editor in 2004, and led the journal through an extraordinary period of growth, in which the journal increased from a quarterly to six issues per year in 2007, then to eight issues per year in 2013. Building on the strong foundation laid by JTST Founding Editor Chris Berndt, FASM, TS HoF, Moreau enlarged the editorial staff to its current complement of five associate editors by identifying individuals who were both well qualified technically as well as representative of the journal's international readership. Further, he created the position of Lead Editor to focus on special topical and event-related issues.

Throughout Moreau's term as editor, the journal has continued to grow in number of submissions, quality, and articles published. Working closely with former JTST Committee chair Jockel Heberlein and Chris Berndt, Moreau brought into reality an annual special double issue containing invited and expanded papers originating from the International Thermal Spray Conference. He also led the journal through its transition into the publishing partnership with Springer, which has greatly increased the journal's international visibility and accessibility.

A professor at Concordia University (Canada Research Chair, Thermal Spray and Surface Engineering), Moreau will continue to offer the journal the benefit of his experience by remaining involved as a member of the JTST Committee.

Mary Anne Fleming, ASM's senior content developer, Journals, said, "On behalf of the ASM staff who have worked with Christian on JTST, I thank him for unceasingly providing his insight and dedication as he has skillfully led the journal for the past 12 years and for ensuring its future success by identifying a capable and qualified successor. We are delighted that Armelle has agreed to step into the editor position."


McDonald


Moreau


Vardelle

Armelle Vardelle (D.Sc. 1987; Ph.D. 1979, M.Sc. 1975, B.Sc. 1973) is professor, University of Limoges, France. She is Co-Chair of the Department of Materials (Surface Treatments and Environment) at the Engineering School of the University of Limoges (Ecole Nationale Supérieure d'Ingénieurs de Limoges, ENSIL). She holds the title of Distinguished Professor and is involved in research in the laboratory of Sciences of Ceramics and Surface Treatment Processes, UMR-CNRS in the European Ceramic Center.

Her current research interests include thermal spray and thermal plasma processes, modeling of plasma processes and torch operation, transport and chemical rate phenomena at high temperature, thermal spray coatings, and green manufacturing. Her teaching interests include thermal spraying, surface engineering, thermal sciences, transport phenomena in surface engineering processes, materials properties, industrial ecology, and life cycle analysis.

Vardelle has authored or coauthored more than 111 peer-reviewed scientific journal publications, 141 publications in international and national conference proceedings, and seven book chapters. She has presented 42 invited lectures at international conferences and 11 invited seminars at foreign universities. She has been a member of the editorial board of *Plasma Chemistry and Plasma Processing* since 2009. She became a Fellow of the International Plasma Chemistry Society in 2015 and a Fellow of ASM International in 2012.

As newly appointed editor-in-chief of JTST, Vardelle joins Tucker in announcing that McDonald has been named Lead Editor of the journal. McDonald is chair of the ASM Thermal Spray Society Training Committee, Lead Editor of the 2015 International Thermal Spray Conference Proceedings, and has served as a guest co-editor of the journal.

Currently an associate professor in the Department of Mechanical Engineering at the University of Alberta, McDonald received his BSME from the City College of New York (CCNY) in 2001, where he was the Dupont Mechanical Engineering Distinguished Graduate and won the Peggy Benline, Eliza Ford, and ALCOA awards. He was awarded his MSME from that same institution in 2002. He received his Ph.D. from the University of Toronto in 2007, followed by a short post-doctoral fellowship at the Industrial Materials Institute - National Research Council Canada (IMI-NRC) in Boucherville, Québec.

McDonald's current research includes development of flame-sprayed coatings to provide wear and erosion resistance and to provide heating and structural health monitoring to polymer-based airfoil structures. In the area of cold-spraying, he has been working to develop a variety of metal matrix composite coatings with alumina or tungsten carbide as the reinforcing particle material.

Since 2006, his work has resulted in 33 peer-reviewed journal articles, 39 conference articles, a textbook on the practical design of thermo-fluids systems, an industrial manual for thermal spraying for the oil and gas industry, 26 industrial reports, and several awards including the International Thermal Spray Conference and Exposition Best Paper Award, the Harold C. Simmons Best Paper Award from ILASS-Americas, the Composites Conference Best in Track Technical Paper Award for Manufacturing, and the Association of Professional Engineers and Geoscientists of Alberta's Early Accomplishment Award. Since becoming a professor, McDonald has trained 50 students, at both the graduate and undergraduate levels, in the areas of thermal spraying and/or heat transfer.

THERMAL SPRAY SOCIETY EDUCATION COURSES

Visit asminternational.org/learning to find out more about these valuable courses.

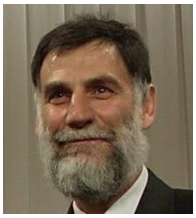
Introduction to Thermal Spray
Date: March 21-22
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Richard A. Sayman

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.

Thermal Spray Technology
Date: July 26-27
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Chris Berndt, FASM

Coating reliability and effectiveness requires overlay coatings to be selected, engineered, and applied correctly. This course provides a thorough grounding and understanding of thermal spray processes, depicts complex scientific concepts in terms of simple physical models, and integrates this knowledge into practical engineering applications and commonly accepted thermal spray practices.

Advanced Thermal Spray Technology
Date: July 26-27
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Chris Berndt, FASM


Berndt

Thermal spray is increasingly used to manufacture net shapes, advanced sensors, and materials for the biomedical and energy/environmental industries. These and a vast array of emerging applications take advantage of the rapid and cost-effective capabilities of thermal spray technology in the OEM and repair industries.

THERMAL SPRAY ALUMINUM COATINGS FOR SPLASH ZONE STRUCTURES—PART II

Recent advances in thermal spray techniques enable thermal spray aluminum coatings to reliably protect offshore structures in splash zones. Part I of this article appeared in the November/December 2015 issue of iTSSe.

***Deepashri D. Nage,** L&T Hydrocarbon Engineering Ltd., Mumbai, India*

Offshore structures are exposed to various corrosion zones depending on sea level as datum. Both submerged steel surfaces and steel immersed in mud are typically not coated, instead relying solely on cathodic protection due to slow predicted corrosion rates. Splash zones in the -3 to +6 m range of Mean Sea Level (MSL) encounter the most severe degradation due to continuous contact with highly aerated sea water splashes. This zone requires special protective care by exotic painting techniques because cathodic protection is ineffective.

To shield splash zone structures from corrosion and other environmental degradation, coating is the best protective measure. Coatings for this zone have evolved from Monel sheath to high build epoxy and other organic formulations. Recent advances in thermal spray techniques have found thermal spray aluminum coatings (TSAC) to be an effective protection method in splash zones. Although thermal spray of just a few microns thick offers corrosion resistance and functional properties in precision jobs, there is concern about whether or not it is effective when applied to very large structures. This article focuses on challenges as well as successful implementation of TSAC by arc spray on splash zone structures. Here we look at an oil and gas platform recently installed off the east coast of India.

Figures 4 and 5 illustrate bend tests (ASTM D522) and adhesion tests (ASTM D4541), respectively, performed for every shift, each operator, and adhesion on the companion coupon. Figure 6 shows TSAC application on an actual job and the components of an offshore jacket coated with TSAC. Figure 7 shows the TSAC job completed and installed in Indian waters.

CHALLENGES FACED IN IMPLEMENTING TSAC

Coating of piping, equipment, and structural components is generally the final step in the sequence of fabricating equipment—or an entire plant—after all assembly/fabrication work is complete. Because TSA coating is a hot process with certain limitations, individual pieces should be coated at the component level with the connecting joints coated upon assembly. Although the companies and thermal spray applicators who are able to handle this magnitude of coating work are limited, a proper qualification and readiness was ensured within this particular project's timeline and specifications.

Aluminum metallic coatings offer several advantages, including excellent corrosion protection of steel due to the cathodic protection phenomenon, consumables with no shelf life expiration, zero volatile organic compounds, and

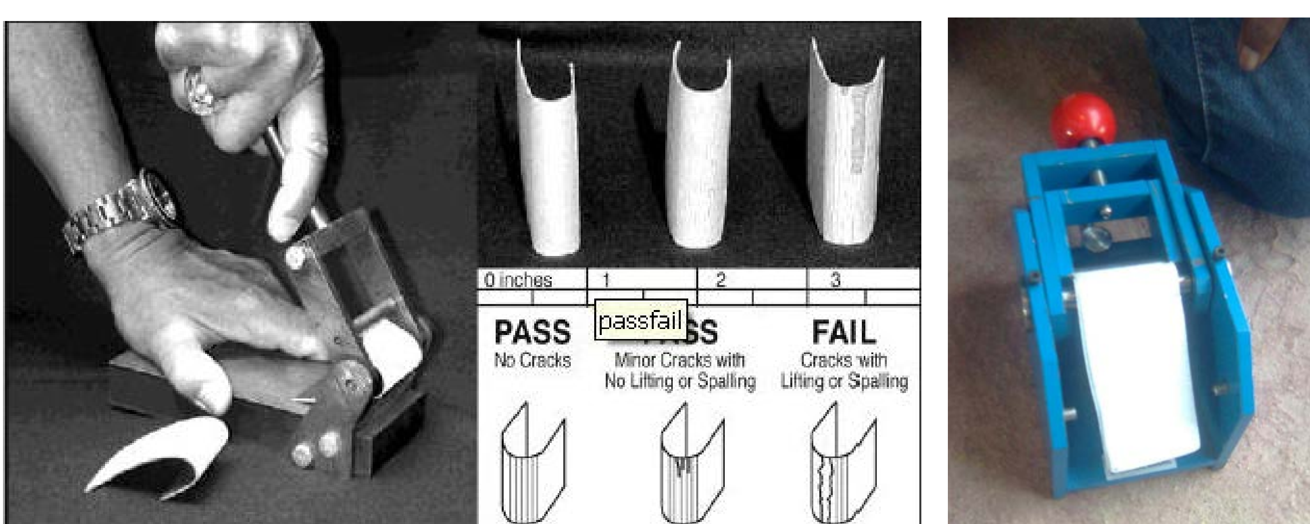


Fig. 4 — From left to right, bend test method (ASTM D522) and photograph of test performed on TSAC sample.

TABLE 2–TSAC VERSUS CONVENTIONAL ORGANIC COATINGS

Features	Organic coating system	TSA + sealer coat
Surface preparation	25-50 micron (S a 2 $^{1}/_{2}$)	>65 micron (S a 3)
Process temperature	Ambient	Torch at >1000°C Metallizing at >675°C Substrate at 120-150°C
Productivity	200 m^2 per shift	20-25 m^2/shift
Accessibility	Using brush can cover entire area	Coating of nooks and corners, T-welds, assembled components, and recess areas is nearly impossible.
Welding/repair/rework	Possible	Questionable
Hot permit	Not required	Required (even at later stage)
Safety	Minimum protection	Complete protection (metal fumes, UV, thermal radiation and noise hazard)
Contractors	Quality contractors are easily available	Limited vendor base with proven capability
Handling of coated components	Not an issue	Same quality cannot be restored
Corrosion protection in splash zone	Other proven coating systems are available. 1500 microns DFT are specified.	Adequate TSA coating (200 microns) for splash zone
Operator shift time	One operator can work continuously	Need to relieve operator after maximum of two hours
Top coat application	Primers are available where coating interval can vary up to six months	Immediate sealer coating (within six hours)
Rework on splash zone	Systems are available	Difficult to achieve surface finish and coating application in low tide duration

low lifecycle costs. These benefits outweigh the drawbacks, which include the necessity of using a hot process, sensitivity to dust, wind, and moisture, potential for operator error, and shock and noise hazards.

The procedural details, readiness report, and inspection checklist were prepared to ensure guaranteed quality in every aspect of this project. Thermal spray aluminum requires rigorous process control over the entire operational sequence, from initial blasting to spraying the final sealer coat. Specifications provided by the client, PMC, were quite stringent, with required parameters that are only achievable at laboratory scale. Interactions with PMC engineers regarding various technical issues served to make the process conditions less stringent while adhering to internationally accepted parameters. Issues such as adhesion bond strength, procedure qualification record, surface preparation, dew point, and final shade of sealer coat on the jacket splash zone were all successfully resolved.

Table 2 summarizes limitations of TSAC with respect to widely adopted organic coatings for the splash zone. When the coating application is to be done “in yard,” constraints are imposed such as absence of control over environmental conditions. Further, because in-yard application occurs in an open environment, safety is a top concern and the area must be barricaded. Operators and personnel in the vicinity must use ear protection and protective UV glasses. The process is labor intensive and proper ventilation must be in place for operator health. Further, aluminum metal dust is prone to cause electric shocks and must be appropriately contained. Once the coating process is underway, coated objects must be handled with care using canvas slings and shrink wrap. Proper masking to protect surfaces not to be coated is another vital step that must occur before TSAC application. Paying close attention to all of these parameters will enable successful achievement of bond strength for a long and maintenance-free service life with an optimized lifecycle cost.

PROPER APPLICATION OF TSAC OVERCOMES CONSTRAINTS

- Repair/touch-up/patchwork are very difficult once TSA application is complete, compared to conventional paint. Therefore, the structure was released for TSA coating only after all QA/QC reports were received and cleared. All QA/QC requirements of such structures were completed on time with the help of the QC team to avoid any downtime. The slings of the assembly cranes were wrapped with cloth and care was taken to avoid any repairs.

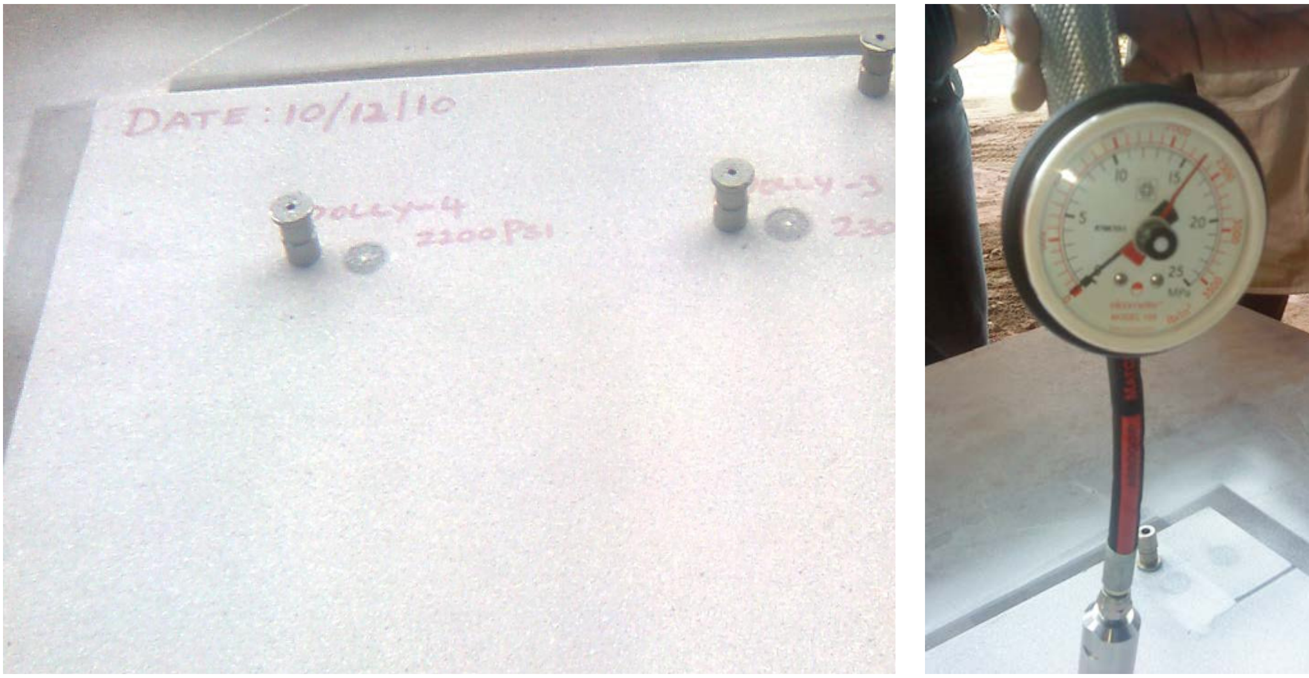


Fig. 5 — From left to right, dollies pasted for adhesion bond strength test (ASTM D4541) and photograph indicating strength level on dial gauge.

Fig. 6 — From left to right, TSAC application on actual job and completed job.

- The structure was released for TSA coating after complete fabrication and an inspection release note was signed. After TSA coating, it was released for assembly.
- Issues such as adhesion bond strength, surface preparation, dew point, and its impact on the project schedule were taken care of during execution. Relative humidity was a major constraint in achieving the desired bond strength of 1500 psi for this job. An additional twin wire electric arc thermal spray unit was mobilized to keep production on track.
- All safety requirements were closely monitored. Operators were allowed to work in rotation with maximum two-hour shifts.

The coating process was performed in stages, with legs, cross bracings, guide cones, and other parts at a minimum rate of 100 m^2 per day, including surface preparation, coating, and sealer coat application. In spite of unpredictable weather, all coating operations were completed well within the schedule.

Fig. 7 — TSAC applied on splash zone of installed offshore platform.

SUMMARY

Thermal spray aluminum coatings are one of the most effective ways to protect the corrosion-prone splash zones of offshore marine structures. TSACs offer a cost effective and reliable way to enhance the structure's service life when applied carefully. However, successful implementation that must adhere to a strict timeline requires a systematic approach for monitoring the process. Proper coordination with respect to planning and execution is essential. Monitoring includes extensive quality control and inspections at each step of the TSAC application process to ensure high coating quality and optimize lifecycle cost. **iTSSe**

For more information: Deepashri D. Nage is Deputy General Manager, L&T Hydrocarbon Engineering Ltd., R&D Building, Powai Campus, Gate No. 1, Saki Vihar Road, Powai, Mumbai - 400 072 (INDIA), +91 22 6705 2780, deepashri.Nage@larsen-toubro.com, lnthydrocarbon.com

MAGNESIUM REPAIR ON LIGHTWEIGHT AEROSPACE COMPONENTS

REASON TO CONSIDER SURFACING

Magnesium components feature unique structural strength combined with lightweight attributes. However, these components are difficult to repair due to a heat-sensitive corrosion reaction. “Magnesium alloys have been developed that have good mechanical properties, low densities, can be cast into complex shapes, and also feature good machining characteristics. These characteristics make them ideal for use in weight-critical applications, especially in helicopters,” explains Tim Eden, head of the Materials Processing Division, Penn State Applied Research Laboratory.* “A disadvantage of magnesium alloys is that they have a very high anodic index, which means they are electrochemically active and very susceptible to galvanic corrosion when coupled to another metal. Care must be taken to apply coatings that isolate the magnesium alloys from other metals and to create an environmental barrier to prevent corrosion. Once the coating is damaged, corrosion is initiated and quickly propagates.”

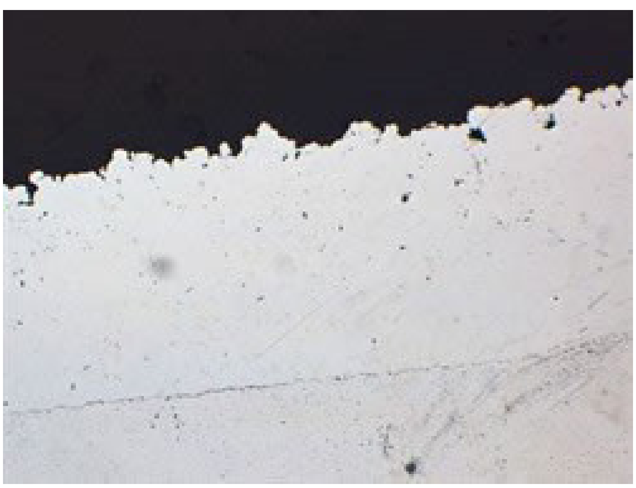


Fig. 1 — Micrograph shows commercially pure aluminum applied via high pressure cold spray.

Fig. 2 — Hydraulic pump pad in the as-sprayed condition shows the AA4047 coating. Courtesy of Applied Research Laboratory, Penn State.

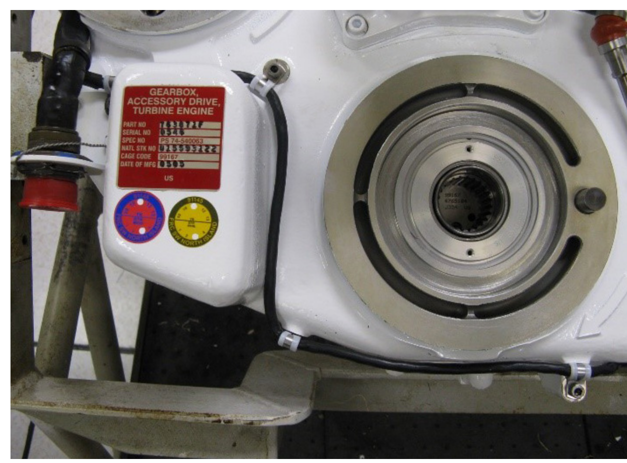


Fig. 3 — Hydraulic pump pad after final machining of cold spray repair. Transmission is fully assembled and resting in the engine test stand. Courtesy of Applied Research Laboratory, Penn State.

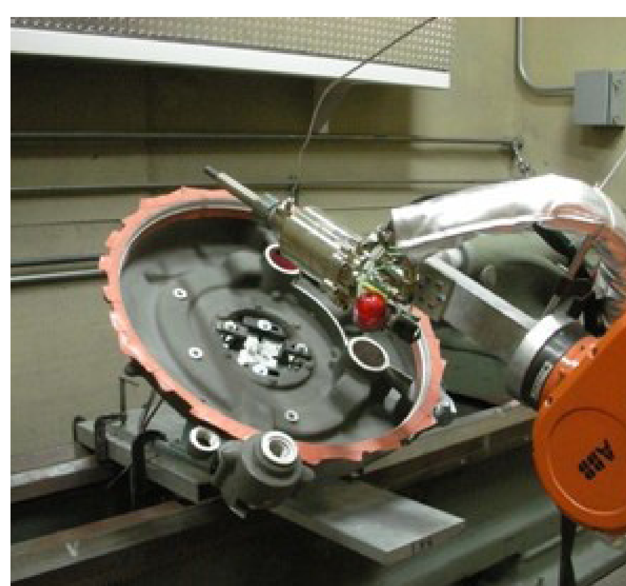


Fig. 4 — Aluminum repair on magnesium sump. Courtesy of ASB Industries.

*Excerpt from Tim Eden’s contribution to “High Pressure Cold Spray: Principles and Applications,” a new book from ASM to be published in May.

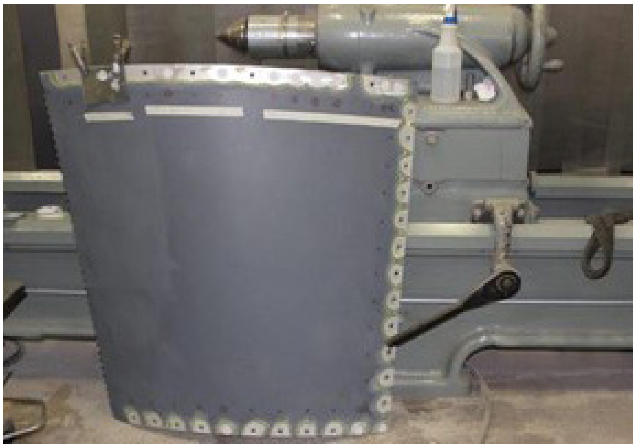


Fig. 5 — Aluminum repair on lightweight aircraft panel. Courtesy of ASB Industries.

VALUE OF REPAIR

Limited repair options for damaged magnesium parts have led to a massive stockpile of unusable aerospace components, necessitating the purchase of costly replacement parts.

OPTION

High pressure cold spray (HPCS) using aluminum feedstock can be used to repair worn areas of aerospace components, which can then be easily machined to OEM specifications.

BENEFITS

- Allow stockpile of expensive worn components to be repaired.
- HPCS commercially pure aluminum exhibits a notably dense microstructure, highly bonded interface, and is easily machined.
- Components can be repaired multiple times. iTSSe

For more information: Charles Kay is vice president, marketing, ASB Industries Inc., 1031 Lambert St., Barberton, OH 44303, 330.753.8458, cmkay@asbindustries.com, www.asbindustries.com.

INTERNATIONAL THERMAL SPRAY CONFERENCE AND EXPOSITION 2016

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Plan now to attend the 2016 International Thermal Spray Conference and Exposition, the premier annual event for the global thermal spray community to meet, exchange information, and conduct business. This event presents the latest advancements in application, research, and development in the field of thermal spray. The theme of ITSC 2016 is *Thermal Spray: Fostering a Sustainable World for a Better Life.* In addition to the technical program, a three-day exhibition will include both an industrial forum and poster session.

ITSC 2016 will be held in the Shanghai International Convention Center connected to the Oriental Riverside Hotel. It is located in the heart of Lujiazui, the dynamic financial district of Shanghai, which offers easy access to all parts of the city. Shanghai is a popular tourist destination renowned for its historical landmarks such as The Bund, City God Temple, and Yu Garden as well as the extensive Lujiazui skyline and major museums including the Shanghai Museum and the China Art Museum.

CONFERENCE HIGHLIGHTS

Comprehensive Technical Programming
Tuesday, May 10 through Thursday, May 12

Attendees will learn about the latest research and development taking place in their specific field while gaining a global perspective from leading scientists and engineers from around the world. Visit asminternational.org/web/itsc-2016-expo/home for technical program details.

Exhibit Floor • Tuesday, May 10 through Thursday, May 12

The ITSC show floor offers an unparalleled exposition featuring the world's largest gathering of thermal spray equipment suppliers, consumable and accessory suppliers, vendors, and service providers. You will find information about equipment for thermal spraying, research and specialist institutes, applied research, and the latest innovations conveniently located in one big forum.

Young Professionals Session • Tuesday, May 10 • 3:40 p.m.

Now in its fifth year, ITSC 2016 organizers and Oerlikon Metco will sponsor a young innovative scientists/professionals

EXHIBITOR LIST

Company	Booth
AMS	145
AMT AG	108
Ardleigh Minerals Inc.	169
Artec S.p.A./Turbocoating S.p.A.	164
Beijing SunSpraying New Material Col Ltd.	181
BGRIMM Advanced Materials Science & Technology Co. Ltd.	183
C&M Technologies GmbH	114
Carl Zeiss (Shanghai) Co. Ltd.	124
Carpenter Powder Products	156
Chengdu Huarui Industrial Co. Ltd.	118
Chengdu Revitalization Metals Powder Co. Ltd.	135
DeWAL Industries Inc.	100
DIAMANT Metallplastic GmbH	147
Dura-Metal (s) Pte. Ltd.	154
Fujimi Inc.	116
Ganzhou Achteck Tool Technology Co. Ltd.	158
Green Belting Industries Ltd.	153
GTV Verschleiss-Schutz GmbH	119
Guangzhou SanXin Metal S&T Co. Ltd.	138
H.C. Starck GmbH/Flame Spray Technologies B.V.	143
Impact Innovations GmbH	139
Innovator Surface Technologies Co. Ltd.	129
Kermetico Inc.	106
KGS Diamond (Guangzhou) Co. Ltd.	103
Kunshan Chuang Yi Fa Thermal Spray Technology Co. Ltd.	131
LSN Diffusion Ltd.	115
Luoyang Golden Egret Geotools Co. Ltd.	136
Metallizing Equipment Co. Pvt. Ltd.	150
Millidyne Oy Surface Technology	162
Ningbo Novelmetal Technologies Co. Ltd.	170
North American Hoganas	187
Oerlikon Metco	141
Oseir Oy	107
Plasma Giken Co. Ltd.	104
Polymet Corp.	155
Praxair Surface Technologies	144
Progressive Surface Inc.	148
Saint-Gobain	142
Sewon Hardfacing Co. Ltd/Changzhou Sewon Metal Products Co. Ltd.	184
Shanghai Dahao Ruifa Thermal Spraying Machinery Co. Ltd.	102
Tecnar Automation Ltd.	140
Thermal Spray Centre (CPT)	117
Treibacher Industrie AG	161
UniqueCoat Technologies	159
United Coating Technologies	167
Wall Colmonoy	134
WEL Trading Co. Ltd.	112
Wisdom Import & Export (Shanghai) Co. Ltd.	110
Wuxi City Xinke Surface Engineering Material Co. Ltd.	101
Zhengzhou Ruite Diamond Belt Co. Ltd.	130
Zhuzhou Jiangwu Boda Hard-facing Materials Co. Ltd.	177
Zhuzhou Seed Cemented Carbide Technology Co. Ltd.	132

Note: Exhibitor list current as of January 1.

competition-based awards program, which seeks to encourage participation of young scientists in ITSC and provide attractive opportunities in the global thermal spray community.

Networking Events

Each year, ITSC offers a wide variety of networking opportunities for attendees and exhibitors. From the exhibitor networking reception to a special boat trip on the Huangpu River, all attendees will have an opportunity to relax and socialize with colleagues and friends within the thermal spray community.

Industrial Forum • Wednesday, May 11 • 9:00 a.m.–5:00 p.m.

The Industrial Forum will be held in the Shanghai International Convention Center, 3C + 3D Room. Invited companies will present talks on industry-related topics and products during conference and exposition hours. All presentations are given in English and are limited to 20 minutes including question & answer sessions.

Industrial Tour—SICCAS—Shanghai Institute of Ceramics, Chinese Academy of Sciences • Friday, May 13 • 7:30 a.m.

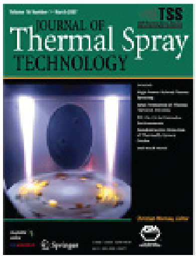
EXPOSITION HOURS

Tuesday, May 10 • 12:00–7:00 p.m.

Wednesday, May 11 • 9:00 a.m.–5:00 p.m.

Thursday, May 12 • 9:00 a.m.–2:00 p.m.

Note: Exposition hours are subject to change.



The *Journal of Thermal Spray Technology (JTST),* the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal spray information transfer, its mission is to synergize the rapidly advancing thermal spray industry and related industries by presenting research and development efforts leading to advancements in implementable engineering applications of the technology. Articles from the January issue, as selected by *JTST* Editor-in-Chief Armelle Vardelle and Lead Editor André McDonald, are highlighted here. This issue features papers based on presentations at ITSC 2015. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, please visit www.asminternational.org/tss.

"PYRAMIDAL FIN ARRAYS PERFORMANCE USING STREAMWISE ANISOTROPIC MATERIALS BY COLD SPRAY ADDITIVE MANUFACTURING"

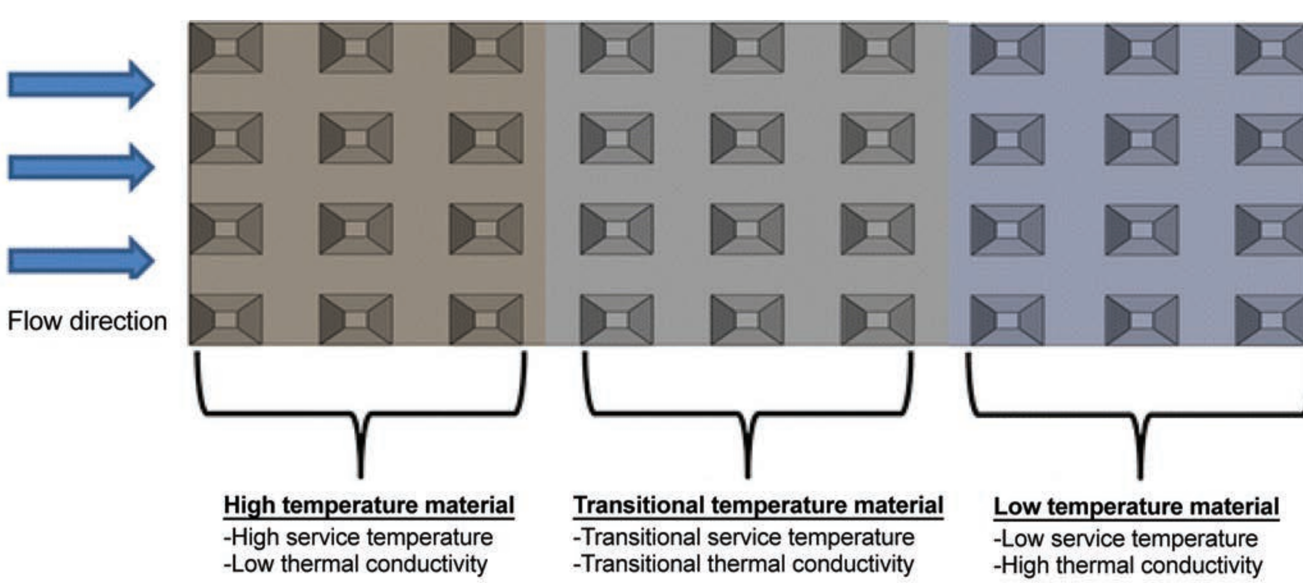
Yannick Cormier, Philippe Dupuis, Bertrand Jodoin, and Antoine Corbeil

This work evaluates the thermal and hydrodynamic performance of pyramidal fin arrays produced using cold spray as an additive manufacturing process. Near-net-shaped pyramidal fin arrays of pure aluminum, pure nickel, and stainless steel 304 were manufactured. Fin array characterization such as fin porosity level and surface roughness evaluation was performed. The thermal conductivities of the three different coating materials were measured by laser flash analysis. The results obtained show a lower thermal efficiency for stainless steel 304, whereas the performances of the aluminum and nickel fin arrays are similar. This result is explained by looking closely at the fin and substrate roughness induced by the cold gas dynamic additive manufacturing process. The multi-material fin array sample has a better thermal efficiency than stainless steel 304. The work demonstrates the potential of the process to produce streamwise anisotropic fin arrays as well as the benefits of such arrays.

"LASER PATTERNING PRE-TREATMENT BEFORE THERMAL SPRAYING—A TECHNIQUE TO ADAPT AND CONTROL THE SURFACE TOPOGRAPHY TO THERMO-MECHANICAL LOADING AND MATERIALS"

Robin Kromer, Sophie Costil, Jonathan Cormier, Laurent Berthe, Patrice Peyre, and Damien Courapied

Coating characteristics are highly dependent on substrate preparation and spray parameters. Hence, the surface must be adapted mechanically and physicochemically to favor coating/substrate adhesion. Conventional surface preparation methods such as grit blasting are limited by surface embrittlement and produce large plastic deformations throughout the surface resulting in compressive stress and potential cracks. However, laser patterning is suitable for preparing the surface of sensitive materials. No embedded grit particles are observed, and high quality coating can be achieved. Further, laser surface patterning adapts the impacted surface by creating a large anchoring area. Optimized surface topographies can then be elaborated according to the materials as well as their applications. This paper compares the adhesion bond strength for two surface preparation methods, namely grit blasting and laser surface patterning for two materials used



Schematic of a multi-material fin array separated into three sections.

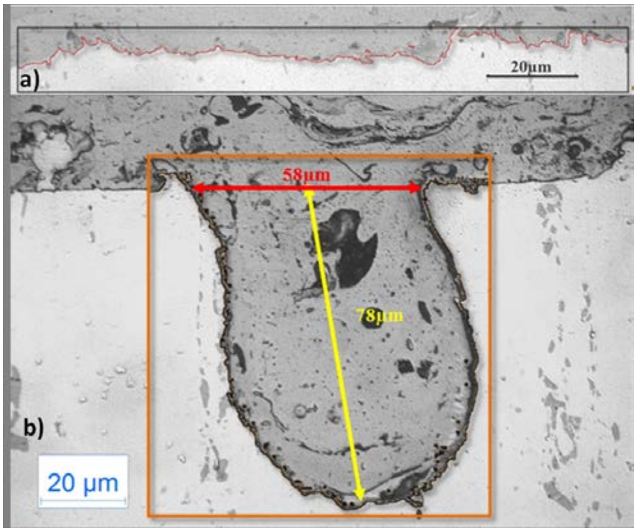


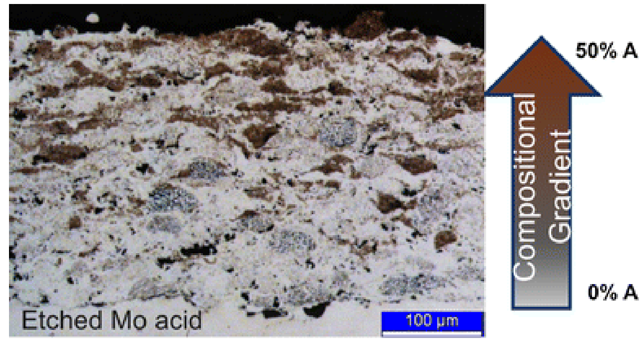
Image analysis of surface area with laser surface texturing—shown in red is the interface computed for one keyhole (each keyhole adds 11× the adhesion area compared to a plane surface).

in aerospace applications: 2017 aluminum alloy and AISI 304L stainless steel coated with NiAl and YSZ, respectively. Laser patterning significantly increases the adherence values for similar contact areas due to a mixed mode failure (cohesive and adhesive failures). The coating is locked in the pattern.

"MODULAR COATING FOR FLEXIBLE GAS TURBINE OPERATION"

J.R.A. Zimmermann, J.C. Schab, A. Stankowski, P.D. Grasso, S. Olliges, and C. Leyens

In heavy-duty gas turbines, the loading boundary conditions of MCrAlY systems are weighted differently for various operation regimes as well as for each turbine component or individual part locations. For overall optimized component protection, it is of interest to produce coatings with flexible and individually tailored properties. In this context, ALSTOM developed an Advanced Modular Coating Technology (AMCOTEC) based on several powder constituents, each imparting specific properties to the final coating, in combination with a new application method, allowing in-situ compositional changes. With this approach, coating properties such as oxidation, corrosion, and cyclic lifetime can be modularly adjusted for individual component types and areas. For demonstration purposes, a MCrAlY coating with modular ductility increase was produced using the AMCOTEC methodology. The method was proven to be cost effective and highly flexible, enabling fast compositional screening. A calculation method for final coating composition was defined and validated. The modular addition of a ductility agent enabled increasing the coating ductility with up to factor 3 with only a slight decrease in oxidation resistance. An optimum composition with respect to ductility is reached with the addition of 20 wt% of the ductility agent.

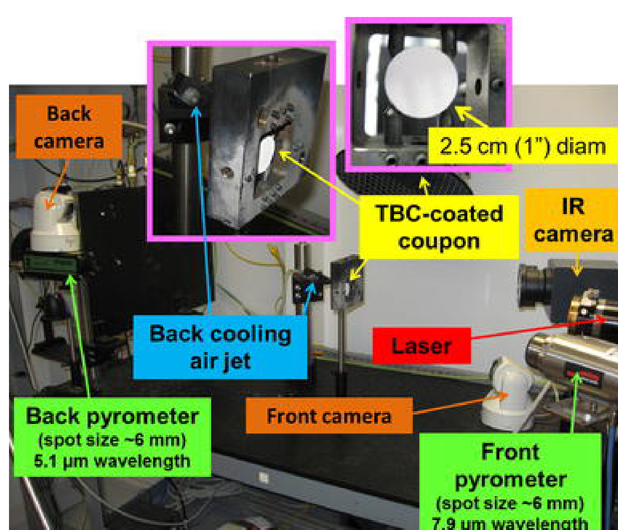


Bright field microscopic image of a graded MCrAlY-based coating (after etching) produced with the incremental addition of powder A. Brownish phase corresponds to ductility agent A.

"THERMAL GRADIENT BEHAVIOUR OF TBCs SUBJECTED TO A LASER GRADIENT TEST RIG: SIMULATING AN AIR-TO-AIR COMBAT FLIGHT"

Rogerio S. Lima, Basil R. Marple, and P. Marcoux

A computer-controlled laser test rig (using a CO_2 laser) offers an interesting alternative to traditional flame-based thermal gradient rigs in evaluating thermal barrier coatings (TBCs). The temperature gradient between the top and back surfaces of a TBC system can be controlled based on the laser power and a forced air back-face cooling system, enabling the temperature history of complete aircraft missions to be simulated. An air plasma spray-deposited TBC was tested and, based on experimental data available in the literature, the temperature gradients across the TBC system (ZrO_2-Y_2O_3 YSZ top coat/CoNiCrAlY bond coat/Inconel 625 substrate) and their respective frequencies during air-to-air combat missions of fighter jets were replicated. The missions included (i) idle/taxi on the runway, (ii) take-off and climbing, (iii) cruise trajectory to rendezvous zone, (iv) air-to-air combat maneuvering, (v) cruise



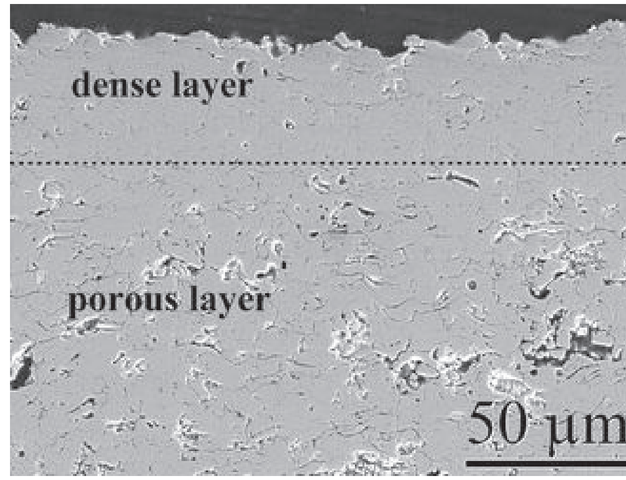
Thermal gradient laser rig of the NRC.

trajectory back to runway, and (vi) idle/taxi after landing. The results show that the TBC thermal gradient experimental data in turbine engines can be replicated in the laser gradient rig, leading to an important tool to better engineer TBCs.

"PLASMA-SPRAYED THERMAL BARRIER COATINGS WITH ENHANCED SPLAT BONDING FOR CMAS AND CORROSION PROTECTION"

Tao Liu, Shu-Wei Yao, Li-Shuang Wang, Guan-Jun Yang, Cheng-Xin Li, and Chang-Jiu Li

The infiltration of molten CMAS in thermal barrier coatings (TBCs) at high temperature is significantly affected by the microstructure of the ceramic coating. Enhancing the bonding ratio between splats can reduce the interconnected pores and suppress infiltration of the molten CMAS into the coating. In this study, a dual-layered (DL) TBC with the dense 8YSZ on top of the conventional porous 8YSZ was proposed to enhance CMAS corrosion of atmospheric plasma-sprayed YSZ. The dense YSZ coating with improved lamellar bonding was deposited at a higher deposition temperature. The microstructure of the coatings before and after the CMAS attack test was characterized by scanning electron microscopy. It was revealed that by adjusting the microstructure and applying a dense ceramic layer with the improved interface bonding on top of porous TBC, infiltration of CMAS into the porous YSZ coating can be effectively suppressed. Moreover, by designing DL TBCs, the thermal conductivity of the TBC system exhibits a limited increase. Thus with the design of the DL structure, TBCs with high CMAS corrosion resistance and low thermal conductivity can be achieved.



Microstructure of DL-8YSZ coating deposited by APS.

ASMNEWS

AFFILIATE SOCIETIES NAME COMMITTEE CHAIRS FOR 2015-2016 TERM

The Boards of the Electronic Device Failure Analysis Society (EDFAS), Heat Treating Society (HTS), International Metallographic Society (IMS), and Thermal Spray Society (TSS) have appointed chairs to each of their committees for the 2015-2016 term. Chairs for ASM Society and General Committees and Councils appeared in the January 2016 issue of *ASM News*. The purpose of each committee is stated on the ASM website, asminternational.org. Click on Membership and Committees, followed by Committee Involvement, and then Affiliate Committees.

Electronic Device Failure Analysis Society (EDFAS)

Cheryl Hartfield, business manager-Omniprobe Products, Oxford Instruments, USA, continues to serve as president of EDFAS.

Jeremy A. Walraven, technical staff, Sandia National Laboratories, Albuquerque, N.M., serves as immediate past president and chair of the EDFAS Nominating Committee.

Mayue Xie, engineering TD manager, Intel Corp., Chandler, Ariz., was named chair of the Education Committee.

Tom Moore, president, Waviks Inc., Dallas, continues as chair of the EDFAS Membership Committee.

Efrat Moyal, cofounder, LatticeGear LLC, serves as co-chair.

Felix Beaudoin, functional characterization engineer, GlobalFoundries, Hopewell Junction, N.Y., is chair of the *Electronic Device Failure Analysis* Magazine Committee.

Martin Keim, engineering manager, Mentor Graphics, Wilsonville, Ore., was named chair of the Events Committee and is general chair of ISTFA 2016. **Sam Subramanian,** senior member of technical staff, Freescale Semiconductor, Austin, Texas, serves as vice chair.

David Su, director, TSMC, Taiwan, was named chair of the International Growth Committee.


Hartfield


Walraven


Xie


Moore


Moyal


Beaudoin


Keim


Subramanian


Su


Kowalski

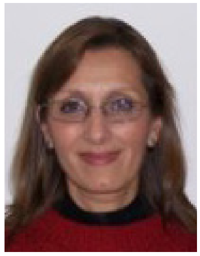

Jones


Schneider

In This Issue

HIGHLIGHTS AFFILIATE COMMITTEE CHAIRS


Ahmad


Papp

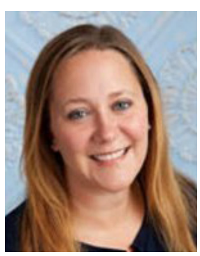

Rollings


Faulkner


Frafjord


Blackwell


Martinez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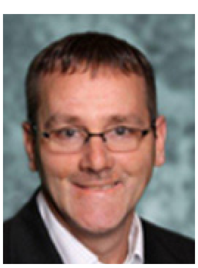

Covert

Heat Treating Society (HTS)

Stephen G. Kowalski, president, Kowalski Heat Treating Co., Cleveland, was elected president of HTS.

Roger A. Jones, corporate president, Solar Atmospheres Inc., Souderton, Pa., is currently serving as HTS immediate past president, as well as chair of the HTS Awards & Nominations and the HTS Finance Committees.

Michael J. Schneider, FASM, general manager, Prod. Materials and Metallurgy, The Timken Co., North Canton, Ohio, continues as chair of the HTS Education Committee.

Aquil Ahmad, retired senior principal engineer, Eaton Corp., West Bloomfield, Mich., continues as chair of the HTS Research and Development Committee.

Rozalia Papp, business development specialist, Air Liquide US LP, is serving as chair of the HTS Technology & Programming Committee.

David Rollings, VP business development, Advanced Abrasives Corp., Pennsauken, N.J., serves as chair of the HTS Membership Committee.

Chuck Faulkner, marketing manager, Heat Treatment, Houghton International, Valley Forge, Pa., continues as chair of the HTS Expositon Commtitee.

International Metallographic Society (IMS)

Jaret J. Frafjord, technical director, IMR Test Labs—Portland, Ore., serves as president of IMS.

Richard Blackwell, FASM, appplications specialist, Precision Surfaces International Inc., Ontario, Canada, serves as IMS immediate past president and chair of the IMS Nominating Committee.

James E. Martinez, materials scientist, NASA, Houston, serves as IMS vice president and chair of the Publications Committee and the Awards Committee.

Laura Moyer, lab manager, Lehigh University, Bethlehem, Pa., was named chair of the IMS Education Committee.

Abdallah Elsayed, R&D engineering coordinator, Nemak Canada, Windsor, Ontario, is chair of the IMS Technology Committee.

Michael Covert, senior metallographer, Ellwood Group, Ellwood City, Pa., continues as chair of the IMS Membership, Marketing and Outreach Committee.

Thermal Spray Society (TSS)

See page 3 of *iTSSe* in this issue for the TSS committee chairs.

If you are interested in serving on an Affiliate Society committee, contact the respective committee chair directly or email joanne.miller@asminternational.org.

ASM, HTS, IMS and TSS Seek Student Board Members

We're looking for Material Advantage student members to provide insights and ideas to the ASM, HTS, IMS, and TSS Boards. We are pleased to announce the continuation of our successful Student Board Member programs. Each Society values the input and participation of students and is looking for their insights and ideas.

- An opportunity like no other!
- All expenses to attend meetings paid for by the respective Society
- Take an active role in shaping the future of your professional Society
- Actively participate in your professional Society's Board meetings

- Gain leadership skills to enhance your career
- Add a unique experience to your resume
- Represent Material Advantage and speak on behalf of students
- Work with leading professionals in the field

Application deadline is **April 1.** Visit asminternational.org/students/student-board-member-programs for complete form and rules.

Opportunities specific to each Society:

ASM International

- Attend four Board meetings (June 20-22, October 23-26 during MS&T16, March and June 2017)
- Term begins June 1

ASM Heat Treating Society

- Attend two Board meetings (October 2016 during Furnaces North America and spring 2017)
- Participate in two teleconferences
- Term begins in September

ASM International Metallographic Society

- Attend one Board meeting (July 2017)
- Participate in monthly teleconferences
- Term begins in August

ASM Thermal Spray Society

- Attend one U.S. Board meeting in the second half of 2016
- Participate in two teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins in October

IMC: Fewer Classes, Larger Prize Money

Deadline July 9

The International Metallographic Contest (IMC), an annual event cosponsored by the International Metallographic Society (IMS) and ASM International to advance the science of microstructural analysis, continues to offer fewer classes and larger prize money. These updates, initiated two years ago, were designed to encourage participation and to simplify the process for participants to submit entries. There are now just five different classes of competition 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

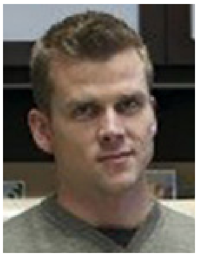
All classes offer increased prize money. Best-In-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of $3000. For a complete description of the rules, tips for creating a winning entry, and judging guidelines, visit metallography.net.

SMST Announces New Board Members

In accordance with their rules and governance, the International Organization on Shape Memory and Superelastic Technologies (SMST) completed its elections for board members for 2016. **Aaron Stebner,** assistant professor, Colorado School of Mines, continues as president of SMST, while **Jeremy Schaffer,** engineer, Fort Wayne Metals, continues as vice president/finance officer. **Matthias Mertmann,** president, Redsystem GmbH, continues as immediate past president.

The SMST membership elected new board members **Frederick "Tad" Calkins,** associate technical fellow, Boeing Research & Technology, Seattle; **Neil Morgan,** director, Advanti Ltd., UK; and **Petr Sittner,** department head and vice director, Institute of Physics of the ASCR, Prague. Board members serve a three-year term.


Stebner


Schaffer


Mertmann


Calkins


Morgan


Sittner

Call for Volunteers

ASM International is seeking qualified volunteers for 2016-2017 Committee and Council appointments. Review the Committee Job Descriptions for further details on activities, time commitments, and subcommittees at asminternational.org/membership/committee-involvement. Next, fill out the Volunteer Interest Form found under the Membership tab at asminternational.org. Appointments will be finalized by the end of June with terms beginning September 1.

ASM Seeks Vice President and Board of Trustees Nominations

ASM is seeking nominations for the position of vice president as well as three trustees. The Society's 2017 vice president and trustee elects will serve as a voice for the membership and will shape ASM's future through implementation of the ASM Strategic Plan.

Qualifications: Members must have a well-rounded understanding of the broad activities and objectives of ASM on a local, Society, and international level, and the issues and opportunities that ASM will face over the next few years. Further, they must also have a general appreciation for international trends in the engineered materials industry.

Duties: The duties of board members include various assignments between regular meetings. Trustees also assume the responsibility of making chapter visits and serving as a board liaison to ASM's various committees and councils.

Guidelines: Nominees for vice president must have previously served on the ASM Board and those selected to serve as trustees should be capable of someday assuming the ASM presidency.

Deadline for nominations is **March 15.** For more information, visit asminternational.org/vp-board-nominations or contact Leslie Taylor, 440.338.5151 ext. 5500, or leslie.taylor@asminternational.org.

2016 Bradley Stoughton Award for Young Teachers

Winner receives $3000

Deadline March 1

This award recognizes excellence in young teachers in the fields of materials science, materials engineering, design, and processing.

Do you know a colleague who:

- Is a teacher of materials science, materials engineering, design, and processing
- Has the ability to impart knowledge and enthusiasm to students
- Is 35 years of age or younger by **May 15** of the year in which the award is made
- Is an ASM Member

Nominate a colleague for the 2016 award!

2016 ASM International Student Paper Contest

Deadline April 1

The ASM International Student Paper Contest recognizes the best technical paper with a graduate or undergraduate student as first author that is published in an ASM sponsored publication during the year. The winner will receive their award during the ASM Leadership Awards Luncheon in Salt Lake City, during the week of October 23-26, in conjunction with MS&T16. The award consists of a certificate, $500 cash prize, and up to $500 toward expenses to attend MS&T16. The paper will also be published in one of ASM's publications.

Engineering Materials Achievement Award

Deadline March 15

The Engineering Materials Achievement Award recognizes an outstanding achievement in materials or materials systems related to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product. Do you know of an innovative, cutting-edge scientific achievement that has distinctly impacted industry, technology, and society within the past 10 years? If so, consider submitting a nomination for the 2016 award!

View sample forms, rules, and past recipients at asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination link.

Steven May receives the 2015 Bradley Stoughton Award for Young Teachers from Sunniva Collins, ASM Past President.

Paul Turner, left, and Paul Jablonski, right, receive the 2015 Engineering Materials Achievement Award from Sunniva Collins.

FROM THE FOUNDATION

Strategic Planning: Part I

David B. Spencer
Chairman of the Board, wTe Corp.


Spencer

The VISION of the ASM Materials Education Foundation is as follows:

A diverse workforce skilled in science, technology, engineering and mathematics (STEM) through hands-on, discovery-based learning.

In our previous Strategic Plans, we sought to implement this vision by putting Materials Camps in place. We are proud to have met our goal of 50 Teachers Camps and 25 Student Camps two years ahead of schedule. But that creates a new challenge: What to do next?

Our MISSION is *"To excite young people in materials, science, and engineering careers."* Our Board of Trustees is choosing to continue our camp programs and scholarships, but we also believe a strong need exists within the materials field for more—and better trained—technical workers. Further, we want to help create a more diverse STEM community by getting kids interested in science, engineering, and materials at an earlier age. Finally, we believe that when we develop exciting curricula, we should give it away—and share it on a broad platform both in the U.S. and globally—using the Internet as our pathway to potential learners.

The Foundation has implemented a system of powerful business committees, which will reach into the ASM community, engage members with a broader mission, draw on past board members for leadership and counsel, and pull in diverse outside resources as needed in the following areas:

1. STEM Curricula for K-6 students—exciting kids about STEM in grade school
2. Middle School after-school programs—*Materials Matter*
3. Underserved/Workforce Development & Community College Programs
4. Broader Global Outreach sharing our development programs through the Internet
   a. Attracting new members
   b. Reaching into the broader community both nationally and internationally

We are proud of the accomplishments achieved through the Materials Camp programs for teachers and students and with our scholarships. These efforts will continue. In addition, we are also excited about our new initiatives aimed at giving back even more to educational efforts in our community. We hope you will volunteer to help.

EMERGING PROFESSIONALS

Transitioning from Technical Contributor to Manager

Dharma Maddala,
Alcoa Technical Center


Maddala

For many individuals, their initial career is based on technical merit and advancement depends on enhancing technical skills, expertise, and capabilities. At some point, a career in management appears, presenting different challenges. This new role is based on a skill set that involves delegating, mentoring, coaching, situational awareness, monitoring behaviors, handling and managing conflicts, and many other tasks that are distinctly different from dealing with technical issues as an individual contributor.

Making the transition from technical contributor to manager is challenging. In my case, the Emerging Leaders Alliance (ELA) gave me an arsenal of tools and acquainted me with "soft skills," which are difficult to master but important to focus on. I felt privileged to attend the ELA conference in November 2015 via a sponsorship provided by the TMS Foundation. It was a great learning opportunity and very timely, as I recently moved into a managerial role.

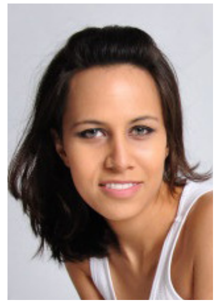
Valuable aspects of the program included learning how to acknowledge various social styles, engineering an ideal team by building productive relationships, recognizing and managing conflict, and managing upward. The ELA platform not only provides training to help prepare future leaders to advance their organizations within complex business and social environments, but also provides a venue to network with individuals in other professional organizations. For example, the "gummies" team exercise emphasized the need for effective communication and concise messaging, which will enhance my work skills as well as future leadership roles within ASM and TMS. To learn more about the ELA conference, visit emergingleadersalliance.org.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Jacquelyn MacCoon, Product Specialist,
Hitachi High Technologies

Jacquelyn MacCoon's day job is at Hitachi High Technologies, Ontario, Canada, where she works on application engineering and sales of giant electron and transmission microscopes. But the 25 year-old University of Toronto graduate moonlights for the Toronto ASM Chapter and describes herself as "a strong advocate for getting beyond the books and increasing our emotional intelligence."



MacCoon

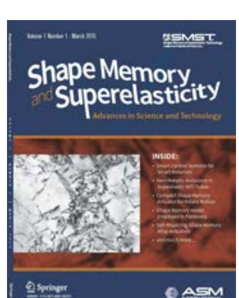
MacCoon credits ASM with helping improve her professional skills and confidence. She's grateful for friendships formed with career veterans, including three mentors who generously share wisdom not found in a textbook or online. "Everyone pretends we have a plan but we're all shaking in our boots," she observes. "So many people just fall into their careers. At ASM, I've found people willing to talk about this."

As an undergraduate in materials science and engineering, MacCoon began attending Chapter meetings, attracted to broad meeting topics and a balance of industry veterans and students. "It's nice to go with a social safety net of other students—and be brave enough to talk with people well-established in their careers," she says. MacCoon became an ASM university representative and after completing her master's degree became communications director. She is currently vice chair. "I have a title now and can reach out and ask for speakers at our events. It's so much fun!" she says with a smile.

MacCoon sees a need to build awareness of ASM and attract members beyond materials science, especially from fields like bio-materials or even dentistry. "We collaborate with so many fields one step removed but still dealing with materials and metals." She's excited about creative Toronto Chapter events like "Young Professionals Night" featuring trampoline dodge ball followed by dinner and "Speed Interview Night" for members to practice being both interviewer and interviewee. "We don't usually practice until we need it. This brings in new people we don't often see at meetings!"

Free Access to Shape Memory and Superelasticity

Did you know that you can read the first volume of *Shape Memory and Superelasticity: Advances in Science and Technology* for free? This journal functions as a forum for researchers, scientists, and engineers of various disciplines to access information about the ever-expanding field of shape memory materials. To access this official publication of the International Organization on Shape Memory and Superelastic Technologies, an affiliate society of ASM, visit link.springer.com/journal/40830.



For more information about *Shape Memory and Superelasticity,* including instructions for authors, visit the journal home page at springer.com/40830. To submit online, visit mc.manuscriptcentral.com/shapememory.

CHAPTERS IN THE NEWS

Albuquerque Celebrates Henning's 33 Years as Treasurer

The Albuquerque Chapter announces that Robert "Bob" Henning has retired as Chapter treasurer after 33 years of service. Henning began his metallurgy career with the Air Force Research Lab at Wright-Patterson AFB near Dayton, Ohio. He later worked at Sandia National Laboratories in Albuquerque, N.M., first as a contractor and later as an employee. In 1954, he was one of the charter members of the Albuquerque Chapter. In addition to serving as chair in 1987, Henning worked with 27 other chairs during his 33-year tenure as treasurer. Several years ago, he received the ASM Allan Ray Putnam Service Award in recognition of his longstanding service to the Society.

From left to right, Bob Henning and Don Susan.

Italy-Switzerland Chapter Hosts Ceramic Lecture

Arrigo Borin (center), chair of the Italy-Switzerland Chapter, recently gave a presentation on the evolution of advanced ceramic materials at the University of Ferrara, Italy. Approximately 75 students and graduates attended the lecture.

Pune Welcomes New Members

ASM's Chapter in Pune, India, recently welcomed 21 new members. Pictured here is Mr. L.D. Deshpande with special mementos presented to each new member in December 2015.

MEMBERS IN THE NEWS

Olson Presents Winegard Lecture

The Department of Materials Science & Engineering at the University of Toronto hosted the 4th annual Winegard Visiting Lectureship in New Materials Engineering in December 2015. The Winegard lecture, made possible through the support of **William C. Winegard, FASM,** is an annual event that brings together a world-renowned academic or industrial professional to give a seminar series. The 2015 Winegard Lecturer was **Gregory B. Olson, FASM,** Walter P. Murphy Professor of Materials Science and Engineering, Northwestern University.

From left to right, Gregory Olson, William Winegard, and Jun Nogami. Courtesy of Jason Tam.

Winner Picked for ASM Handbook Giveaway

Jeff Easter of Illinois is the winner of a free copy of the latest in the *ASM Handbook* series, Volume 7, *Powder Metallurgy*. When describing why he wanted the free copy, Easter mentioned his role advising on alternate methods to manufacture products in the metal forming and machining industry. One such process is powder metal, and he explained that the newest edition of this resource would be very useful in his work.

Abbaschian to Lead Winston Chung Global Energy Center

Abbaschian

Reza Abbaschian, FASM, dean of the Bourns College of Engineering, University of California, Riverside (UCR), will step down in June to become director of the Winston Chung Global Energy Center. In 2010, Abbaschian oversaw the largest gift from an individual donor in UCR's history—a $10 million cash endowment and more than $3 million worth of batteries from Chinese inventor **Winston Chung.** As director of the new center, Abbaschian will hold a Winston Chung Endowed Professorship and continue his research focusing on solidification and materials processing involving interfacial kinetics, high temperature intermetallics, composites, and diamond crystal growth.

Anderson Joins National Academy of Inventors

Anderson

U.S. Department of Energy's Ames Laboratory senior metallurgist **Iver Anderson, FASM,** was recently named a Fellow of the National Academy of Inventors. An induction ceremony will take place in April at the U.S. Patent and Trademark Office. Anderson is best known for his co-invention of lead-free solder. The solder patent is the top-earning patent for Ames Laboratory, Iowa State University, and Sandia National Laboratory. It has generated approximately $60 million in royalty income throughout the life of the patent, which expired in 2013.

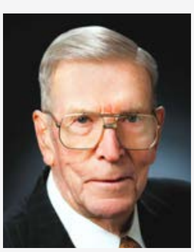
Apelian Honored with Bernard M. Gordon Prize

Diran Apelian, second from left, and his WPI colleagues.

The National Academy of Engineering announced that Worcester Polytechnic Institute (WPI) is being honored with the 2016 Bernard M. Gordon Prize for Innovation in Engineering and Technology Education. **Diran Apelian, FASM,** is among the four WPI educators recognized "for a project-based engineering curriculum developing leadership, innovative problem-solving, interdisciplinary collaboration, and global competencies." Among other honors, Apelian received ASM's Bradley Stoughton Award for Young Teachers in 1980, the Henry Marion Howe Medal in 1989, and served as the ASM-TMS Distinguished Lecturer in 2004.

IN MEMORIAM

W. Stuart Lyman passed away on November 23, 2015, at age 91. He was a registered professional engineer and recognized as an expert in copper metallurgy. Lyman spent most of his career at the Copper Development Association (CDA). He began his career at the National Advisory Committee for Aeronautics before enlisting as a naval intelligence officer in WWII. After the war he continued his metallurgical work at the Engineering Research Institute of the University of California, Berkeley, and served as a staff metallurgist for the Materials Advisory Board of the National Academy of Sciences. Prior to joining CDA in 1964, Lyman was division chief at Battelle Memorial Institute where he led research and development programs in metalworking. As senior VP of CDA, he supervised the technical aspects of their development work as well as market research, statistical analysis, and the Copper Data Center. Lyman held degrees in metallurgy from the University of Notre Dame and the University of California, Berkeley, and was an ASM member since 1947.



Henry M. Rowan passed away on December 9, 2015, at age 92. A native of Ridgewood, N.J., Rowan was the founder and chairman of Rancocas-based Inductotherm Group. He and his late wife, Betty, started the business in 1953, building the company's first furnace at home in Ewing Township, N.J. A graduate of the Massachusetts Institute of Technology, Rowan donated $100 million—the largest gift to date to a public college or university—to then-Glassboro State College with the request that it build a top-notch school of engineering. The school was named Rowan College in 1992 and became Rowan University in 1997. Mr. Rowan and the Henry M. Rowan Family Foundation have donated to numerous other organizations as well, including generous gifts to the ASM Materials Education Foundation over the past three years. Rowan was a WWII veteran of the Army Air Corps, member of the Aviation Hall of Fame, and competed in the 1992 Olympic sailing trials. He published his autobiography "The Fire Within" in 1995. Among numerous honors, Rowan received the William Hunt Eisenman Award from ASM's Philadelphia Chapter in 1997, was inducted into the National Academy of Engineering in 1998, inducted into *Foundry Management & Technology* magazine's Hall of Honor in 2003, and received the Distinguished Life Membership Award from ASM in 2014.

Walter L. Riggs, II, passed away on Dec. 25, 2015, at age 64. He was recently diagnosed with Parkinson's disease, but continued to work as a metallurgical Enegineer. Riggs earned his bachelor's degree in engineering from the University of Missouri and his master's in engineering from the University of Illinois. His work took him to many parts of the world as he developed metal coatings for various companies. Riggs also made significant contributions involving the topics of testing and characterization in *ASM Handbook,* Volume 5A, *Thermal Spray Technology,* published in 2013.

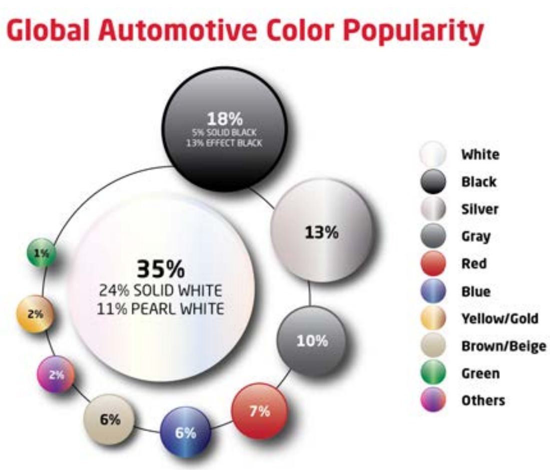
Oleg Dimitri Sherby, FASM, died on November 9, 2015, at age 90. He was born in 1925 in Shanghai to parents who had fled Russia one year earlier amidst the Russian Revolution. Sherby attended the University of California, Berkeley, and after brief service in the U.S. Army earned his bachelor's and master's degrees and doctorate in metallurgy. He was a National Science Foundation Fellow at Sheffield University in 1956-57 and then scientific liaison officer in metallurgy with the U.S. Office of Naval Research, London, in 1957-58. In 1958, Sherby joined the Stanford University faculty in the department of materials science and engineering, where he taught for 30 years until he was named professor emeritus in 1988. He was a pioneer in discovering the atomic mechanisms controlling creep and was well known in the field of superplasticity. Elected to the National Academy of Engineering in 1979, Sherby received numerous awards and honors. An ASM member since 1948, Sherby won the ASM Gold Medal Award in 1985 and the Albert Sauveur Achievement Award in 2000.

STRESS RELIEF

FUNGUS-MADE FURNITURE

Terreform One, Brooklyn, N.Y., produced a suite of complex, curving furniture out of a biopolymer called Mycoform, made of fungus-digested biomatter. The furniture is designed and cut digitally, with segments grown into specific 3D geometries from strains of the fungus Ganoderma lucidum. The project occupies “the intersection of parametric CAD design and synthetic biology,” according to the firm. To create the Mycoform, a mix of wood chips, gypsum, and oat bran is fed to the fungus, which then receives an external skin of bacterial cellulose. The resulting tough, natural plastic is suitable for numerous architectural applications. The low-tech production process is pollution free, requires little energy, and is easily transferable to the developing world. In addition, Mycoform is naturally biodegradable. *terreform.org.*

Bench produced from Mycoform, a natural plastic grown by mushrooms. Courtesy of Terreform One.



Source: Axalta *Global Automotive 2015 Color Popularity Report*

AUTOMOTIVE INDUSTRY DOES IT WHITE

Axalta Coating Systems, Philadelphia, recently released its 63rd annual “Global Automotive 2015 Color Popularity Report.” According to the study, white remains the worldwide leader in automotive colors since overtaking silver in 2011. Regional preferences are also highlighted: North America likes red (11%), while Europe enjoys black (21%) and blue (9%) more than other regions. South America and Asia are loving white—the color’s popularity rose by 19% percent in China alone.

According to Nancy Lockhart, color marketing manager, insights into how consumer color preferences change over time allow the industry to look ahead. “Since 1953, Axalta’s color popularity data has been an important tool in partnering with vehicle manufacturers to forecast the designs and color preferences that will engage customers in the years to come,” she says. Down the road, Lockhart predicts “highly chromatic” reds, blues, and violets. On small cars, she expects “niche colors” like unique blues, greens, and golds. And while warm, earthy tones are gaining popularity, cool neutrals like white, gray, and black will have staying power. *axaltacoatingsystems.com.*

QUIETEST ROOM ON EARTH

Microsoft sets Guinness World Record for quietest place on Earth with Eckel Anechoic Chamber. Courtesy of Business Wire.

Microsoft established a new world record for the quietest room on Earth with their Redmond, Wash., audio lab, designed by Eckel Noise Control Technologies, Cambridge, Mass. At -20.6 dB, this chamber shatters the previous record of -13dB and far surpasses the engineers’ prediction of -16 dB. To put this peace in context, the theoretical noise produced by Brownian motion—the random movement of particles in air—is the quietest known sound outside the vacuum of space, and is measured at -23 dB. Decibel levels for calm breathing register at 10, rustling leaves at 20, and a jet plane takeoff at 150 dB. The record-setting room is an anechoic chamber, an echo-free environment with sound absorption levels of 99-100%. The chamber is isolated from the rest of the building’s foundation with anti-vibration mounts, and its walls, ceilings, and door are fitted with Eckel’s sound-absorbing anechoic wedges. “This chamber gives us the opportunity to look for those really small signals that can have an impact on the end user,” says LeSalle Munroe, senior engineer of surface devices at Microsoft. *eckelusa.com.*

ADVANCED MATERIALS & PROCESSES

EDITORIAL PREVIEW

MARCH 2016

Modern Materials for Energy/Automotive/ Power Generation

Highlighting:

- Automotive Composites Testing
- Field Assisted Sintering Technology
- Al Alloys for Automotive Powertrain Systems

Special Supplement:

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

Bonus Distribution:

23rd IFHTSE Congress
April 18–22, Savannah, Ga.

Advertising closes February 4

APRIL 2016

Materials Testing/Characterization

Highlighting:

- Neutron Techniques for Characterization
- Understanding Semantic Technology
- High-Resolution EBSD

Special Supplement:

International Thermal Spray and Surface Engineering newsletter covering coatings in the energy and power generation industries.

Bonus Distribution:

ITSC 2016
May 10–12, Shanghai

Advertising closes March 4

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AD INDEX

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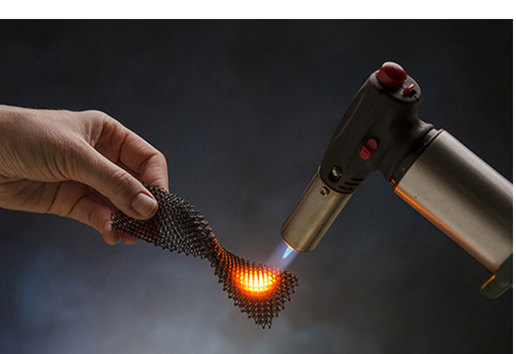
3D PRINTSHOP

NEW RESIN ENABLES CERAMIC PARTS PRINTING

Scientists at HRL Laboratories LLC, Malibu, Calif., report a new milestone in 3D printing technology by demonstrating an approach to additively manufacture ceramics. They say the method overcomes the limits of traditional ceramic processing and enables high temperature, high strength components. Zak Eckel and Chaoyin Zhou invented a resin formulation that can be printed into parts of virtually any shape and size. The printed resin can then be fired, converting it into a high strength, fully dense ceramic. The resulting material withstands ultrahigh temperatures in excess of 1700°C and exhibits strength 10 times higher than similar materials. Ceramics are more difficult to process than polymers or metals because they cannot be cast or machined easily. Ceramic parts are traditionally consolidated from powders by sintering, which introduces porosity and limits both achievable shapes and final strength.

"With our new 3D printing process, we can take full advantage of the many desirable properties of this silicon oxycarbide ceramic, including high hardness, strength, and temperature capability as well as resistance to abrasion and corrosion," says program manager Tobias Schaedler. The process could be used in applications ranging from large components in jet engines to intricate parts in electronic device packaging. HRL, a corporate R&D laboratory owned by The Boeing Co. and General Motors, is seeking a commercialization partner for this technology. *For more information: 310.317.5000, innovation@hrl.com, www.hrl.com.*



A new ceramic resin can be 3D printed into parts of any size. Courtesy of HRL Labs/Dan Little Photography.

INTELLIGENT MACHINE TOOL MAKES DECISIONS

A research group at Kobe University Graduate School of Engineering, Japan, developed a prototype machine tool that works like a 3D printer to manufacture metal components. Traditional metal cutting machine tools follow preprogrammed instructions, which require extensive labor to develop. In addition, the machines cannot make adjustments on the fly or respond to unforeseen issues. Components can also be made with metal 3D printers, but drawbacks include the need for expensive metal powders as base materials and poor quality of finished surfaces, which require additional work.

The Kobe prototype moves away from rigid instructions and instead entrusts the machine tool to figure out operational details. Based on both a 3D model and a material model of the component, the tool determines the optimum machining process using a database of machining information and cutting conditions. The team says this development could pave the way for intelligent manufacturing systems, reduced costs, and faster production cycles. *www.eng.kobe-u.ac.jp/en.*

Intelligent machine tool prototype. Courtesy of Kobe University.

NORSK TITANIUM ACHIEVES TRL 8 STATUS

Norsk Titanium AS, Norway, recently achieved Technology Readiness Level Eight (TRL 8) by concluding a test plan coordinated through the Federal Aviation Administration, which began in September 2012. Results of the multiyear testing campaign conducted by Westmoreland Mechanical Testing & Research Inc., Youngstown, Pa., demonstrate that Norsk's rapid plasma deposition titanium parts meet demanding aerospace requirements. Parts can now be supplied to aerospace and defense manufacturers for final certification and airframe integration. Delivery of commercial aviation qualification parts is underway, with the first approvals expected in early 2016. Full commercial production of titanium aerospace components is expected by the second half of 2016. *norsktitanium.com.*

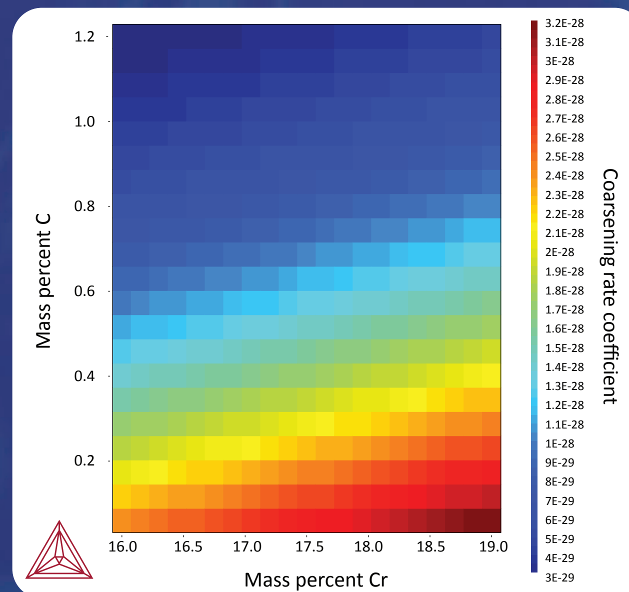
Norsk Titanium's additively manufactured structural parts await final qualification testing. Courtesy of Business Wire.

Thermo-Calc Software

Powerful Software for Thermodynamic and Diffusion Calculations

Software:

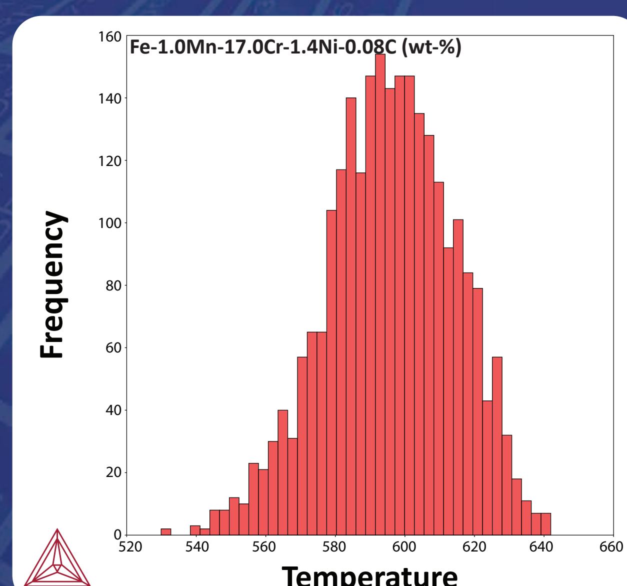
- ✓ **Thermo-Calc** for thermodynamics and phase equilibria in multicomponent systems
- ✓ **DICTRA** for modelling diffusion controlled transformations
- ✓ **TC-PRISMA** for modelling precipitation kinetics
- ✓ **Software development kits** for linking Thermo-Calc to your own software codes
- ✓ **Over 30 Databases** for thermodynamic and mobility applications



Variation of Coarsening rate of the carbide $M_{23}C_6$

Benefits:

- ✓ **Predict** what phases form as a function of composition, temperature
- ✓ **Reduce** costly, time-consuming experiments
- ✓ **Base decisions** on scientifically supported predictions and data
- ✓ **Shorten** development time and accelerate materials development while reducing risk
- ✓ **Improve** the quality and consistency of your products through deeper understanding of your materials and processes



Variation of phase transition temperature of Sigma as a function of chemistry

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