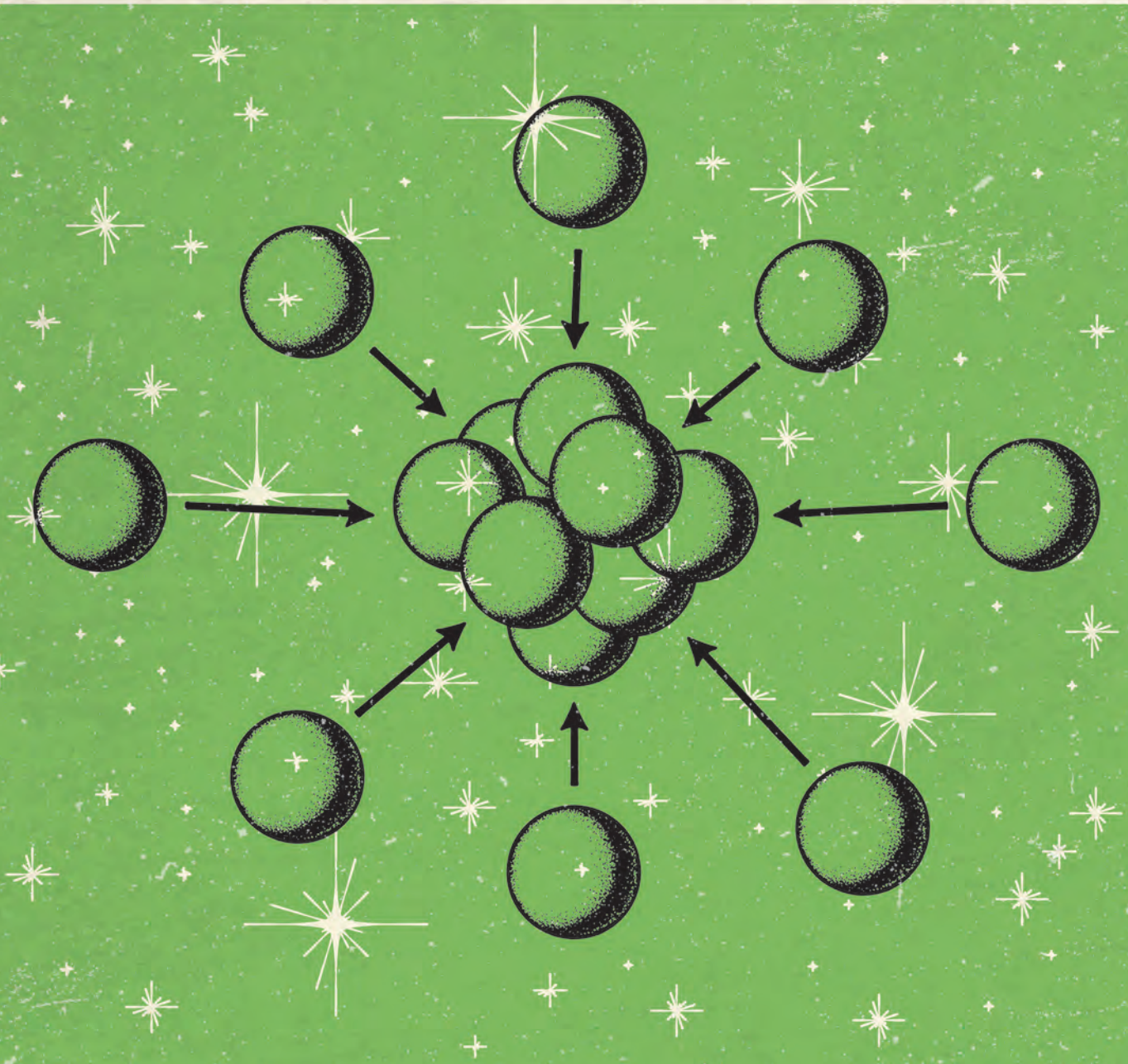
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Failure Analysis & Prevention

INCLUDED IN THIS ISSUE

- Preventing Corrosion Failures
- Fatigue of Threaded Fasteners
- Analyzing Electronics Failures

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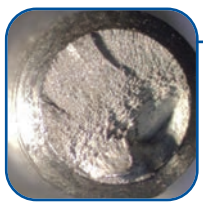


ON THE COVER:
Pulp and paper mill basement, Ontario, Canada. The manufacture of paper generates excessive humidity, which can result in extensive corrosion. Courtesy of Achim Hering, Wikimedia Commons.

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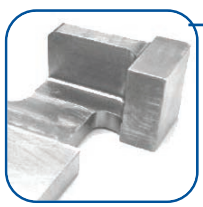
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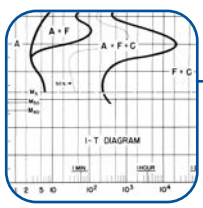
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Advanced Materials & Processes (ISSN 0882-7958, USPS 762080) is published monthly, except bimonthly November/December, by ASM International, 9639 Kinsman Road, Materials Park, OH 44073-0002; tel: 440.338.5151; fax: 440.338.4634. Periodicals postage paid at Novelty, Ohio, and additional mailing offices. Vol. 172, No. 8, August 2014.

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materials witness

Aliens and other gremlins



Have I ever mentioned the aliens that live inside my car doors? They occasionally try to contact me using startling and screechy "radio type" sounds, like someone tuning a shortwave device trying to find a usable frequency. If you recall *Close Encounters of the Third Kind* or *Contact,* you know the kinds of sounds I'm talking about. Mind you, these alien voices only occur when I am alone. Friends and family are skeptical of the entire situation. Mechanics are of no help either. The ones I've talked to blame it on "probably something in the electronic control unit."

Or not.

This brings me to the pure joy I experienced working on our annual "Failure Analysis" issue, and more specifically, the article beginning on page 23 about electronic system failure analysis. As it turns out, I may not be so crazy after all. The author talks about the growing complexity of electronic systems and devices, as designs become smaller and smaller and incorporate extremely complex materials and processes. He goes on to say, "Today's automobiles are similarly complex, containing as many as 100 electronic control units (ECUs) or more, for systems ranging from backup cameras to lane-changing warning systems." My favorite part of the article (spoiler alert!) is this: "To make failure analysis even more difficult, *many failures occur only intermittently.* [Now imagine this phrase as an echo.] System challenges vary widely by industry and application, with each functional element in a design often requiring specialized domain knowledge to understand a failure's root causes and mechanisms." Now, if only I could get someone to bring the focused ion beam described in the article over to my car to analyze the ECU.

Keeping pace with the complexity and financial burden of ultramodern electronic system failures is the age-old problem of corrosion. According to the authors of our feature article on prevention methods (page 15), direct and indirect corrosion costs in the U.S. now exceed $1 trillion dollars—roughly 6% of GDP. Making matters even more challenging are all the new technologies being developed, especially regarding energy production. For example, the authors point out an urgent need for *affordable* corrosion-resistant alloys that can be used in deep offshore high temperature/high pressure oil and gas wells. Regular inspections of corrosion-susceptible structures using state-of-the-art monitoring techniques will also go a long way in detecting and avoiding problems before failure occurs.

Elevated risks of catastrophic failure also arise from fastener fatigue. Because fasteners are so critical to the lifetimes of engineered structures, we address this important issue "head on" beginning on page 18. Here we take a look at fatigue failure of threaded fasteners, using a case study to explore some typical issues. The bottom line? Don't be afraid to tighten those bolts and apply a goodly amount of preload. Well, it's actually more complicated than that, but you will need to read the article to learn the details.

Next month we will highlight some of the most interesting emerging technologies in the world of materials science and engineering as we look ahead to MS&T14, taking place October 12-16 in Pittsburgh. It promises to be a very exciting week and we hope to see you there! Mark your calendars now.

F. Richards

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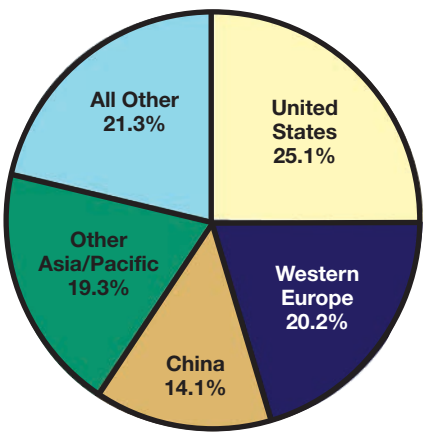
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Global hydrogen appetite sees healthy growth

World consumption of both captive and merchant hydrogen will increase 3.5% annually through 2018 to more than 300 billion cubic meters, according to *World Hydrogen,* a new trends report from market research firm The Freedonia Group Inc., Cleveland. Gains will be driven by increasing use in refinery hydroprocessing, especially in developing Asian countries. According to analysts, the merchant market for hydrogen will expand more than 5% annually as the need for hydrogen in petroleum refineries exceeds available captive resources.

Over the past two decades, motor vehicle emissions regulations in developed countries have led to the need for low-sulfur and ultralow-sulfur gasoline and diesel fuels, greatly increasing hydrogen consumption in petroleum refining. This trend will continue to drive demand going forward as developing countries address air quality issues by enforcing more stringent clean fuel regulations. Additionally, a shift in the world's crude oil supply toward heavier, lower quality crudes and rising demand for distillate fuels will support increased use of hydrogen in refinery processes to break down heavier petroleum fractions into more valuable products.

World Hydrogen Demand by Region, 2013 (255 billion cubic meters)



Source: The Freedonia Group Inc.

In addition to refining needs, hydrogen is also heavily used in chemical production, as well as in the metals, electronics, and thin-film solar industries. Further, the global adoption of hydrogen energy technologies continues to make headway and fuel cells are expected to find increasing mainstream commercial use. Despite technical challenges, the emergence of a hydrogen market for fuel-cell-powered vehicles remains a possibility, say analysts.

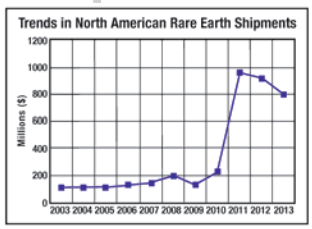
Although the U.S. will remain the world's largest hydrogen market in volume terms, the greatest share of growth through 2018 is expected to occur in China. With environmental concerns receiving heightened attention, the country is expected to aggressively target motor vehicle emissions by enacting and enforcing tighter clean fuel regulations. Countries such as India and Russia, which will seek to export ultra-low sulfur fuels, will experience the fastest gains. In contrast, demand for hydrogen in most developed countries will grow only modestly, if at all. However, the outlook in the U.S. and Canada will be more positive due to relatively low energy and feedstock prices. Consumption in Western Europe and Japan is expected to be weak as the refining and chemical industries in these countries face stagnant domestic demand combined with a highly competitive global market.

The merchant hydrogen industry is highly concentrated among four leading suppliers—Air Products, Air Liquide, Praxair, and Linde—together accounting for 90% of sales. For more information, call 440.684.9600 or visit freedoniagroup.com.

feedback

Rare earths data dilemma

The recent piece on rare earths ["Market Spotlight," June] could do with a bit of clarification. The graph shows a huge one-year gain, then a two-year drop without a good explanation. China? Economic graphs simply do not look like that unless something big happens, as in China refusing to sell rare earths to us anymore:





Carl Auer von Welsbach, discoverer of mischmetal.

The report also fails to make note of the most iconic use of rare earths. Back in my day (50s, 60s, 70s), everyone carried around a slug of rare earths and used it 20, 50, even 100 times a day—the Zippo lighter. The so-called "flints" in Zippos are actually an alloy of rare earths called *mischmetal,* which is run of the mill ore, refined but not separated into its component metals. Interestingly, a fraction of a percent of mischmetal added to molten cast iron in place of magnesium makes very fine nodular iron.

Chuck Dohogne

Rare earths rebuttal

The chart reflects the value of North American rare earth shipments, which are the product of both quantity and price. The former does indeed fluctuate around end-use market demand, but the latter is rather sensitive. Much of the swing reflects the latter.

Dr. Kevin Swift,
American Chemistry Council

Rare books find good home

Thank you for including the information about ASM Life Member J. Gray Bossard and his historical books and files in need of a new home ["Feedback," June]. I am a collector and former steel researcher now working in automotive. I enjoy *AM&P* magazine very much and have always held this publication high on my reading list. I am especially enjoying the "Metallurgy Lane" series that is running now.

Daniel L. Galiher

[Galiher and Bossard are now in touch to discuss the historical collection.—Eds.]

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

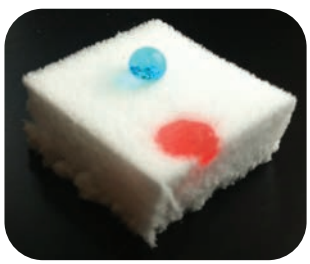
Ancient chisel found beneath Western Wall



2000-year-old chisel. Courtesy of Clara Amit/IAA.

A 2000-year-old stonemason's chisel thought to have been used in the construction of Jerusalem's Western Wall was discovered along with a number of Second Temple-era objects, according to an Israeli archaeologist. Eli Shukron, an archaeologist working for the Israel Antiquities Authority (IAA), found the chisel last summer during a dig near a tunnel at the lower base of the Western Wall. Also known as the Wailing Wall, the massive structure is venerated by Jews as the sole remnant of their Second Temple, destroyed by the Romans in 70 A.D. To the Muslims, the Western Wall is revered as the Wall of Buraq, where Muhammad tethered his winged horse Buraq after being transported from Mecca to Jerusalem.

"The chisel was found inside rubble of stone chips that fell from the stonemasons working on the rocks comprising the Western Wall," says Shukron. About 6 in. long, the metal tool features a flattened head as a result of being repeatedly banged on rock. The IAA will not comment on the discovery until analysis of the chisel and other findings is complete. *antiquities.org.il.*


A drop of oil (red) and water (blue) on top of the silylated sponge. Courtesy of Empa.

Soaking up oil spills with nanosponges

Swiss Empa researchers in collaboration with the University of Bordeaux, France, developed a highly absorbent material that separates oil film from water and can be easily recovered. The "silylated" nanocellulose sponges absorbed up to 50 times their own weight of mineral oil or engine oil in lab tests and also kept their shape so they could be removed from the water with pincers.

In one-step production, nanofibrillated cellulose (NFC) from cellulose plants is extracted from cellulose-containing materials like wood pulp, agricultural byproducts (such as straw), or waste materials (such as recycled paper) by adding water and pressing aqueous pulp through several narrow nozzles at high pressure. This produces a suspension with gel-like properties containing long and interconnected cellulose nanofibers.

When water from the gel is replaced with air by freeze-drying, a nanocellulose sponge is formed that absorbs both water and oil. Researchers modified the chemical properties of the nanocellulose in just one step by admixing a reactive alkoxysilane molecule into the gel before freeze-drying, causing the nanocellulose sponge to lose its hydrophilic properties, and only bind with oily substances. *www.empa.ch.*


Compostable plastic bags are made with lignin, a natural polymer that helps form the cell walls of plants, and is discarded in the papermaking process.

Easy compost plastic bags make headway

During three decades with Virginia Tech's College of Natural Resources and Environment, Wolfgang Glasser worked with many students as they advanced the field of natural polymers. But the most recent breakthroughs came in partnership with two University of Arkansas graduates. When Nhiem Cao, a chemical engineer, and Kevin Oden, an industrial engineer, had to write a business plan to complete their MBA degrees, they planned to use lignin, a natural polymer that helps form the cell walls of plants, for biodegradable plastic bags. Lignin is a compound of plant cell walls that is discarded in the papermaking process. Glasser began working with it because it was plentiful and inexpensive and can be used to make "green" polymers.

"My 'ah ha' moment came when, in addition to viewing it from a resource viewpoint, I realized its environmental benefits," he recalls. "It could be compostable. Plastic bags and bottles needn't last forever." Together, the scientists created Fayetteville, Ark.-based cycleWood Solutions. The company has produced single-use plastic bags, trash can liners, and meat bags, and is testing cups and plates. "The compostability was tested by a commercial lab in Belgium, and the bags meet the requirements of disintegrating to particles less than 2 mm in size in 180 days," said Glasser. "The bags are made with natural components and can be composted just like any other plant-based material." *cyclewood.com.*

briefs

AMG Advanced Metallurgical Group N.V., the Netherlands, announces that **AMG Titanium Alloys and Coatings** was selected by **SNECMA,** France, to provide titanium aluminides for production of the CFM International LEAP engine. AMG's TiAl materials will be used to produce low-pressure turbine blades for the engine, which will be used in single aisle aircraft. The new materials withstand very high temperatures (750°C) and will replace nickel-base superalloys, reducing blade mass and weight. This lightweight material will reduce fuel consumption by 15% compared to the best engine in its class. amg-nv.com, snecma.com.

RTI International Metals Inc., Pittsburgh, acquired **Dynamet Technology Inc.,** Boston, a pioneer in titanium powder metallurgy and supplier of near-net shape titanium and titanium alloy preforms and components to commercial aerospace, defense, biomedical, and industrial customers. Dynamet will be included in RTI's Titanium Segment. Purchase terms of the transaction were $15.5 million, plus potential future cash consideration. rtiintl.com, dynamettechnology.com.

Wayne State University, Detroit, finalized a license agreement with start-up company **Detroit Materials Inc.** for a Wayne State University patented portfolio of high strength, low alloy steels and cast irons for demanding applications in the defense, off-highway, tooling, and automotive industries. Researchers have been working to create advanced materials with high yield strength, fracture toughness, and ductility. The result is a portfolio of bainitic steels and austempered ductile irons exhibiting an excellent combination of mechanical properties previously only available in highly alloyed and costly exotic steels. wayne.edu.

Predicting metal's electrical response to extreme pressures

The semiconductor industry has long manipulated materials like silicon through the use of pressure, a strategy known as strain engineering, to improve the performance of transistors. But as the speed of transistors has increased, the limited speed of interconnects—the metal wiring between transistors—has become a barrier to increased computer chip speed. New research opens the door to a new variant of strain engineering that can be applied to the metal interconnects, and other materials used to conduct or insulate electricity.

"We looked at a fundamental physical property, the resistivity of a metal, and show that if you pressurize these metals, resistivity decreases. And not only that, we show that the decrease is specific to different materials—aluminum will show one decrease, but copper shows another," explains Nicholas Lanzillo, a doctoral candidate at Rensselaer Polytechnic Institute, Troy, N.Y. *For more information: Nicholas Lanzillo, 518.276.6310, rpi.edu.*

British buildings use too much steel



Courtesy of Andreas Levers via Flickr.

New research from the University of Cambridge, UK, found that the amount of steel used by the construction industry, and the resulting carbon emissions, could be significantly lowered by optimizing the design of new buildings in order to use less material. Currently, to keep labor costs down, the construction industry regularly uses double the material required by safety codes. Analysis of more than 10,000 structural steel beams in 23 buildings across the UK found that on average, beams were only carrying half the load they were designed for. Researchers also found that building designs are exceeding Eurocode Safety Standards by a factor of two and are unnecessarily using double the amount of steel and concrete needed. Additionally, many buildings are being designed to last for 100 years but on average are replaced after just 40.

By designing for minimum material rather than minimum cost, steel use in buildings could be drastically reduced, leading to an equivalent reduction in carbon emissions, at relatively low cost. The net result of avoiding over-design and early replacement is that the UK could provide the same amount of built space with just 20% of the materials. *www.cam.ac.uk.*

How to build a space laser

To construct a satellite that will measure all the bumps and dips of planet Earth, NASA engineers started with a black box built of a composite honeycomb material to make it as light as possible. The structure was precisely manufactured with an opening to allow lasers to beam to Earth, and other windows sized for a telescope that will capture photons that bounce off the planet and return to the satellite. The box was measured and marked to denote where the assembly of aligned mirrors, electronics, lasers, and photon detectors would be attached. It must be tough enough to handle the rigors of a rocket launch and years in a harsh space environment. Further, the box structure must be hardy enough to withstand the tests engineers use to simulate those conditions.



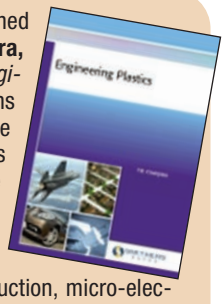
ICESat-2's instrument, the Advanced Topographic Laser Altimeter System (ATLAS) will measure the elevation of Earth's surfaces, from ice sheets to forests to oceans. Six beams will generate a more detailed elevation portrait than a single beam of the original ICESat, which flew from 2003 to 2009. And with the beams paired, scientists will be able to measure surface slope and better calculate height changes.

An engineer checks ICESat-2's box structure, shortly after its arrival in a NASA cleanroom in May. Over the next two years, engineers and technicians will attach electronics, optics, lasers, a telescope and more to the box, testing its function at each step. Courtesy of NASA's Goddard Space Flight Center/Kate Ramsayer.

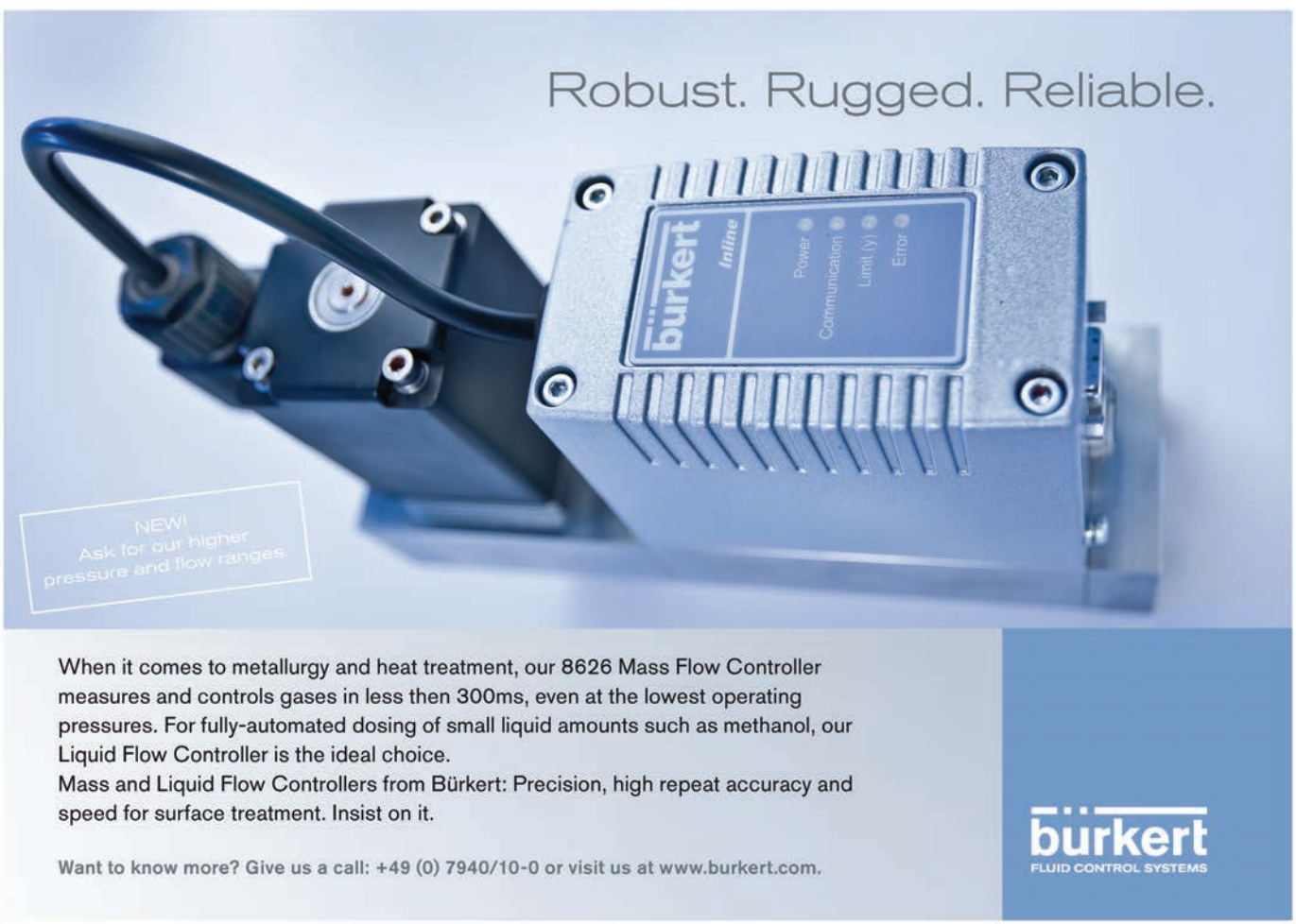
To measure elevation, ATLAS beams light with a green laser that pulses 10,000 times per second. Only a few photons will bounce off the surface and return to the satellite, but an incredibly sensitive detector counts those that do come back. Using the time of the photons' return trip, the speed of light, and some geometry, scientists can determine the distance the photons traveled and, therefore, the height of Earth below the satellite's orbit. ATLAS will provide scientists with measurements that create a global portrait of Earth's elevation, and will gather data that can precisely track changes, including melting glaciers and thinning sea ice. *icesat.gsfc.nasa.gov.*

Metals collaboration to develop high-performance materials

FEI, Hillsboro, Ore., and The University of Manchester, UK, will collaborate on the Metals Lab at The University of Manchester's Electron Microscopy Centre in the School of Materials. The lab will focus on steels and nonferrous alloys research in an effort to develop high-performance materials for use in automotive, aerospace, nuclear, oil and gas, and other industrial sectors where advanced metallic alloys play a critical role. The multiscale workflow permits investigations of the root causes of behavior and failure at the atomic scale, while ensuring that those small-scale observations accurately represent the structure and composition of the material at larger scales. This ability to characterize the same sample on different length scales is crucial to improve properties like strength, creep, fatigue, and corrosion of metals, where these macroscopic properties are linked to microscopic effects down to the atomic scale. *fei.com, www.manchester.ac.uk.*



A new book published by **Smithers Rapra,** Ravenna, Ohio, *Engineering Plastics,* aims to provide complete coverage of the types of plastics that are increasingly specified in applications as diverse as gears, aircraft body construction, micro-electronics and extreme high temperature applications, steel replacement, and artificial hip joints. The book also provides a complete review of the use of engineering polymers. Mechanical, electrical, and thermal polymer properties are discussed along with applications in food packaging as well as solvent and detergent resistance, plus frictional and hardness properties, and gas barrier data. smithersrapra.com.



briefs

Element Materials Technology, the Netherlands, acquired **Accutek Testing Laboratory,** Fairfield, Ohio, a materials testing business serving the aerospace and medical device sectors. Accutek, a specialist in a wide range of mechanical tests, metallurgical tests, weld services, and consultation, is based in a 54,000-sq-ft laboratory in Cincinnati. The lab is Nadcap accredited for both metallic and nonmetallic materials testing. element.com.

Nanoelectronics research center **imec** and **Ghent University,** both in Belgium, and their partners in the European FP7 project known as **SmartFiber** demonstrated what is reportedly the world's first miniaturized fiber-optical sensor system than can be fully embedded in a composite material. The achievement paves the way toward smart composites that enable continuous, automatic structural health monitoring of composite materials used in tidal blades, wind turbines, airplanes, or marine structures, for example. www.smartfiber-fp7.eu.



"Interrogator" (10 cm diameter) after embedding in a protective epoxy shell with shape optimized for minimal impact on composite structural strength.

The University of Notre Dame, South Bend., Ind., and **General Electric Co.** will build a $36 million research and test facility with the goal of making better massive gas turbines used by aircraft, power plants, and the oil and gas industry. The facility will include five test bays to allow researchers to simulate full-scale engine operating environments. Construction is scheduled to begin this summer at the former **Studebaker Corp.** site in South Bend, which closed in 1963. nd.edu, ge.com.

Imaging institute to accelerate materials development

The Department of Energy's (DOE) Oak Ridge National Laboratory, Tenn., launched the Institute for Functional Imaging of Materials to accelerate discovery, design, and deployment of new materials. The facility will meld world-class capabilities in imaging, high-performance computing, materials science, and other scientific disciplines to probe materials.



Sergei Kalinin is the inaugural director of ORNL's Institute for Functional Imaging of Materials. Courtesy of Jason Richards, ORNL.

The new institute also creates a focal point for ORNL's core capabilities: The lab is home to several major DOE Office of Science user facilities, including the fastest supercomputer in the U.S., the world's most intense pulsed neutron beam, and world-class facilities for electron/atom probe and scanning probe microscopy; mass spectrometry; and optical, x-ray, and chemical imaging. Its Center for Nanophase Materials Sciences, chemical sciences division, and materials science and technology division provide state-of-the-art imaging capabilities.

ORNL's newest institute will integrate computing and experimentation in real-time to allow researchers to capture and analyze immense data streams. That new knowledge will enable scientists to tailor materials to improve efficiency of tasks such as converting solar energy to electricity, transporting energy to the grid, and converting chemical to electrical energy in batteries. *ornl.gov.*

Self-propelled robot detects pipe leaks

Explosions caused by leaking underground gas pipes frequently make headlines, but methods to address such failing infrastructure have lagged far behind. Leaks are typically found using aboveground acoustic sensors, which listen for faint sounds and vibrations caused by leakage, or in-pipe detectors, which sometimes use video cameras to look for signs of pipe breaks. However, these systems are slow and can miss small leaks altogether.

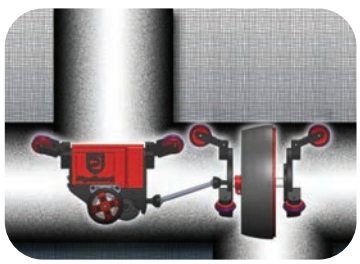


Illustration of robotic device that can speed through pipes, pinpointing leaks more accurately than existing methods. Courtesy of Christine Daniloff/MIT.

Researchers at Massachusetts Institute of Technology (MIT), Cambridge, and King Fahd University of Petroleum and Minerals in Saudi Arabia devised a robotic system that can detect leaks at a rapid pace and with high accuracy by sensing a large pressure change at leak locations. The new system "can detect leaks of just 1 to 2 mm in size, and at relatively low pressure," says Dimitrios Chatzigeorgiou, a Ph.D. student in mechanical engineering at MIT. The small robotic device can move as fast as 3 mph through pipes and is almost entirely automated. Such robots could eventually be put into a system of pipes and left in place indefinitely, conducting automatic, nonstop system monitoring.

The device consists of two parts—a small robot with wheels to propel it through pipes and a drumlike membrane that forms a seal across the width of the pipe. When a leak is encountered, liquid flowing toward it distorts the membrane, pulling it slightly toward the leak site. That distortion can be detected by force-resistive sensors via a carefully designed mechanical system and the information sent back through wireless communications. Due to the membrane's sensitivity, the team believes the system can detect leaks one-tenth to one-twentieth the size of those that can be detected by current methods. *For more information: Dimitrios Chatzigeorgiou, dchatzis@mit.edu, mit.edu.*

Using protons to capture microscopic images

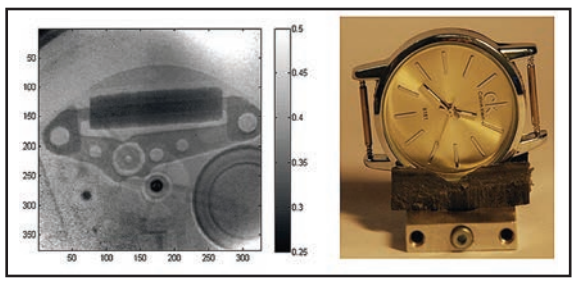
A new facility that uses protons to take microscopic images was recently commissioned at the ring accelerator of the Helmholtz Centre for Heavy Ion Research (GSI) in Germany. The



Instrumentation and controls company **Spectris plc,** the Netherlands, acquired **La Corporation Scientifique Claisse Inc.,** Canada, a leader in sample preparation for atomic spectroscopy analysis (including x-ray), for an undisclosed sum. Claisse designs, manufactures, and sells consumables and instruments used to prepare samples for spectroscopic analysis in mining, pharmaceutical, academic research, and industrial applications. Claisse will become part of the materials analysis segment of Spectris and will be integrated into PANalytical. panalytical.com.

proton microscope was developed by an international collaboration consisting of Los Alamos National Laboratory, GSI, the Technical University Darmstadt, and the Institute for Theoretical and Experimental Physics, Russia. Similar to x-rays, protons can be used to radiograph objects, generating images of them. Protons are able to penetrate hot dense matter that cannot be examined with light or x-rays. Proton radiography was originally invented at Los Alamos National Laboratory in the 1990s, but has been adopted around the world. In the future, the technique will be used at an accelerator currently under construction in Darmstadt called the Facility for Antiproton and Ion Research (FAIR) and at the proposed Matter and Radiation in Extremes (MaRIE) facility at Los Alamos.

In their first experiments, researchers used a proton beam accelerated to an energy of 4.5 gigaelectronvolts (more than 98% of the speed of light) by the GSI accelerator facility. A special setup of four quadrupole magnets served as optics to magnify objects with the beam. Initially, different items such as sets of wires and a wristwatch were radiographed. Scientists succeeded in resolving objects and structures down to a size of 30 µm. The GSI facility achieved resolutions comparable to existing facilities in the U.S. or Russia. Scientists plan to improve this to a value of up to 10 µm in experiments this year. Another goal is to record image sequences of moving objects. *lanl.gov.*



A wristwatch was one of the first items imaged by the new proton radiography system. At left, the inner workings of the mechanism are visible.



briefs

Quantum Materials Corp., San Marcos, Texas, reports securing 3D printing anti-counterfeiting quantum dot detection technology developed at the **Institute for Critical Technology and Applied Science** and the **Design, Research, and Education for Additive Manufacturing Systems (DREAMS) Laboratory** at **Virginia Tech., Blacksburg.** Quantum dots are embedded within objects being 3D printed to produce a unique, physically uncloneable signature known only to the object's manufacturer. The method will help positively identify any object through a variety of application and detection methods. Novel uses of embedded nanomaterials cover a wide field of growing industries of encryption, secure key exchange, protection of hardware from tampering, and other secure identification needs. qmcdots.com, ictas.vt.edu.

The **Department of Energy** (DOE) announces a funding extension of $14 million over four years for an Energy Frontier Research Center (EFRC) first established at its **Brookhaven National Laboratory,** Upton, N.Y., in 2009. The **Center for Emergent Superconductivity,** led by Brookhaven with partners from the **University of Illinois** and DOE's **Argonne National Laboratory,** aims to understand the fundamental nature of superconductivity in complex materials. Scientists are exploring methods to improve the critical properties of known high-temperature superconducting materials—which operate above the extreme cold temperatures required for conventional superconductivity—and accelerate the search for new ones. bnl.gov.

New batteries conquer range anxiety

A team from George Washington University (GWU) led by chemistry professor Stuart Licht developed a novel solution to electric vehicle range anxiety called the "molten air battery." These rechargeable batteries, which use molten electrolytes, oxygen from air, and special multiple electron storage electrodes, have the highest intrinsic electric energy storage capacities of any other batteries to date, say researchers. Their energy density, durability, and cost effectiveness give them the potential to replace conventional electric car batteries, explains Licht.



A molten air battery configuration: The air electrode (circle, left) and the metal electrode (right) are lowered into the crucible (white cup), then covered with electrolyte, which is heated until it is molten. Courtesy of William Atkins, GWU.

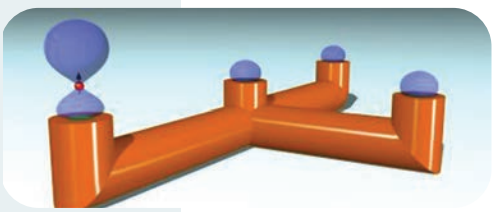
Molten air batteries made with iron, carbon, or vanadium boride can store three, four, and 11 electrons per molecule, respectively, giving them 20 to 50 times the storage capacity of a lithium-ion battery, which is only able to store one electron per molecule of lithium. The new molten air batteries offer both high storage capacity and reversibility. Air acts as one of the battery electrodes, while nickel or iron electrodes can serve as the other. *Molten* refers to the electrolyte, which is mixed with reactants for iron, carbon, or vanadium boride, then heated until the mixture becomes liquid. The liquid electrolyte covers the metal electrode and is also exposed to the air electrode. Batteries are able to recharge by electrochemically reinserting a large number of electrons. The rechargeable battery uses oxygen directly from the air, not stored, to yield high battery capacity. The high activity of molten electrolytes is what allows this charging to occur, says Licht.

Electrolytes are melted to a liquid by temperatures between 700° and 800°C, which is challenging to operate inside a vehicle, though such temperatures are reached in conventional internal combustion engines. The new batteries could also be used for large-scale energy storage for electric grids. *gwu.edu.*

Magnetic hose holds promise for quantum computing

A magnetic hose designed by researchers at Universitat Autonoma de Barcelona consists of a ferromagnetic cylinder covered by a superconductor material, a simple design given the complicated theoretical calculations and numerous lab tests it had to undergo. The concept is similar to the way light is effectively conducted through optical fibers. The team built a 14-cm prototype, which transports the magnetic field from one end to the other with an efficiency of 400% compared to traditional methods used to transport these fields.

Despite this impressive operation, researchers theoretically demonstrated that the efficiency can be further boosted by covering the ferromagnetic tube with thin layers of alternating superconducting and ferromagnetic materials. The newly designed device can be implemented at any scale, even the nanometer level. Such a nanohose—capable of individually controlling quantum systems—could help solve some of today's challenges in quantum computing, say researchers. *www.uab.cat.*



Schematic representation shows that the magnetic field generated at the magnetic hose inlet is transmitted to the outlets. Courtesy of UAB.



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briefs

Semprius Inc., Durham, N.C., in collaboration with researchers at the **University of Illinois at Urbana-Champaign** and **Solar Junction,** San Jose, Calif., manufactured the first four-junction, four-terminal stacked solar cell using its proprietary printing process. The stacked solar cell is comprised of a three-junction microcell stacked on top of a single-junction germanium microcell using a high-speed micro transfer printing method, enabling simultaneous formation of thousands of stacked microcells with very high yields. By using four junctions, light is captured across a broader portion of the solar spectrum and efficiencies much higher than conventional silicon and thin-film single-junction solar cells are achieved. Initial trials yielded solar cells with efficiencies up to 43.9%. semprius.com.

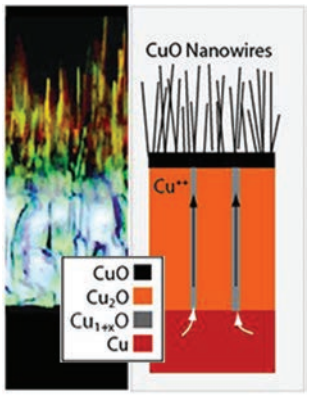
AML Superconductivity and Magnetics, Palm Bay, Fla., and **Argonne National Laboratory,** Ill., announced that one of the world's most sophisticated superconducting magnet systems passed a landmark reliability test. The successful test is the latest in a series of recent AML milestones that promises to accelerate the mainstreaming of superconductivity into high-impact applications. amlsuperconductivity.com, anl.gov.

A team led by researchers at **Oxford University,** UK, demonstrated that the lead in solar cells based on lead halide perovskites can be replaced with tin. Perovskite solar cells promise to be inexpensive and easy to mass produce and have already achieved 17% efficiency at turning sunlight into electricity. The prototype lead-free material degrades in the presence of oxygen and moisture, but researchers are confident that further work will enable manufacturing of stable cells that can operate in air for long periods of time. www.ox.ac.uk.

Copper nanowires for new solar cells

By looking at a piece of material in cross-section, a research team led by Parag Banerjee, Washington University, St. Louis, discovered how copper sprouts grasslike nanowires that could one day be made into solar cells. The team worked with copper foil, a simple material similar to household aluminum foil. When most metals are heated, they form a thick metal oxide film. However, a few metals, such as copper, iron, and zinc, grow grasslike structures known as nanowires, which are long, cylindrical structures a few hundred nanometers wide by many microns tall. Researchers set out to determine how the nanowires grow.

Raman spectroscopy was used to reveal an underlying thick film made up of two different copper oxides (CuO and Cu_2O) with narrow, vertical columns of grains running through them. In between these columns, grain boundaries acted as arteries through which the copper from the underlying layer was being pushed through when heat was applied, creating the nanowires. *For more information: Parag Banerjee, 314.935.3537, parag.banerjee@wustl.edu, engineering.wustl.edu.*



Schematic illustration of the cross-section and phases observed during copper oxidation. Center photo shows copper being pushed upward through the grain boundaries to become nanowires.

Dual carbon battery is energy dense and sustainable

Power Japan Plus, San Francisco, launched a new battery technology—the Ryden dual carbon battery that offers energy density comparable to a lithium ion battery, but over a much longer functional lifetime with drastically improved safety and sustainability. The new battery makes use of a unique chemistry, with both the anode and cathode made of carbon. It charges 20 times faster than lithium-ion batteries and is more powerful than other advanced batteries, operating above four volts. The battery allows for consolidation of the supply chain by using only one active material. Additionally, manufacturing of the Ryden battery is under no threat of supply disruption or price spikes from rare metals, such as rare earths or heavy metals. It is said to be the first high-performance battery that meets consumer lifecycle demand, rated for more than 3000 charge/discharge cycles. It also eliminates the unstable active material used in other high performance batteries, greatly reducing fire and explosion hazards. The Ryden battery can be charged and discharged with no damage to the battery and is 100% recyclable. *powerjapanplus.com.*

Better battery design reduces fire risk

As news reports of lithium-ion battery (LIB) fires in Boeing Dreamliner planes and Tesla electric cars remind us, these batteries—which are in everyday devices like tablets and smartphones—have their downsides. Scientists designed a safer kind of lithium battery component that is far less likely to catch fire and still promises effective performance. Lynden Archer, Geoffrey Coates, and colleagues at Cornell University, Ithaca, N.Y., explain that the danger of LIBs originates with their electrolytes, which usually contain a flammable liquid. To minimize this fire hazard, more stable, solid electrolytes are being developed. However, although solid electrolytes are less likely to fuel a fire, their ability to transport ions has fallen short, especially at room temperature. The Coates team set out to tackle both issues and develop a safer, high-performance battery component, while Archer's team studied the electrochemical characteristics of the materials. Their efforts have led to a new family of solid polymer electrolytes that is both good at conducting lithium ions at room temperature and minimizing the risk of fire. Not only are these materials safer than their liquid counterparts in LIBs, they could also be used in high-energy lithium-metal batteries, such as promising lithium-sulfur and lithium-air batteries. *For more information: Lynden Archer, 607.254.8825, laa25@cornell.edu, mse.cornell.edu.*

Mobile lab for offshore testing

Exova, UK, will provide an innovative "laboratory in a box" concept for Subsea 7, London, to support its offshore project work near the Republic of Congo and Angola. Designed and built in Daventry, UK, and shipped ready for on-site testing at the Angola site this summer, the mobile concept consists of a fully-fitted laboratory and machine shop created in two 40-ft purpose-built units. This technically demanding project is part of a two-year agreement between the companies. The facility will deliver pipeline coating qualification tests including cathodic disbondment to ensure compatibility with potential corrosion protection systems, adhesion, and peel testing of coatings to ensure a high integrity barrier to sea water ingress. Differential scanning calorimetry will be used to verify correct coating cure of the critical fusion bonded epoxy (FBE) corrosion coat. The mobile lab will be on site for approximately four months, with a team of seven rotating employees operating on a 24/7 basis. Testing will be carried out on a variety of coating types using specialized equipment and testing methods. *exova.com, subsea7.com.*

Breakthrough interconnect technology

Applied Materials Inc., Santa Clara, Calif., released the Applied Endura Volta CVD Cobalt system, said to be the only tool capable of encapsulating copper interconnects in logic chips beyond the 28 nm node by depositing precise, thin cobalt films. The two enabling applications, a conformal cobalt liner and a selective cobalt capping layer, provide complete enclosure of the copper lines, improving reliability by an order of magnitude. The introduction of cobalt as a superior metal encapsulation film marks the most significant materials change to the interconnect in more than 15 years.

The first step deposits a thin, conformal CVD cobalt liner to increase the gap fill window of copper in narrow interconnects. This improves device performance and yield by integrating the pre-clean, PVD barrier, CVD cobalt liner, and copper seed processes under ultra-high vacuum on the same platform. The second step, a new "selective" CVD cobalt capping step, is deposited after chemical mechanical planarization (CMP) to encapsulate the copper lines for enhanced reliability. Complete envelopment of copper lines with cobalt creates an interface with an improvement of more than 80-fold in device reliability. *appliedmaterials.com.*

Nature inspires low-friction bearings

Biological lubrication is much more efficient than synthetic lubrication—especially in joints, where a thin, watery solution prevents friction. The thin film stays put due to a polymer layer that is anchored to the cartilage at the end of bones that protrude from the cartilage and form "polymer brushes." These brushes attract the extremely fluid lubricant and keep it in place at the contact point.

Researchers at Forschungszentrum Jüelich, Germany, are trying to mimic this using two different polymers at the contact point to prevent entanglement. "Using supercomputers, we simulated what would happen if we applied water-soluble polymers to one side and water-repellent polymers to the other," says physics professor Martin Müser. "This combination of water-based and oil-based liquids as a lubricant reduces friction by two orders of magnitude—around a factor of 90—compared to a system comprising just one type of polymer. The two different phases of the liquid separate because they repel each other. This simultaneously holds the polymers back and prevents them from protruding beyond the borders." *For more information: Martin Müser, +49.2461.61.9095, m.mueser@fz-juelich.de, www.fz-juelich.de.*



Due to biological lubrication, natural joints move almost frictionless and withstand enormous loads. Courtesy of Tom Page.

briefs

Researchers at **Durham University,** UK, are focused on new smart materials called oleophobic-hydrophilic coatings that let water through but repel oil for use in oil-spill cleanups. They developed these coatings for the surfaces of metal mesh. When an oil-water mixture is poured onto the mesh, water drips through into the container below, while oil remains on top of the mesh surface. Separation is instantaneous and more efficient than existing films, and only one step is required to make the coating. The team also demonstrated that it could serve as an anti-fogging and self-cleaning film. www.dur.ac.uk.

Scientists at the **Fraunhofer Institute for Microelectronic Circuits and Systems IMS,** Germany, developed a new type of high-temperature process to fabricate extremely compact microchips that operate flawlessly at temperatures up to 300°C. To fabricate the heat-tolerant minichips, researchers use a specialized high-temperature silicon-on-insulator (SOI) conventional semiconductor chip process. The insulation prevents leakage currents from influencing chip operation. Researchers also use tungsten metallization, which is less temperature sensitive than aluminum and increases the chips' operating life. www.ims.fraunhofer.de/en.

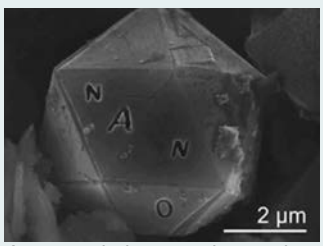


Extremely compact microchips keep their cool at 300°C. Courtesy of Fraunhofer IMS.

NANOTECHNOLOGY

briefs

University of Technology, Sydney, researchers are the first to etch structures less than 100 nm in size on the inclined surfaces of diamond by using a variable pressure scanning electron microscope (SEM). Key to the approach is use of an electron beam in a water vapor environment, which dissociates surface-adsorbed water molecules into radical fragments. The resulting volatile reaction products create voids on the surface when they leave the diamond substrate. By exploiting the high resolution, precise beam steering capabilities of an SEM, sub-100 nm lines were etched on the inclined planes of a single crystal diamond. www.uts.edu.au.



A new technique can be used to etch smaller structures on diamond than was previously possible. Courtesy of NPG.

Haydale, UK, announces publication of research showing its functionalized graphene nanoplatelets (GNP) significantly improve the nanoreinforcement of resin. Research was conducted by the Material Science Department at **The Aerospace Corp.,** El Segundo, Calif. The report states significant strength improvements in toughened epoxy composites. The reported increases are >2 times in tensile strength and modulus of an epoxy composite using a number of HDPlas O_2-functionalized GNP, manufactured by Haydale. The addition of increasing amounts of GNP results in strength increases of more than 125% and toughness improvements of 100% over that of similarly cured, unreinforced material. haydale.com.

Unexpected behavior of nanotubes discovered

Lydéric Bocquet, a visiting professor at Massachusetts Institute of Technology, Cambridge, conducted tests on carbon nanotubes (CNTs) and boron nitride nanotubes (BNNTs) and found that at least in terms of one key property, friction, the two seemingly identical types of tubes are not only different, but nearly opposite in their characteristics: CNTs are so slippery that they are described as having an extreme form of frictionlessness called superlubricity. BNNTs, on the other hand, display a very high level of friction—a completely unexpected discovery.

Tests were carried out in an apparatus that allows a nanotube to be suspended between two supports, which can then pull it apart with precisely calibrated force. The tubes—actually a set of nested pieces, much like an old-fashioned telescope—eventually break under the strain. One or more of the tubes can be pulled out from within the others, like extending the telescope. The force needed to pull one tube out of the other can then be measured. *For more information: Lydéric Bocquet, lbocquet@mit.edu, web.mit.edu.*

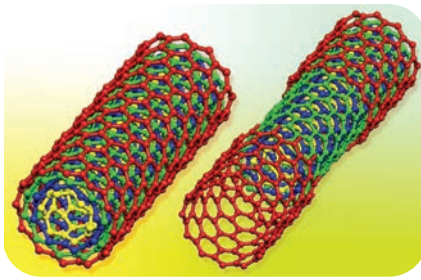


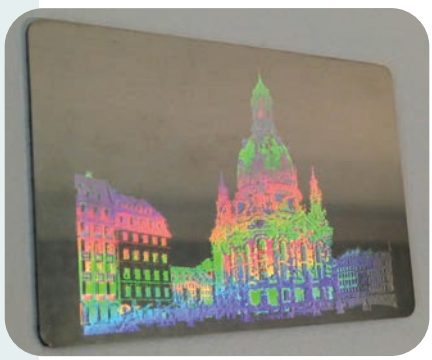
Illustration of tested characteristics of multi-walled boron nitride nanotubes, which consist of several nested tubes that are each just one atom thick. When attached to a device that can pull apart the tube from its two ends, the outer tube cracks, allowing the concentric tubes to separate. Measuring the force required to pull the ends apart reveals the amount of friction between the layers. Courtesy of the authors.

New technique captures nanoscale fluid movies

Researchers at Caltech, Pasadena, applied a new imaging technique called 4D electron microscopy to the nanofluid dynamics problem. The 4D microscopy technique was created and directed by Ahmed Zewail, the Linus Pauling Professor of Chemistry and professor of physics, to advance understanding of the fundamental physics of chemical and biological behavior. In 4D microscopy, a stream of ultra-fast-moving electrons bombards a sample in a carefully timed manner. Each electron scatters off the sample, producing a still image that represents a single moment, just a femtosecond in duration. Millions of still images can then be stitched together to produce a digital movie of nanoscale motion. Single laser pulses were used to melt the lead cores of individual zinc oxide nanotubes and then, using 4D microscopy, researchers captured how the hot pressurized liquid moved within the tubes—sometimes splitting into multiple segments, producing tiny droplets on the outside of the tube, or causing the tubes to break. *caltech.edu.*

Laser system fabricates micro and submicroscale structures

Scientists of the Fraunhofer IWS, Germany, developed a unique solution to fabricate structures at the micro and submicroscale. For the first time, scientists have a technology that allows structuring of areas up to 500 × 500 mm^2 in only a few minutes. The compact system can be adjusted to precisely meet individual user requirements and can be used to fabricate arrays with structure widths from 150 nm to 20 µm. Scientists apply the direct laser interference patterning (DLIP) technique for large area micro structuring and functionalization processes. This technique allows for large area and maskless lithography to fabricate complex structures within one step. Conventional structuring technologies are either too slow (sequential procedure) or not flexible enough (mask technique). *www.iws.fraunhofer.de.*



DLIP structured decorative element (Dresden Church of our Lady) on stainless steel. Courtesy of Fraunhofer IWS Dresden.

Preventing **Corrosion Failures**

Jose E. Ramirez
Christopher D. Taylor
DNV GL – Oil & Gas
Dublin, Ohio

Modern methods for preventing and controlling corrosion can reduce or eliminate its impact on public safety, the economy, and the environment.

Corrosion is commonly defined as the deterioration of a material or its properties because of a reaction with its environment. It is a natural process due to a high energy state induced in metals and alloys during refining, processing, and manufacturing. Therefore, corrosion cannot be avoided but it can be managed. The direct cost of corrosion in the U.S. is estimated at $276 billion for 1998 (Fig. 1)[1]. Indirect costs, such as loss of production, environmental impacts, transportation disruptions, injuries, and fatalities are estimated to be in the same order of magnitude. Projections to June 2013 indicate that total corrosion costs, direct and indirect, in the U.S. now exceed $1 trillion dollars or roughly 6% of GDP. According to the World Corrosion Organization, corrosion costs are approximately 3-4% of the GDP of all industrialized countries[2].

Corrosion can cause dangerous and expensive damage and failures of everything from pipelines, bridges, and public buildings to vehicles, ships, and airplanes, and from water and wastewater systems to medical implants, communication systems, and electronic devices. However, there are well established methods to prevent and control corrosion that can reduce or eliminate its impact on public safety, the economy, and the environment. It is estimated that 25-30% of the total direct cost could be saved by using state-of-the-art corrosion management practices.

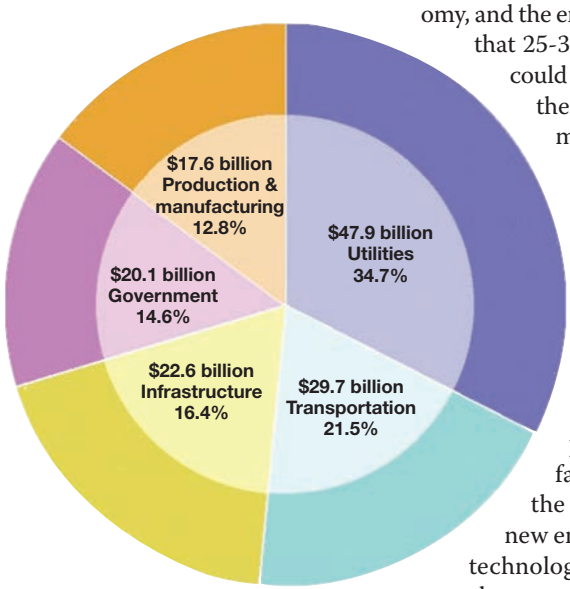


Fig. 1 — *Direct corrosion costs in five major economic sectors[1].*

That said, the increasing need for reliable and inexpensive sources of energy continually pushes the development and use of new technologies. As with any emerging technology, additional corrosion problems and potential failures arise as a result of the use of new materials in new environments. A few recent technologies that have been proposed, matured, or introduced to the market include: Deep offshore HT/HP oil and gas production; CO_2 sequestration; fuel cells, offshore wind energy, solar energy; new fuel types; ultra-supercritical boilers; lightweight structures; ultra-efficient car and jet engines; geothermal energy; and nuclear waste disposal.

These and other new technologies push materials to withstand increasingly demanding conditions as a result of higher temperatures and pressures, and environments with greater corrosivity. Therefore, the risks of new types of corrosion failures need to be considered along with methods to avoid them, as described in this article.

New corrosion challenges

Deep offshore HP/HT oil and gas wells: In the search for new reserves of energy, the oil and gas industry is continually moving offshore to deeper wells. Generally, increasing well depth means increasing pressure and temperature. High pressure/high temperature (HPHT) wells have generally been considered wells in which



temperatures and pressures at the bottom of the well exceed 300°-350°F (149°-177°C) and 10,000 psi (69 MPa). Conditions exceeding 400°F (204°C) and 20,000 psi (138 MPa) at the bottom hole have been labeled variously as extreme HPHT (xHPHT) and ultra HPHT. Additionally, a large fraction of the world's remaining oil reserves consist of crude oil with either high H_2S or CO_2 content that requires high quality, corrosion-resistant materials. The same is true of gas fields that are highly corrosive. Reliable materials for deep well construction must have high strength and corrosion resistance at high temperatures to avoid potential failures.

Oil and gas developers need to leverage every available technical solution to avoid failures and maintain optimal production. However, current corrosion resistant alloys (CRAs) suitable for harsh corrosion environments are expensive and can account for an appreciable fraction of the cost of developing these resources. As a result, some oil and gas fields are not economical to develop.

Additionally, there is limited corrosion resistance data available for CRAs at temperatures that exceed ~450°F (232°C), and even less above this temperature. In order to prevent corrosion failures, fundamental materials characterization and testing methods are needed to determine the service limits of CRAs for localized corrosion attack and corrosion fatigue in the presence of hydrogen; to develop new CRAs that are less expensive to manufacture; and to develop surface modification of lower-cost materials to impart required corrosion resistance.

Carbon dioxide capture and storage: The manmade atmospheric release of CO_2 during

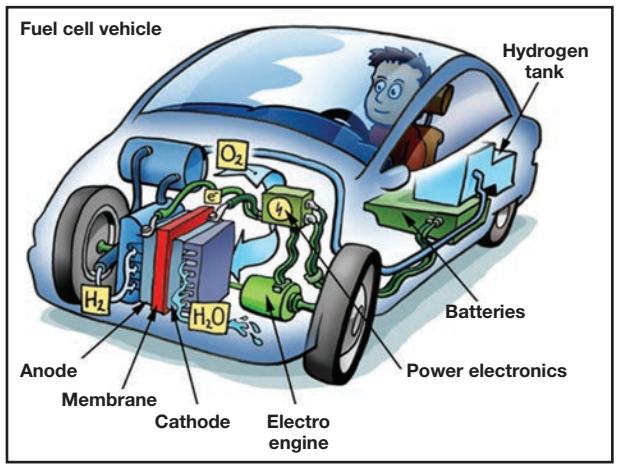
energy, steel, and concrete production needs to be reduced dramatically over the coming decades. CO_2 capture and storage is an important technology in reducing greenhouse gas emissions. In the case of large-scale underground storage of CO_2 in depleted gas reservoirs or aquifers, the integrity of carbon steel down-hole tubing is strongly endangered by CO_2 corrosion due to much more severe environmental conditions than normally encountered in traditional oil and gas production. Severe corrosion problems may occur due to unknown concentrations of impurities such as oxygen, carbon monoxide, sulfur dioxide, or hydrogen sulfide that are inevitably present in exhaust gases. One alternative could be the use of CRAs, but most likely at a huge cost. CRAs may not be completely immune to corrosion attack due to the high salinity, impurities, temperature, and design-caused crevices found in these service conditions[3,4].

New and sustainable corrosion control concepts are needed to ensure equipment integrity and achieve long, failure-free lifetimes. Reliable material use requires suitable prediction models concerning corrosion behavior under such conditions. Models are needed not only for lifetime prediction, but also for a better understanding of the corrosion processes under conditions of CO_2 sequestration. The respective models must be developed and verified using experimental data. Testing methods with high repeatability and reproducibility need to be developed and standardized as well[4].

Offshore wind energy: Land-based wind farms have reached a significant level of reliability. However, an additional challenge from a corrosion standpoint comes into play when wind energy plants move offshore. All major components are susceptible to corrosion and many types are possible due to a much more severe corrosive environment stemming from sea spray and seawater conditions in conjunction with higher wind forces. One of the main challenges is to prevent corrosion fatigue under these severe environments[5]. For example, coatings in general may have strain limits that can be exceeded by the wind forces or the periodic action of rotating blades. Evaluation of the effect of superimposed mechanical stresses on corrosion protection systems is needed to avoid failures.



Fuel cells: Independent of the type of fuel cell (proton exchange membrane, solid oxide, or molten carbonate versions), the electrochemical reactions and reactant/product gases within these cells promote harsh environments. Therefore, corrosion of metal plates is something that is virtually unavoidable over the required lifetime of a fuel cell. A significant issue is corrosion of the bipolar plates, where a compromise must be reached between high conductivity and high corrosion resistance in the fuel cell environment[6, 7]. The solid oxide fuel cell (SOFC), in particular, operates at intermediate (500°-700°C) or high (700°-900°C) temperatures, which offer the advantages of fuel flexibility and lower cost catalysts. Operation at elevated temperatures, however, also results in high-temperature materials degradation issues. A major issue is the resistance of these



materials to oxidation at elevated temperatures, where oxide scales are formed that are usually not of high conductivity. The oxidation of Fe-Cr interconnect materials also forms Cr_2O_3 with simultaneous volatilization of the oxide, which results in Cr-poisoning of the cathode. In order to avoid SOFC failures, development of very thin and protective—yet highly conductive—oxide scales on the surface of interconnect alloys with long stability under operating conditions is necessary.

Lightweight structures: Lightweight materials are of high importance to the transportation industry to reduce both fuel consumption and greenhouse gas emissions. Alloys based on both magnesium and titanium aluminides are of special interest for certain applications due to a combination of their low specific density and mechanical properties. Although magnesium is a light material, it is among those with the least corrosion resistance, especially when in contact with other metallic materials. Generally, the method of modifying the alloy through alloying compounds for increased corrosion resistance is limited and coating systems must be developed.

Intermetallic titanium aluminides are another useful alloy for lightweight construction, as they feature half the weight of steel or nickel-base materials currently used in car engines while offering similar mechanical performance. The biggest drawback of these materials is, however, their limited oxidation resistance at temperatures above 700°-800°C. Again, innovative surface protection systems are needed.

Corrosion failure prevention strategies

Given the severe environments materials will face as critical enablers of future global energy industries, preventing corrosion failures requires developments in four key directions according to the tetrahedron in Fig. 2, including materials design, corrosion mitigation, lifetime prediction, and inspection.

Materials design: For the most challenging environments in which low cost, inexpensive metals may not be employed, corrosion-resistant alloys need to be developed. CRAs can be designed based on principles that reduce the number of corrosion failures by optimizing microstructure and composition, and possibly employing nanotechnology. Techniques such as grain-boundary engineering can be used to design materials resistant to failure from intergranular corrosion and stress corrosion cracking (SCC). Modern high-performance computing has enabled the integrated

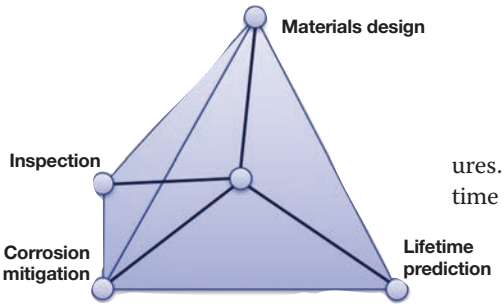


Fig. 2 — *Strategy tetrahedron for corrosion failure prevention.*

computational materials engineering (ICME) paradigm that has already begun to accelerate the timeline for materials development and lead to cost reduction[8]. Surface composition and hydrophobicity control can be achieved using techniques like physical and chemical vapor or electrochemical deposition. Recent developments in additive manufacturing of alloy components may provide unique opportunities for tailoring customized alloys with graded compositions. Other advanced concepts include diamond-like carbon and graphene coatings[9].

Corrosion mitigation: When a CRA is incompatible with design constraints, or when dealing with an existing system, environmental controls to mitigate corrosion must be employed. Protecting metallic surfaces via coatings, introducing aqueous or vapor phase inhibitors, cathodic (electrochemical) protection, and/or sacrificial anodes are several proactive methods that can be used to bias systems away from corrosion and toward a passive, failure-resistant state. Process controls should be employed as much as possible to monitor and control factors such as temperature, humidity, pH, and ionic content. Contemporary challenges in mitigation include developing chromate-free, environmentally friendly inhibitor compounds, and gaining a better understanding of the influence of process conditions on corrosion rate, particularly for localized corrosion[10]. Avoiding the occurrence of galvanic corrosion cells by minimizing dissimilar metal joints is a way to prevent corrosion failure at the design stage[11].

Lifetime prediction: Given a specific material choice and a mitigation strategy, models can be employed to develop a risk assessment of the material's susceptibility to corrosion failure as a function of age and environment. Model accuracy depends on the known science behind the particular problem, plus data reliability for conditions and corrosion rates. In many cases, empirical models have been constructed from historical data, and find the most application in industry. At the same time, science-based thermodynamic and kinetic models assess the corrosivity of a given environment-materials combination. Science-based models have the advantage of being independent of time and space, unlike historically derived empirical models. Science-based predictions are also highly constrained according to the physics, chemistry, and metallurgical awareness incorporated into the model.

Given the differences between empirical and science-based models, recent modeling has moved toward Bayesian inference, which synthesizes empirical, probabilistic estimates of corrosion failure with science-based models[12]. Furthermore, multiscale modeling is moving toward an integrated simulation of materials chemistry and microstructure alongside finite element simulation of transport phenomena and stress states in the material, with environment-side chemistry via reactive-transport models.

Inspection: Materials design and corrosion mitigation enable design-level decisions that prepare against corrosion failures. Lifetime prediction allows engineers to estimate the time to failure and the most critical locations where corrosion is likely to occur. The final defense is then to actively monitor assets in response to the anticipated risk. The development of microelectronics and wireless technology has increased the application of sensor and inspection technologies. Examples include ultrasound techniques for probing corrosion under insulation, and more recently, backscatter computed radiation tomography[13]. Updated information regarding the state of materials degradation provides an opportunity to refresh failure models, and possibly construct new models that more accurately represent system evolution. Numerical simulation can also be coupled with data generated from inspection to help assess the risk of failure, such as the incorporation of dent measurements with finite-element simulation to assess risks for SCC[14]. Given the uncertainties associated with modeling, lifetime prediction, and experimental testing, inspection will always be necessary to detect corrosion events before failure occurs.



Pipeline inspection under insulation using backscatter computed tomography[13].

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Fatigue of Threaded Fasteners

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Fasteners play a critical role in many engineering structures, and their failure can result in significant consequences.

Fasteners play a critical role in engineered structures as a method of nonpermanent joining for the aerospace, infrastructure, civil, automotive, energy generation/distribution, and many other industries. Fastener failures can lead to disastrous consequences and substantial financial losses. One of the most common fastener failure modes is fatigue crack initiation and growth. Inadequate design considerations, material problems, insufficient preload, loosening, and excessive loads can all contribute to fastener fatigue.

Fastener failure background

Similar to other metallic components, fastener failures include overload, corrosion-related cracking, embrittlement, creep, and fatigue. Fastener overload can occur upon installation or in service due to an externally applied load. Fastener overload failure investigation should include assessment of the material properties to determine fastener strength, as well as the loads that contributed to the break. Stress corrosion cracking (SCC), or hydrogen embrittlement in some metals, represents an important failure mode in fasteners due to the static tensile nature of the loading in many applications. Given the expected stresses on fasteners, the material and environment must be carefully considered to appropriately mitigate SCC or hydrogen embrittlement potential.

Hydrogen embrittlement can also be caused by improper manufacturing conditions, particularly in plating processes. To reduce hydrogen embrittlement in susceptible materials, fasteners must be subjected to appropriate baking treatments. Creep failures can occur when fasteners are subjected to sufficient stress at elevated temperatures. Again, stresses, materials, and the environment (temperature) must be considered to help mitigate creep damage and potential failure.

Fastener fatigue

Fatigue is the most common form of fracture of metal structures, accounting for up to 80% of all costs associated with fracture. Fasteners are no exception, as fatigue remains the most common cause of fastener breaks. Fatigue crack initiation and growth occurs when cyclic stresses exceed the fatigue strength of local material for a sufficient number of loading cycles. Fastener material, geometry, stress amplitude, mean stress, and assembly parameters all affect fatigue performance[3].

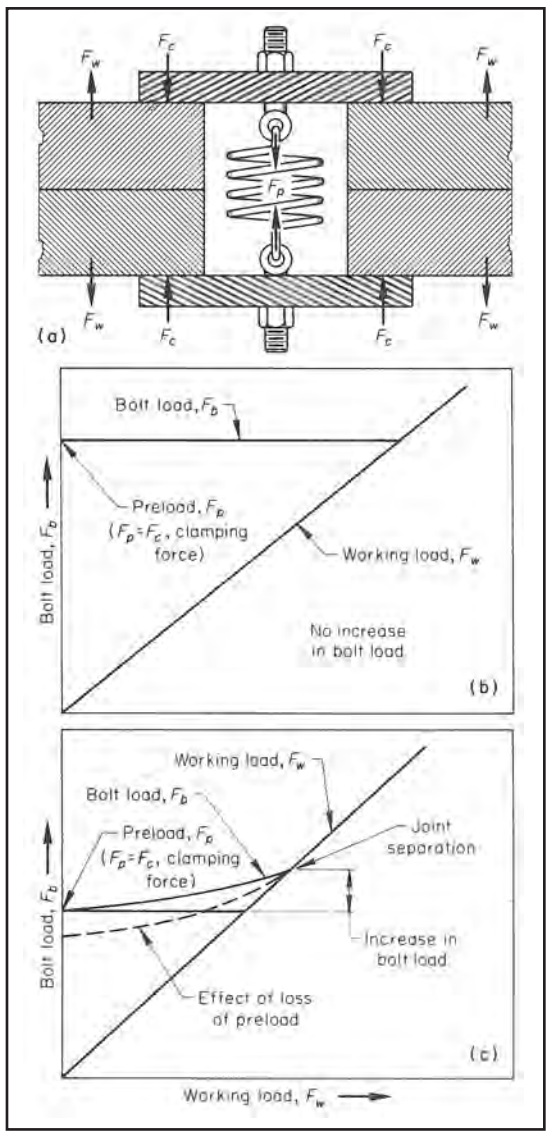


Fig. 1 — *Schematics from the* ASM Metals Handbook *highlight the difference between ideal behavior shown in (b) and real behavior shown in (c)[3].*

The fastener assembly process is one of the most important, but often overlooked, contributors to fatigue performance. The cyclic-stress amplitude imposed on a given fastener (and therefore fatigue performance) is highly dependent on preload. Specifically, increased preload results in decreased cyclic stress-amplitude, particularly at loads below the clamping force imposed by the fastener. To illustrate, Fig. 1 includes a series of schematics from the *ASM Metals Handbook* showing the differences between an ideal joint (Fig. 1b) and an actual

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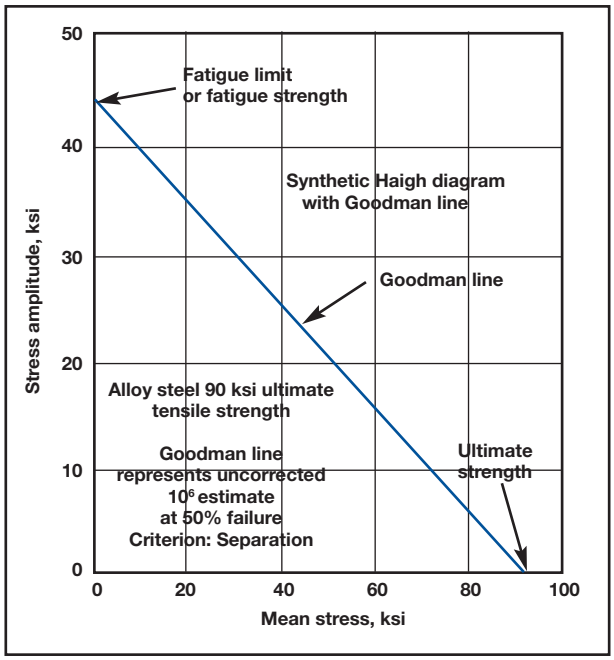


Fig. 2 — *Schematic plot shows the typical relationship between alternating and mean stress.*

joint (Fig. 1c)[3]. As indicated, loading on the bolt is minimal until the working load exceeds preload. Thus, for a condition where cyclic loads are smaller than preload, little or no cyclic damage occurs to the fastener. The concept of higher preloads resulting in increased fatigue performance may be counterintuitive, which might otherwise suggest that increasing the tightening force of a bolt may increase propensity for failure. Insufficient preload has been attributed to the cause of the majority of fastener fatigue failures[4]. Therefore, understanding preload is critical in both the design and failure analysis of fasteners.

Pretension is often adjusted by applying torque to the bolt, screw, or nut. Torque application increases tension in the fastener and clamping force between components. It is necessary to understand the difference between clamping force and the amount of torque applied to the screw or bolt. These two metrics generally correlate, but are differentiated by frictional forces. Fatigue susceptibility can be reduced by increasing clamping force and fastener tension, which is most often controlled by applied torque. However, factors such as material hardness and surface finish affect friction[3], and therefore affect the extent to which applied torque is translated into increased fastener tension and clamping force.

Guidance is provided with respect to the degree to which fasteners should be tightened. Bolts in tension should exert as much force on the joint as it and the joint members will stand[4]. A rule of thumb is to load the bolt to 60% of the material's yield strength[5].

While tension and high clamping force are critical for joints, applied forces (often cyclic) can significantly reduce preload. Generally, increased preload reduces the propensity for fastener loosening. To minimize susceptibility to loosening, the highest preloads possible should be used—up to, but not exceeding yield[4]. Loosening reduces preload and the force required for joint separation, and can greatly increase the propensity for fatigue failure and fretting. However, increasing the preload also increases susceptibility to overload upon installation, or may increase susceptibility to SCC.

Excessive preloads can also increase mean stress to levels that may contribute to fatigue for joints subjected to relatively low cyclic stress amplitudes. The effect of increased mean stress on fatigue performance is often described by a Goodman line, which plots stress amplitude as a function of mean stress. A schematic Goodman line is shown in Fig. 2, where increasing mean stress results in decreased ability for the component to withstand applied alternating stress. As shown by the Goodman line, excessive mean stresses (near the fastener tensile stress) can reduce fatigue performance. However, in most joints, high preloads preclude significant cyclic stresses, as shown in Fig. 1.

Hex-head case study

A short case study highlights some common issues observed in fastener failures. In this example, multiple broken steel hex-head screws were submitted for failure analysis. These screws had been part of equipment used in a silicon wafer fabrication system. The screw service environment was in a cleanroom, with exposure to no known corrosive media. In addition to the failed screws, material specifications, drawings, and installation instructions and specifications were provided. Representative images from some of the screws are presented here.

Laboratory analysis

Through the course of the investigation, it was established that the screws in question were installed with a torsional specification of 50 in.-lb. During service, screws were subjected to cyclic bending loads. Screws had the following specifications:

- UNRF 10-32 thread-form
- 38-43 HRC
- Minimum yield and tensile strengths of 162 and 180 ksi
- Max recommended load: 3150 lb
- Recommended torque setting: 79 in.-lb
- Material composition in accordance with ASTM A 574 specifies 10 different steel alloys, the majority of which are 41xx-series steels.

Screws were analyzed to look for macroscopic indications of failure mode. As shown in Fig. 3, fracture occurred in the threaded region. The fracture plane was generally perpendicular to the screw length, with no significant plastic deformation. Given that the screws were known to be loaded in tension and bending, fracture perpendicular to



Fig. 3 — *Photographs show a relatively flat fracture surface in relation to screw length.*

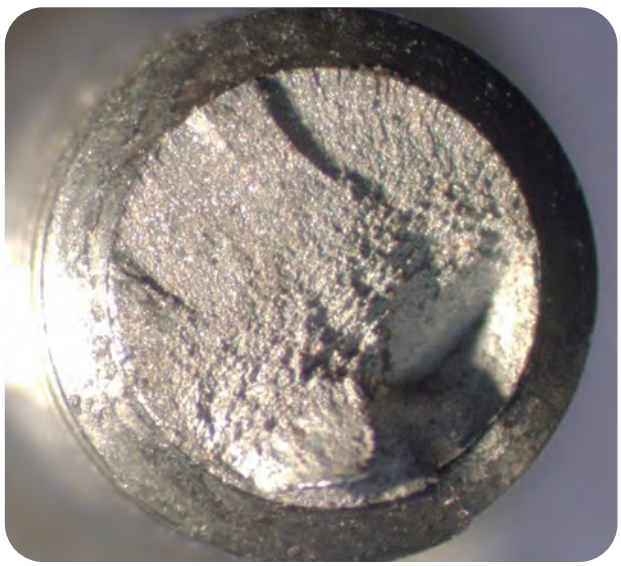


Fig. 4 — *Stereoscope optical image of the screw's fracture surface, showing signs of fatigue. Ratchet marks are visible between the 9 and 12 o'clock positions, while the final overload region occurs roughly at the 5 o'clock position.*

the length indicates fatigue, SCC, or brittle overload.

Higher magnification optical microscopes were used for fractography, as shown in Fig. 4. In this image, multiple ratchet marks are visible. These marks are caused by multiple cracks that initiate on separate planes and eventually grow together to minimize crack surface energy. Fatigue fractures typically exhibit ratchet marks where high stresses cause multiple crack initiation, or in areas of high stress concentration, such as at the threaded fastener root. Final overload fracture was observed on the side opposite the fracture origin. Beachmarks were also observed as indicated in Fig. 4. These are typically concentric bands that radiate from a crack origin(s), are formed by the advancement of a crack front as it travels through the part, and often indicate fatigue crack growth. Fracture surfaces associated with other progressive cracking mechanisms, such as SCC, can also show beachmarks in metals. However, given the observed ratchet marks, beachmarks, and general lack of evidence to suggest corrosion or the presence of a corrosive environment, optical microscopy indicates that fatigue is the most likely cause of the screw fractures.

Fractured screws were analyzed using scanning electron microscopy (SEM) to confirm fatigue crack initiation and growth. An overall image is presented in Fig. 5, similar to the optical image in Fig. 4. Generally, the fracture surface was relatively featureless, which is typical of fatigue in high strength steels[1]. Two regions were targeted for inspection, an area near a crack initiation location (A) and an area in the overload region (B) where final fracture occurred. Areas of intergranular fracture were observed at the crack origin area, as shown in Fig. 6. Intergranular fracture is undesirable and consistent with embrittlement in 41xx steel. The final fracture region (Fig. 7) shows microvoid coalescence, which is expected of overload following the stable crack propagation region.

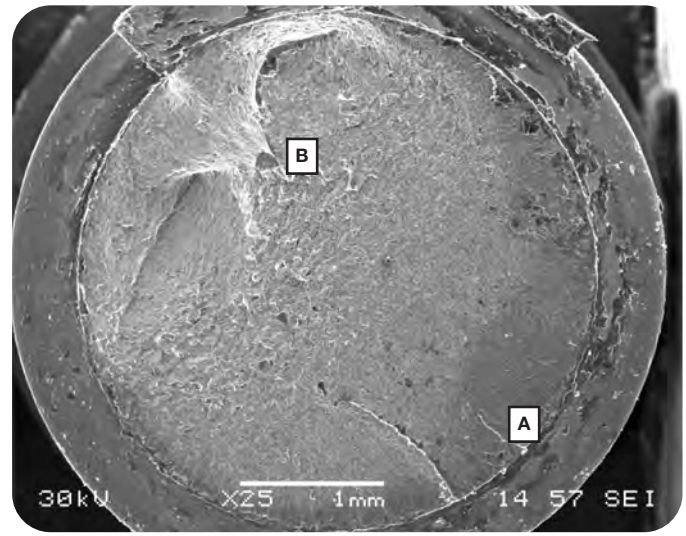


Fig. 5 — *SEM image of the fracture surface showing the ratchet mark(s) located at the 5 o'clock position and the final fracture region at the 11 o'clock position. These two regions have been labeled "A" and "B" respectively, and are shown at higher magnification in subsequent figures.*

Energy dispersive spectroscopy (EDS) was used to assess material composition. While not quantitative, EDS can provide useful information. For example, the incident screw contained carbon, manganese, iron, and chromium. Nickel was not detected. The lack of observed nickel and the listed ASTM A 574 specification suggest that the screws were likely 41xx-series alloys. Microhardness measured at 419 HV, which correlates to approximately 43 HRC and a tensile strength of roughly 200 ksi. These values are on the high end of the product specification, which is up to 43 HRC and 180 ksi tensile strength.

SEM-based fractographic analysis shows that incident screws suffered from small areas of intergranular fracture at the initiation sites. Embrittlement-based intergranular fracture in these screws could have been caused by hydrogen embrittlement, tempered martensite embrittlement (TME), or reversible temper embrittlement (RTE). Any of these forms of embrittlement can reduce fatigue performance of quenched and tempered steels. Given the screw hardness values and that only a limited fracture area exhibits intergranular fracture, TME is the most likely cause of the small intergranular initiation areas. TME can occur when tempering a susceptible steel for relatively short times (one hour) in the 260°-370°C temperature range[9].

The measured hardness value of 419 HV suggests the 41xx steel alloy was tempered in the embrittlement-susceptible range. TME is known to be exacerbated by the diffusion of tramp elements (P, Sn, Sb, As) to prior austenite grain boundaries[9] and formation of cementite at these same locations. Hydrogen embrittlement is unlikely due to the relatively small affected areas, and the intergranular cracks arrested prior to fatigue. Quench cracking was ruled out because no evidence of temper oxide was seen in fracture origins. Once intergranular cracks were initiated, likely during torqueing, they provided preferential sites for the fatigue crack growth that ultimately resulted in the screw fractures.

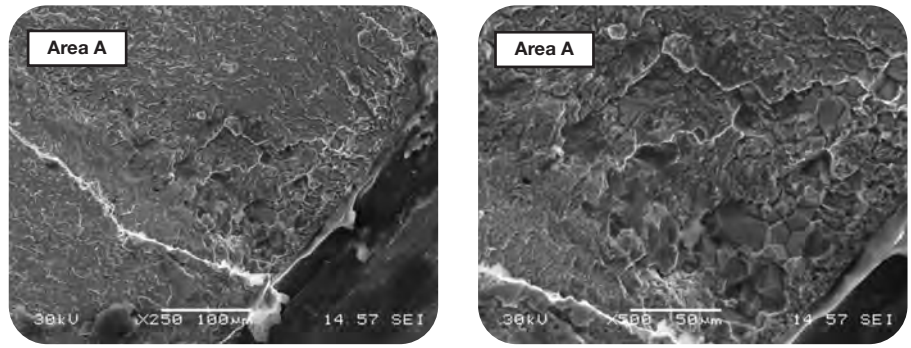


Fig. 6 — *SEM images of area A as defined in Fig. 5. The area shown is a crack origin, with a ratchet mark appearing in the lower left corner of each image. Intergranular fracture is observed, indicating embrittlement.*

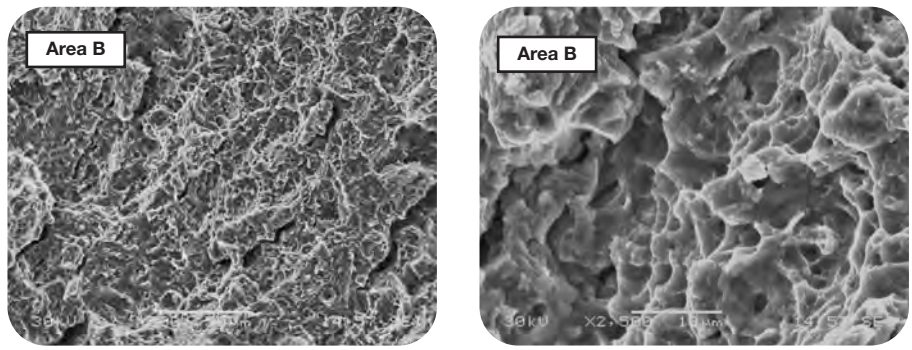


Fig. 7 — *SEM images of area B as defined in Fig. 5. The area shown is the final fracture area, where the crack exits the material. Microvoid coalescence is shown, indicative of ductile overload.*

Preload analysis

Analysis shows screw fatigue failures were at least initiated by an embrittlement mechanism. Nevertheless, the amount of applied torque was also evaluated, as lack of adequate preload is widely known to cause fatigue failures in fasteners[4].

Joints should be loaded to a high percentage of the material's yield strength[3]. Typical joints should be loaded to half the fastener yield strength. Known problematic joints should be loaded to higher preloads corresponding to three-quarters of the material yield strength[4]. To apply these parameters in the real world, however, these numbers must be converted to a torque that can be applied to the bolt or screw.

The equation below describes a linear relationship between applied torque and resulting preload[4]. In this relationship, applied torque is also a function of friction and fastener geometry. Using this equation, Fig. 8 was generated, which plots the percentage of yield strength achieved as a function of applied torque and the coefficient of friction for the material properties relevant to this case study. The amount of tension achieved in the fastener (percentage of yield strength) is a function of both applied torque and coefficient of friction.

$$T = F\left(\frac{P}{2\pi} + \frac{\mu_t r_t}{\cos\beta}\right)$$

T = Torque (in.-lb)
F = Preload (lb)
μ_t = Coefficient of friction of threads
r_t = Thread radius (in.)
β = 30° for UN

The subject joint used a 41xx steel screw to clamp stainless steel components. Handbook values list the kinetic friction of alloy steel on stainless steel as 0.53. Assuming this coefficient of friction, Fig. 8 shows that the 50 in.-lb torque specification listed by the fastener user corresponds to a preload of only 25% of the estimated screw yield strength. This is below the recommended value of 50% for normal use applications. It is even further below the recommended preload of 75% of the yield strength for problematic joints. The fastener manufacturer recommended a torque specification of 79 in.-lb, which in low-friction situations would result in an appropriate amount of fastener tension. However, assuming a friction coefficient of 0.53, Fig. 8 shows that 79 in.-lb would result in a

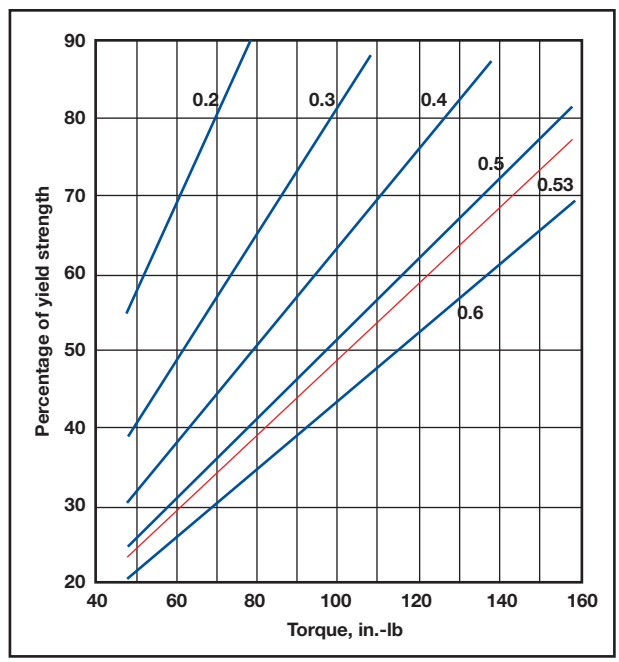


Fig. 8 — *Preload, expressed as a percentage of yield strength and plotted as a function of applied torque for various coefficients of friction, including the handbook value of 0.53.*

fastener tension of only 40% of yield strength. Thus, increasing the torque specification would be expected to decrease the screw's susceptibility to fatigue failure.

Summary

Fasteners play a critical role in many engineering structures, and their failure can result in significant consequences. The most common cause of fastener failure is fracture by fatigue, which is often created by inadequate tension and clamping force upon installation. Contrary to what may be intuitive, susceptibility to fatigue can be reduced by increasing the amount of tensile preload in screws or bolts. A case study of steel screw failures highlights some of the critical manufacturing and design factors that affect fastener fatigue. The investigation determined that the steel screws fractured in fatigue for two reasons. First, short intergranular cracks, likely caused by tempered martensite embrittlement, contributed to fatigue crack initiation. Second, the specified assembly torque was insufficient to provide adequate preload and clamping force between components. Lack of adequate preload promoted fatigue, and led to fatigue crack growth under service loads.

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Advanced Designs Pose Challenges for **Electronic System Failure Analysis**

Taqi Mohiuddin
EAG Inc.
Sunnyvale, Calif.

Finding and fixing electronics failures is more challenging than ever as devices are being built with increasingly advanced materials and processes.

As today's electronics systems continue to shrink and become more complex and pervasive, failures can cause costly downtime, product delays and recalls, and debilitating reputational damage. Finding and fixing failures before they do damage is important, but becomes increasingly challenging when devices are built using ever more complex designs. The solution is to employ a comprehensive, multidisciplinary approach to electronic system failure analysis. In addition, many failures can be avoided altogether by thorough testing, coupled with the latest focused ion beam (FIB) circuit edit techniques. These advanced methods quickly and inexpensively debug and validate design fixes or explore design optimization opportunities in integrated circuits (ICs) without having to commit to costly and time-consuming full mask spins.

System complexity continues

Systems are becoming more complex at all levels—board, die, IC, and package. Today's devices can contain billions of transistors, and integrate a wide variety of previously discrete components and independent systems. With the arrival of FinFET, metal gate, low-k dielectric, and other advanced process nodes, devices are getting even smaller. Packaging complexity is also growing, with options including system-in-package (SiP), multi-chip modules (MCM), SiSub, stacked die, through-silicon via (TSV), and Cu wire. Devices also increasingly feature multi-layer metal stacks and are produced in flip chip and other advanced chip scale form factors. Meanwhile, the materials, coatings, and molding compounds associated with advanced packages and boards are also growing more complex. In the power arena, many devices are moving to silicon carbide (SiC), gallium nitride (GaN), and other wide bandgap materials that create additional challenges related to design and characterization, process monitoring, and reliability.

To make failure analysis even more difficult, many failures occur only intermittently. System challenges vary widely by industry and application, with each functional element in a design often requiring specialized domain knowledge to understand a failure's root causes and mechanisms. Networking and automotive systems offer prime examples of the depth of today's failure analysis challenges. A networking system can span multiple boards containing thousands of components, including complex ICs and SoCs that may also contain many types of RF, power supply, high-speed digital, and storage media.

Today's automobiles are similarly complex, containing as many as 100 electronic control units (ECUs) or more, for systems ranging from backup cameras to lane-changing warning systems. Further, tomorrow's assisted driving and sensor-guided autopilot systems are expected to include a dozen ultrasonic detectors and multiple cameras and radar sensors. Failures can occur anywhere in a complex chain of standalone and multiple interrelated systems. Meanwhile, counterfeit components may also have entered the automotive supply chain, introducing additional risks and accentuating the need for screening and analysis in addition to various types of verification and authentication tests against reliability specifications.

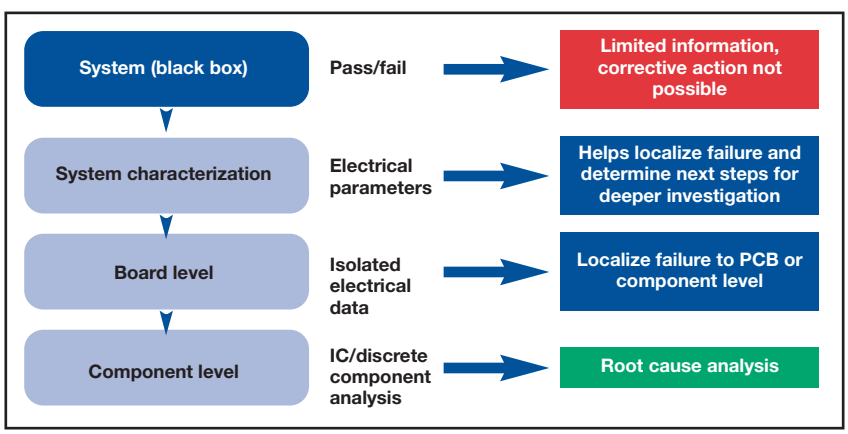


Fig. 1 — *Multi-level failure analysis should extend across the full continuum of possible root causes and failure mechanisms.*

Failure analysis: The first line of defense

The ideal failure analysis approach must span both electrical and physical analysis to optimize root cause identification and determine the associated failure mechanism and how to prevent future failures. The focus must be on the entire system, including the electronics, materials, and failure mechanisms occurring at the IC transistor level (Fig. 1).

Effective failure analysis also requires highly experienced and well trained technicians with expertise that extends from the component to the system level, along with a comprehensive set of lab equipment. Failure analysis service providers must be able to perform parallel pro-

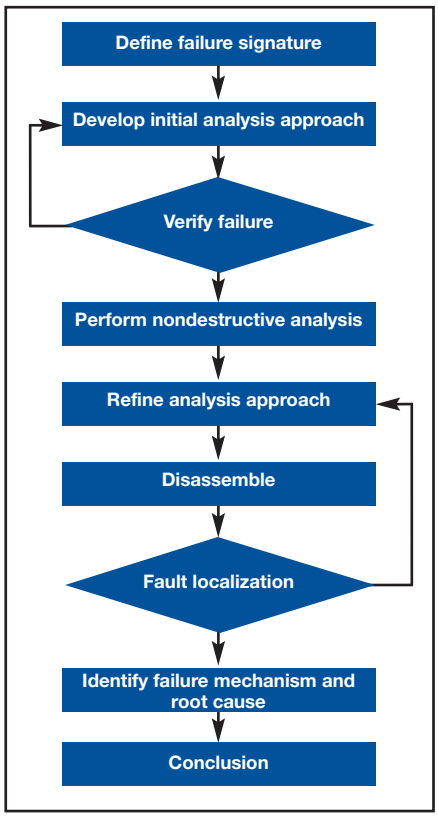


Fig. 2 — *System-level failure analysis methodology and workflow.*

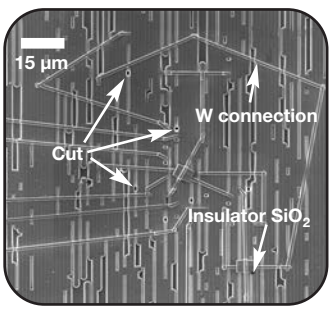


Fig. 3 — *Multiple front-side FIB circuit edit connections and cuts.*

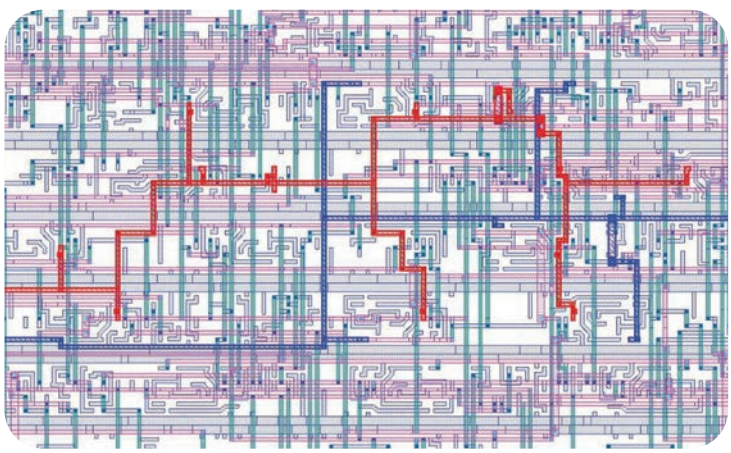


Fig. 4 — *CAD layouts enable operators to perform FIB circuit edit.*

cessing of large projects, and should have the capability to scale their services as needed. Other key ingredients include system redundancy and specialized equipment such as advanced high-resolution microscopy imaging systems that enable component-level analysis. To handle failure characterization, labs also must have fundamental capabilities including x-ray, thermal mapping, curve trace, time domain reflectometry, and functional test equipment, as well as more advanced tools such as laser timing probe for real-time, no-loading, and noncontact signal waveform acquisition. At advanced nodes below 28 nm, nanoprobing and more sophisticated equipment may also be necessary, so failures can be localized down to a single transistor. Materials analysis using various spectroscopy techniques (EDS, Raman) or x-ray (diffraction, reflectivity, or fluorescence) may be useful to characterize materials issues as well.

Another critical aspect is having a comprehensive methodology and workflow (Fig. 2), beginning with a definition of the electrical failure signature and continuing through failure mechanism identification and problem resolution. In order to address multiple complex and interdependent components and features, the process must also be periodically disciplined and refined based on data and incremental findings. This typically involves developing hypotheses and then working to validate or reject them. Various experiments may also be necessary in order to duplicate or model a given failure.

Customizing the failure analysis approach is also critical. Each situation has its own specific characteristics and issues to address, and requires a methodical approach that begins with the right questions in order to develop a customized workflow.

Preventing IC failures before they occur

Another strategy to decrease failures is to thoroughly test ICs and follow-up use of FIB circuit edit during the development process, especially at advanced process nodes where it would be difficult, if not impossible, to anticipate future problems based on previous design work. Electrical characterization, functional testing, and reliability qualification can help uncover many issues before the production stage. Once issues are identified, FIB circuit edit can be used during the process of debugging and validating fixes to in-progress designs, or design optimization changes can be explored before committing to the high cost and lengthy timetables of a full mask spin.

Barriers to success can be even higher at advanced process nodes because of high mask costs and greater difficulty associated with finding and fixing bugs. It can be extremely difficult to anticipate problems at these nodes based on experience gained during earlier design work. Devices manufactured at today's 20-nm process nodes have 10 times smaller feature sizes than the laser light wavelength that is generally used in lithography. At these advanced nodes, pre-silicon testing is more difficult, simulations take much longer, and it is impossible to fully verify many designs. Even more problematic are extremely complex designs that may have flawed simulation models, and which can easily be stressed by packaging.

With each new technology node, design and integration complexity grows. Challenges range from multiple patterning and layout-dependent effects (LDE) to the use of local interconnect layers. Server signals and power electro-migration can also create difficulties. The smaller the metal pitch becomes, the more chance of coupling effects and signal integrity issues. Higher wire and via resistance also requires more advanced and variable wire sizing and tapering techniques. There are also challenges related to extraction, timing, signal integrity analysis, and modeling, and each must account for many variation issues in order to ensure accuracy without jeopardizing performance. Plus, lithography limitations at 20 nm often create the need for significant fixing in order to achieve signoff. Finally, there are many different chip and intellectual property (IP) integration challenges, packaging issues, and additional

complexity as all of these issues interact with one another.

To address some of these issues, electronic design automation (EDA) tool providers are already offering advice related to design flow and other solutions to difficult technical challenges. Beyond these design flow modifications, however, developers can also apply FIB circuit edit at the prototype stage during debug. The same techniques can also be employed to explore design optimization opportunities, enabling developers to quickly and inexpensively create, test, and validate physical prototypes before committing to the high cost or lengthy timetables of a full mask spin. FIB-edited device prototypes can then be used on a one-time basis to guide mask modifications, as an alternative to successive trial-and-error mask versions.

With today's solutions, it is possible to edit circuits fabricated with 28 nm and smaller technology nodes that feature multiple-layer metal stacks and occupy flip chip and other advanced chip scale form factors. To perform the edits, a nanoscale-resolution, gallium (Ga+) ion beam is used in the process of imaging, etching, and depositing materials on the IC. This is done with an extremely high level of precision. To cut and connect circuitry within the live device, material is removed and deposited, and the same process can also be employed to create probe points that are used for electrical testing (Fig. 3). Advances in tools, methodologies, and techniques have improved beam guidance, enabling operators to perform more intricate operations in smaller areas, on both the back and front sides of the device, and for handling copper layers.

To locate areas of interest, the FIB tool is coupled to a CAD navigation system and the designer's graphic database system (GDS) files are typically used to navigate to the precise area. This provides a very precise method for finding subsurface features and ensuring that the right edits are made (Fig. 4). One of the most important requirements for a successful FIB circuit edit is the ability to accurately position the beam.

A variety of valuable applications for FIB circuit edit exist at every available commercial node, including verifying a design change on the tester and validating that change at the system board level. The process can be implemented both at the simulation stage and later during de-bug to optimize success rates during the IC design process (Fig. 5). Typical applications include debugging and optimizing devices in production, exploring and validating design changes, and prototyping new devices without costly and time-consuming mask set fabrication. FIB circuit edit also can be used to scale fixes to a handful or more devices to provide samples to internal test, validation, and qualification teams and even customers. Finally, FIB circuit edit can be used to accelerate time-to-market, speeding up the entire cycle for getting customers into production and avoiding loss of reputation or late penalties, or keeping potential competitors from getting their foot in the door.

Electronic system failures are becoming increasingly difficult and expensive to identify, diagnose, and resolve. The stakes have never been higher to quickly find and fix them before they create problems. This requires a comprehensive, multidisciplinary electronic system failure analysis methodology and workflow that extends from the component to system level and is backed by specialized expertise and equipment. Meanwhile, the challenges associated with IC design verification and validation continue to intensify as nanoscale geometries move downward. Adding FIB circuit edit to an overall failure analysis and resolution arsenal can significantly increase design success rates and preempt failures before they happen, by improving debug and validation, and making it easier to explore design optimization opportunities without committing to a full mask spin.

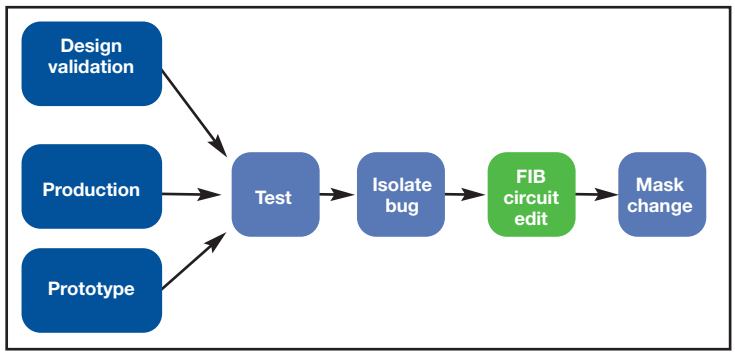
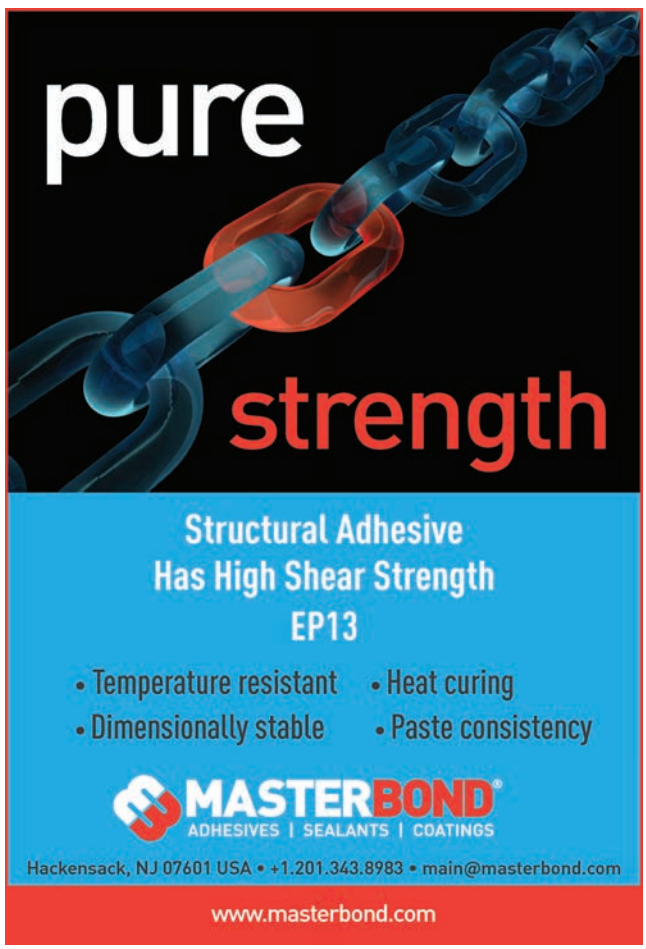


Fig. 5 — *Process flow for FIB circuit edit.*

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Linear Friction Welding Enables Near-Net Manufacturing

Additive manufacturing (AM) continues to make significant technology advancements and attract widespread interest in industry, academia, and the general media. However, the technology is likely still a decade away from attaining meaningful implementation in industry and has yet to find adoption in large-scale or part-critical manufacturing operations, such as airframe structural component production. As a bridge technology that takes advantage of existing manufacturing methods while AM is being fully developed, *near-net manufacturing* is a promising alternative. Near-net fills the gap between classic subtractive manufacturing and AM, and it may be accurately described in terms of grain size.

In any AM technology, parts are built by using an energy source (laser, electron beam) to join or fuse a large number of uniformly shaped items to each other. The process is repeated layer-by-layer until a part is constructed. For the purposes of this article, "grain size" refers to the size of the items used to build the part. As an example, consider *laser sintering*. In this 3D printing process, a computer is loaded with a 3D CAD file of the part to be made. The computer directs the laser to move around on the surface of the powdered material, while powder grains fuse together and harden once the laser moves on. Each time the laser traces the powder, the hardened material is lowered incrementally. Over time and many layers, the hardened material creates a complete part. In this case, the grain size of the particles being fused is orders of magnitude smaller than the part being created, even for small parts. Parts made this way are considered to have been built with 100% additive manufacturing.

At the other end of the spectrum are parts made with 100% subtractive manufacturing. The term *subtractive manufacturing* is used to describe a process where the material used to make the part is about the same size as the part being made, a traditional method used for many decades. In general, subtractive manufacturing is most suitable when the part's overall size, tensile strength, fatigue performance, or some other physical performance criteria demands that parts be made from billet or forgings. Aerospace structural components are a classic example.

In many aerospace applications, due to weight and size restrictions, parts must perform near the physical limits of the materials used to make them. Finished parts must be uniform, reliable, and meet well defined performance specifications. Parts also must be as compact and light as possible. Many aerospace parts are manufactured from blocks of titanium, stainless steel, or other alloys and then machined away to achieve the final part shape. Figure 1 is an example of how an aerospace part is manufactured today, with much of the material removed to create the final part.

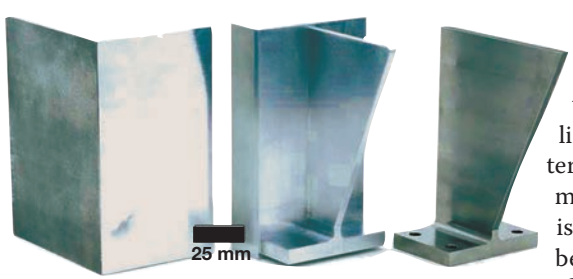


Fig. 1 — *Traditional subtractive manufacturing used to make an aerospace part. Courtesy of TWI Ltd.*

This method is known as "hogging out a part" and is the reason the aerospace industry talks about *buy-to-fly ratios*—how many pounds of a particular material one must buy to end up with one pound that makes it into the air. Specific buy-to-fly ratios are extremely proprietary and actual ratios for existing parts are closely guarded secrets, but aerospace companies routinely talk about ratios of between 10 and 20 being common. While buy-to-fly ratios allude to the high material cost associated with subtractive manufacturing, the ratio ignores the other cost—manpower. It takes a lot of time by a skilled machinist to whittle a part out of a solid block of titanium and wastes a significant amount of material. Yet many reasons remain with regard to the continued use of subtractive methods. Figure 2 illustrates how grain size is related to both additive and subtractive manufacturing processes.

The two main reasons that AM is not yet widely implemented both relate to grain size. First, a huge number of grains must be fused together to make even a small part, which takes a relatively long time compared to traditional machining methods. Second, it is difficult to control the mechanical properties of fused particles—much less the entire part—with existing technologies. Companies, universities, and research organizations are making great strides to overcome these issues and ultimately will succeed. Today, however, these and a few other smaller issues are keeping AM from being used to any great extent in the manufacturing industry. Compared to AM, subtractive manufacturing is incredibly wasteful and costly but it provides a well-established, reliable, and accepted way to produce high quality, high strength parts. As a bridge technology between these two methods, near-net manufacturing must be considered.

Near-net manufacturing

Near-net fills the middle ground of grain size between 100% additive and 100% subtractive manufacturing (Fig. 2). With near-net manufacturing, companies can gain some of the benefits of AM without having to give up the speed and mechanical properties available from subtractive methods. As its name implies, near-net manufacturing means creating a form that approximates the shape of the final part. This is accomplished by joining relatively large components (large grains) of a desired alloy, like titanium, in such a way that the material's physical properties are retained. Figure 3 illustrates the concept of near-net manufacturing.

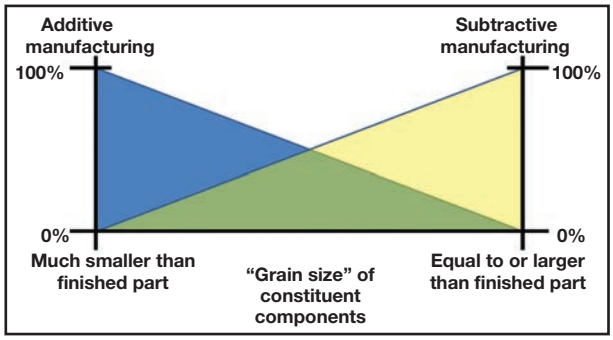


Fig. 2 — *Near-net manufacturing fills the middle ground of grain size, between 100% additive and 100% subtractive methods. Courtesy of APCI LLC.*

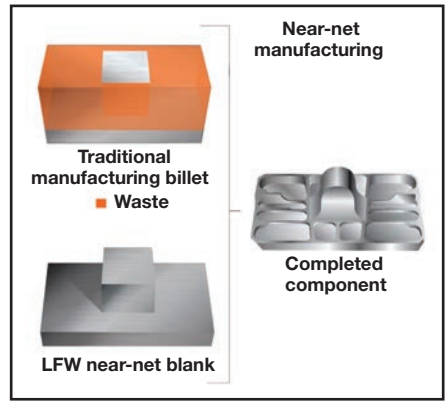


Fig. 3 — *Traditional subtractive manufacturing processes waste significantly more material than near-net processes such as linear friction welding. Courtesy of APCI LLC.*

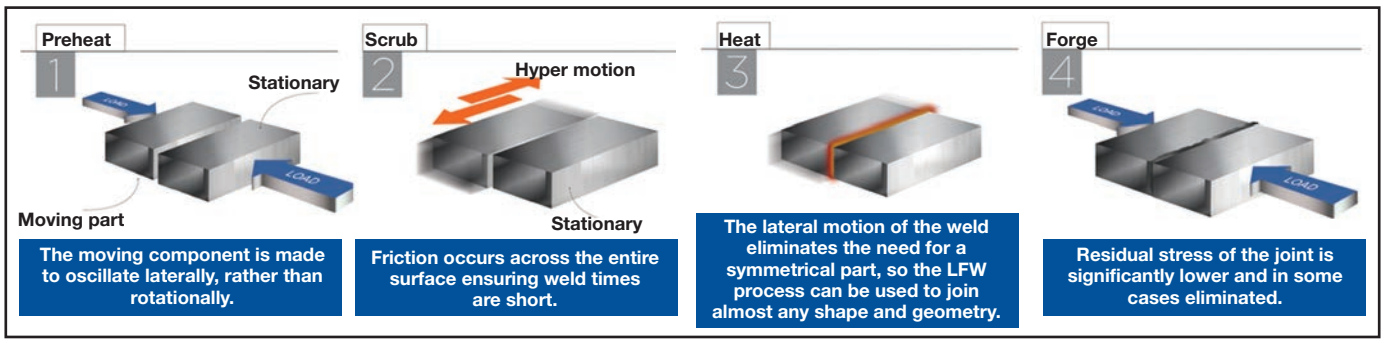


Fig. 4 — *Linear friction welding process workflow. Courtesy of APCI LLC.*

In this example, the desired part is a boss rising from flat plate. Using traditional subtractive methods, a large amount of material waste occurs as the rectangular billet material is removed to create the boss and mounting plate. With a material like titanium, this is a long and expensive process. In contrast, with near-net manufacturing, a smaller rectangular piece of titanium is joined to a large, flat titanium plate. This creates a tailored blank that approximates the final part shape, minimizing the amount of machining and waste and thus saving a significant amount of money. In order to join two pieces of titanium so that the resulting part is just as strong as if it had been milled it out of titanium billet, one option to consider is linear friction welding (LFW). Figure 4 provides a brief description of the LFW process.

LFW offers the ability to accurately, quickly, and repeatedly join two materials such that the resulting bond or joint is as strong—if not stronger—than the parent materials being joined. It can do this not just for titanium, but for nearly any metal or combination of metals. LFW has been used to join copper to aluminum, steel to titanium, and dozens of other useful combinations. As a member of the solid state bonding family of technologies, which includes rotational friction welding and friction stir welding, LFW does not use any filler material such as that used in traditional welding and brazing. Specific features of LFW include:

- Ability to join parts of any geometry
- Joints can be formed with cross-sectional areas >10 sq. in.
- Minimal material loss
- Materials typically joined in 3-5 seconds
- Accurate bonds with tolerances of 0.002 to 0.005 in.
- Formation of extremely repeatable welds
- Eliminates deformation and deterioration of original parts

Figure 5 shows how LFW can be used to create a tailored blank for a fictional aerospace part. The image shows four regular rectangular blocks joined using LFW to create a basic representation of the final part. The minimum amount of milling required to arrive at the final part shape is also illustrated. This example is highly representative of aerospace structural parts that can be made using near-net manufacturing processes enabled by LFW.

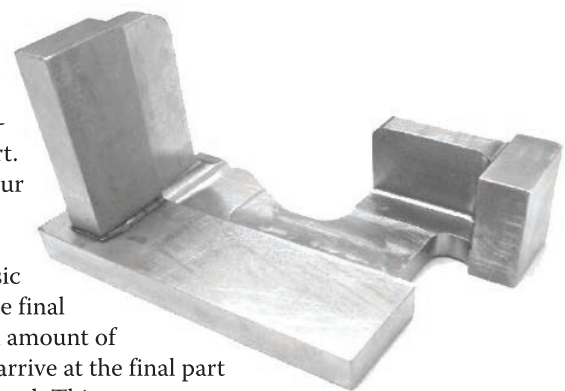


Fig. 5 — *Linear friction welding can be used to create tailored blanks for aerospace parts. Four rectangular blocks are joined to create a basic representation of the final part.Courtesy of TWI Ltd.*

Despite its advantages, LFW is often viewed as cost prohibitive, because machines tend to be large, complex, and expensive. The cost factor is why LFW machines are primarily used to produce high-value parts, such as bladed disks for jet engines. More recently however, new technology has entered the market, radically decreasing both machine cost and complexity. LFW is now financially viable for nearly any market, from automobile axles to fire sprinklers to pipe, building a commercially acceptable bridge between the subtractive manufacturing of yesterday and the additive manufacturing of tomorrow.

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Metallurgy Lane

The History of Alloy Steels: Part II

Throughout metal making history, nothing has exceeded the technical importance, scientific complexity, and human curiosity involved in the hardening of steel.

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

After the bustling 1890s, with its exciting and productive discoveries around steel metallography in England, France, Germany, Russia, Japan, and the United States, a period of quiet consolidation occurred in the early 20th century. By then, most metals pioneers had either joined or established metallurgy departments or metallographic sections within existing mining or chemical engineering departments at universities throughout the industrial world. Henry Marion Howe, America's earliest metals researcher, joined Columbia University, New York, in 1897 to become its first fulltime professor of metallurgy. By 1905, he had a new laboratory and staff of five, including William Campbell of Great Britain, who had come to America to study under Howe and then remained to serve a lifetime career teaching metallography to students.

Increased use of heat-treated alloy steel during and after World War I lead to the development of a variety of different alloys with emphases on special compositions that provide superior properties. No two manufacturing companies seemed to use the same alloy steel for the same application. It was qualitative rather than quantitative, and a lot of expensive alloy elements were wasted as well. A greater understanding of alloys in steel was desperately needed to sort out the transformation of austenite to martensite.

The first published research that questioned longstanding ideas about steel transformation was a paper by well-known French metallurgist Albert Portevin and his co-author M. Garvin, in 1919. They showed for the first time that transformation to hard martensite did not occur until the steel being quenched had cooled to temperatures well below those where pearlite (layers of iron and iron carbide) formed. In 1922, W.R. Chapin, an American production metallurgist, showed that a carbon tool steel could be quenched to 570°F and still be austenitic. He further demonstrated that with slow cooling below 570°F, steel could be studied as it gradually transforms to martensite with falling temperatures. Chapin's observations were the most significant on martensite formation at the time and should have ended confusion about how it formed. However, although these two early studies did not change the thinking of many established metals researchers, they were of immediate interest to Zay Jeffries, Marcus Grossman, and Edgar Bain.

Austenite, martensite, bainite

Edgar Bain was among the earliest Americans to apply x-ray diffraction to the study of metals. He showed that steel heated to the hardening temperature—*austenite,* named after Sir William Chandler Roberts-Austen—had a face centered cubic (fcc) crystal structure, whereas ferrite and quench-hardened steel—*martensite,* named after Adolf Martens—were body centered cubic (bcc). The next major scientific advancement in hardened steel was the discovery through precision x-ray diffraction by William Fink and Edward Campbell that martensite was not a simple bcc structure like iron, but a distorted tetragonal crystal structure. Finally, after 35 years of studying martensite, a rationale was discovered for its great hardness. Unlike iron, which contains no carbon or pearlite, martensite features carbon trapped within its crystal structure on an atomic scale.

In the late 1920s, Edgar Bain and E.S. Davenport of the U.S. Steel Corp. Research Laboratory at Kearny, N.J., published their world renowned paper, "Transformation of Austenite at Constant Subcritical Temperatures." As part of their groundbreaking research, Bain and Davenport quenched a series of thin samples from the hardening temperature to a transformation temperature and held them at this temperature for various times before water quenching to martensite. By using metallography and thermal expansion measurements, they were able to follow the formation process of the new product from the beginning, through the reaction period, and onto the end. They plotted individual transformation curves of percent transformed as a function of time at each transformation temperature.

At last, the sequence of events occurring at decreasing temperatures could be observed, accurately described, and quantitatively measured as the austenite transformed to a variety of structures depending on the transformation temperature. Data resulting from plotting the beginning and end of the transformation is called a *time-temperature-transformation (TTT) diagram,* and many of these have been determined for numerous steels in

the years since Bain and Davenport's original work.

Bain's studies showed that austenite transformed to ferrite and/or coarse pearlite at temperatures of 1200°-1300°F, and a finer pearlite at temperatures of 900°-1100°F. At lower temperatures, a unique structure formed that was not previously known. Later, Bain's colleagues at U.S. Steel Corp. honored him by calling this new structure *bainite.* The term was officially adopted and Edgar C. Bain, perhaps America's most outstanding metallurgist, is the only native whose name has become part of everyday metallographic nomenclature.

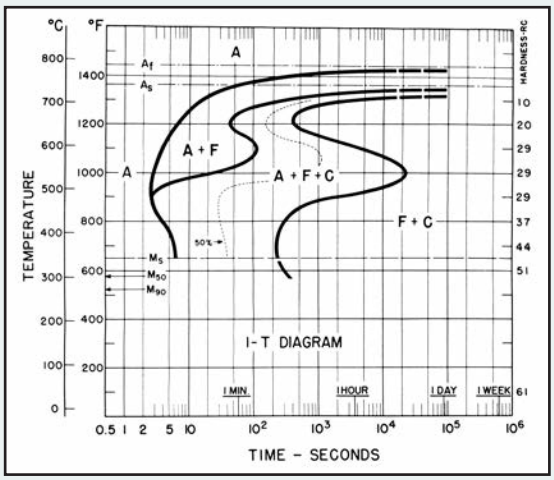
Hardenability testing breakthrough

The next breakthrough came when Walter P. Jominy and A.L. Boegehold at the Buick Motor Division of General Motors developed a test for measuring the *hardenability* of any particular steel or heat of steel. Hardenability does not refer to the degree of hardness, but rather to the depth of the maximum hardness in a quenched bar. This test consists of heating a 1-in.-diameter by 3-in.-long bar of alloy steel to the heat treating temperature, inserting it into a fixture, and directing a stream of water onto one end of the hot bar until the entire sample is cooled from the hardening temperature.

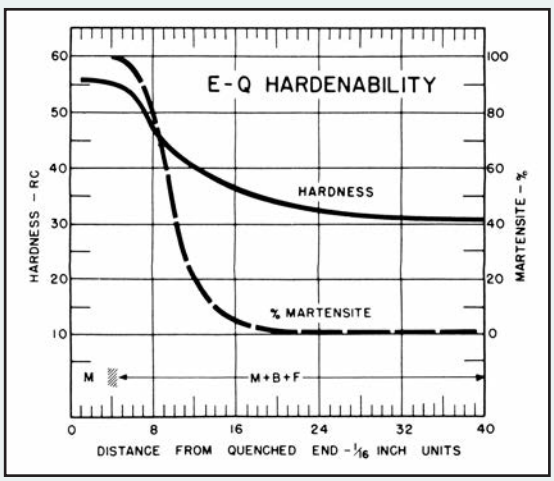
Two flats are then ground on opposite sides of the bar. One side is placed on the anvil of a hardness testing machine and a series of hardness readings are taken every sixteenth of an inch starting on the opposite flat side, at 1/16th of an inch from the quenched end. These hardness readings are then plotted as a function of the distance from the quenched end. The resulting plot is known as the *end quench hardenability curve* and serves as permanent identification of a given composition for a given set of heat treating variables. Alloy steels are sold based on hardenability as well as composition, and the Jominy hardenability test is performed hundreds of times per day in steel mills and manufacturing plants around the world to ensure proper heat treat performance.

Alloy steels for every situation

At this point in history, the knowledge and tools were finally available to make a science of alloy steel heat treatment. This detailed knowledge came just in time to tailor the use of critical alloying elements to World War II. A new series of alloy steels, called National Emergency Steels, was designed to minimize alloy content for maximum hardenability. These new steels took their place among all the previous alloys, each of which could be used with an understanding of just where and when it was needed.



Transformation of austenite to lower temperature phases at a constant temperature. The time-temperature-transformation (TTT) diagram shows the beginning and end of transformation as a function of the log of time, for 4140 Cr-Mo steel. Diagrams courtesy of ASM International.



Hardness in Rockwell C as a function of distance in 1/16-in. increments from the quenched end of the test sample, for 4140 Cr-Mo steel.

In all of metal making, nothing has exceeded the technical importance, scientific complexity, and human curiosity involved in the hardening of steel. To convey the magnitude of the available strength properties in hardened alloy steel, a comparison to structural steel is useful: Common structural steel has a yield strength of roughly 40,000 psi in cross section, compared to 150,000 to 200,000 psi for alloy steel (along with ductility and toughness), to as high as 250,000 to 300,000 psi for special applications, and even higher for tools, bearings, and other severe uses. Hardened alloy steel is a metal of enormous versatility—nature's bountiful gift to mankind for the technological age, and all of this at a reasonable economic cost.

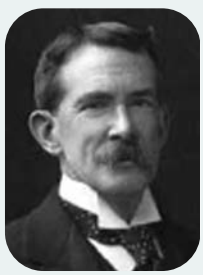
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For more metallurgical history, visit metals-history.blogspot.com.



Sir William Chandler Roberts-Austen, of austenite fame. Courtesy of blackheathvillage archive.com.



Adolf Martens, namesake of the steel structure martensite. Courtesy of www.bam.de.



Henry Marion Howe, America's earliest metals researcher and Columbia University's first fulltime metallurgy professor. Courtesy of columbia.edu.



American metallurgist Edgar C. Bain, whom bainite is named after. Courtesy of Library of Congress.

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Course	Date	Location
FEATURED: **Metallographic Techniques** **Advanced Metallographic Techniques**	**9/22-25** **9/29-10/2**	**ASM World Headquarters**
Introduction to Thermal Spray Thermal Spray for Gas and Oil Industries	10/6-7 10/8	ASM World Headquarters *These courses run consecutively*
Superalloys	10/6-8	ASM World Headquarters
Practical Interpretation of Microstructures	10/6-9	ASM World Headquarters
Practical Fracture Mechanics Practical Fractography	10/20-21 10/22-23	IMR Testing Labs – Lansing, NY, USA *These courses run consecutively*
Metallurgy for the Non-Metallurgist™	10/20-23	ASM World Headquarters
Applied Techniques in Failure Analysis	10/20-23	ASM World Headquarters
Metallurgy of Steel for the Non-Metallurgist™	11/3-5	ASM World Headquarters
Aluminum and Its Alloys	11/3-5	ASM World Headquarters
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Corrosion	11/10-12	Singapore
Introduction to Heat Treating Advanced Heat Treating	11/10-12 11/13-14	ASM World Headquarters *These courses run consecutively*
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AUGUST 2014 • VOL 9 • ISSUE 3

iTSSe™

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY



Thermal Spray Coatings in the Automotive Industry/ Industrial Applications

***JTST* Highlights**

Society News

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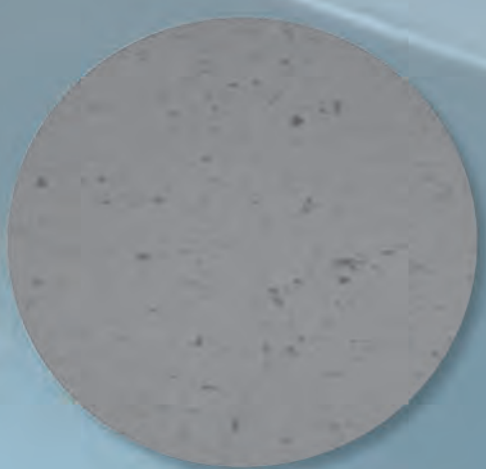
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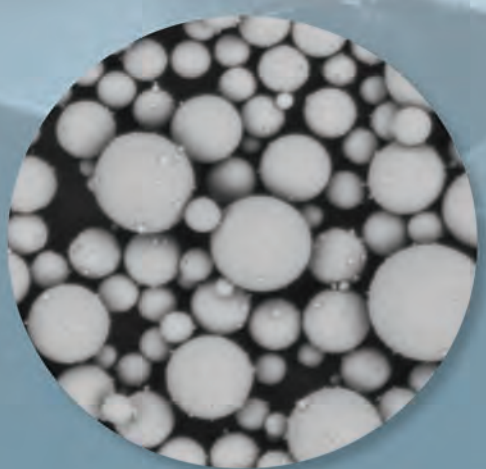
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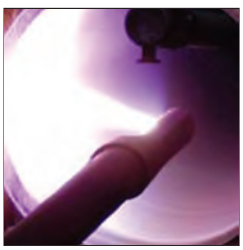
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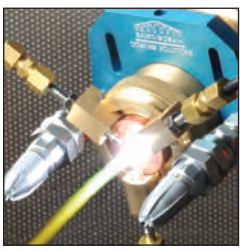
AUGUST 2014 • VOL 9 • ISSUE 3

ASM Thermal Spray Society
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INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

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About the cover
The SST family of cold spray equipment includes the series EP Cold Spray system, which comes complete with portable cabinet, HMI controls, pressurized feeder, and robotic style spray gun. Here it is used to repair an aluminum alloy wheel. Courtesy of Centerline Windsor Ltd., centerline.com.

Editorial Opportunities for iTSSe in 2014

The editorial focus for iTSSe in 2014 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing new opportunities for coatings and surface engineering.

November Emerging Technologies

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

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Thermal spray for automotive applications on the rise



Thermal spray coatings play an important role in the automotive industry from the high-performance racing sector to domestic automotive production. North American automobile production is predicted to hit an 11-year high as stated in autoguide.com, June 2014. New vehicle production in North America continues to increase and according to two major forecasters, production will surpass the prior year's total of 15.5 million units. LMC Automotive expects production to reach 16 million units while IHS Automotive predicts 16.1 million. If those forecasts come true, North American production will have crested levels not seen since 2002 when the auto industry turned out 16.5 million. This represents a considerable market opportunity for the coatings industry. Thermal spray parts and components for these vehicles involve a large network of organizations including automotive manufacturers, Tier 1 suppliers, thermal spray companies, equipment producers, and materials suppliers.

One recent success story in the automotive industry relates to the development of plasma transferred wire arc (PTWA) for aluminum engine blocks. Driven by the demand to increase fuel efficiency, automakers put a strong emphasis on decreasing overall vehicle weight as well as improving engine efficiency by reducing internal friction losses. Consequently, the last couple of decades have seen a strong push to produce engine blocks out of light cast alloys, such as aluminum. An article by Dr. Villafuerte, Centerline Windsor Ltd., is provided in this edition to discuss this development in the automotive industry. In addition to an automotive contribution, TSS is providing a two-part article on the importance of safety in thermal spray environments. In this August edition, we are providing Part 1 of this important safety article.

Important ASM TSS events coming up include the North American Cold Spray Conference (NACSC) 2014: Covering the World of Cold Spray, and the Aerospace Coatings Conference 2014: Development and Manufacturing Trends for the 21st Century. NACSC takes place September 16-17 in Bromont, Quebec, Canada. Attendees will gain a basic understanding of the cold spray process, get a chance to follow global R&D programs on cold spray technology, receive firsthand information on industrial applications, and network with international experts. Advancements in cold spray technology are helping expand the commercial and academic applications of this technically superior metal deposition process.

ASM's third TSS Aerospace Coatings Conference will be held in Hartford, Conn., October 8-9. This symposium brings together thermal spray professionals involved in a wide range of responsibilities. Attendees will be able to understand future coating and process requirements, learn about cost reduction improvements related to quality and reliability factors, and gain an appreciation of existing thermal spray coatings for the aerospace industry. Job shop sprayers, engineers, technicians, end-users, suppliers of equipment and material, academicians, researchers, materials scientists, marketing companies, and entrepreneurs will all benefit from this event. The is a great opportunity to gain a key perspective of the industry with exciting presentations from invited presenters including Rolls-Royce, Sulzer Metco, PWA, Curtiss-Wright Surface Technologies, LLC Surface Technologies, Delta Airlines Inc., Lufthansa Technik AG, Naval Aviation Department, Pratt & Whitney, KLM Engineering and Maintenance, and other leading organizations.

ASM members' regular and active participation in these events is very important and ensures that we can keep organizing such world-class conferences in the future. We hope you will attend these events, we thank you in advance, and look forward to seeing you there.

Robert Gansert, Ph.D.
iTSSe co-editor
Advanced Materials & Technology Services Inc.

Seeking Nominations for Thermal Spray Hall of Fame

The Thermal Spray Hall of Fame, established in 1993 by the Thermal Spray Society of ASM International, recognizes and honors outstanding leaders who have made significant contributions to the science, technology, practice, education, management, and advancement of the thermal spray industry. For a copy of the rules, nomination form, and list of previous recipients, visit tss.asminternational.org or contact Sarina Pastoric at sarina.pastoric@asminternational.org. Nominations are due September 30.

EDUCATION

Introduction to Thermal Spray Education Course
October 6-7
ASM Headquarters, Materials Park, Ohio
Instructor: Rick Sayman

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

ITSC 2014 is an outstanding success

ITSC 2014—Not Fiction: Thermal Spray the Key Technology in Modern Life! The International Thermal Spray Conference and Exhibition (ITSC) featured a three-day exposition, conference, poster session, education courses, young professional competition, social events, and much more. At ITSC, attendees found information about thermal spray equipment, research and specialist institutes, applied research, and the latest innovations conveniently located in one big forum. The exposition was held in the Palau de Congressos de Catalunya in northwest Barcelona, Spain, in May.



The first plenary session at ITSC 2014, Plasma sprayed solutions: From the coating of the top to their integrated functionality on aeroengine components, by K. Ostolaza, ITP Technical Fellow Material and Processes, was well attended.



ITSC attendees enjoyed an awards banquet on Thursday, May 22.



ITSC 2014 attendees enjoyed a networking reception on the exhibition floor.

TSS members honored at ITSC



Mitchell R. Dorfman, FASM, (left), was recently inducted into the TSS Hall of Fame. He was recognized for innovations in thermal spray turbine engine coatings, for exceptional contributions to the thermal spray industry and technical community, and for dedicated mentoring of the next generation of thermal sprayers. The award was presented to him by TSS President Luc Pouliot during ITSC 2014.



Charles M. Kay (left) received the 2014 TSS President's Award for Meritorious Service for his many years of dedicated and outstanding service to TSS. The award was presented by TSS President Luc Pouliot during ITSC 2014.



Journal of Thermal Spray Technology Volume 22 Best Paper Awards

The Journal of Thermal Spray Technology (JTST) announces the winners of the *JTST* Volume 22 Best Papers Awards, as chosen by an international committee of expert judges. The awards were presented at the International Thermal Spray Conference & Exposition 2014, in Barcelona, Spain.

Voting resulted in a tie between two papers, "Plasma-Sprayed Thermal Barrier Coatings: New Materials, Processing Issues, and Solutions," by Georg Mauer, Maria Ophelia Jarligo, Daniel E. Mack, and Robert Vaßen, and "Colour Matching in Decorative Thermally Sprayed Glass Coatings," by Thierry Poirier, Pierre Bertrand, and Christian Coddet.

The Editorial Committee believes it is important to evaluate the quality of engineering and scientific contributions published in *JTST* and to provide recognition of excellent work and its publication. Each paper is reviewed and evaluated on its merits for scientific and engineering content, originality, and presentation style. The two papers are recognized as outstanding and the authors received awards of recognition for their excellent work.

The international committee of judges led by Dr. Roland Seals, Chair of the Journal of Thermal Spray Technology Best Paper Subcommittee, includes: David Bucci, Andrew Gouldstone, Jose Maria Guilemany, Jan Ilavsky, Keehyun Kim, Timothy McKechnie, Shiladitya Paul, James Ruud, Richard Schmid, Igor Sevostianov, Atin Sharma, Philip Shipway, Yoshiki Tsunekawa, Erja Turunen, Anirudha Vaidya, and Petri Vuoristo.



Journal of Thermal Spray Technology Editor-in-Chief Christian Moreau (right) presents the JTST Volume 22 Best Paper Award to (from left) Georg Mauer and Robert Vaßen, who also accepted on behalf of their coauthors Maria Ophelia Jarligo and Daniel E. Mack (not pictured) for their paper, "Plasma-Sprayed Thermal Barrier Coatings: New Materials, Processing Issues, and Solutions."



Accepting the JTST Volume 22 Best Paper for "Colour Matching in Decorative Thermally Sprayed Glass Coatings" is Christian Coddet (left), who also accepted on behalf of his coauthors Thierry Poirier and Pierre Bertrand (not pictured). The award was presented by Journal of Thermal Spray Technology Editor-in-Chief Christian Moreau.

Congratulations are extended to the winning authors from the JTST Editorial Board and the ASM Thermal Spray Society Executive Board of Directors.



Plasma Transferred Wire Arc Process Fortifies Aluminum Engine Blocks

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

Thermal spray technology was invented in the late 1800s to restore worn metal parts and provide surface protection. Initially known as "metallizing," it became more popular during World War II for fast repair of tanks and other vehicles in high demand. Today, thermal spray encompasses a whole family of coating processes used to apply metals, polymers, ceramics, cermets, and other combinations of materials to a wide variety of metallic, polymeric, composite, and ceramic substrates.



The new all-aluminum engine block manufactured by Honsel uses Ford's patented plasma transferred wire arc (PTWA) cylinder liner technology to reduce weight and increase efficiency.

Generally, feedstock materials are projected toward the substrate in a liquid, semi-liquid, or solid state to apply coatings with thicknesses greater than 100 µm. Traditionally, feedstock materials (in powder, wire, or rod forms) are melted by combustion or electric arc/plasma, and then accelerated against the substrate by a high-velocity gas jet. In newer thermal spray processes, such as cold spray, special feedstock materials are accelerated by a supersonic gas jet to conform a deposit in the solid-state.

Combustion-based thermal spray processes include powder flame spray, wire flame spray, detonation spray, high velocity oxygen fuel (HVOF), and warm spray (lower temperature HVOF that uses nitrogen to cool combustion gases). Electric arc-based processes include plasma spray, arc wire spray, and their variations. The extremely high temperatures (>10,000°C) of plasma spray make it suitable for depositing elevated temperature materials, such as ceramics. On the other end, the new cold spray family includes processes such as downstream injection (low pressure) and up-stream injection (high pressure) which rely on the ability of the materials to deform at high impact velocities and at low process temperatures.

Traditionally, thermal spray has been widely used in the aerospace industry. Over the past few decades, and driven by the need to improve fuel efficiency, thermal spray is increasingly used in a wide range of automotive applications requiring corrosion and wear resistance, elevated temperature resistance, enhanced lubricity, and dimensional restoration. Examples include:

- Plasma spraying of Molybdenum for piston heads
- Plasma spraying of Mo-Ni-Cr for performance valve seats
- Twin-arc spray of various materials on top of resistance spot welds to improve aesthetics in luxury cars

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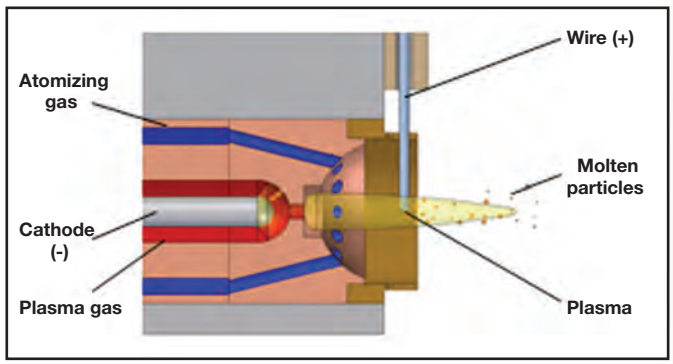


Fig. 1 — *Schematic of the plasma transferred wire arc (PTWA) torch commercial system. Courtesy of Comau[9].*

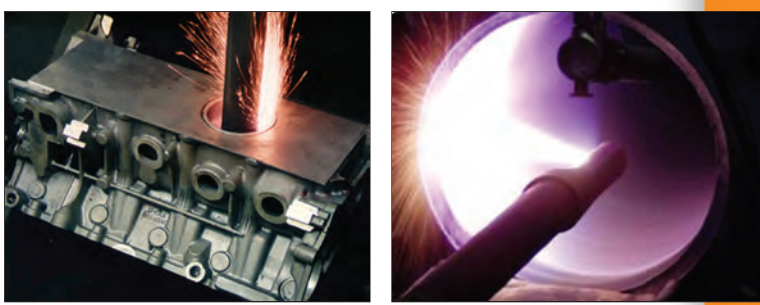


Fig. 2 — *Application of ferrous materials on internal surfaces of engine blocks by PTWA.*

- Plasma spraying of ceramic thermal barriers on exhaust manifolds, turbo-charge components, and diesel combustion chambers
- Twin-arc wire spray of aluminum to improve corrosion resistance
- Plasma transferred wire arc to improve tribological properties of cylinder bores in engine blocks made of low silicon aluminum castings

Plasma transferred wire arc process overview

One of the most recent success stories for thermal spray in the automotive industry involves the development of plasma transferred wire arc (PTWA) for aluminum engine blocks. Driven by the demand to increase fuel efficiency, automakers are placing emphasis on decreasing overall vehicle weight as well as improving engine efficiency by reducing internal friction losses. Consequently, over the past few decades there has been a strong push to produce engine blocks made of light cast alloys, such as aluminum-silicon cast alloys.

Hyper-eutectic aluminum-silicon cast alloys with silicon content higher than 12.6 wt% offer excellent tribological properties for engine block applications. However, their high silicon content makes them difficult to cast and machine, and therefore too expensive to produce. Unfortunately, the generally preferred A356 hypo-eutectic alloy (around 7-8% silicon) displays poor tribological characteristics for engine applications compared to high silicon alloys but it is cheaper to produce. Therefore, low-silicon aluminum blocks require reinforcement of the cylinder



Fig. 3 — *Ford Mustang Shelby GT500.*

bores, which is achieved by either using cast iron liners or electroplating with nickel and silicon carbide.

PTWA was codeveloped by Ford Motor Co., Dearborn, Mich., and Flame-Spray Industries Inc., Port Washington, N.Y.,[1-7] in an effort to eliminate the need for cast iron liners and further reduce weight. In this process, a high temperature (>10,000°C) plasma jet is created between a nonconsumable electrode and a consumable composite ferrous wire with a 1.6 mm diameter (Fig. 1). The plasma melts and atomizes the ferrous wire, which is continuously fed into a rotating spray gun that fits within the cylinders (Fig. 2). Pressurized air atomizes and accelerates metal droplets (20 to 30 µm diameter) onto the internal surface of engine block cylinders. The molten composite wire oxidizes and builds up a rapidly solidified ferrous structure consisting of nanocrystalline iron and ferrous-oxide to a final thickness of about 150 µm.

The resulting surface structure of the composite coating promotes favorable lubrication, low friction, wear resistance, improved heat transfer, and decreased bore distortion. Ford implemented the technology in their 2011 GT500 Shelby Mustang 5.4-L V8 (Fig. 3)[8]. The PTWA process eliminated approximately 3.8 kg of cylinder liners compared with previous models[8].

iTSSe

For more information: Julio Villafuerte, Ph.D., P.Eng, is corporate technology strategist at CenterLine Windsor Ltd., 595 Morton Dr., Windsor, Ontario, Canada, 519.734.8868 ext. 474, julio.villafuerte@cntrline.com, cntrline.com/en.

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Safety in Thermal Spray Settings: Part 1

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

Workplace safety is not a subject that typically captivates an audience, but in the thermal spray trade, hazards of all types are faced on a daily basis. Safety talk is typically thought of as a matter of common sense, and formal programs to communicate and enforce safe practices can seem unnecessary or, in worst case scenarios, as an opportunity to issue penalties based on grudges, rather than evenhanded enforcement. Unlike truly dangerous workplaces, such as shipyards or construction sites, where situational awareness is necessary to stay alive and well, the extra cost and time safety programs consume can make them unattractive in comparatively comfortable thermal spray shops. However, compelling reasons to embrace the safety topic still exist.

For starters, maintaining a safe workplace is the law. Title 29 Part 1900 of the Code of Federal Regulations outlines the mandate, reach, and policies of the Occupational Safety and Health Administration (OSHA). Despite rumors that OSHA's jurisdiction does not apply to shops below a certain size, there is not likely a thermal spray or welding shop immune to OSHA's regulations.

Because of this, safety discussions can broaden awareness of operating requirements that some smaller facilities might not know. It is also important for frontline employees to be aware of the potential hazards faced daily in order to motivate them to voluntarily take appropriate precautions. The topic can be discussed clearly and concisely in this manner, making it easier to ensure requirements are met. Involving people at every operational level during the development of plant policies ensures that employee safety will not hinder workload.

Dust and fume hazards

Another reason safety discussions are especially important in the thermal spray workplace is that hazards appear throughout the coating operation, from incoming orders to final inspection. Dust and fume hazards are an excellent example. Technically speaking, dust consists of airborne fine solid particles such as fractured grit blasting media or thermal spray powders, which can irritate lungs and mucous membranes. Fumes are finer suspended particles released when materials are heated or burned, for example, when thermal spray feedstock enters the combustion zone or plasma plume of a spray gun.

Dust and fume exposure occurs during degreasing, blasting, powder handling, spraying, sealing, and even maintenance and cleaning. Some thermal spray fumes, such as hexavalent chromium, are known cancer causing agents. Vapors are emitted by liquids that evaporate at room temperature, including solvents such as acetone and trichloroethane, which are commonly used for cleaning and degreasing parts. Inhaling these vapors can damage the lungs and internal organs.

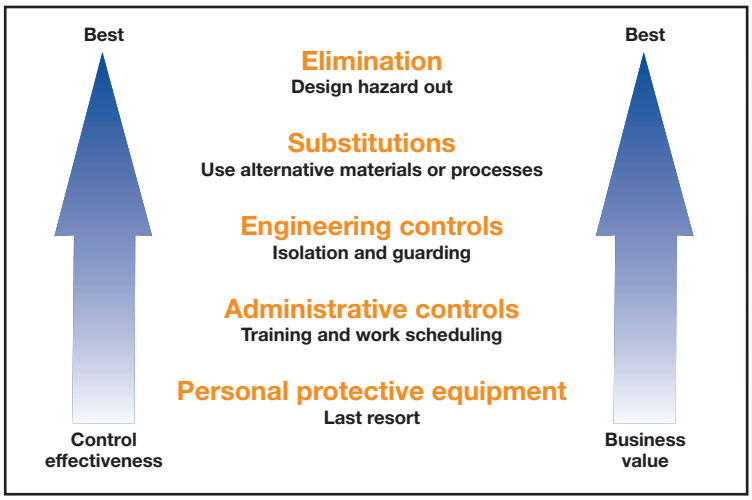


Fig. 1 — *Hierarchy of controls. Courtesy of www.cdc.gov/niosh/docs/2013-136.*

Most dusts and fumes common in spray shops irritate the lungs, but others have more reactive effects. For example, nickel, cobalt, and chromium can cause eczema and contact dermatitis. Fumes released during twin arc wire spraying of zinc can cause nausea, fever, and other flu-like symptoms, known as "zinc fever." The hazard of the airborne carcinogen hexavalent chromium is so acute that the code places specific requirements on employers who are known generators. Part 1910.1026 requires regular physical testing of employees who may be exposed, and makes the provision and handling of specialized protective clothing, among other things, the employer's responsibility.

As with all hazard categories, several methods to eliminate or remediate hazards caused by dust and fumes exist (Fig. 1). The most effective option is to eliminate the hazard altogether, though this is seldom an option. The next best alternative is to substitute a less hazardous material or process. Depending on the application, this also may not be a viable alternative. Engineering controls are methods by which equipment can be added or a process design can be modified to reduce or eliminate the hazard to employees. In the case of dust and fumes, use of sufficient air filtration is an engineering control that can ensure contaminated air is drawn away from operators, removing the hazard. It also effectively cleans the air before it is reintroduced to the environment.

Administrative controls are the next layer of hazard mitigation available to employers. These consist of policies and procedures that mandate specific safe working practices for each workplace hazard. Training, signage, procedures, and employee exposure are all administrative controls that can aid in the mitigation of dust and fume hazards. Finally, personal protective equipment (PPE), such as dust masks and gloves, protect employees from harm when direct contact with a hazard is likely. Though it is perhaps the most common workplace safety measure, PPE is considered the least effective measure because it depends on employee participation and supervision. **iTSSe**

Look for Part 2 of this article in the November/ December issue of iTSSe.

Two exciting thermal spray conferences are coming up this fall!

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

Plan today to attend the North American Cold Spray Conference and Exposition where attendees will gain basic understanding of the cold spray process, follow global R&D programs on cold spray technology, receive firsthand information on industrial applications, and network with international experts. Advancements in cold spray technology are helping to expand the commercial and academic applications of this technically superior metal deposition process.



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Technical Program at-a-glance

Day 1 – September 16

8:30 a.m. – 6:00 p.m. Table-Top Exhibition

8:00 – 8:30 a.m. Continental Breakfast

8:30 – 9:15 a.m. Welcoming Remarks – André McDonald, University of Alberta
Keynote Speaker – Stephen Gaydos, Boeing Research and Technology

Session 1: Quality Control and Diagnostics
Session Chair: Luc Pouliot

9:15 – 9:45 a.m. Eric Irissou, National Research Council – Industrial Materials Institute

9:45 – 10:15 a.m. Matt Mordasky, United Technologies Research Center

10:15 – 10:30 a.m. Break; Visit Student Posters and Exhibitors

Session 2: Applications – Case Studies and Production
Session Chair: André McDonald

10:30 – 11:00 a.m. Phuong Vo, National Research Council – Industrial Materials Institute

11:00 – 11:30 a.m. Leonardo Ajdelsztajn, GE Global Research

11:30 a.m. – 12:00 p.m. Elvi Dalgaard, Pratt & Whitney Canada

12:00 – 1:00 p.m. Lunch; Visit Student Posters and Exhibitors

Session 3: Fundamentals – Physics and Science I
Session Chair: Christian Moreau

1:00 – 1:30 p.m. Bertrand Jodoin, University of Ottawa

1:30 – 2:00 p.m. Volf Leshchynsky, University of Windsor

2:00 – 2:30 p.m. Christian Widener, South Dakota School of Mines

2:30 – 3:00 p.m. Chang-Jiu Li, Xi'an Jiaotong University

3:00 – 3:15 p.m. Break; Visit Student Posters and Exhibitors

Session 4: Powders and Consumables
Session Chair: Charles Kay

3:15 – 3:45 p.m. Jun Akedo, National Institute of Advanced Industrial Science & Technology

3:45 – 4:15 p.m. Satya Kudapa, Sulzer Metco

4:15 – 4:45 p.m. Kazuto Sato, Fujimi Inc.

5:00 – 6:00 p.m. Round Table Event and Discussion
Master of Ceremony: Jean-Gabriel Legoux and Luc Pouliot

6:00 – 9:00 p.m. Dinner and Awards Banquet
Student Poster Presentations: Sponsored by TECNAR Automation

Day 2 – September 17

8:30 a.m. – 5:00 p.m. Table-Top Exhibition

8:00 – 8:30 a.m. Continental Breakfast

Session 5: Characterization I
Session Chair: Julio Villafuerte

8:30 – 9:00 a.m. Tim Eden, Penn State

9:00 – 9:30 a.m. Heli Koivuluoto, Tampere University of Technology

9:30 – 10:00 a.m. Stephen Yue, McGill University

10:00 - 10:15 a.m. Break; Visit Student Posters and Exhibitors

Session 6: Equipment, Parts & Modifications
Session Chair: Jean-Gabriel Legoux

10:15 – 10:45 a.m. Julio Villafuerte, SST Centerline Ltd.

10:45 – 11:15 a.m. Hirotaka Fukanuma, Plasma Giken Co. Ltd.

11:15 – 11:45 a.m. Peter Richter, Jr., Impact Innovations GmbH

11:45 a.m. – 12:15 p.m. Jeganathan Karthikeyan, ASB Industries

12:15 – 1:00 p.m. Lunch

Session 7: Modeling and Fundamentals – Physics and Science II
Session Chair: Bertrand Jodoin

1:00 – 1:30 p.m. Thomas Klassen, Helmut Schmidt University

1:30 – 2:00 p.m. Xuemei Wang, United Technologies Research Center

2:00 – 2:30 p.m. Dominique Poirier, National Research Council – Industrial Materials Institute

2:30 – 3:00 p.m. André McDonald, University of Alberta

3:00 – 3:15 p.m. Break; Visit Student Posters and Exhibitors

Session 8: Characterization II
Session Chair: Jeganathan Karthikeyan

3:15 – 3:45 p.m. Richard Chromik, McGill University

3:45 – 4:15 p.m. Kumar Sridharan, University of Wisconsin - Madison

4:15 – 4:45 p.m. Wilson Wong, Sulzer Metco

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

From sprayers to coating designers, this symposium brings together a wide variety of thermal spray professionals. The event will aid understanding future coating and process requirements, cost reduction improvements related to quality and reliability factors, and also provides an in-depth review of existing thermal spray coatings. Gain key perspectives with exciting presentations from invited presenters including Rolls-Royce, PWA, Curtiss-Wright Surface Technologies, LLC Surface Technologies, Delta Airlines Inc., Lufthansa Technik AG, Naval Aviation Department, Pratt & Whitney, KLM Engineering and Maintenance, and other leading organizations.

Technical Program at-a-glance

Day 1 – October 8

8:30 a.m. – 5:00 p.m. Table-Top Exhibition

7:30 – 7:45 a.m. Continental Breakfast

7:45 – 7:50 a.m. Welcoming Remarks – Luc Pouliot

7:50 – 8:20 a.m. Richard Bajan – Curtiss Wright

8:20 – 8:40 a.m. Keynote Speaker 1 – Ray Sinatra – Rolls-Royce

8:40 – 9:00 a.m. Exhibit/Coffee break

Session 1: Equipment & Materials
Session Chair: Howard Wallar

9:00 – 9:30 a.m. Albert Feuerstein – Praxair Surface Technologies

9:30 – 10:00 a.m. Dave Hawley – Sulzer Metco

10:00 – 10:30 a.m. Adrian Vogel –AMT

Session 2: Coatings & Applications I
Session Chair: Mike Maloney – Pratt & Whitney

10:30 – 11:00 a.m. Keynote Speaker 2 – Marcel von Wonderen – KLM

11:00 – 11:30 a.m. Nick Cortese – Delta Airlines

11:30 a.m. – 12:30 p.m. Lunch

12:30 – 1:00 p.m. Marc Froning – The Boeing Co.

1:00 – 1:30 p.m. Ross Lunato – Component Repair Technologies

1:30 – 2:00 p.m. Ann Bolcavage – Rolls-Royce

2:00 – 2:15 p.m. Exhibit/Coffee break

Session 3: Coatings & Applications II
Session Chair: Steve Glancy – Flame Spray Technologies

2:15 – 2:45 p.m. Lars Ostergren – GKN Aerospace

2:45 - 3:15 p.m. Nicole Zelazny – Moog Aerospace

3:15 – 3:45 p.m. Francis Moverie-Moulin – SAFRAN

3:45 – 4:15 p.m. Chin Ma – Curtiss Wright

4:15 – 4:45 p.m. Robert Vassen – Juelich

6:00 – 8:00 p.m. Dinner

Day 2 – October 9

8:00 a.m. – 5:00 p.m. Table-Top Exhibition

7:10 – 7:25 a.m. Continental Breakfast

Session 5: Research & Emerging Processes
Session Chair: Rick Sisson – Worcester Polytechnic

7:25 – 8:05 a.m. Keynote Speaker 3 – Keith Legg – Rowan Technology Group

8:05 – 8:35 a.m. Jeff Smith – Material Processing Technology, LLC

8:35 – 9:05 a.m. Eric Jordan – University of Connecticut

9:05 – 10:35 a.m. Rogerio Lima – NRC, Canada

10:35 – 11:05 a.m. Dongming Zhu – NASA

11:05 – 11:20 a.m. Exhibit/Coffee break

Session 6: Complimentary Technologies
Session Chair: Bruce McMordie – Coatings for Industry

11:20 – 11:50 a.m. Al Matarese – Technical Metal Finishing

11:50 a.m. – 12:20 p.m. David Fairbourn – Aeromet Technologies Inc.

12:20 – 12:50 p.m. Keith Parker – Coherent Inc.

12:50 – 1:50 p.m. Lunch

Session 7: Equipment & Materials II
Session Chair: TBA

1:50 – 2:20 p.m. Mo VandenBerg – VandenBerg & Associates

2:20 – 2:50 p.m. Frank Accornero – Robotic Synergy

2:50 – 3:20 p.m. Troy McAlister – McAlister Design Inc.

3:20 – 3:35 p.m. Exhibit/Coffee break

Session 8: Coating Specifications, Testing & Characterization
Session Chair: Doug Puerta, IMR

3:35 – 4:05 p.m. Stephen Tefft – GE Aviation

4:05 – 4:30 p.m. John Sauer – Sauer Engineering

4:30 – 5:00 p.m. Wally Birtch – Centerline Engineering

5:00 – 5:30 p.m. Richard Blackwell – Buehler

5:45 p.m. – 7:15 p.m. Curtiss-Wright Plant Tour



Conference Sponsor:

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For additional information on either conference, please contact Kelly Thomas at 440.338.1733 or via email at kelly.thomas@asminternational.org.



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

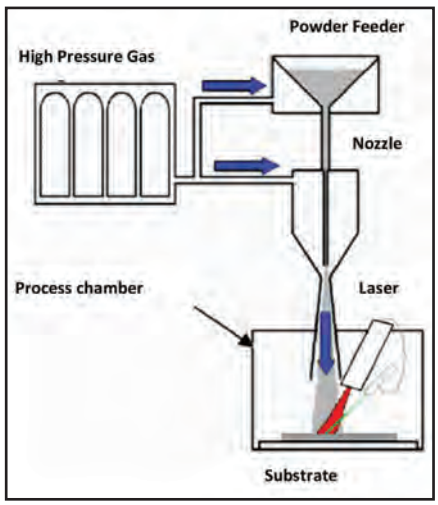
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"Laser-Assisted Cold-Sprayed Corrosion- and Wear-Resistant Coatings: A Review"

E.O. Olakanmi and M. Doyoyo

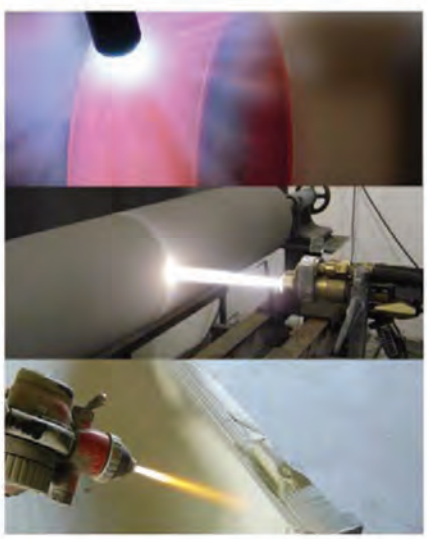
Laser-assisted cold spray (LACS) processes are likely to increase in use for coating deposition due to its unique advantages—solid-state dense, homogeneous, and pore-free coatings are deposited onto a range of substrates; and high build rates at reduced operating costs are achieved without use of expensive inert gases. Depositing coatings via LACS demands accurate knowledge and control of processing and material variables. By varying process parameters and their interactions, functional properties of coatings can be manipulated. In order to provide a basis for follow-on research that leads to development of high-productivity LACS coatings, this review focuses on the latest developments in depositing corrosion- and wear-resistant coatings with an emphasis on the composition, structure, and mechanical and functional properties.



Schematic of LACS.

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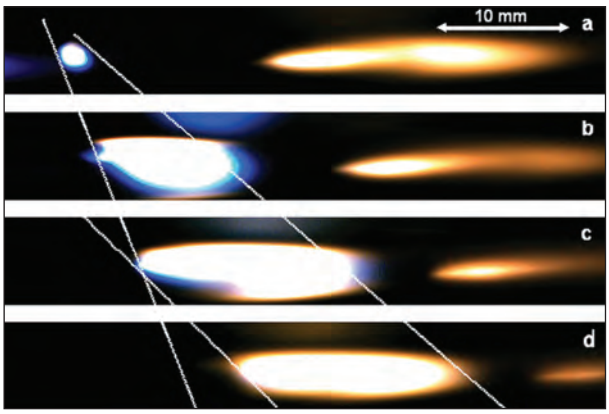


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"Synchronization of Suspension Plasma Spray Injection with the Arc Fluctuations"

J. Krowka, V. Rat, S. Goutier, and J.F. Coudert

Some difficulties encountered in suspension plasma spray include poorly controlled heat and momentum transfers between the plasma and material and plasma instability. To improve this method, arc fluctuations are often reduced. This paper offers an alternative to the injection of reactive material in an arc jet. The principle is to produce a pulsed laminar plasma jet combined with phased injection of liquid droplets.



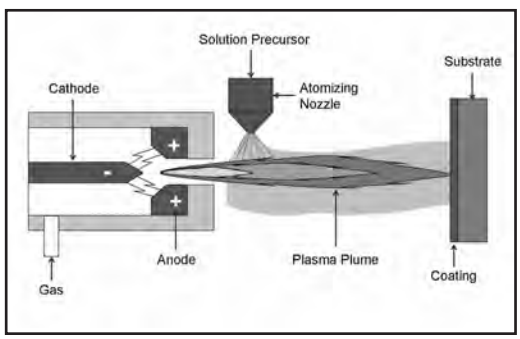
Fast imaging (6000 frames/s, time aperture 100 µs) of synchronized injection of TiO_2 suspension in nitrogen pulsed arc plasma jet for the injection time delay t_j = 260 µs. Time is increased by 166 µs between successive pictures (a), (b), (c), and (d) (enhanced on-line).

The particular design of the plasma torch works at moderate power and follows a resonant mode. Droplets are injected using a piezoelectric device, based on drop-on-demand method, triggered by the voltage signal sampled at the torch connections. Results are evaluated by a time-resolved imaging technique that shows how trajectories are influenced the moment at which droplets penetrate the plasma jet.

"Low Thermal Conductivity Yttria-Stabilized Zirconia Thermal Barrier Coatings Using the Solution Precursor Plasma Spray Process"

Eric H. Jordan, Chen Jiang, Jeffrey Roth, and Maurice Gell

Thermal barrier coatings (TBCs) primarily insulate underlying metal from high temperature gases in gas turbine engines. As a result, low thermal conductivity and high durability are the primary properties of interest. In this work, the solution precursor



Schematic diagram of solution precursor plasma spray with atomizing nozzle.



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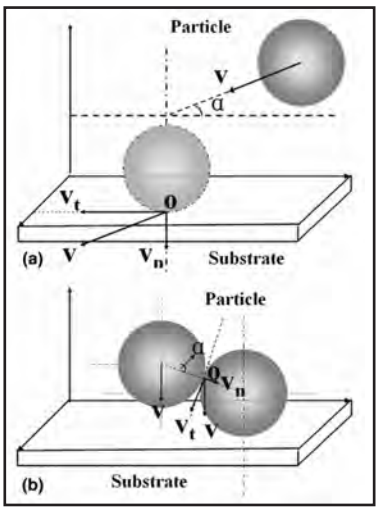
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plasma spray (SPPS) created layered porosity, called inter-pass boundaries, in yttria-stabilized zirconia (YSZ) TBCs. IPBs have been shown to be effective in reducing thermal conductivity. Optimization of the IPB microstructure by SPPS produces YSZ TBCs with a thermal conductivity of 0.6 W/mK, approximately a 50% reduction compared to standard air plasma spray (APS) coatings. Preliminary tests show SPPS YSZ with IPBs exhibit equal or greater furnace thermal cycles and erosion resistance compared to regular SPPS and commercially made APS YSZ TBCs.



Schematic illustration of a semi-molten particle impact condition: (a) at an off-normal spray angle on a flat substrate, (b) at a normal spray angle on a previous particle. V: impact velocity; V_n: normal velocity; V_t: tangential velocity.

"Deposition Behavior of Semi-Molten Spray Particles During Flame Spraying of Porous Metal Alloy"

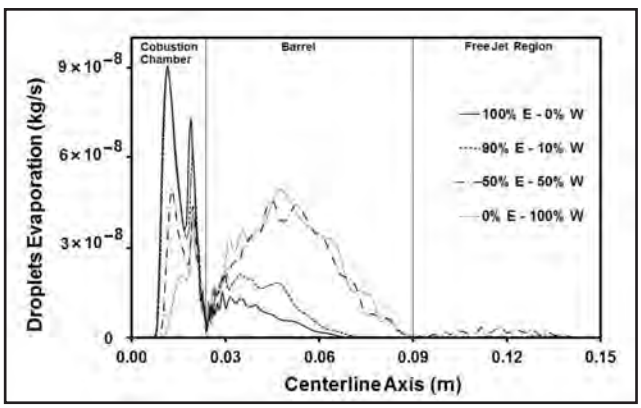
Jian-Tao Yao, Jun-Qiang Ren, Hui-Bin Huo, Guan-Jun Yang, Cheng-Xin Li, and Chang-Jiu Li

To understand semi-molten spray particle deposition behavior, porous 316L stainless steel deposits were fabricated by flame spray with semi-molten particles with different melting degrees and spray angles. The effects of spray angle relative to deposition efficiency and deposit porosity were investigated. The morphology of individual splats deposited on flat surfaces at different angles was examined. Results show that spray angle significantly influences deposit porosity, pore structure, and deposition efficiency. The slipping of solid cores in semi-molten spray particles was clearly observed when semi-molten particles impact the polished substrate with an inclined angle. A random model simulated the particle deposition process and, after considering the effects of both solid particle slipping upon impact and particle melting degree, simulated porosity calculations agreed well with the experimental observation.

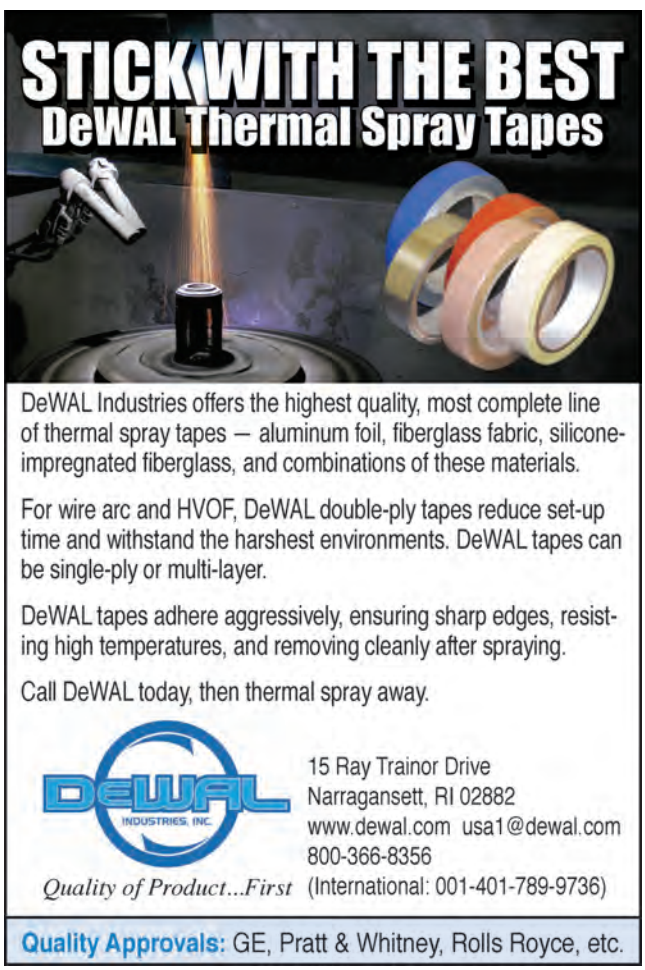
"Numerical Analysis of Multicomponent Suspension Droplets in High-Velocity Flame Spray Process"

Ebrahim Gozali, Mahrukh Mahrukh, Sai Gu, and Spyros Kamnis

The liquid feedstock or suspension as a different mixture of liquid fuel ethanol and water is numerically studied in the high-velocity suspension flame spray (HVSFS) process, and results for homogenous liquid feedstock of ethanol and water are compared. The mixture's effects on droplet aerodynamic breakup, evaporation, combustion, and gas dynamics of the HVSFS process are thoroughly investigated. The exact location where particle heating is initiated (above the carrier liquid boiling point) can be controlled by increasing water content in the mixture. In this way, particle inflight time in the high-temperature gas regions can be adjusted to avoid adverse effects from surface chemical transformations. The mixture is modeled as a multicomponent droplet, and a convection/diffusion model, which takes into account the convective flow of evaporating material from the droplet surface, is used to simulate the suspension evaporation. The model consists of several sub-models that include premixed combustion of propane-oxygen, non-premixed ethanol-oxygen combustion, modeling of multicomponent droplet breakup and evaporation, as well as heat and mass transfer between the liquid droplets and gas phase.



Evaporation rate of droplets carrying four different percentages of ethanol-water in solvent along the centerline.



ASM Handbook,
Volume 5A: Thermal Spray Technology

Volume 5A is a replacement for the *Handbook of Thermal Spray Technology,* edited by J.R. Davis (2004). It provides an introduction to modern thermal spray processes including plasma spray, high velocity oxy-fuel, and detonation gun deposition, as well as a description of coating properties and their wear, corrosion, and thermal barrier characteristics. Principles, types of coatings, applications, performance, and testing/analysis also are covered.

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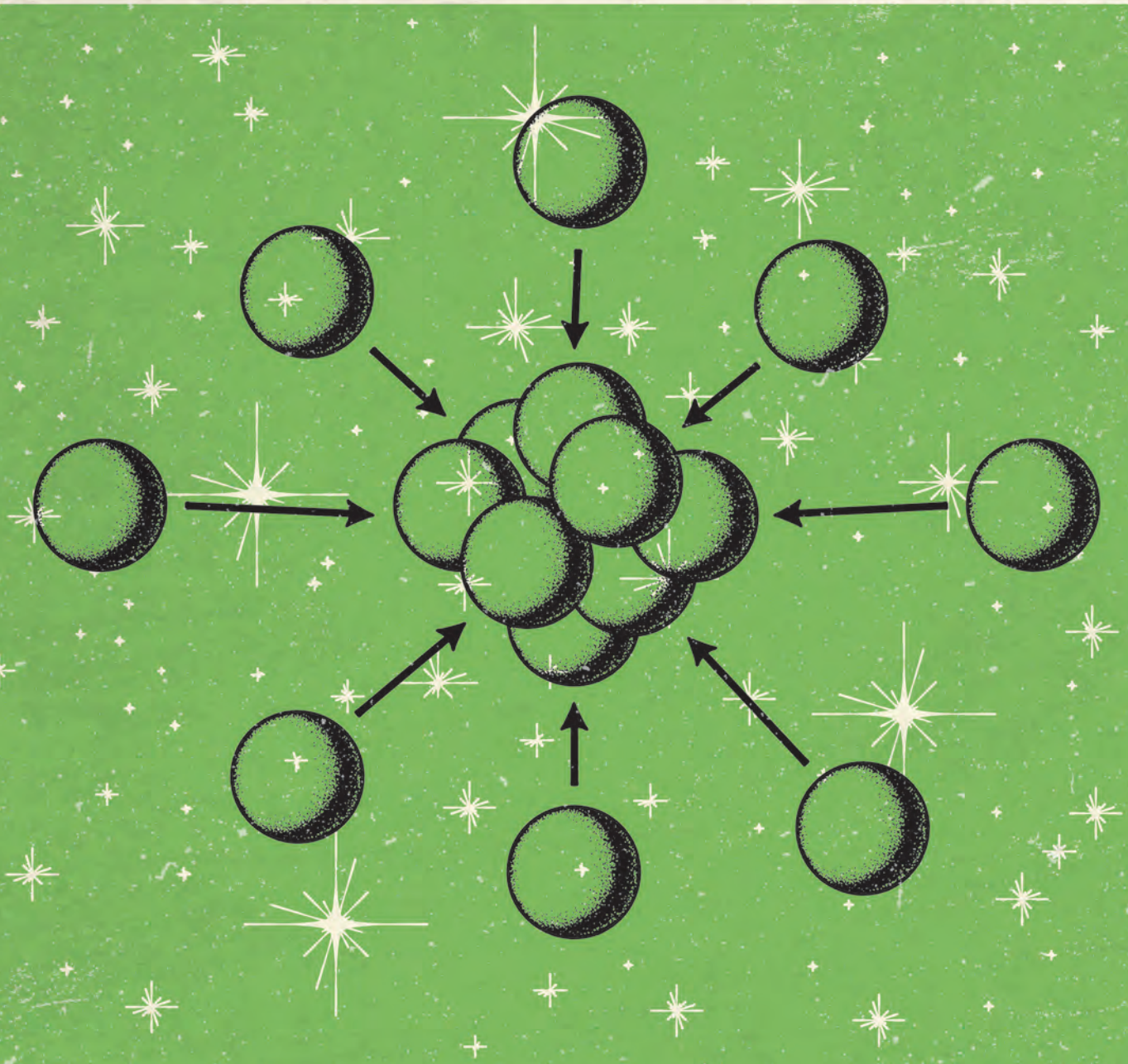
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2014 ASM Award Program Recipients

The ASM International Board of Trustees has named award program recipients for 2014. The awards program recognizes achievements of members of the materials science and engineering community. Awards will be presented at ASM's annual Awards Dinner, October 14 in Pittsburgh, during MS&T14. Tickets for the Awards Dinner are $90 each and can be ordered by using the MS&T registration form. Those interested in purchasing a table may contact Christine Hoover, ASM International, Materials Park, Ohio 44073-0002; 440.338.5151 ext. 5509; fax 440.338.6614; christine.hoover@asminternational.org.

Honorary Membership



Dr. Chandra Shekhar Pande, FASM, metallurgist, Naval Research Laboratory, Washington, will receive this year's award "for distinguished service to the materials science and engineering profession by his pioneering and seminal research and teaching and its promotion to the metallurgical community." Honorary Membership in the Society was established in 1919 to recognize distinguished service to the materials science and engineering community, ASM strategic plan and initiatives, and the progress of mankind.

Distinguished Life Membership



Mr. Henry M. Rowan, Chairman, Inductotherm Group, Rancocas, N.J., will receive this year's award "for distinguished lifetime contributions to the advancement of design and manufacture of induction melting and heat treating equipment worldwide, and to enhancing educational opportunities in engineering." Distinguished Life Membership was established in 1954 and is conferred on leaders who have devoted their time, knowledge, and abilities to the advancement of the materials industries.

Gold Medal



Dr. Tresa M. Pollock, FASM, professor, Alcoa Chair, Materials Department, University of California, Santa Barbara, will receive this year's Gold Medal award "for the enlightenment of the microstructure/processing/property relationships of structural alloys and for imparting that knowledge to her students and other technologists in industry, universities, and national laboratories." The medal was established in 1943 to recognize outstanding knowledge and great versatility in the application of science to the field of materials science and engineering, as well as exceptional ability in the diagnosis and solution of diversified materials problems.

Medal for the Advancement of Research



Dr. Aziz I. Asphahani, FASM, president and CEO, QuesTek Innovations LLC, Evanston, Ill., is the recipient of this year's award. He is cited "for the dedicated support and consistent sponsorship of research, not only for new materials, but also for radically new applications of products in the process of commercialization." The award was established in 1943 to honor an executive in an organization that produces, fabricates, or uses metals and other materials. The recipient, over a period of years, will have consistently sponsored research or development, and by foresight and actions, will have helped substantially advance the arts and sciences relating to materials science and engineering.

Engineering Materials Achievement Award (EMAA)



Marie Cole, distinguished engineer, Lead Free Transformation, IBM, Hopewell Junction, N.Y., IBM Lead-Free Solder Server Team, will receive this year's award for "the development and implementation of lead-free solder assembly processes for server and storage systems." Established in 1969, this award recognizes an outstanding

...in this issue

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achievement in materials or materials systems relating to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product.

Albert Sauveur Achievement Award



Prof. Yuntian T. Zhu, FASM, distinguished professor, North Carolina State University, Raleigh, will receive this year's award "for pioneering work on the fundamental understanding of deformation physics in nanocrystalline materials." Established in 1934 in honor of a distinguished teacher, metallographer, and metallurgist, the award recognizes pioneering materials science and engineering achievements that stimulated organized work along similar lines to such an extent that a marked basic advance was made in the knowledge of materials science and engineering.

William Hunt Eisenman Award



Dr. Robert E. Schafrik, FASM, General Manager, GE Aviation, retired, Cincinnati, will receive the 2014 Eisenman award "for outstanding contributions to the aerospace industry in the application of materials science and engineering and the introduction of revolutionary materials through design, development, production, and system application in turbine engines." The award was established in 1960, in memory of a founding member of ASM, and its first and only secretary for 40 years. It recognizes unusual achievements in industry in the practical application of materials science and engineering through production or engineering use.

J. Willard Gibbs Phase Equilibria Award



Prof. Zi-Kui Liu, FASM, professor of Materials Science and Engineering, The Pennsylvania State University, University Park, Pa., will receive this year's award "for his contributions in computational thermodynamics through integrated first-principles calculations and the CALPHAD method and for the advancement of phase equilibria theory, database development, materials design and promotion of thermodynamics." The award was established in 2007 to recognize outstanding contributions to the field of phase equilibria. The award honors J. Willard Gibbs, one of America's greatest theoretical scientists. In addition to many other contributions, Gibbs laid the thermodynamic foundations of phase equilibria theory with his brilliant essay, "On the Equilibrium of Heterogeneous Substances," published in 1876 and 1878 in the *Transactions of the Connecticut Academy.*

Official ASM Annual Business Meeting Notice

The Annual Business Meeting of members of ASM International will be held in conjunction with MS&T14 on:

Monday, October 13

4:00 – 5:00 p.m.

David L. Lawrence Convention Center, Pittsburgh

The purpose of the ASM Annual Business Meeting is the election of officers for the 2014-15 term and transaction of other Society business.

Allan Ray Putnam Service Award



Mr. David J. Fitzgerald, FASM, president, Precision Surfaces International Inc., Houston, will receive the 2014 Putnam award "for quiet, consistent generosity, serving the Houston Chapter for ASM, ASM International, and the affiliated IMS, in appointed and elected offices, providing personal and financial support for education at every level, and enriching materials science by his work with industrial superfinishing." Established in 1988, the award recognizes the exemplary efforts of outstanding members of ASM International on behalf of the Society to further its objectives and goals. The purpose of this award is to recognize those individuals whose contributions have been especially noteworthy and to whom the Society owes a particularly great debt of appreciation.

Albert Easton White Distinguished Teacher Award



Prof. Gary M. Michal, FASM, professor and chairman, LTV Steel Professor of Materials Science and Engineering, Case Western Reserve University, Cleveland, is recognized "for dedicated and inspirational service as a teacher and mentor, sharing wisdom, humor, the love of finding things out, and the joy of materials with students over the last four decades." Prof. Michael passed away after having been selected as the 2014 recipient. The award was established in 1960 in memory of an outstanding teacher and research engineer, who was a founding member and president of ASM in 1921. It recognizes unusually long and devoted service in teaching, as well as significant accomplishments in materials science and engineering, and an unusual ability to inspire and impart enthusiasm to students.

Silver Medal Award

Established in 2010, the honor of Silver Medal of the Society is to recognize members who are in mid-career positions (typically 5 to 15 years of experience), for distinguished contributions in the field of materials science and engineering, and to the Society. The purpose of this award is to recognize leadership at an early stage and encourage individuals to grow, nurture, and further contribute to the growth of the profession, as well as the Society. Winners of the 2014 award include:



Dr. James G. Hemrick, research staff, Materials Science &Technology Division, Oak Ridge National Laboratory, Tenn., is cited for "his world class reputation as an expert in refractory ceramics and insulation materials and leadership in the refractory community, as well as contributions to his local chapter and leadership roles in other materials related professional societies."



Dr. John Nychka, associate professor and associate chair, University of Alberta, Edmonton, Canada, is cited for "innovative and substantial contributions to the pedagogy, style, and structure of education and professional stewardship in materials science and engineering."

Bradley Stoughton Award for Young Teachers



Dr. Amber Genau, assistant professor, Materials Science and Engineering, University of Alabama at Birmingham, will receive this year's award "for outstanding classroom instruction, excellence in student recruiting, and strong support of student chapters of technical societies." This award, accompanied by $3000, was established in 1952 in memory of an outstanding teacher in metallurgy and dean of engineering who was president of ASM in 1942. The award recognizes young teachers of materials science, materials engineering, and design and processing, by rewarding them for their ability to impart knowledge and enthusiasm to students. The recipient must be 35 years of age or younger by May 15 of the year in which the award is made.



Onimus



Bechade



Gilbon

Henry Marion Howe Medal

F. Onimus, J.L. Bechade, and D. Gilbon, for their paper entitled "Experimental Analysis of Slip Systems Activation in Neutron-Irradiated Zirconium Alloys and Comparison with Polycrystalline Model Simulations," *MetTrans* Vol. 44A, 2013. The award was established in 1923 in memory of a distinguished teacher, metallurgist, and consultant, to honor the author(s) whose paper has been selected as the best of those published in a specific volume of *Metallurgical and Materials Transactions.*

Marcus A. Grossmann Young Author Award



Prof. Joo Hyun Park, is the 2014 award recipient for his paper entitled "Structure-Property Relationship of CaO-MgO-SiO: Quantitative Analysis of Raman Spectra," *MetTrans* Vol. 44B, 2013. The award was established in 1960 in recognition of Dr. Grossmann's accomplishments, especially his abiding interest in and encouragement of younger metallurgists and materials engineers whose paper has been selected as the best of those published in a specific volume of *Metallurgical and Materials Transactions* for authors under 40 years of age on January 1 of the year in which the paper was published.

ASM Student Paper Contest



Mr. Thomas Kozmel is recognized for his paper entitled "*Kinetics of Sub-Micron Grain Size Refinement in 9310 Steel.*" The ASM International Student Paper Contest was established in 1985 as a mechanism for student participation in Society affairs. The award 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.

Emerging Professional Achievement Award



Ms. Katherine Jonsson, with IRISNDT, Edmonton, Alberta, Canada, is the 2014 recipient of the Emerging Professional Achievement Award. Established in 2010, the award recognizes extraordinary ASM volunteers with 0-5 years of post-graduation experience who have made a significant impact on ASM International through devoted service and dedication to the future of the Society.

ASM Historical Landmark Designations

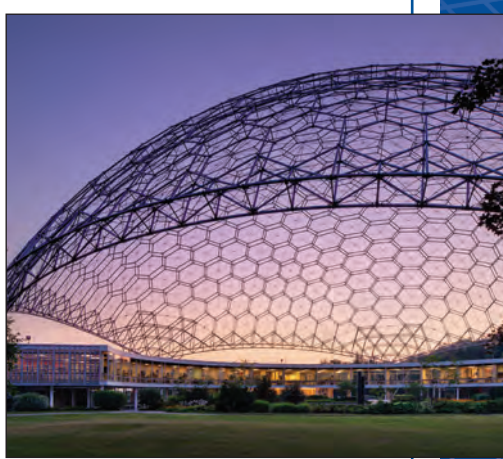


Aluminum Company of Canada Ltd., Kingston, Ontario, has been selected for a 2014 Historical Landmark Award. The citation reads, "At this site, men and women shaped aluminum from wartime need to peaceful use, learning its secrets, and developing new applications for the future."

Oerlikon Metco, Westbury, N.Y., also has been selected as a 2014 Historical Landmark Award. The citation reads, "The first family of exothermically reacting, self-bonding intermetallic forming compounds used by the thermal spray industry for improved surface protection properties was developed at this site. Process and materials were commercialized between 1965 and 1972."

In 1969, the ASM Historical Landmarks Designation was established to permanently identify the many sites and events that have played a prominent part in the discovery, development, and growth of metals and metalworking. In 1987, the scope of this award broadened to include all engineered materials.

ASM Dome Design Competition



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

Register your team and find general guidelines and complete details at asminternational.org/students3.

For a list of upcoming ASM Training Courses, see our ad on page 30 of this issue.

From the Foundation

Building lifelong connections



Jessica Booth
Welding Engineer, GE Oil & Gas
2015 Cleveland Chapter Secretary

As a high school student, I had the good fortune to attend the Eisenman Materials Camp, which introduced me to a world I never knew existed. I didn't know it at the time, but that week marked the beginning of my career in materials and a rewarding association with ASM.

Though I was involved in the Material Advantage Chapter during my undergraduate years at Worcester Polytechnic Institute, my enthusiasm for volunteering with ASM was completely renewed last summer when I not only returned to the Eisenman Camp as a junior mentor, but also began my term as a student member of the ASM Board of Trustees, both within the same week. I suddenly realized what unique organizations both ASM and the ASM Materials Education Foundation are. Being a student board member was an amazing (and at times overwhelming) experience that taught me a lot about the governance and business of ASM, but being a mentor for students at Materials Camp was rewarding on a different level.

My passion for materials science was ignited during my first exhausting week at Materials Park, and as a mentor I hoped that I could have a similar positive impact on students at the camp. I love what I do and the best way I have found to share it is through my involvement with ASM and the ASM Foundation. The wonderful family of like-minded, energetic, altruistic ASM volunteers I have become a part of makes me feel that I will always have a place to not only find professional development and support, but also friendship. My career and life would not be the same without the amazing volunteers, staff, teachers, and students I have worked with since attending Materials Camp, and I know the best is still yet to come.



Auburn University pride!

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

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

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

The qualifications of the lecturer must include:

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

Nominations may be proposed by any member of either Society. Submit your nominations by **September 1** for consideration. Recommendations must be received at the headquarters of either Society.

For a complete listing of the rules and nomination form, visit asminternational.org/membership/awards or contact Christine Hoover at 440.338.5151 ext. 5509, christine.hoover@asminternational.org. Deb Price of TMS may also be contacted at awards@tms.org.

ASM Ambassadors Program a Success!

ASM's Student Board Members, Jesi Booth, Karly Chester, and Ray Hickey, implemented the ASM Ambassadors Program in 2014. The purpose was to create awareness of ASM student programs with Material Advantage chapters and students. ASM provided a presentation slide to MA Chapters who registered for the program. Each chapter shared the slide at their next meeting and submitted a photograph from the meeting. ASM reimbursed meeting expenses of up to $50. We would like to acknowledge the following universities who participated in the program:



UC Davis students held challenges at each meeting, allowing students to meet other members and apply some engineering principles. In one activity, students were given pencils, balloons, a water bottle, cup, tape, and straws. The goal was to transport water from the bottle to the cup without handling anything.

Auburn University
California Polytechnic State University
Case Western Reserve University
Pennsylvania State University
Rensselaer Polytechnic Institute
Rice University
University of Alabama – Birmingham
University of California, Davis
University of Maryland – College Park

ASM looks forward to hosting the Ambassadors Program again in 2015. Watch *ASM News* and the *ASM Student Newsletter* for details this fall.

ASM Chapter Honor Roll

The ASM Volunteerism Committee proudly announces the 2014 Chapter Volunteer Honor Roll recognizing chapter volunteers whose performance is exemplary and the type essential for ASM's success. All chapters were invited to nominate one person. Chapter Executive Committees were encouraged to select a member who serves as a volunteer in an ongoing capacity. Submissions for the 2015 Honor Roll will open in March 2015. Join us in recognizing the following 2014 Chapter Honor Roll volunteers who will each receive an ASM MVP tie or scarf.



Boston Chapter—Peter Jepson

Peter Jepson helped organize the Boston Chapter's ASM Materials Experiences for high school students at WPI since 2005 and at Boston University since 2012. He spearheaded the first ASM Materials Camp for Teachers in New England in 2013 and is leading the 2014 Camp. He helped develop three courses for non-metallurgists and has traveled to Tanzania with Engineers Without Borders.

Brandywine Valley Chapter—Steven Brubaker

Steve Brubaker organized the Brandywine Valley Chapter's first ASM Teachers Camp, including fundraising and coordinating with the University of Delaware to provide the facilities. He judges projects at the annual Delaware Technical Community College Science Fair, organizes the ASM meeting to recognize winners, and coordinates the opportunity for one winner to attend Materials Camp at Drexel University.

Buffalo Chapter—Timothy J. Kosto

When the Buffalo Chapter was about to expire 10 years ago, Tim Kosto spearheaded the effort to reorganize, revitalize, and rejuvenate the Chapter. As a result of his vision and leadership, today the Chapter is once again vibrant, solvent, and successful.

Cleveland Chapter—Warren Haws

In his previous role as Chapter Treasurer, Warren Haws improved the financial record keeping. This year, Warren is the Chapter's Program Chair and also took on the treasurer's role again temporarily. Warren secured excellent speakers for the technical meetings and has done a great job once again in the treasurer role.

Golden Triangle Chapter (Pittsburgh) Chapter—Nathan Eisinger

Nate Eisinger is an outstanding volunteer and ambassador for the Pittsburgh Chapter's activities. He organizes Mini-Camps at MS&T and represents the Chapter at the Pittsburgh Regional Science and Engineering Fair (PRSEF). Eisinger also coordinates activities to select a scholarship recipient who is a high school student planning to pursue a career in metallurgy or materials science.

Gujarat (India) Chapter—Bharat Dave

Bharat Dave has been a dedicated volunteer and with the Gujarat Chapter in India for many years. The Chapter is greatly appreciative of Dave's many contributions and honors him for his efforts.

Hartford Chapter—Arnie Grot

Arnie Grot has been the driving force behind the Hartford Chapter for several years. He organizes the annual ASM Materials Mini-Camp, serves as webmaster, and manages e-newsletters and invitations for technical meetings. As the most active Chapter member over the last 10+ years, his advice has been absolutely crucial in keeping the Chapter alive and well.

Lehigh Valley Chapter—Keith Hill

Keith Hill has a long tenure as a volunteer with the Lehigh Chapter. He has served as Chapter Secretary for many years and prepares meeting minutes for the executive committee. He manages all the reservations for the technical meetings. Hill volunteered for numerous subcommittees along with Materials Camps. Keith is a major contributor to the Chapter's success.

Oak Ridge Chapter—Lindsay Kolbus

In her first year on the executive committee of the Oak Ridge Chapter, Lindsay Kolbus officially served as the public relations chair and also helped with registration, door prizes, and meeting arrangements. She attended nearly every technical and executive committee meeting, and is one of the most dependable members.

Ontario Chapter—Robert Sparling

Serving as chair, vice chair, and treasurer of the Ontario Chapter over the years, Robert Sparling's dedication is admirable. He championed fiscal responsibility to balance the Chapter budget, worked to increase meeting attendance by than 100% over the last five years, and encouraged younger members of the ASM community to take leadership roles.

Pune (India) Chapter—Laxman Deshpande

Laxman Deshpande has been an active executive committee member of the Pune Chapter since 2006. He is chairperson for membership development and member of the India National Council. He attended Leadership Days twice, received the 2013 award for best sustaining membership program, and received the Chapter's outstanding committee award for four straight years. He also brought many new faces into the Chapter.

Quebec Chapter—Kamran Azari-Dorcheh

Kamran Azari-Dorcheh has always had outstanding suggestions and contributions in the Chapter's activities, including generating great ideas for workshops, short courses, conferences, and membership affairs.

Warren Chapter—Richard Polenick

Though his official position is secretary, Richard Polenick has essentially run the Warren Chapter for at least two decades. He makes all the arrangements for speakers at dinner meetings, takes reservations, and hosts the event. He is a lead participant of the executive committee meetings and the main liaison between the Chapter and National headquarters.

Chapter News

Philadelphia Receives Rowan Grant


Henry Rowan

In 2012, Al Singmaster and Tom Reid from the ASM Philadelphia Liberty Bell Chapter began discussions with the Rowan Family Foundation regarding a grant to support the Chapter's Materials Camp activities. In December 2013, the Chapter was notified that their request for a grant was approved. The $75,000 grant will be used to support the Students Materials Camp and develop a Teachers Materials Camp. The Chapter is extremely grateful to the Rowan Family for their support of these camps.

Rhode Island Hosts Asphahani

The ASM Rhode Island Chapter held its May dinner meeting with ASM past president Aziz Asphahani, FASM, speaking on "High-Performance Alloys Design and Development: Then and Now." He is CEO of QuesTek Innovations LLC and chairman of Advanced Motion Technologies. Asphahani discussed improved computational tools and enhanced analytical characterization, based on integrated computational materials engineering, which has proven highly effective in optimizing materials performance. He also spoke with the Chapter's board about ways to enhance member participation and described new directions of the ASM Foundation. He is an active participant in the ASM Materials Camp initiative, a program of great interest and participation of the Chapter.


R.I. Trustees welcome Aziz Asphahani in May. Clockwise: incoming Chapter chairman Paul Forde, Ted Greene, John Goetz, Chapter chairman David Shaner, Aziz Asphahani, Gary Haupt, Robert Baboian, and Greg Dexter.



Student Posters in Chicago

The University of Illinois at Chicago (UIC) was the site of the Chicago Chapter's Student Poster night held in April. There was a strong turnout with 17 posters on display submitted by undergraduate and graduate students from UIC, Northwestern, IIT, and NIU. Shown are students on a tour of the UIC lab. Far left is Didem Ozevin, assistant professor of UIC's Civil and Materials Engineering Department, who gave a presentation on monitoring civil engineering structures to predict failure using acoustic emission. Far right is David Rollings, Chapter chair.

ASM INTERNATIONAL | Emerging Professionals

MS&T 2014 Symposium for Emerging Professionals:

Career Opportunities and Experiences in Materials Science and Engineering

What are the common career experiences of successful materials engineers and scientists? How do they help shape careers? What lessons are learned along the way? For more established engineers, the answers may come easily. However, for early career professionals, the answers may not seem so obvious.

At MS&T14 in Pittsburgh (October 12-16), materials professionals with various backgrounds will share the narrative of their careers so that early career professionals can make informed decisions about their own paths. The ASM Emerging Professionals Committee is excited to announce the 7th Annual Symposium **"Perspectives for Emerging Materials Professionals: Career Opportunities and Experiences in Materials Science and Engineering."** The symposium is designed for the emerging professionals' community and is part of Tuesday's (October 14th) daylong programming for the early career professional.

This year's program includes invited presentations from an outstanding group of speakers, ranging from those established in their field to those in the early stages. The topics include: seasoned career and early career perspectives and advice from government labs, academia, and industry; entrepreneurship and small business; the importance of mentoring and networking; international experiences; emerging careers and professional development in the new economy. We also are proud to announce that two keynote speakers will share their career experiences and wisdom for emerging professionals at this symposium: **Paul K. Mason,** president, Thermo-Calc Software Inc., and ASM president-elect, **Sunniva Collins, FASM.**

On behalf of the Emerging Professionals Programming Subcommittee, we personally extend an invitation to attend this symposium. It will provide an excellent opportunity to interact with both emerged and emerging professionals alike. We hope to see you there!

For questions or to participate in future Emerging Professional symposia, contact the symposium organizers: Mark A. Tschopp, Army Research Laboratory, at Mark.A.Tschopp.civ@mail.mil and Khinlay Maung, ATK, at Khinlay.Maung@atk.com.

Members in the News

Ravindrans Visit Pratt & Whitney

Shanti Ravindran and **ASM president Ravi Ravindran, FASM,** visited Pratt & Whitney in East Hartford, Conn., on May 12 to review aerospace materials technology and how ASM International is working to support engineering design and manufacturing with advancements in materials data technology. Ravi reviewed the Computational Materials Data Network and how this emerging capability will support rapid development of new materials and processing methods through the use of modeling and simulation. The ideas he presented were well received and aligned with many efforts within Pratt & Whitney and industry in general. **David Furrer, FASM,** senior fellow discipline lead and past ASM trustee, served as their guide.



Schadler Named Vice Provost and Dean for Undergraduate Education at RPI



Linda Schadler, FASM, has been named vice provost and dean for undergraduate education at Rensselaer Polytechnic Institute (RPI), effective October 13. A member of the ASM Board of Trustees, she is currently the Russell Sage Professor and associate dean for academic affairs for RPI's School of Engineering. In her new role, Schadler will be responsible for overseeing the Institute's undergraduate degree programs. Along with enhancing the core curriculum and growing opportunities for undergraduate research and international experiences, Schadler will strengthen Institute programs focused on student advising, retention, graduation, and other student support services. She will continue to advance initiatives in teaching and learning, such as the Mandarin Project and Art Across the Curriculum.

IN MEMORIAM



Stephanie Kwolek, of Wilmington, Del., a pioneer chemist credited with inventing the body armor component Kevlar, died on June 18 at age 90. Kwolek made her discovery in the mid-1960s while working on specialty textile fibers. She invented a liquid crystalline solution that could be spun into exceptionally strong fibers. She was proud of her invention and worked to get more women into science. Kwolek was among DuPont's recipients of ASM's Engineering Materials Achievement Award (1978) and she received the National Medal of Technology and Innovation (1996). In 1995, she became the fourth woman to be added to the National Inventors Hall of Fame.



On May 11, **John A. "Jay" Millane, FASM,** of Doylestown, Pa., passed away. A beloved member of the Philadelphia Chapter, he was awarded ASM Distinguished Life Membership in 1994. He was a fifth generation owner and past president of the Chapter's oldest Sustaining Member Company, Tinius Olsen Testing Machine Co., in Horsham, Pa., which is now 134 years old. He graduated from Lehigh University in 1958 with a degree in metallurgical engineering and was a member of Beta Theta Pi Fraternity. He retired as president in 2001, and remained chairman of the board until his passing. Millane received the William Hunt Eisenman Award in 1983 from the Chapter and Tinius Olsen Co. was recognized by ASM as a National Historical Landmark in 1996.

Donald A. Bergh of Fenton, Mich., died on June 1 in Bradenton, Fla. He was a past chair of the Saginaw Valley Chapter. He received a bachelor's degree in metallurgical engineering in 1944 and a graduate degree in process and metallurgical engineering, both from Michigan State University. Serving in the U.S. Army, he was a field spotter for an artillery battery in the 71st Infantry Division and participated in combat against German forces in France, Germany, and Austria until the end of the war in 1945. Bergh was a professor of engineering at General Motors Institute (now Kettering University) and served as faculty advisor for their Sigma Nu fraternity. Contributions are welcomed at The Kettering University FIRST Robotics Scholarship program at Kettering.edu/give.





Goerge Hebel III of Royal Oak, Mich., passed away on July 6. Hebel received a degree in mechanical technology from Lawrence Institute of Technology in 1970 and did post-graduate studies at Lawrence Tech's School of Industrial Management. He served Bonal International Inc. in various capacities throughout a 50-year period, starting as a machinist in 1963. Hebel retired as president and CEO in 2010 and remained chairman of the Board of Directors until this past February. He coined the name "Meta-Lax" for the stress relief technology he patented. In 2002, Hebel was honored by Entrepreneurs for Energy Efficiency Inc. and was a finalist for Ernst & Young's 2008 Central Great Lakes Entrepreneur of the Year. Hebel was a member of ASM's Detroit Chapter.

Word has been received at ASM Headquarters of the death of Life Member **Andrew Tulecki** of Kitchener, Ontario, Canada. (Ontario Chapter).

Members in the News

The Universal Language of Metallography



An IMS past president and world traveler, **George F. Vander Voort, FASM,** recently ventured to Russia to instruct a two-day class on Metallography & Failure Analysis. He can attest that the science of metallography transcends language barriers. Vander Voort is currently vice president of Alpha Sigma Mu, the international honor society for materials science and engineering.

Tau Beta Pi Selects Scholars

The Fellowship Board of Tau Beta Pi, the engineering honor society, recently announced the selection of 242 Tau Beta Pi Scholars for undergraduate study during the 2014-15 academic year. Most recipients will receive a cash award of $2000 for their senior year of engineering study. Scholarships are awarded on the basis of high scholarship, campus leadership and service, and promise of future contributions to the engineering profession. Awardees include the following joint student members of ASM: **Brittany Gallagher** and **Ziyin Huang** (Drexel Univ.), **Alexandra Glover** (Michigan Technological Univ.), and **Christie Hasbrouck** (Trine Univ.).

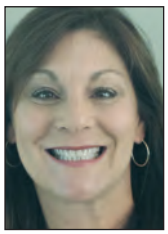
Wicks Awarded ACerS Distinguished Life Membership



In May, the American Ceramic Society (ACerS) announced that **George Wicks** earned the honor of Distinguished Life Membership. He will be inducted at the Society's Annual Awards and Honors Banquet on October 13 during MS&T, in Pittsburgh. Regarded as a national and international expert in nuclear materials, Wicks recently retired after 40 years at Savannah River National Laboratory. As president of Wicks Consulting Services LLC, he now provides independent consulting services, working with the Applied Research Center in South Carolina, and is adjunct professor at Georgia Health Sciences University-Georgia Regents University.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer



Diane Nielsen
Strategic Account Manager – Oil & Gas
Materion Performance Alloys

Diane Nielsen began her career in the steel industry as an intern with Bethlehem Steel. With her Lehigh University degree in metallurgy and materials engineering, manufacturing seemed like a natural fit—until she discovered it was more exciting to learn about technologies in different fields as a sales engineer.

For the past 24 years, Nielsen has done just that for Materion Performance Alloys (formerly Brush Wellman) in Houston. With expertise in the oil field, she became a strategic account manager, working with global oil and gas companies to develop materials solutions for advancing technologies in challenging environments.

"My first involvement with ASM was in college, where I gained exposure to a broad scope of industries and jobs," recalls Nielsen. When she moved to Cleveland to work for Latrobe Steel, Nielsen jumped into ASM Cleveland's executive committee. "It was great to meet people with similar technical interests, but in a new city," she recalls.

With ASM Houston, Nielsen devoted 20+ years of service to the executive committee including serving as Chapter chairperson. She remains a valuable chapter resource as an advisor. Education is her greatest passion. She organized teacher and student Materials Camps and ASM courses, including Houston's own *Practical Oilfield Metallurgy.* "We get experts teaching courses over an eight-week period. It's one of our chapter's strengths," says Nielsen.

She also embraces the challenge to attract younger ASM members. "We need to connect with new people joining our profession. For example, we're having a chapter meeting with an Oktoberfest theme at a popular local brewery!"

What does volunteering add to her life? "I'm a sales engineer working far away from my company's headquarters—so teamwork with ASM colleagues is rewarding. We support each other to get things done. We're focused on the growth and improvement of the ASM Houston Chapter."

Heat Treater's Guide Companion App – New Version!



The *Heat Treater's Guide Companion* app, created by ASM International and the ASM Heat Treating Society, provides ready reference data on more than 330 steel alloys. The app can be used by itself or as a companion to the ASM Heat Treater's Guide print and online database products. The latest version features the addition of tool, stainless, and ultrahigh-strength steel alloys, plus enhanced searching. The free app can be downloaded from the Apple and Google App stores.

Micrograph Database—Composites Release



The ASM Micrograph Database is a growing collection of more than 4000 micrograph images and associated information, published by ASM International, in cooperation with the International Metallographic Society (IMS). Nearly 200 micrographs and associated data, with a special focus on composites, were recently added to the database. The new content includes natural composites and polymer matrix records. For more information, contact Denise.Sirochman@asminternational.org, 440.338.5151 ext. 5663.

25th AeroMat Conference Features Tuskegee Airman

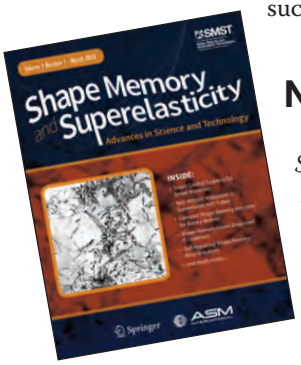
The 25th AeroMat Conference and Exposition, held June 16-19 in Orlando, Fla., featured a theme of "the latest word in aerospace materials." The well attended conference offered forward looking plenary sessions, multiple presentations about additive manufacturing, and more than 200 papers on topics ranging from aluminum, magnesium, and titanium to high-strength steels, high-temperature alloys, and thermomechanical processing.

As part of the festivities, ASM International and Allegheny Technologies Inc. (ATI), Pittsburgh, partnered to put on an outstanding VIP reception featuring Lieutenant Colonel Leo Gray, one of 27 remaining Tuskegee Airmen from World War II. Gray shared some very interesting, funny, and personal stories from his time flying P-51 Mustangs over Germany during nearly four years of active duty. Several tales involved combat missions, downing of German aircraft, and the oppressive racial prejudice so prevalent during the 1940s. Many audience members asked questions and encouraged Gray to keep telling stories, which he gladly did. As a parting gift, ASM and ATI gave away custom prints of a P-51 aircraft drawing made by aviation artist Ernie Boyette and signed by Lt. Col. Gray.



Tuskegee Airman Lt. Col. Leo Gray (left) with Phil Morton of ATI.

The catered event was enjoyed by all attendees and serves as a stark reminder of why aerospace innovation remains such an important endeavor. For more information, visit asminternational.org and atimetals.com.



New Journal is Shaping Up: Coming in 2015

The International Organization on Shape Memory and Superelastic Technologies introduces *Shape Memory and Superelasticity.* This new quarterly journal will be a focused publication on shape memory. Authors will now have a home dedicated to publishing their original shape memory research. Additionally, the journal will function as a forum for researchers, scientists, and engineers to access information about the latest innovations in this ever-expanding field. The first issue will be available in March 2015. If interested in submitting a paper or becoming a reviewer for the journal, contact the editor, Huseyin Sehitoglu, at Huseyin@illinois.edu or the editorial office at ann.britton@asminternational.org.

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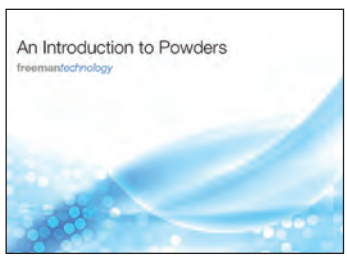


products & literature



Instron, Norwood, Mass., announces a **free brochure** regarding *Pipe & Tube Testing Solutions.* The 3-page, applications-focused brochure was developed as a resource for manufacturers affected by the recent growth in oil drilling and gas extraction in the energy market. In addition to the increased demand for oil country tubular goods (OCTG), global product standards pertaining to pipe and tube testing—including ANSI/API Spec 5L, ISO 3183:2012, ISO 6892-1:2009, ASTM A370, and ASTM E8M—are evolving to facilitate global standardization, which creates a challenge for pipe and tube manufacturers. The brochure includes information regarding testing of curved-shape specimens, preventing crushed pipes and tubes, impact testing of high-strength materials, and suitable strain measurement. instron.com.

Freeman Technology, UK, announces a **free guide** titled *An Introduction to Powders.* Written in a straightforward style, the new booklet explains how and why powders behave the way they do, and how this impacts powder processing and characterization. It provides a valuable foundation for those with little prior knowledge of powders and is a useful resource for anyone looking to expand their understanding of the factors relevant to product development and processing performance. The new booklet focuses on how the three components of a powder—particles, surrounding air, and moisture—interact to define powder behavior, and provides answers to the most frequently encountered powder processing issues throughout industry. www.freemantech.co.uk/index.php?id=415.



MagneGas Corp., Tampa, Fla., launched a second-generation **cutting fuel,** MagneGas 2. Independent tests on track-based cutting systems show that, in comparison to acetylene, MagneGas 2 has 38% faster cutting speeds on 2 in. carbon steel, and roughly a 34% reduction in oxygen consumption. The fuel is a rich mix of gases resulting in a lower flow rate and a flame that behaves like legacy cutting fuels such as acetylene. MagneGas 2 can also be used for brazing and welding, making it a complete replacement for flame applications of acetylene and propane. magnegas.com.

Well suited for electromagnetic interference and radio frequency interference shielding applications, an **aqueous-based, sodium silicate system** with graphite filler was introduced by Master Bond, Hackensack, N.J. MB600G was tested with aluminum as the reference material based on test method IEEE 299, 2006. Unlike other shielding systems, the coating shows little variation throughout the 1-18 GHz range. At 1 GHz, it is 40 dBs, and at 18 GHz it is 45 dBs with the highest reading of 50 at 1.2 GHz and the lowest at 27 dBs at 1.8 GHz. The combination of shielding effectiveness and temperature resistance is impressive with a service temperature range extending from 0° to 700°F. It is also highly effective as a moisture barrier. masterbond.com.



Micromeritics Instrument Corp., Norcross, Ga., introduces AutoPore V Series **mercury porosimeters** that can determine a broader pore size distribution more quickly and accurately than other methods. In addition to offering speed, accuracy, and a wide measurement range, mercury porosimetry permits calculation of numerous sample properties such as pore size distributions, total pore volume, total pore surface area, median pore diameter and sample densities (bulk and skeletal). These instruments also include enhanced safety features and offer new data reduction and reporting choices that provide more information about pore geometry and fluid transport characteristics. Porosimeters are available in two models: AutoPore V 9620 has a pore size range of 500 to 0.003 micrometers with two high-pressure (60,000 psia maximum pressure) and four low-pressure analysis ports. AutoPore V 9605 contains two high-pressure (33,000 psia maximum pressure) plus four low-pressure analysis ports measuring pore sizes from 500 down to 0.005 micrometers. micromeritics.com.



tecsis LP, Worthington, Ohio, offers the Model XLUS88, a subminiature, bidirectional, **tension/compression load cell** for ranges from as low as 150 g to 1000 lb. With a compact size of only 0.50-0.75 in. diameter, this load cell is suitable for applications where space is limited. The stainless steel XLUS88 is fully welded and built to perform in rugged conditions with an overload capacity of 150% FS. Mechanical overload stops are standard on ranges below 1000 g, and an option on all other ranges. Accuracy specs include 0.10% repeatability, ±0.50% linearity, and ±0.50% hysteresis (FSO). The unit has an op-



erating temperature of -65° to 250°F, and is temperature compensated from 60° to 160°F. tecsis.us.

Park Systems, Korea, announces Park NX-Wafer, a revolutionary **atomic force microscopy (AFM) design** for bare wafer manufacturing that fully automates the defect review process and increases production throughput by 1000%. The microscope produces sub-Angstrom roughness measurements for the flattest substrates and wafers with tip-to-tip variation of less than 2%. The device also features a long range sliding stage that combines with NX-Wafer to become an atomic force profiler (AFP). The new low noise AFP provides very flat profiling to 50 mm with profiling speed as fast as 1 mm/sec for both local and global uniformity measurements including dishing, erosion, and edge-over-erosion (EOE) after chemical mechanical polishing (CMP). parkafm.com.

SiVance LLC, Spartanburg, S.C., a subsidiary of Milliken & Co., released SiVance C1008 Curative, a **new silicone curative** that significantly improves the durable flexibility of epoxy polysiloxane protective topcoats in marine and infrastructure applications, without sacrificing weatherability. This development solves a major challenge common to epoxy polysiloxanes—brittleness and cracking that can develop over time as the coating cures. The product is fully miscible with hydrogenated bisphenol-A epoxy resins. Compatibilization of C1008 Curative in other epoxy resins is possible with the use of solvents (methyl ethyl ketone (MEK), xylenes, etc.) or reactive diluents. millikenchemical.com/sivance.

ZEISS, Germany, introduces its latest **photomask qualification system,** the AIMS 1x-193i. The new system supports the further extension of 193-nm lithography and meets the challenging requirements of advanced lithography techniques such as multi-patterning and source mask optimization. It also enables users to qualify the optical performance of a mask under scanner equivalent illumination conditions. The AIMS 1x-193i works with 193-nm illumination and benefits from a completely redesigned optical system. Another highlight is a significantly improved CD repeatability enabling more accurate defect qualification that stays ahead of the requirements of the ITRS roadmap as the industry move to smaller feature sizes. zeiss.com/sms.



The NanoSteel Co., Providence, R.I., announces a portfolio of **ferrous powders** designed to extend steel's capabilities in near-net shape wear parts for highly abrasive environments. These new alloys feature hardness in excess of 1400 HV, wear resistances well below 10 mm^3 volume loss (ASTM G-65), and spherical morphology that results in excellent packing factors and flowability important for producing high-density parts under tight dimensional control. This family of new powders enables production of extreme hardness wear parts through a wide variety of consolidation processes, including additive manufacturing, without the need for subsequent heat treatment. nanosteelco.com.

WANTED

Metallurgist/Material Scientist

Established company in Central California looking for a qualified Process Engineer. Responsibilities will include technical oversight of atomization, powder processing and R&D projects. Experience with production manufacturing and process engineering is required. The right candidate will have a Degree in either Metallurgy or Mechanical, Electrical, or Material Science Engineering. They will also have a minimum of three years experience managing people, projects, and resources.

The candidates we are looking for will have strong analytical skills, interpersonal skills, effective communication skills, and high ethical standards. We value dependability, strategic thinking, and innovation with a focus on safety, security, and quality in all tasks.

This is an exempt, salaried position with pay based on experience. We offer a strong and diverse benefits package including medical insurance, company funded retirement program, paid time off, and relocation assistance.

Please send your resume and cover letter to atomizationengineer@gmail.com.

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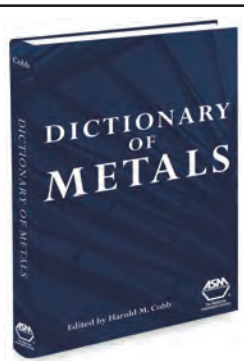
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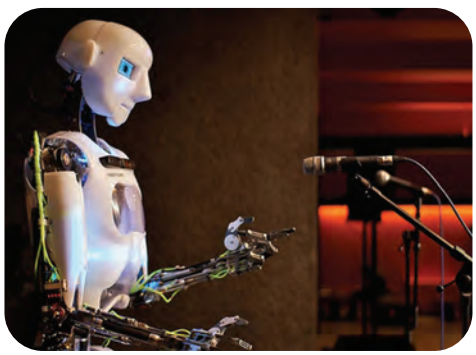
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stress RELIEF



Comedy Lab: Human vs. Robot, by Toby Harris, a Ph.D. student at Queen Mary University of London's Cognitive Science Research Group, stole the show ahead of many other stunning pictures featuring research in action, which were entered into EPSRC's inaugural competition.

Stand-up robot

The image of a joke-telling robot that can tailor its repartee while performing a stand-up comedy routine won the overall prize in a national science photography competition organized by the Engineering and Physical Sciences Research Council (EPSRC), UK. The competition's five categories included: Weird and Wonderful, Discovery, Equipment, Innovation, and People. Winner Toby Harris said, "We're thrilled that our experiment pitting human stand-up comedians against a robot is inspiring others. This groundbreaking research is helping us to understand both what makes for a great performance and what makes for a compelling audience experience. We use new technologies to analyze people's moment-by-moment responses, so while teaching a robot stagecraft was fun, it was the ability to read and react to the audience that made it work." The competition drew more than 250 entries, from a pool of researchers in receipt of EPSRC funding. *www.epsrc.ac.uk.*

Champagne science and caviar dreams

The importance of fizz, more technically known as effervescence, in sparkling wines and champagnes is not to be underestimated—it contributes to the complete sensory experience of a glass, or flute, of fine bubbly. A scientist closely examined the factors that affect these bubbles, and came up with an estimate of just how many are in each glass. Gérard Liger-Belair, professor at the University of Reims Champagne-Ardenne, France, notes that effervescence plays an important role in the look, taste, aroma, and mouth feel of champagne and other sparkling wines. Wine journalists and bloggers often cite 15 million as the average number of bubbles fizzing in a single glass of champagne, based on simple mathematics. Liger-Belair suspected that the formula leading to this estimate oversimplified the matter as it does not take into account the fact that some of the dissolved carbon dioxide escapes from a glass without forming bubbles. Also, the size of the bubbles changes over time and could affect the final number.

Taking into consideration temperature, bubble dynamics, and the tilt of a flute, Liger-Belair came up with a new way to calculate the number of bubbles in a glass of champagne. And the result is far lower than what has been cited. "One million bubbles seems to be a reasonable approximation for the number of bubbles likely to form if you resist drinking champagne from your flute," he concludes. He also found that if you prefer more fizz in your bubbly, serve it warmer than you normally would and be sure to tilt the flute when pouring. *www.univ-reims.fr.*



Wine enthusiasts significantly overestimated the number of bubbles in a single glass of champagne. Courtesy of Flickr upload bot.



VCU's Virtual Curation Lab is using 3D scanning and printing technology to create chess sets, with each piece a replica of historical artifacts found at archaeological digs at Jamestown, Mount Vernon, Montpelier, Thomas Jefferson's Poplar Forest, and elsewhere.

3D printed historical chess sets

Over the past month, a Virginia Commonwealth University, Richmond, lab has been using 3D scanning and printing technology to create chess sets, with each piece a replica of historical artifacts found at archeological digs at Jamestown, Mount Vernon, Montpelier, Thomas Jefferson's Poplar Forest, and elsewhere.

According to Bernard Means, director of VCU's Virtual Curation Laboratory, the chess sets are proving to be an excellent way of engaging the public, students, and others interested in archaeology and the lab's 3D scanning technology. In one of the sets, each piece is a 3D plastic replica of artifacts from 1607-1610 found at a dig at the Jamestown Settlement. The pawn of the Jamestown set is a scaled-down model of a bust based on the skull of a 14- or 15-year-old boy killed by an arrow in 1607. The bust was recently on display at the Smithsonian Museum of Natural History. This week, the lab will donate two chess sets to the Society for Pennsylvania Archaeology, to be auctioned off to support student attendance at future conferences for undergraduate researchers. In the future, says Means, the team will display the sets at high schools, VCU public events, and archeological conferences. *spectrum.vcu.edu.*

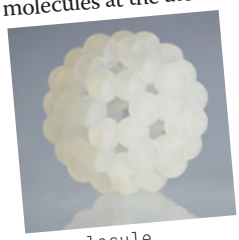
SUCCESS ANALYSIS

Specimen Name:

3D Printed Crystallography

Vital Statistics:

2014 is the International Year of Crystallography. According to the International Union of Crystallography database, roughly 10,000 crystallographers worldwide are organized into national societies that support their specialized discipline. More than 75% of these scientists use x-ray diffraction techniques to reveal and determine the structures of solids, liquids, and molecules at the atomic level. This data enables a systematic understanding of the chemical and physical properties of inorganic materials and the biological functions of macromolecules.



C_{60} molecule.



Models of caffeine and salt molecules.

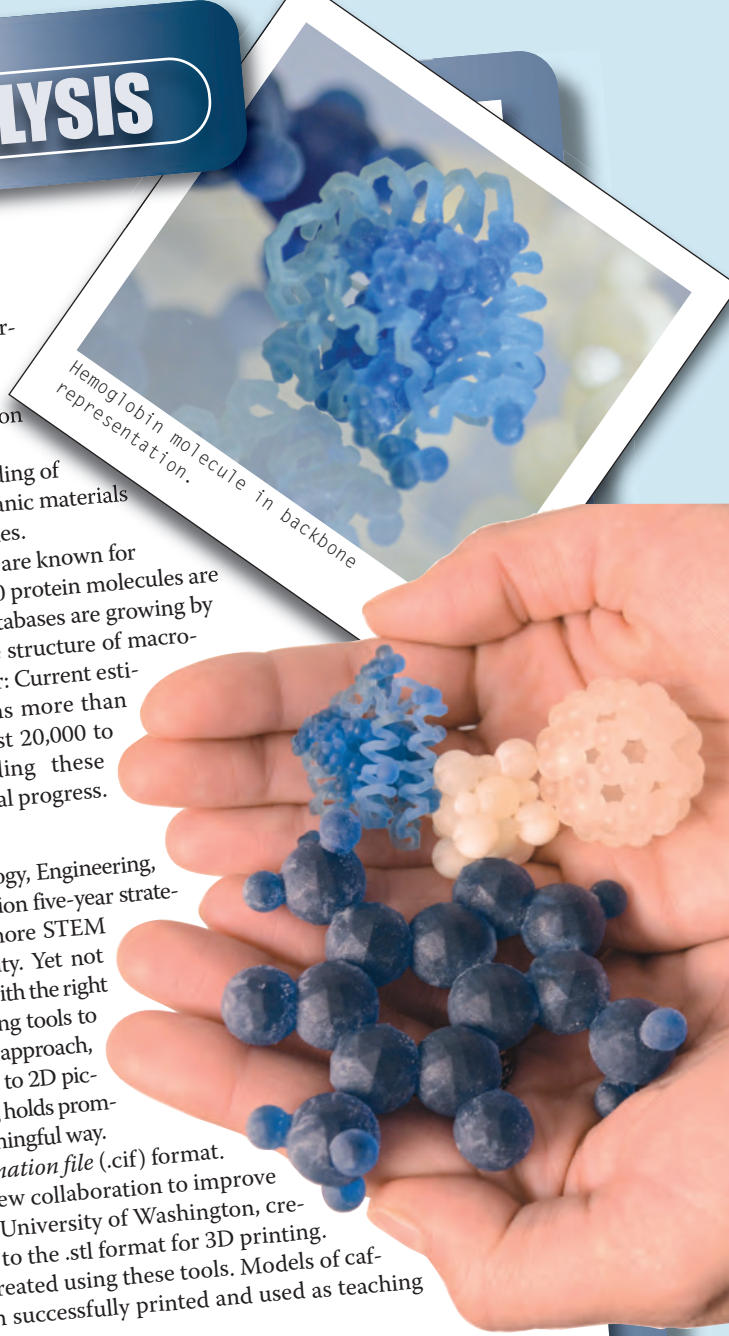
Approximately 900,000 atomic structures are known for inorganic materials, while only about 100,000 protein molecules are currently defined. Major crystallographic databases are growing by 50,000 entries per year and determining the structure of macromolecules is today's critical research frontier: Current estimates state that the human body contains more than two million types encoded by just 20,000 to 25,000 genes, and understanding these structures is vital to future medical progress.

Success Factors:

The federal Science, Technology, Engineering, and Mathematics (STEM) education five-year strategic plan states that generating more STEM professionals is a national priority. Yet not enough students are graduating with the right skills to fill available positions. Part of the problem is a lack of teaching tools to keep scientific concepts interesting and relevant for students. As one approach, hands-on physical models are proven to enhance learning compared to 2D pictures of complex 3D information. As a disruptive method, 3D printing holds promise for communicating spatial information in a memorable and meaningful way.

Crystallographic data is created in the *crystallographic information file* (.cif) format. However, this file format is not widely accessible. As part of a new collaboration to improve the situation, Werner Kaminsky, a staff crystallographer at the University of Washington, created programs that can read .cif file information and convert it to the .stl format for 3D printing. Numerous molecular models of crystal structures have been created using these tools. Models of caffeine, salt, sugar, aspirin, nicotine, and beer hops have all been successfully printed and used as teaching aids, as well as more complex structures such as myoglobin.

These models are being displayed at numerous conferences including the grand opening of the International Year of Crystallography in Place de Fontenoy, Paris, and the recent STEM Expo in Washington.



Hemoglobin molecule in backbone representation.

Handful of 3D printed crystallography pieces. All models shown here were made using the ProJet 3500 3D printer from 3D Systems.

About the Innovators:

Peter Moeck, an applied crystallographer, studied in Leipzig and Berlin and is now at Portland State University's physics department. Werner Kaminsky studied at the Institut für Kristallographie and is now a research professor and staff crystallographer at the University of Washington. Trevor Snyder, who studied at Washington State University, worked on 2D printer development for Tektronix and Xerox and is now principal scientist for 3D Systems Inc. Jennifer Stone-Sundberg studied at Oregon State University and is now working with Portland State University on projects related to crystal growth and science education.

What's Next:

The collaborators are now focusing on three main objectives: Organizing files into a worldwide database; developing educational modules to supplement 3D printed molecules for K-16 learning; and making these models and modules available for all fields of study—including art, science, math, and physics—for all education levels.

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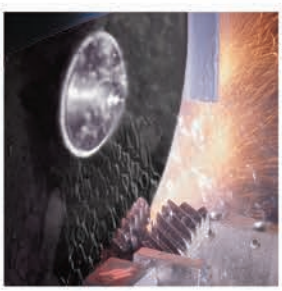
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