SEPTEMBER 2020 | VOL 178 | NO 6

ADVANCED MATERIALS & PROCESSES

NONDESTRUCTIVE TESTING

MICROWAVE NDT INSPECTION TECHNIQUES

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ASM INTERNATIONAL

UPCOMING EVENTS 2021

Staying current is key to staying relevant, so ASM Conferences and Expositions cover the latest trends and developments in industries like heat treating, thermal spray, shape memory alloys, aerospace materials, and more.

SMST May 17 - 21, 2021 | San Diego, CA

SMST is the leading worldwide conference and exposition for shape memory and superelastic technologies and is highly focused on the manufacturing and application of shape memory materials. The event is part of ASM's Shape Memory and Superelastic Technologies Society.

AeroMat May 24 - 26, 2021 | Quebec City, Canada

AeroMat focuses on innovative aerospace materials, fabrication, and manufacturing methods that improve performance, durability, and sustainability of aerospace structures and engines with reduced life-cycle costs. Co-located with ITSC.

ITSC May 24 - 27, 2021 | Quebec City, Canada

ITSC is the world's foremost international conference and exhibition for thermal spray technologists, researchers, manufacturers, and suppliers. This conference rotates between North America, Europe, and the Pacific Rim and is organized by the ASM Thermal Spray Society, the German Welding Society (DVS), and International Institute of Welding (IIW). Co-located with AeroMat.

IMAT September 13 - 16, 2021 | St. Louis, MO

IMAT, ASM's annual meeting, is the only targeted event on advanced materials, applications, and technologies in key growth markets that will have a focus on economic trends and business forecasts. The event will include a diverse group of materials experts, including the ASM Programming Committees, AeroMat Committee, and all six of ASM's Affiliate Societies, who are heavily involved in building the technical symposiums, which will have a strong focus on real-world technologies that can be put to use today. Co-located with Heat Treat.

Heat Treat September 14 - 16, 2021 | St. Louis, MO

Heat Treat, the biennial show from the ASM Heat Treating Society, is considered the premier, can't-miss event for heat treating professionals in North America. Heat Treat features an exciting mix of new technology, exhibits, technical programming, and networking events geared toward the heat treating industry. Co-located with IMAT.

ISTFA October 31 - November 4, 2021 | Phoenix, AZ

ISTFA is the only North American event devoted to the semiconductor, electronic sample preparation, and imaging markets. ISTFA offers the best venue for failure analysts and the FA community for sharing challenges and acquiring the technical knowledge and resources needed to take them on. The event is part of ASM's Electronic Device Failure Analysis Society.

ASM Global Materials Summit December 7 - 9, 2021 | Naples, FL

ASM Global Materials Summit is a unique opportunity to connect with visionaries in the materials community in an interactive environment about the future of the materials world. This exclusive (invitation-only) FASM and senior-level event will provide a platform for our distinguished leaders to have meaningful discussions and develop tangible solutions to the biggest challenges facing the materials community.

Learn more:
asminternational.org

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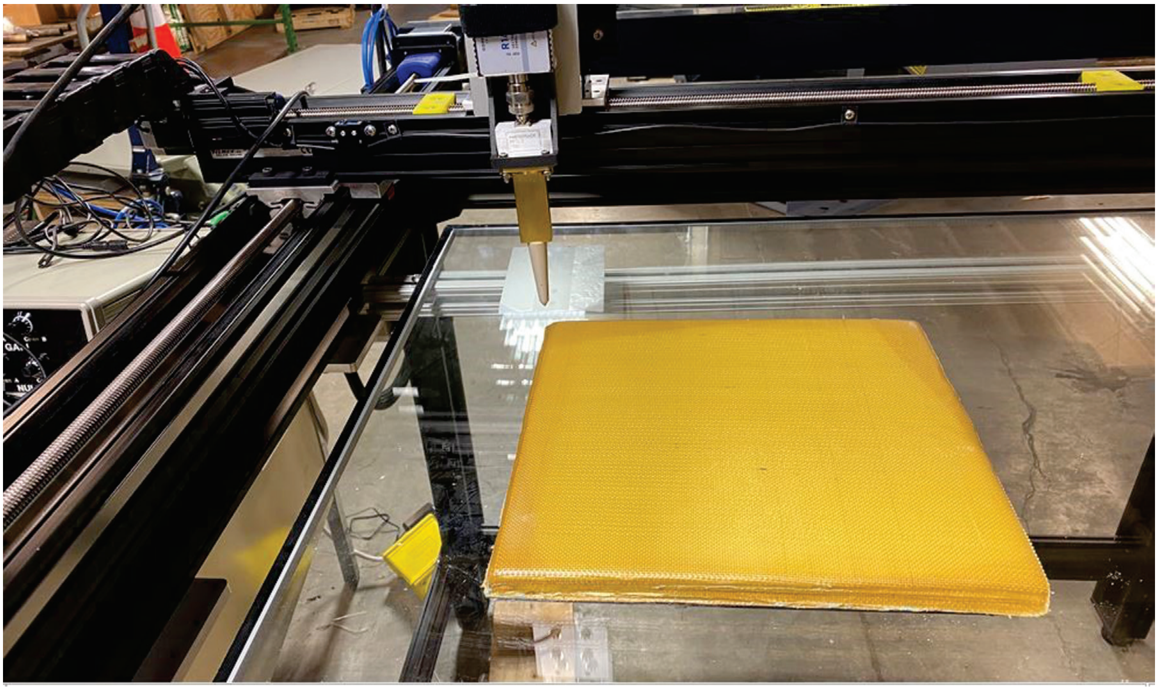
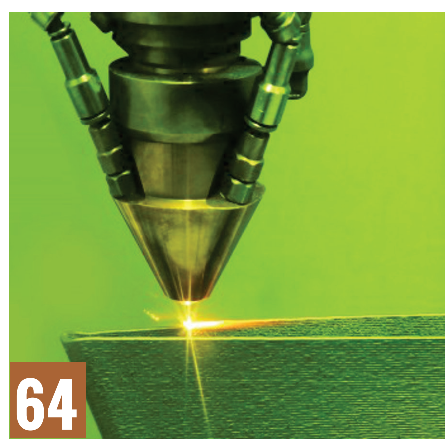


On the Cover:

Multicolored weathering of 100-year-old historic Monel on the south stairs at Bryn Athyn Cathedral, Pa. Courtesy of James E. Churchill.



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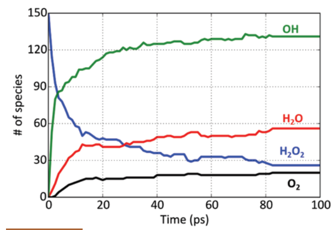
FEATURES



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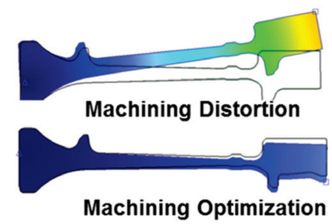

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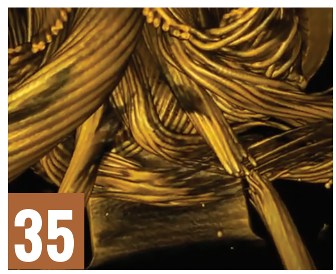

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ADVANCED MATERIALS & PROCESSES

ASM International
9639 Kinsman Road, Materials Park, OH 44073
Tel: 440.338.5151 • Fax: 440.338.4634

Joanne Miller, *Editor*
joanne.miller@asminternational.org

Victoria Burt, *Managing Editor*
vicki.burt@asminternational.org

Frances Richards and Corinne Richards
Contributing Editors

Jan Nejedlik, *Layout and Design*

Kelly Sukol, *Production Manager*
kelly.sukol@asminternational.org

Press Release Editor
magazines@asminternational.org

MAKING CONNECTIONS

This summer saw the sad passing of Ed Kubel, ASM member, retired staff person, former chief editor of *AM&P,* and most recently, a contributing editor to this publication and several ASM handbooks. He was a dear colleague, mentor, and friend. For more than 20 years, Ed positively impacted the content development of ASM's magazines, technical books, and conferences. For a glimpse into his accomplishments, see the "In Memoriam" page of ASM News.

In his last *AM&P* editorial in May 2013, Ed stated, "One of the things I will miss most is dealing with authors from all over the world to bring the results of their work to the attention of the readers of *AM&P* and the engineering community in general."

Like Ed, I enjoy working with our wide array of authors. I also relish connecting like-minded members. An obvious opportunity came to mind while working on this issue.

I made introductions via email between James Churchill, author of the "Historic Monel" article, and Donald Tillack, featured in our "Members in the News" section for receiving an American Welding Society award. Tillack is an ASM Fellow who developed the composition of bare wire Monel Filler Metal 60 back in the 1960s. To my delight, both gentlemen were eager to communicate with each other and quickly started dropping names of who each knew in the industry. Despite being at opposite ends of the career spectrum, their shared enthusiasm for the topic created a new professional weld.

These types of connections seem to happen organically at technical events. However, even without the in-person networking events of IMAT 2020, there are many other opportunities to grow these vital connections that help individuals develop professionally and advance technical research in key areas.

First, visit the ASM website for details on the new event, IMAT: The Virtual Edition, October 26-28, which will offer previews of 2021 technical content. In addition to technical sessions, there will be multiple ways to network with global attendees via live chats, online messaging, a virtual exhibit hall, digital conference lounge, and more. Take advantage of this unique way to keep up with industry trends and continue to build your professional network.

Second, members now have the benefit of a robust networking platform in ASM Connect. In an article in this issue, "Residual Stress: Both Friend and Foe," Dave Furrer, FASM, describes how ASM Connect is being used to draw members together into technical communities. Just completing his year as ASM's immediate past president, Furrer explains how the topic of residual stress was used to pilot the first official ASM Technical Committee. He invites members to join that committee or propose the formation of others around specific technical areas.

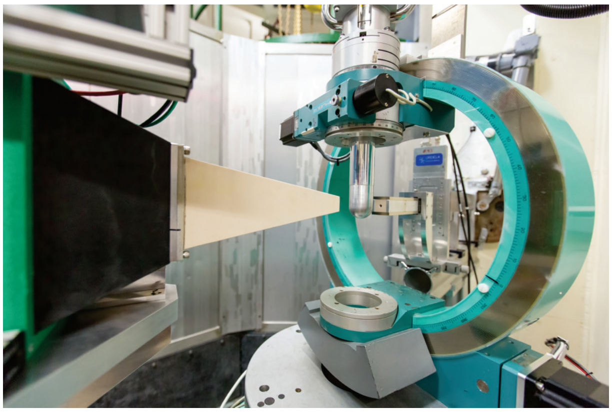
Likewise, Ray Fryan, in his article on the development of ASM's data ecosystem on page 58, is leveraging ASM Connect to gather members with a passion for materials data to join in advancing this important society initiative.

Ed Kubel's pastime was golf, perennially considered the ultimate networking sport. Ed signed off his last editorial this way, "It will be odd not having deadlines looming and content to produce, but it should make golfing that much more enjoyable." Ed, I hope you're making some good connections up there.

Joanne Miller

joanne.miller@asminternational.org

RESEARCH TRACKS



Researchers performed single-crystal neutron diffraction using the HB-3A four circle diffractometer to confirm the first intrinsic ferromagnetic topological insulator. Courtesy of Genevieve Martin/ORNL.

NEUTRONS VERIFY NEW TOPOLOGICAL MATERIAL

A team led by researchers at the University of California, Los Angeles recently discovered the first intrinsic ferromagnetic topological insulator—and the scientists have now used neutrons at the DOE's Oak Ridge National Laboratory (ORNL), Tenn., to help verify their finding. Topological insulators act as insulators on the inside while allowing electrons to flow across their surfaces. Their ferromagnetic counterparts are not as well known, but are thought to hold useful properties for quantum technology.

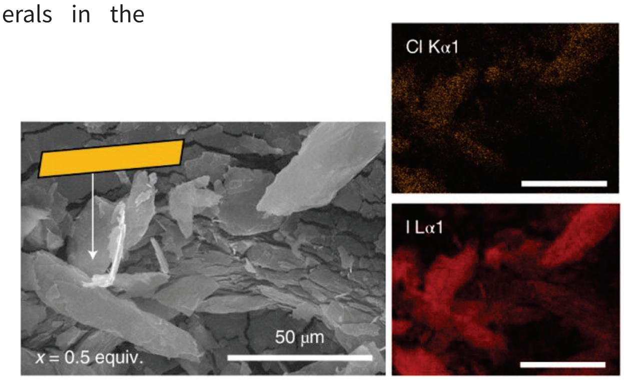
The researchers discovered the new topological insulator—consisting of manganese, bismuth, and tellurium atoms—by stacking ferromagnetic molecular layers. To confirm the material's intrinsic nature, they used the High Flux Isotope Reactor at ORNL. "Neutron diffraction's high contrast can distinguish magnetic manganese atoms from others," says ORNL's Huibo Cao, co-author on the study. "It is well-suited for the new two-dimensional material and its magnetism." *ucla.edu, ornl.gov.*

SCIENTISTS FINE-TUNE HYBRID PEROVSKITES

Researchers from MIT, Cambridge, Mass., and Northwestern University, Evanston, Ill., worked together to fine-tune the electronic properties of hybrid perovskite materials. The materials are considered hybrid because they contain inorganic components like metals, plus organic molecules with elements such as carbon and nitrogen, organized into nanoscale layers. The team showed that by varying the composition of the organic layers, they could tune the color of light absorbed by the perovskite as well as the wavelength at which the material emitted light. "Until now, most experimental and theoretical evidence indicated that the organic layers simply act as inert spacers whose only role is to separate the electronically active inorganic layers," says Professor Will Tisdale of MIT. "These new results show that we can teach the organic layer to do much more."

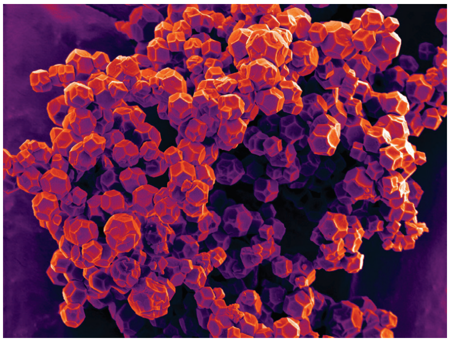
Perovskites, first discovered as naturally occurring minerals in the Ural Mountains nearly 200 years ago, have been thoroughly investigated after it was determined they could turn light into usable electricity. However, perovskite solar cells are far less durable and stable than silicon-based versions in outdoor conditions due to their sensitivity to heat and moisture. Scientists recently found that splitting the traditional 3D structure of perovskites into many thin layers—ranging from a few atoms to dozens—improves stability and performance. In layered perovskites, the inorganic layer absorbs light and produces charges that are required to produce electrical energy. The organic layers are typically insulating and act like walls, preventing the light-generated charges from moving out of the inorganic layer.

The Northwestern-MIT collaboration began after a chance encounter at a 2018 conference. The Stupp laboratory at Northwestern had previously performed pioneering work on the synthesis of inorganic-organic hybrid materials for potential applications in energy and medicine, while MIT's Tisdale group specializes in using lasers to probe the properties of nanomaterials. These interests overlapped perfectly, as the Stupp group developed the hybrid perovskite structures and the Tisdale group performed the spectroscopic measurements necessary to confirm the interactions within the systems. In the future, the ability to fine-tune the electronic properties of these materials could be applied to various optical or electronic sensors as well as solar cells and light detectors. *web.mit.edu, northwestern.edu.*



Left: Scanning electron microscope image of film fragments. Right: Elemental mapping indicates creation of hybrid perovskites. Courtesy of MIT.

MACHINE LEARNING | AI



Crystalline MOF. Courtesy of David Fairen-Jimenez.

PROBING POROUS MATERIALS WITH MACHINE LEARNING

A group of international researchers led by a team at the University of Cambridge, U.K., recently used machine learning techniques to accurately predict the mechanical properties of metal organic frameworks (MOFs), which could be useful in applications from storing dangerous gases to powering hydrogen-based cars. The scientists used their machine learning algorithm to predict the properties of thousands of existing MOFs, as well as those yet to be synthesized in the laboratory. Their results could significantly speed up the way materials are characterized and designed at the molecular scale.

The crystalline structure of MOFs means that they can be made like building blocks, where individual atoms or molecules can be switched in or out of the structure, a level of precision not possible with materials such as plastics. The structures are highly porous with massive surface area: An MOF the size of a sugar cube laid flat would cover an area the size of six football fields. In addition, they make highly effective storage devices. The pores in any given MOF can be customized to form a perfectly-shaped storage pocket for different molecules, just by changing the building blocks. MOFs are synthesized in powder form, then put under pressure and formed into larger pellets. Due to their porosity, many MOFs are destroyed in the process.

To address this problem, an algorithm was developed to predict the mechanical properties of MOFs, so that only those with the necessary mechanical stability are manufactured. The researchers used a multi-level computational approach to build an interactive map of the structural and mechanical landscape of MOFs. First, they used high-throughput molecular simulations for 3385 MOFs. Then they developed a free machine learning algorithm to automatically predict the mechanical properties of existing and future MOFs, along with an interactive website where other scientists can design and predict the performance of their own versions. *www.cam.ac.uk.*

SCIENTIFIC MACHINE LEARNING TAKES OFF

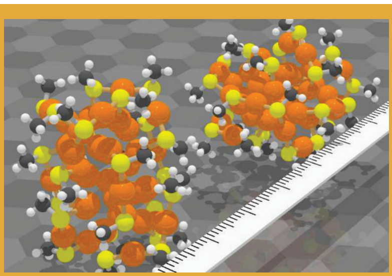
To address challenges involved in jet engine design, researchers at The University of Texas at Austin (UT) are developing *scientific machine learning*, a new field that blends scientific computing with machine learning. By combining physics modeling and data-driven learning, it is possible to create reduced-order models—simulations that can run in a fraction of the time required by traditional methods.

The new technique has been applied to a combustion code used by the Air Force known as General Equation and Mesh Solver (GEMS). The UT group received "snapshots" generated by running the GEMS code for a particular scenario that modeled a single injector of a rocket engine combustor. These snapshots represent pressure, velocity, temperature, and chemical content in the combustor and serve as the training data from which the researchers derive the reduced-order models. Generating that training data in GEMS takes about 200 hours of computer processing time. Once trained, the reduced-order models can run the same simulation in seconds, as well as simulate into the future. Although not perfect, the models are particularly effective at capturing the phase and amplitude of the pressure signals, key elements for making accurate engine stability predictions. *utexas.edu.*

Researchers are developing a faster modeling technique to test jet engine performance under various conditions.

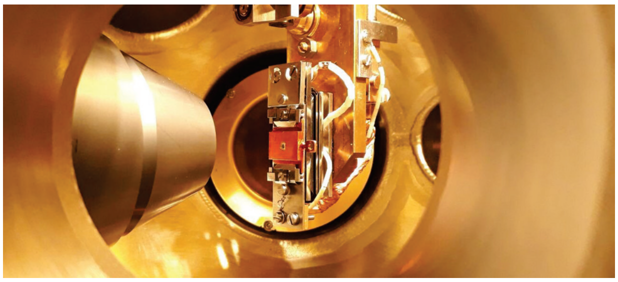
BRIEF

Researchers at the **University of Jyväskylä,** Finland, developed distance-based machine learning methods capable of reliably predicting the structures and atomic dynamics of nanoparticles. The new techniques should facilitate more efficient explorations of particle-particle reactions. *www.jyu.fi/en.*



Thiol-covered gold nanoparticles. Courtesy of Antti Pihlajamäki.

METALS | POLYMERS | CERAMICS



A sample of tungsten ditelluride in an ultrahigh vacuum chamber. Courtesy of AG Bauer.

STUDYING TUNGSTEN DITELLURIDE IN REAL-TIME

For the first time, physicists at Kiel University (CAU) in cooperation with researchers at the Max Planck Institute for Chemical Physics of Solids (MPI-CPfS), both in Germany, Tsinghua University in Beijing, and Shanghai Tech University, have observed changes to the electronic properties of tungsten ditelluride in real-time experiments. Using laser pulses, they put the atoms in a sample of tungsten ditelluride into a state of controlled excitation and were able to follow the resulting changes in the electronic properties using high-precision measurements.

"If these laser-induced changes can be reversed again, we essentially have a switch that can be activated optically, and which can change between different electronic states," explains CAU professor Michael Bauer. Such a switching process has already been predicted by another study, in which researchers from the U.S. were able to directly observe the atomic movements in tungsten ditelluride.

Some of the electrons in tungsten ditelluride are highly mobile, so they are excellent information carriers for electronic applications. This is because they behave like so-called Weyl fermions, say researchers. Weyl fermions are massless particles with special properties that have previously only been observed indirectly as quasi-particles in solids like tungsten ditelluride. To capture the minute changes in the electronic properties, a highly sensitive experimental design, extremely precise measurements, and extensive data analysis were required. Follow-up research aims to explore whether such electronic switching processes can be triggered even faster—directly by the irradiating laser pulse—as has already been predicted for other topological materials. *www.uni-kiel.de.*

FIRST NON-CUTTABLE MATERIAL DEBUTS

Researchers at Durham University in England and Germany's Fraunhofer Institute developed a material they call "Proteus" that they say is the first manufactured uncuttable material. The compound is made of porous aluminum and ceramic, so it is lighter than steel but will withstand any grinder. The team reports that Proteus resists cutting by turning the cutting tools against themselves and dulling them. The material is comprised of an aluminum matrix, or foam, embedded with ceramic spheres. It is 15% less dense than steel, making it well suited in applications such as lightweight armor.

As the cutting tool bites into the aluminum, it suffers extreme vibrations when it hits the ceramic spheres. This resonance causes the tool to start bouncing, thereby dulling its cutting edge. Further, as the ceramic is hit, fine dust particles fill in the matrix. The interatomic forces between the grains

Proteus is currently patent-pending and the team's goal is to commercialize the material. Courtesy of Fraunhofer Institute.

BRIEFS

NewAge Industries Inc., Southampton, Pa., a manufacturer of plastic and rubber tubing, announced a significant expansion near its headquarters about 25 miles north of downtown Philadelphia. The company purchased two buildings featuring 46,000-sq-ft of production space and another 3000-sq-ft of office space. *newageindustries.com.*

Yajima Industry Company Ltd., Japan, a manufacturer of automotive and aerospace components and supplier to Subaru of Indiana Automotive Inc., will establish Yajima USA in **Purdue Research Park** in West Lafayette, Ind. The new location will focus on lightweight components that take advantage of carbon fiber-reinforced polymer composites and noncombustible magnesium alloy parts. *purdue.edu.*

increase proportionately to the amount of energy applied, making the material even harder the faster the tool spins.

Proteus is effective against angle grinders, drills, other conventional cutting tools and even high-pressure water jet cutters. The researchers see possible applications in the safety and security industries. For example, armored vehicles could be stronger and lighter and locks could prove impenetrable by cutting tools. The material could also be used to make protective equipment for personnel who use cutting tools. *www.dur.ac.uk.*

MAKING COMPOSITES FROM NEW RAW MATERIALS

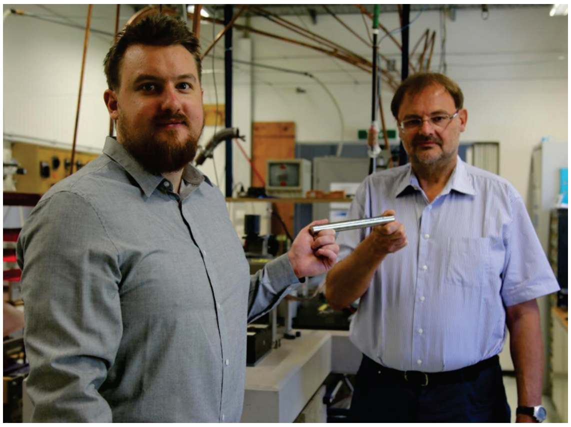
Materials scientists from the National University of Science and Technology (NUST MISIS), Moscow, developed a novel method to produce aluminum matrix composites from new raw materials—leading to promising composite powders for 3D printing of light, durable cases for aircraft and automotive engineering. The new technique increases the uniformity of properties and hardness of the obtained 3D-printed composites by 40% in comparison with analogs.

Aluminum matrix composites are lightweight, have high strength low thermal expansion coefficient, and excellent wear resistance, with applications in the automotive, aerospace, and defense industries. Their properties are due in part to a special method of production—3D printing using selective laser melting (SLM) technology. The resulting composite consists of spherical aluminum particles hardened with ceramic additives or coated with a layer of aluminum oxide.

An advantage of this method is the high activity of the powder particles and uniformity of their properties, which cannot be achieved using alternative methods, like introducing ceramic fillers into molten aluminum. *www.en.misis.ru.*

Alexander Gromov, professor at NUST MISIS, heads up the aluminum project. Courtesy of Sergey Gnuskov/NUST MISIS.

TESTING | CHARACTERIZATION



Small balls cut from a steel rod, like the one shown, are now being examined on the ISS. Courtesy of Baustädter/TU Graz.

STUDYING STEEL ON THE SPACE STATION

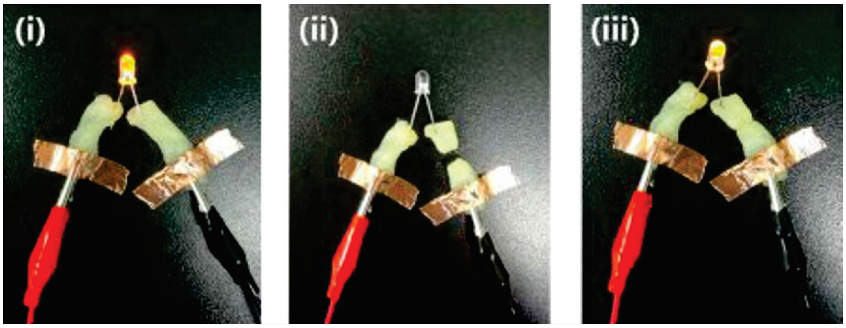
For many years, the Institute of Experimental Physics at Graz University of Technology and the industrial company Böhler Edelstahl, both in Austria, have conducted research on the surface tension and temperature dependence of different types of steel. Conventional examination methods only work up to a certain upper temperature limit. At higher temperatures, problems can occur with the sample container that can then affect measurement results.

For the experiments, the Austrian team is working with several Japanese and American researchers using the Electrostatic Levitation Furnace (ELF). The furnace is an experimental setup of the Japanese Aerospace Exploration Agency (JAXA) in the experiment module Kibo on the International Space Station. The sample is fed into the experimental unit where a laser heats and melts the floating steel sample. Next, sensors measure the density, surface tension, and viscosity of the molten material. When the material cools, the researchers can observe and measure this process as well. The experiment is controlled from Earth, where the team follows the event live while the data is obtained and passed down. Later this year, the L331 steel sample will be examined again in zero gravity onboard a reduced-gravity aircraft. *www.uni-graz.at/en.*

SELF-HEALING STRAIN SENSOR

Researchers at Fudan University, Tongji University, and the Chinese Academy of Sciences, all in China, developed a new strain sensor that is highly stretchable, efficient, and sensitive to motion-related changes in its environment. The sensor also features self-healing abilities, as it is made of an ionic and conductive poly(acrylamide) (PAAm) hydrogel and can quickly repair itself when torn or damaged.

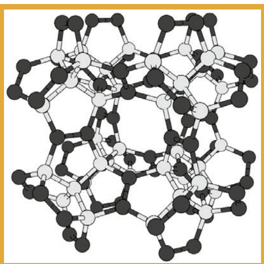
The new sensor can monitor human motions in real time. When combined with silicon integrated circuits, it can then transfer data directly to a smartphone or other device via Bluetooth. To demonstrate its wireless capabilities, the researchers wired one of their sensors to a printed circuit board, attached it to a human joint, and used it to record motion data. The sensor can also be used to create technology that recognizes human gestures. For example, the team fabricated a smart glove that integrates five of their sensors on each finger to record information about a person's hand motions. It can also be used to wirelessly control a robotic hand, by performing the desired hand gestures while wearing the glove. The sensing device shows great potential for applications such as human-machine interfaces, interactive robots, health monitoring systems, and fitness trackers. *www.fudan.edu.cn/en.*



A sensor's motion capabilities are tested by researchers. Courtesy of Hang, et al.

BRIEF

Researchers at the **University of Tsukuba,** Japan, used computer calculations to design a carbon-based material they call "pentadiamond" that is harder than diamond. The new structure has the potential to replace synthetic diamonds in difficult cutting applications. *www.tsukuba.ac.jp/en.*



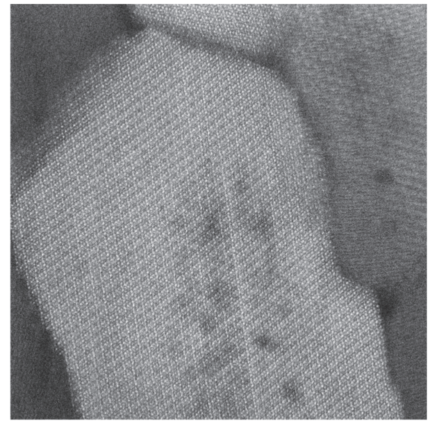
Geometric structure of pentadiamond. Courtesy of University of Tsukuba.

SCIENTISTS STUDY HUMAN ENAMEL

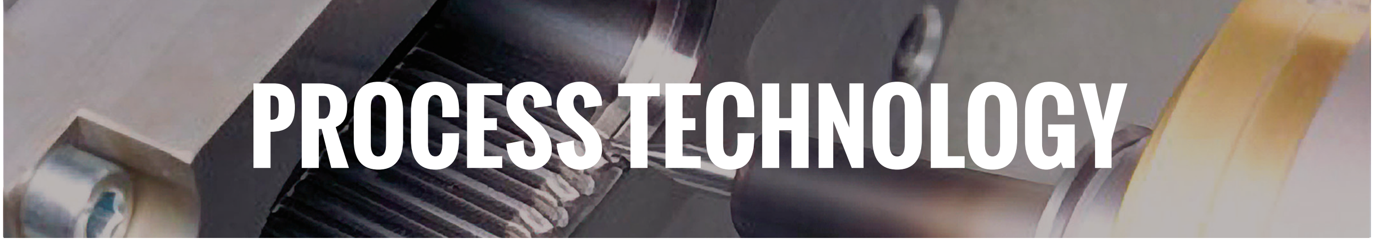
In a new study of human enamel, materials scientists at Northwestern University, Evanston, Ill., identified a small number of impurity atoms that may contribute to strength, but also make enamel more soluble. The team is also the first to determine the spatial distribution of the impurities with atomic-scale resolution. The discovery about the building blocks of enamel, with detail down to the nanoscale, could lead to a better understanding of human tooth decay.

One obstacle hindering enamel research is its complex structure, which consists of a 3D weave of rods. Each rod, approximately 5 microns wide, is made up of thousands of individual hydroxylapatite crystallites. These nanoscale crystallites are the fundamental building blocks of enamel. Perhaps unique to human enamel, the center of the crystallite seems to be more soluble. The researchers set out to test if the composition of minor enamel constituents varies in single crystallites.

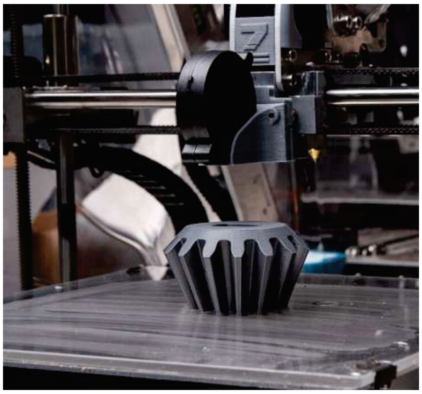
Using quantitative atomic-scale techniques, the team discovered that human enamel crystallites have a core-shell structure. Each crystallite has a continuous crystal structure with calcium, phosphate, and hydroxyl ions arranged periodically (the shell). However, at the center, more of these ions are replaced with magnesium, sodium, carbonate, and fluoride (the core). Within the core, two magnesium-rich layers flank a mix of sodium, fluoride, and carbonate ions. Detecting and visualizing the sandwich structure required scanning transmission electron microscopy at cryogenic temperatures (cryo-STEM) and atom probe tomography (APT). The team found strong evidence that the core-shell architecture and resulting residual stresses impact the dissolution behavior of human enamel crystallites. *northwestern.edu.*



An atomic resolution STEM image of an enamel crystallite in which dark areas show magnesium ions forming two layers on either side of the core. Courtesy of Northwestern University.



PROCESS TECHNOLOGY



New methods for the development of powder composites are efficient while also reducing waste. Courtesy of Pixabay/CC0 Public Domain.

NEW DESIGN FOR MIXING POWDER COMPOSITES

Researchers from South Ural State University, Russia, developed a new method for creating powder metal composites while reducing waste and improving the quality of electrical products. The process is expected to increase the economic efficiency of production by 30%.

The scientists introduced a new design for a mixing machine that makes composite powder based on graphitoplast compositions and coke pitch. The new machine and associated method produce a high-quality blend and increase material use up to 98%. The novel method improves the quality of finished raw materials for the subsequent pressing process and could reduce waste in the fields of nuclear energy, metallurgy, electric transport, as well as the aviation and space industries.

The team of scientists believes that companies involved in the production of mixing machines might be interested in these developments, as they increase the efficiency of the equipment due to less waste when mixing, improve the quality of the finished blend, and simplify the design of mixing machines. In the future, the researchers plan to create high-entropy powder blends, which could be useful in powder metallurgy and additive manufacturing applications. *www.susu.ru/en.*

CREATING 3D HETEROSTRUCTURED MATERIALS

In collaboration with Iowa State University researchers, scientists from the DOE's Ames Laboratory developed a new approach for generating layered, heterostructured solids that could open new avenues for electronic and energy applications. These materials, composed of layers of dissimilar building blocks, display unique electronic transport and magnetic properties that are governed by quantum interactions between their structurally different building blocks.

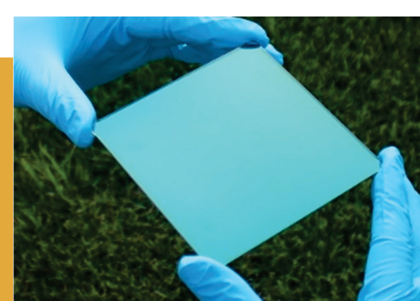
The technique for making them is simple yet counterintuitive: It involves smashing the pristine materials to build new ones. Called mechanochemistry, the technique uses ball milling to take apart structurally incommensurate solids—ones that do not have matching atomic arrangements—and reassembles them into unique 3D "misfit" hetero-assemblies.

As one example, the team worked with metal chalcogenides, which are often unique in their properties and uses. They can display significant electron transport behaviors ranging from complete lack of electrical conductivity to superconductivity, photoelectric and thermoelectric properties, mechanical pliability, and perhaps most important, the ability to form stable 2D monolayers, 3D heterostructures, and other nano-scaled quantum materials.

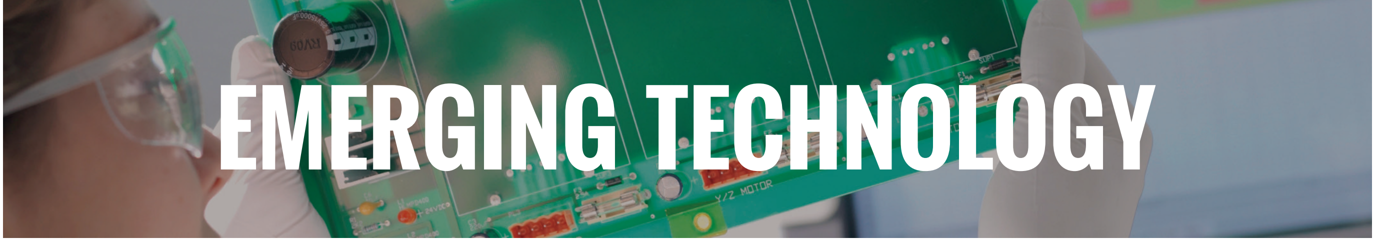
Typically, these complex materials, especially ones with the most unusual structures and properties, are made using two different synthetic approaches—top-down synthesis and the broadly defined bottom-up synthesis. The Ames team combined these two methods into one mechanochemical process that simultaneously exfoliates, disintegrates, and recombines starting materials into new heterostructures even though their crystal structures do not fit each other well. Theoretical calculations, supported by the results of x-ray diffraction, scanning transmission electron microscopy, Raman spectroscopy, electron transport studies and, for the first time ever, solid state nuclear magnetic resonance experiments, explained the mechanism of the reorganization of precursor materials. These calculations also help explain the driving forces behind the formation of novel 3D heterostructures during mechanical processing. *ameslab.gov, iastate.edu.*

BRIEF

Scientists at **Ningbo Institute of Materials Technology and Engineering,** China, developed a novel direct growth method of vertically orientated nanocavity arrays to generate plasmonic structural colors, which feature wide gamut, improved color saturation, excellent stability in ambient condition, and mass-production scalability. *english.nimte.cas.cn.*



Plasmonic structural color sample.



EMERGING TECHNOLOGY

Programmable balloons could pave the way for new shape-morphing devices. Courtesy of Bertoldi Lab/Harvard SEAS.

DESIGNING SHAPE-MORPHING DEVICES

Research out of Harvard's John A. Paulson School of Engineering and Applied Sciences (SEAS), Cambridge, Mass., provides a new platform for the design and application of shape-morphing devices. Scientists designed materials that can control and mold a balloon into preprogrammed shapes using kirigami sheets—thin sheets of material with periodic cuts—embedded into an inflatable device. As the balloon expands, the cuts in the sheet guide the growth, permitting expansion in some places and constricting it in others. The researchers were able to control the expansion not only globally to make large-scale shapes but also locally to generate small features.

The team also developed an inverse design strategy, an algorithm that finds the optimum design for the kirigami inflatable device that will mimic a target shape upon inflation. An individual cut on a sheet contributes to the larger shape of the balloon, much like a pixel helps form an image on a 2D surface. The researchers found that by tuning the geometric parameters of these cuts, they could control and embed complex shapes. To demonstrate this, they programmed a balloon to mimic the shape of a squash complete with the characteristic bumps and ridges along the side.

Next, the researchers aim to use these kirigami balloons as shape-changing actuators for soft robots. The work lays a foundation for the design of structures at multiple scales, from micro minimally invasive surgical devices to macro structures for space exploration. *seas.harvard.edu.*

WORLD'S LIGHTEST SHIELDING MATERIAL

Researchers at Empa, Switzerland, are using cellulose nanofibers as the basis of a new aerogel. The work produced a composite of cellulose nanofibers and silver nanowires, creating ultralight fine structures that provide excellent shielding against electromagnetic radiation. The effect of the material is significant—it intercepts virtually all radiation in the frequency range of high-resolution radar radiation.

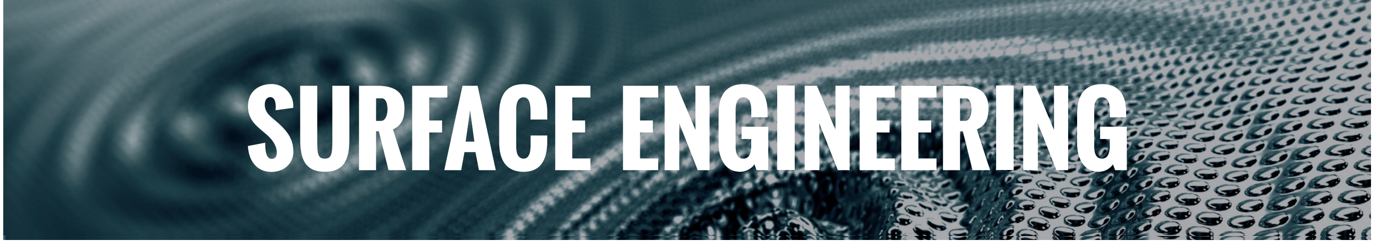
The correct composition of cellulose and silver wires in addition to the material's pore structure is essential to the shielding effect. Within the pores, the electromagnetic fields are reflected back and forth and trigger electromagnetic fields in the composite material, which counteract the incident field. To create pores of optimum size and shape, the researchers pour the material into precooled molds and allow it to freeze out slowly. The growth of the ice crystals creates the optimum pore structure for damping the fields.

With this production method, the damping effect can be specified in different spatial directions. Shielding structures cast in this way are highly flexible. Even after being bent back and forth a thousand times, the damping effect is practically the same as with the original material. The desired absorption can be easily adjusted by adding more or less silver nanowires to the composite as well as by the porosity of the cast aerogel and the thickness of the cast layer. In relation to the weight of the material, no other material can achieve such shielding. This ranks the titanium carbide nanocellulose aerogel as by far the lightest electromagnetic shielding material in the world. *www.empa.ch/web/empa.*

A sample of Empa's electromagnetic shielding material—a composite of cellulose nanofibers and silver nanowires.

BRIEF

Norman Noble Inc., Highland Heights, Ohio, started improvements on a new 50,000-sq-ft facility at its headquarters. The facility will provide additional manufacturing space to meet medical OEM customers' growing requirements for products, including Nitinol-based structural heart implants and neurovascular devices as well as multileaf collimator assemblies used in cancer radiation therapy equipment. The new space is scheduled to be operational in late 2020. *nnoble.com.*



SURFACE ENGINEERING

Candida albicans.

POLYMER COATING PREVENTS FUNGI

All over the world, fungi cause diverse and significant socioeconomic problems—globally, $30 billion is spent each year in the fungicide industry. Now, scientists from the U.K.'s University of Nottingham developed a new way to control harmful fungi without using chemical bioactives such as antifungals. The innovative solution passively blocks fungal attachment to surfaces using a coating of methacrylate polymers, eliminating the need to use potentially harmful chemicals.

Through previous work, the team found different combinations of fungicides that worked against fungi and produced new understanding of preservative action against spoilage fungi. Potential bioactive-free technologies for combatting fungi are increasingly attractive to the industry as regulations and restrictions continue to tighten and public resistance grows against chemically based strategies.

For their alternative fungal control method, the scientists identified polymers that resist the attachment of different kinds of fungi, including pathogens. Specific chemical features of the methacrylate polymers such as their nontoxic nature were associated with weak fungal attachment. A similar approach against bacterial pathogens is also being developed for a catheter coating to prevent infections in patients. The scientists say their work is the first high-throughput study of polymer chemistries resisting fungal attachment. *www.nottingham.ac.uk.*

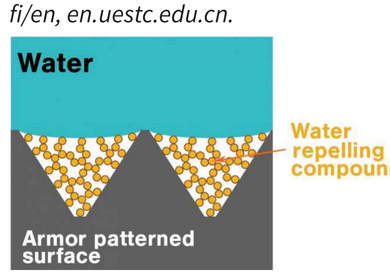
ARMOR-PLATED MATERIAL REPELS WATER

A collaboration between researchers in Finland and China produced an armor-plated superhydrophobic surface that can take repeated damage from sharp and blunt objects while repelling liquids with world-record effectiveness. The team designed superhydrophobic surfaces that can be made of metal, glass, or ceramic. Nanosized structures covering the surfaces—in a honeycomb-like pattern with tiny inverted pyramids—enable the superhydrophobic properties after a fragile water-repellent chemical is coated within the tiny structures. This prevents any liquid from sticking to the surface, and the fragile chemical coating is protected from damage by the pyramids' walls.

"The armor can be made from almost any material," the scientists say. "It's the interconnection of the surface frame that makes it strong and rigid."

As well as their useful antimicrobial properties for biomedical technology, superhydrophobic surfaces can also be used more generally in any application requiring a liquid-repellent surface. One example is photovoltaics, where the buildup of moisture and dirt over time blocks the amount of light they can absorb, which reduces electricity production. Making a solar panel out of a superhydrophobic glass surface would maintain their efficiencies over long periods of time. Further, as solar cells are often on roof tops and other difficult to reach locations, the repellent coatings would cut down the amount of cleaning that is needed.

Other desirable applications for superhydrophobic surfaces include machines and vehicles, where conditions can be very tough for brittle materials for long periods of time. To simulate these working environments, the researchers subjected their new surfaces to extreme conditions, including baking them at 100°C nonstop for weeks, immersing them in highly corrosive liquids for hours, blasting them with high-pressure water jets, and subjecting them to physical exertion in extreme humidity. The surfaces were still able to repel liquid as effectively as before. *www.aalto.fi/en, en.uestc.edu.cn.*



A depiction of how a superhydrophobic material repels water. Courtesy of Aalto University.

BRIEF

Curtiss-Wright's Surface Technologies Division, Paramus, N.J., reports that its Microseal impingement lubricant coating process has been utilized on numerous components on NASA's Mars 2020 mission, many within the sample caching system on the Perseverance Rover. This mission will seek signs of past microbial life and collect rock and soil samples for potential return to Earth. *cwst.com.*

Perseverance Rover. Courtesy of NASA.gov.

MICROWAVE NDT INSPECTION TECHNIQUES FOR POWER GENERATION AND SPECIALTY APPLICATIONS

Christopher Nelson
Electric Power Research Institute
Charlotte, North Carolina

Robert Stakenborghs
Advanced Microwave Imaging
Baton Rouge, Louisiana

With increasing use of nonmetallic materials in a variety of power generation applications, new opportunities are driving research and development of microwave inspection technologies.

Microwave (MW) nondestructive testing (NDT) is defined as nondestructive inspection of a material using electromagnetic energy in the microwave frequency range as the interrogating medium. The microwave frequency range exists between radio waves and far infrared in the 300 MHz to 300 GHz frequencies. These frequencies roughly correspond to wavelengths between 1 m and 1 mm in a vacuum, respectively.

MW inspection operates in a similar fashion to ground penetrating radar (GPR). That is, the inspection device emits an electromagnetic energy beam in the microwave frequency range and then records the reflected signals from the material under test (MUT). See Fig. 1. These reflected signals are then represented visually, and the image interpreted based on its appearance. The two parameters that determine electromagnetic field propagation, as well as reflection and absorption, are the electrical permittivity and magnetic permeability of the space. This means the method can be used to penetrate any dielectric material for volumetric inspection as well to inspect the surface of metals. Today, MW NDT is commonly used in the inspection of rubber expansion joints in power plants, high density polyethylene (HDPE) butt fusion and electrofusion, fiberglass piping and joints, ceramic materials, and other specialty applications[1-3].

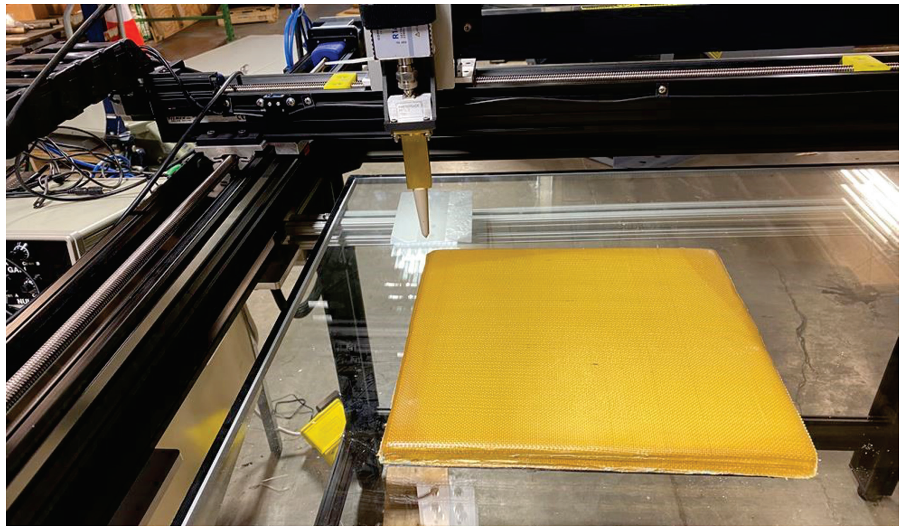


Fig. 1 — Microwave examination of Kevlar panel.

MICROWAVE INSPECTION STANDARDS

For any nondestructive testing method to be successfully used in industrial applications, the equipment needs to be standardized via national and/or international standards. These standards are developed to govern equipment calibration as well as provide information on training and certification of users and specific procedures for various materials. The following list identifies some codes that have been issued or are in progress to date:

- ASNT Recommended Practice No. SNT-TC-1A - 2016 Edition
- ASME Section III Appendix XXVI - HDPE Inspection 2017 Edition
- ASTM E3101-18 "Standard Practice for Microwave Examination of Polyethylene Butt Fusion Joints"
- ASTM E3102-18 "Standard Practice for Microwave Examination of Polyethylene Electrofusion Joints used in Piping Application"
- ISO - Microwave Inspection of HDPE Butt and Electrofusion Joints (in progress)
- ASTM - Standard Practice for Microwave Inspection of Fiber Reinforced Polymer Products (in progress)
- ASME Section V Article on Microwave Inspection (in progress)

Many of these standards are in development or have recently been updated, indicating the growth of new applications in this field.

HISTORICAL MICROWAVE RESEARCH

The Electric Power Research Institute (EPRI) has been involved in active microwave research projects since approximately 2005 when inspection of HDPE pipe fusions was emerging as a best practice in the nuclear power plant arena. This was followed by experimenting with microwave inspection on a sampling of HDPE fusions and inspecting rubber expansion joints in power plants (Fig. 2)[4-7]. These early research efforts were followed by several new projects based on industry input. Many of these were associated with fiberglass pipe inspection and carbon fiber pipe repair inspection. However, the largest project to date is focused on developing MW approaches for inspecting composite wind turbine blades.

INSPECTION OF WIND TURBINE BLADES

Utility-scale wind turbine blades are primarily made of fiberglass reinforced polymer (FRP) with various core materials as a small percentage of the total composition. Over time, blade

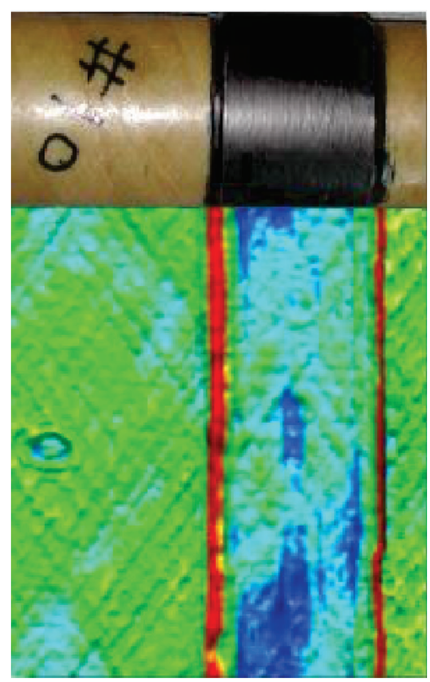


Fig. 2 — Microwave inspection of high-density polyethylene.

integrity can become compromised due to manufacturing defects, operational fatigue, or impact damage, necessitating component repair or replacement. Defects, often present at the time of fabrication, can grow during operation and are not easily detected visually or with other volumetric techniques such as ultrasound until they become irreparable. The ability of microwaves to penetrate nonmetallic materials could provide a new way to inspect blades and find these underlying damages or defects before it is too late.

A laboratory study was conducted using pedigreed samples from the Sandia National Laboratory wind turbine blade archive. These samples are representative of a portion of wind turbine blades and contain manufactured defects representing common issues such as delaminations, dry regions (i.e., low resin percentage), and marcelling (Fig. 3). Generally, the worst defect is marcelling, or out-of-plane wavy laminates, because it remains visually hidden, is difficult to detect with conventional NDT, and can easily result in cracking that could lead to blade failure. The microwave inspection table at EPRI has been used to inspect multiple material samples and represents the latest in microwave inspection capability[8,9].

Fiberglass parts are particularly difficult for most inspection techniques due to glass components in the resin matrix. The glass fibers act like reflectors for ultrasound so that these parts have a relatively high signal-to-noise ratio. In the case of microwave imaging, the glass reflects and refracts the electromagnetic energy of microwaves, but to a much lesser extent than sound energy. As an analogy, consider how light readily penetrates a glass window while sound does not. A further potential advantage of MW in wind turbine applications is that the inspection device does not need to be in close contact with the surface, which is required by techniques such as ultrasonic testing (UT). This makes field deployment using drones or other robotics attractive in situations where access by humans comprises a significant portion of inspection time and costs.

A unique development in this study was the use of a multi-frequency approach to provide additional information and flexibility over previous single frequency microwave devices. Figure 4 demonstrates the capabilities of a multi-frequency scan image. The mock-up wind turbine blade segment was scanned over a frequency range of 8 to 14 GHz. Data was captured at each

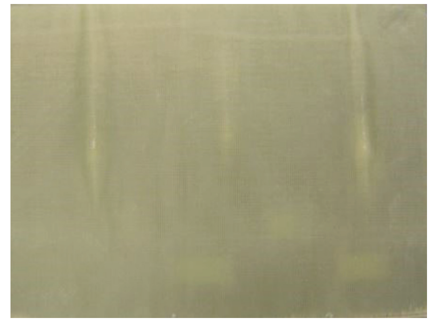


Fig. 3 — Wind turbine blade sample with marcelling.

frequency band in 201 discrete frequency increments. Images are generated by displaying either the real, imaginary, magnitude, or phase of the reflected energy data at each data point. A range of frequencies can be selected for display by manipulating the gate in the "A" scan, shown in the upper left-hand corner of the display. The software displays of the MW data are similar in arrangement to traditional ultrasonic data collected in encoded inspections, with data displayed in quadrants. Reading the image clockwise from upper left, the images in Fig. 4 are (a) S11 versus frequency (scan data), (b) "B" vertical image (c) "C" scan data image, and (d) "B" horizontal image.

The images shown were compared to the blade mock-up design and the

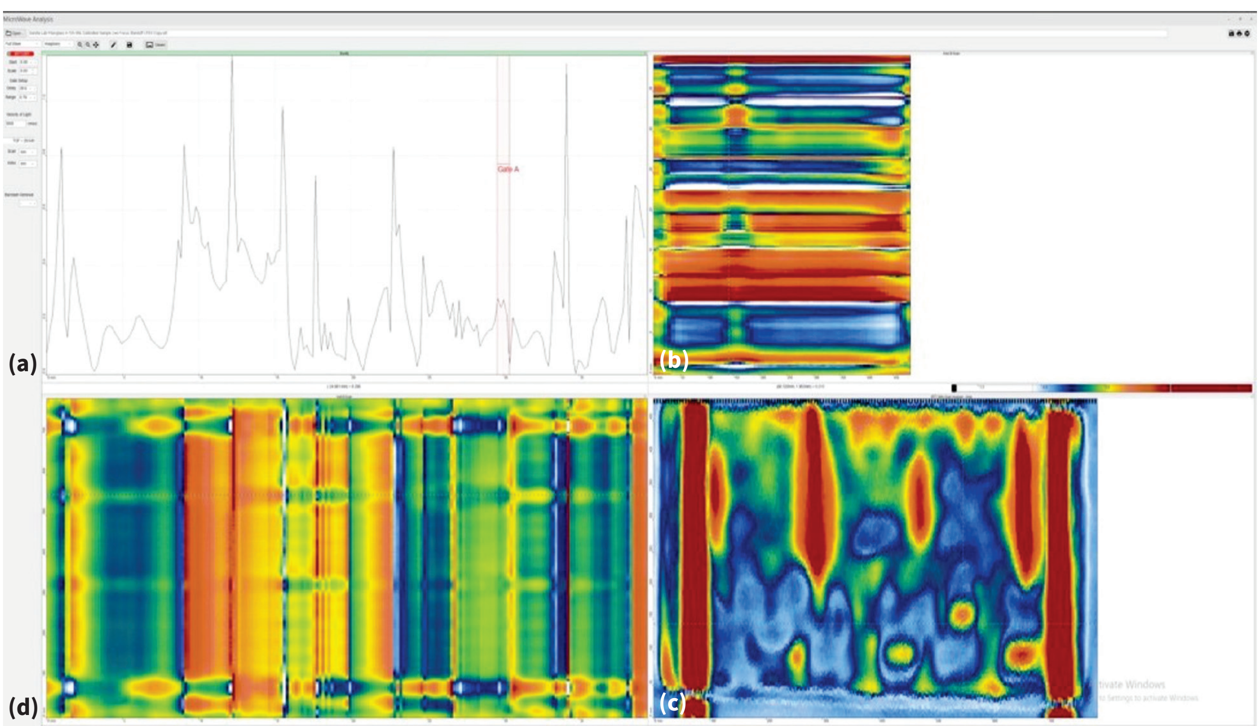


Fig. 4 — MW data image of wind turbine mock-up sample: Frequency and time related responses shown in A, B and C scan format.

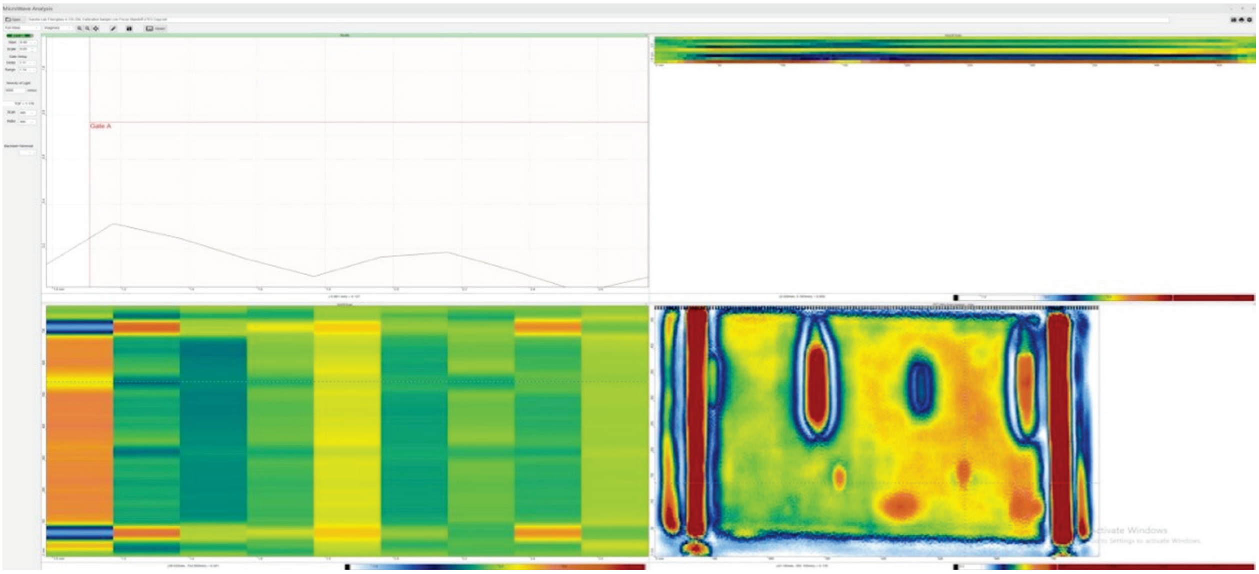


Fig. 5 — Demonstration of MW inspection for defect sizing (depth detection) by using multi-frequency sweeping.

four "wave" defects are clearly shown in the same orientation as the embedded marcelling and pillow insert defects (Fig. 5). The dry layer defects were not as clearly shown in the image at a selected frequency range shown in Figure 4. The two red rectangular indications on each side of the scan image are aluminum rails under the sample and are not embedded defects. The ability to see these features helps validate that a full volumetric inspection of the part was performed despite the dense composite structure. The collection of data in a multi-frequency mode allows one to select different frequency ranges to display the data. At a different selected frequency range (shown in Fig. 5), the "C" scan inspection image shows additional dry defects in the part versus the first frequency range in Figure 4. The four wave features remain very clear in this frequency range. This demonstrates the superior analysis capability of a multi-frequency approach versus a single frequency inspection approach.

Data collection over a range of frequencies allows the application of data analytics to convert the frequency-based signals to time-based signals. Thus, each of the data display modes of real, imaginary, magnitude, and phase can also be displayed versus time. The time-based display represents the time for the signal to travel from the transmitter, reflect from the indication, and return to the receiver. Thus, depth detection capability exists for a data set collected over a range of frequencies versus a single frequency. This method is similar to that used in some UT techniques but is a new area of application for MW technology.

This depth detection methodology, while clearly viable, is not yet completely refined and vetted to provide accurate depth measurement. Overall accuracy is complicated as a result of the possibility of variable dielectric constant in complex materials, the air gap between the material surface and antenna, and the relative difference in magnitude of the speed of light and typical article thickness. Ongoing software improvements and data analysis techniques are expected to refine this approach with additional research enabling a powerful tool for inspection.

Not all defects are easily resolved using MW. For example, one challenge occurs in fiberglass when the sample manufacturer creates voids or delaminations in the part. Voids or delaminations have a dielectric constant close to 1.0 (vacuum or air) while fiberglass has a dielectric constant of approximately 4.4. This makes those types of defects simple to detect using microwave inspection. However, to simulate these defects, common methods use different styles of tape or even more sophisticated means, such as micro-balloons. If the tape or micro-balloon material has a dielectric close to that of fiberglass or is placed in a material that has a dielectric close to the defects, it will make the sample difficult to image with microwave, although it may be easily detectable with UT or other methods. In this research, a sample contained micro-balloon, tape, and pillow insert defects in a layer of adhesive. MW was unable to image the defects in this sample. This is likely because these types of defects have a dielectric that is similar to the adhesive matrix that the defects were contained in. Therefore, proper development of representative samples with particularly close attention

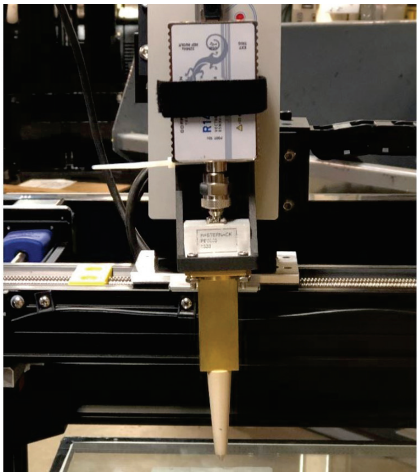


Fig. 6 — Vector network analyzer with specially designed antennae capable of utilizing 6-14 GHz, from Copper Mountain Technologies.

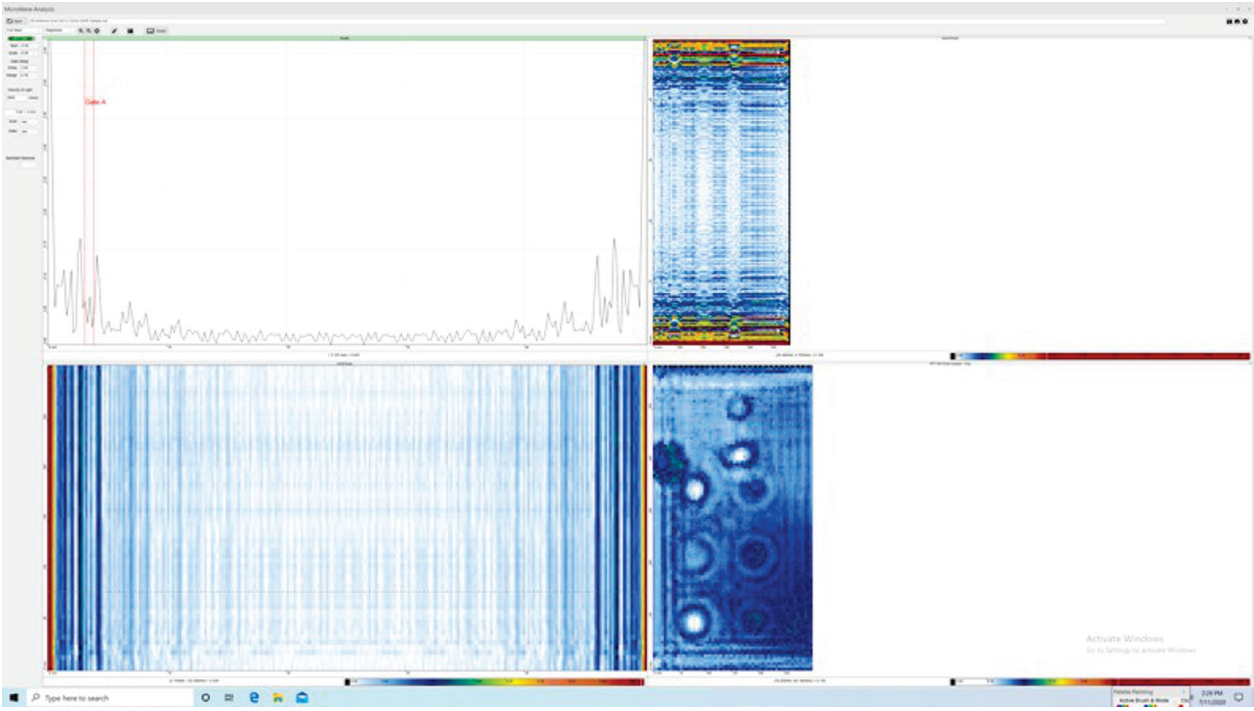


Fig. 7 — HDPE flat plate (24 x 12 x 1 in., inspected in 8 minutes) demonstrating location and sizing of multiple defects using advanced MW technologies now in development.

paid to the materials used is an important consideration. If not done correctly, the results may not provide an accurate assessment of this promising NDT technique.

FUTURE DEVELOPMENTS

EPRI's major focus is on advancing the capability of MW multi-frequency data collection using vector network analyzers (VNA) with specifically designed antennae, as shown in Fig. 6. The use of a bespoke antenna system for specific materials and conditions tremendously improves the response of the device and allows for enhanced defect detection and sizing along with the capability to adjust for varying geometry and material, as well as composition. The antennae are also designed with broadband features that provide for expanded frequency ranges that can be used during the inspection to provide multiple benefits. First, the enhanced range increases the probability of defect detection by expanding the possibilities for a reflected signal from specific defect types. This is particularly true when compared to older single frequency systems. Second, the increased frequency range provides for finer depth increments than a smaller frequency range.

One excellent example of an image created with an early bespoke antenna and VNA is of a defect sample of a high-density polyethylene plate. Figure 7 shows the ability of the multi-frequency system to image, size, and determine the depth of the defects. The part includes multiple back-drilled holes, some of which are filled with aluminum foil, some empty, plus a top and bottom surface metal indicator. EPRI's system was able to successfully capture all defects in a single scan image as well as determine relative depths. The part measures 24 x 12 x 1 in., and was inspected in approximately 8 minutes.

CONCLUSIONS

Ongoing research activities into microwave techniques have resulted in numerous advances within the field that are applicable across several power-related industries. The EPRI microwave inspection table currently available is one of the most advanced tools of its kind. Research continues into various supporting fields, such as mounting a microwave-based inspection system onto a drone for up-tower inspection of wind turbine blades.

Additional research is planned to continue development and refinement of software to improve the accuracy of depth detection routines. Additionally, future work is planned to introduce synthetic aperture focusing techniques and other advanced data analytics, such as artificial intelligence, to improve imaging quality and defect detection and recognition. **~AM&P**

For more information: Christopher Nelson, senior technical leader, Electric Power Research Institute, 704.595.2533, cnelson@epri.com, www.epri.com; Bob Stakenborghs, CEO, Advanced Microwave Imaging, 225.329.5815, rjstak@advancedmwimaging.com, www.advancedmwimaging.com.

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HISTORIC MONEL—PART I: PRODUCTION AND PROCESSES OF THE INTERNATIONAL NICKEL COMPANY INTO WORLD WAR II

Monel's importance in the first half of the 20th century as a decorative metal has been nearly forgotten.

James E. Churchill, Columbia University, New York and Kreilick Conservation, Pennsylvania*

Monel 400, also known as nickel alloy 400, has been used in the industrial and built environment since 1905. A short-lived architectural metal, it was increasingly replaced by its cheaper cousin, stainless steel, from the mid-1930s. Monel suffered from a lack of managerial support as focus shifted toward newer alloys. Extensive competition during the 1940s, and procurement issues due to its high nickel content, led the metal into relative obscurity by the 1950s. Today it remains a specialty alloy used mostly in the marine field.

THE EARLY YEARS

Monel was born out of joint research into a more affordable route to nickel silver by three International Nickel Company metallurgists, David H. Browne, Victor Hybinette, and Robert C. Stanley. It was ultimately Stanley who realized the lower oxidation point of the nickel-copper sulfide found in the Bessemerized matte, refining the first ingot where others had failed[1]. In the process, he accidentally stumbled upon a highly corrosion-resistant proto superalloy. This metal, silvery in color, benefited from Stanley's support and his fortuitous presidency of the corporation 15 years later, and from the International Nickel Company's monopoly on nickel products that increasingly straddled the free world.

At the dawn of the 20th century, American business interests acted to seize control of the world's nickel market. Despite Canada's huge reserves, a lack of refining technology and financing saw the market made up of small mining interests, struggling to find demand. The Canadian Copper Company, the largest concern, joined with Richard M. Thompson of the Orford Copper Company in New Jersey to refine their product in the 1890s. Thompson soon realized the implications for nickel as demand exploded. Approaching the newly formed United States Steel in 1902, he formed a cabal under the auspices of J.P. Morgan. Absorbing the stock of the seven key players, the International Nickel Company was founded to corner the burgeoning market. Streamlining production, the company bought out interests in Sudbury, Canada, and lobbied for exemptions on nickel-copper matte imports. American supremacy was ensured through aggressive trade policy that included export taxes on refined product and later, dumping. Within the decade, the company controlled 50% of world supply. Everything was in place to ensure the success of Monel and its base metal nickel.

*Member of ASM International

Geopolitics at the beginning of the 20th century caused a near 25-year uninterrupted demand for nickel. Yet the aftermath of World War I pushed multiple concerns to the precipice of bankruptcy as easily accessible and cheaply mined surface ore was depleted. Disarmament treaties created a collapse in nickel demand (Sir Alfred Mond estimated 50% of nickel demand prior to the war went to armaments), while European stockpiles sent pricing into a deflationary spiral just as the British pound devalued 25%. Monel was on the chopping block. Yet Stanley, now first vice-president, took the unusual action of going all in at the height of the crisis. Seeing the need to diversify, he lobbied the board for $3 million for a new Monel refining plant to bring mill production in-house. Stanley's long-term bet paid off. As demand recovered in the mid-1920s, the International Nickel Company squeezed out the competition, leveraging their Sudbury ore reserves and a new Huntington, W. Va. plant to build the bottom line. Monel's legacy continues in West Virginia to this day.

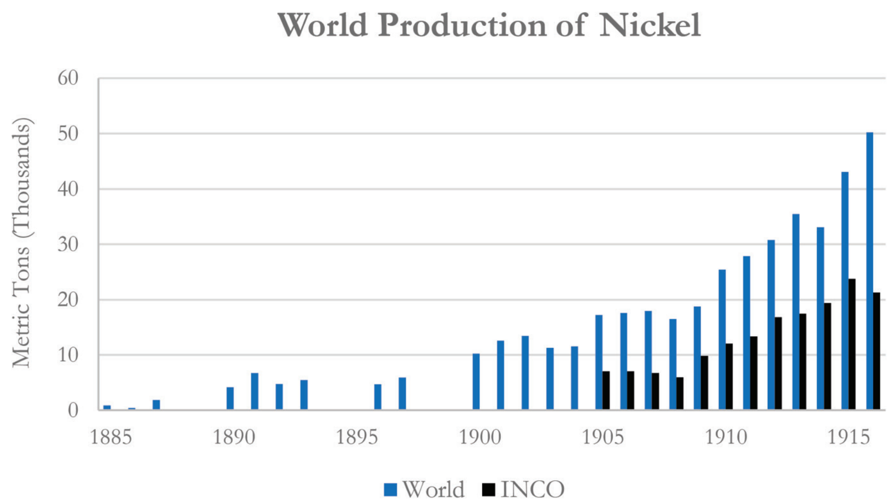

Fig. 1 — The clear jump in nickel production into the outbreak of World War I.

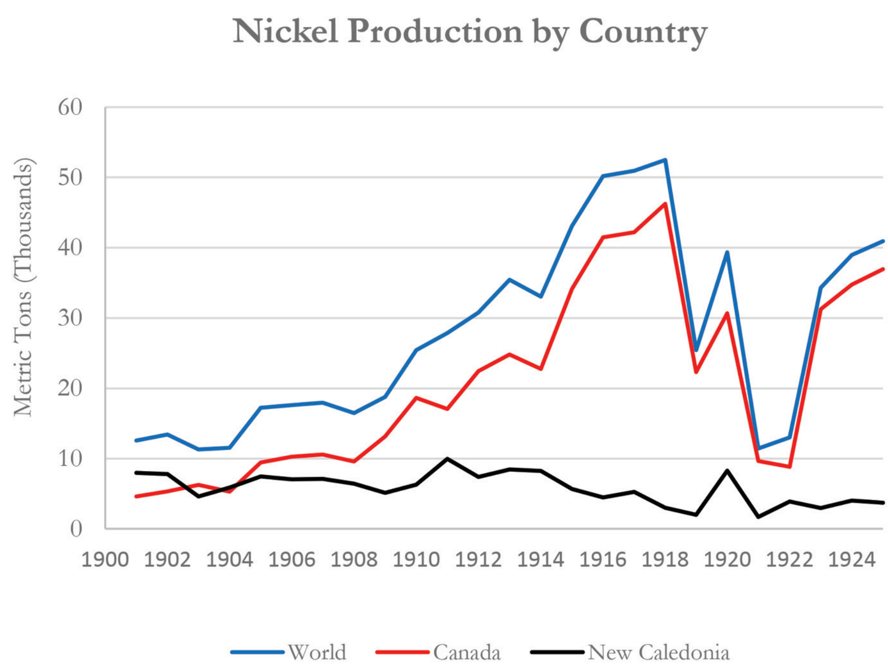

Fig. 2 — The huge swing in Canadian nickel production in the first quarter of the 20th century is shown in this chart.

MINING, SMELTING, AND REFINING

From the very start of operations in Sudbury, ore was collected and separated into four grades: a mixed copper-nickel ore, copper pyrites, pyrrhotite or nickel ore, and diorite rock. Composition varied widely in the early days, with nickel from 1.28-8.12% and copper 0.49%-15.71% between 1892-99[2]. It was at the Sudbury Creighton pit, mined from 1901, that veins of chalcopyrite and pentlandite were found in the pyrrhotite resulting in a 2.3:1 nickel copper ratio that became synonymous with Monel. Ore, hand sorted into three sizes, coarse, ragging, and fines, was syphoned off from waste rock and initially roasted in yards for up to nine months to lower sulfur content from 30% to around 7%[3]. Environmental air pollution forced a permanent replacement to roasting furnaces in 1929. Roasted material was smelted alongside "green ore" and "reverts" using a 3:1:1 ratio in blast furnaces. As top-grade surface ore was depleted during the war, sintering and reverberatory furnaces gradually gained in use from 1911. The product was finally Bessemerized in a converter to remove a 40% iron content through slag that was dumped as waste until collection began in the 1970s.

Shipped to the United States, early refining took place in the original location of Orford's works at Bayonne, New Jersey. While no evidence remains of the exact method, the original patent from Ambrose Monell describes the calcining of the Bessemerized matte to remove the sulfur, reduction of the oxides in a reverberatory furnace with carbon, and then copper or iron to alter the recipe appropriately. Later, president John F. Thompson confirmed this, noting Stanley added magnesium, likely for increased ductility[4]. In 1909, Browne filed a patent using lime in an electric arc furnace to separate off sulphur through a calcium sulphide slag. At Huntington, the process was perfected. The matte was ground into coarse sand by a jaw-crusher, cone crusher, and ball mill before entering a calcining furnace for four hours to remove the remaining 20% sulfur. The resultant oxide was mixed with charcoal and sent to open hearth reverberatory furnaces to cast pigs, before final purification and casting in an electric furnace to produce two-ton ingots[5]. Unlike steel, porosity, slag, folds, or cracks were removed by a cutting down process known as milling, before being passed to the hammer department for chipping off defects. The blooms were then reheated and placed through the rolling mill for billets required at the rod or sheet mill for production[5].

ADVANCEMENTS

The Huntington refining process was continually honed. A Russian citizen, Otto Lellep, described a more efficient conversion process for refining nickel or nickel-copper matte through steadily reducing conditions at very high temperature as early as 1917. It comes as no surprise that later methods of 1923 and 1926 were assigned to the International Nickel Company. The company subsequently filed a new patent in 1928 that blew superheated steam into the matte at much lower temperature, avoiding lining damage to the converter and removing Lellep from the equation. The use of the natural nickel-copper ore and matte continued until 1947, at which time the company shifted to a nickel sinter and copper ingot charge. Today the process uses an air induction method for production.

DISCOLORATION

Despite marketing to the contrary, Monel metal did not stay “silvery” and had notable discoloration issues that became apparent from the late 1920s. A report from the correspondence of the famed Philadelphia metalworker, Samuel Yellin, notes the wrought alloy turned white within one year of installment; a “fogging” problem with nickel that was increasingly discussed by the foremost corrosion scientist W.H.J. Vernon[6]. While atmospheric corrosion in terms of weight loss and pitting has been proven to be minimal, varied reports of greens, browns, blacks, and yellows demonstrate the unusual discoloration of Monel from the usual gray or pewter-like color anticipated by the fabricators[7-9]. This aesthetic issue likely harmed Monel’s ability to be considered for anything but utilitarian purposes by the 1930s and was probably a key reason for its sole remaining use in roofing. ~AM&P

Fig. 3 — Detail of Monel decoration on a door hinge on the Bryn Athyn Cathedral, Pa. Courtesy of James E. Churchill.

Note: Part II of this series will test the corrosion products found on exterior, historic Monel today and the likely metallurgical or atmospheric reasons behind their formation and discoloration of the base metal.

For more information: James E. Churchill, Conservator, Kreilick Conservation, jchurchill@kreilickconservation.com or james.churchill@columbia.edu, haboneh.academia.edu/JamesChurchill.

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MATERIALS SCIENCE AND CORONAVIRUS SERIES

ANTIMICROBIAL COPPER-CONTAINING STAINLESS STEELS SHOW PROMISE

Given the demonstrated antimicrobial properties of copper, it is incumbent upon materials scientists to design potent antimicrobial copper-containing stainless steels as an economical option.

*Olivia Barber, Arman Khan, Erica M. Hartmann, Dieter Isheim, Semyon Vaynman, Q. Jane Wang, and Yip-Wah Chung, FASM**

Northwestern University, Evanston, Illinois

Transmission of bacteria and viruses through touched surfaces is an important public health concern, heightened recently by the COVID-19 pandemic. As discussed in a previous article in this series[1], it has long been known that copper and copper-rich alloys exhibit potent antimicrobial properties. However, instead of copper, stainless steels are in widespread use in hospitals, medical facilities, and public transportation, despite their lack of antimicrobial properties. One reason is the lower cost of stainless steels. Another reason is corrosion resistance and appearance. Stainless steel has a pleasing appearance and is more corrosion-resistant than Cu, which develops an unappealing green or dark brown tarnish when corroded. Finally, stainless steels have higher yield strength (e.g., 250 MPa for stainless steel 304) than annealed Cu and Cu-rich alloys (70-170 MPa) and are therefore more suitable for applications such as hospital beds and handholds used in public transportation.

KILLING BACTERIA AND VIRUSES

Bacteria range in size from 0.5 to 10 µm, whereas viruses are two orders of magnitude smaller, from about 5 to 300 nm. Bacteria come in many shapes such as spheres or rods depending on the species. All species have a cell membrane accompanied by an outer cell wall, which varies in sophistication. In contrast to bacteria, viruses are surrounded by a protein capsid and sometimes have an additional outer lipid envelope acquired from the host. Microorganisms including bacteria and viruses are often sorbed to particulates or contained within aerosolized droplets in the environment. When these droplets land on surfaces, rapid inactivation of the microorganisms contained therein would minimize transmission due to touch.

To test a surface for antimicrobial properties, microbes are first adhered to the surface by direct application or immersion of the surface into a solution containing a known concentration of microorganisms[2]. The microorganisms remain in contact with the sample at a given temperature (room temperature or 37°C) for a certain time period (incubation time), after which the remaining number of live microorganisms is determined. This number is

Two sets of strawberries, one placed on copper mesh and the other on plastic, both at room temperature. From top: (a) starting condition; (b) after 24 hours; and (c) after 43 hours. Note mold development on strawberry placed on plastic and its absence on strawberries placed on copper after 43 hours. Courtesy of Prof. Q.J. Wang.

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compared with either the initial number or the number remaining after the same amount of time on another surface known not to possess antimicrobial properties. This is then stated in the literature as a measure of antimicrobial activity.

REPORTS OF SUCCESS

Over the past 20 years or so, there have been numerous efforts toward the development of antimicrobial stainless steels. For example, Bahmani-Oskooee et al.[3] added 1 to 5 wt% Cu into 410 martensitic stainless steel. After solution treatment at 1100°C to dissolve all alloying elements followed by oil quenching, these steel samples were aged at 500°C for 0.25 to 4 hours. Transmission electron microscopy shows that precipitates of fcc Cu on the order of 10-30 nm in diameter formed after the aging treatment. It was discovered that the addition of 3 wt% Cu along with aging at 500°C for 2 hours was sufficient to deactivate all exposed bacteria (*E. coli* and *S. aureus*) in 24 hours. In another study, Xi et al.[4] added 2.5 and 3.5 wt% Cu into 316L stainless steel. After solution treatment at 1100°C for 30 minutes and water quenching, the steel samples were aged at 700°C. The researchers found that after aging for 6 hours, 95% and 99% of *E. coli* in contact with the Cu-containing steel samples were inactivated within 24 hours.

In other research, Yang and Lu[5] added 3.8 wt% Cu to 316L and explored its antimicrobial properties against four different types of bacteria after an aging treatment of 700°C for 6 hours. The team observed the formation of fcc Cu precipitates with diameters in the range of 10-20 nm. *E. coli* bacteria were deactivated the fastest, with complete inactivation in about 10 hours. In another study, Hong and Koo[6] started with 304 stainless steel and added from 1.5 to 5.5 wt% Cu. After solution treatment at 1050°C, samples were aged at 700° and 800°C for 0.5 to 4 hours. They observed formation of Cu precipitates with diameters on the order of 100 nm after aging at 800°C for 2 hours. Steel samples with 3.5 wt% Cu or higher and after aging at temperatures ≥ 700°C for 30 minutes

RESEARCHERS FOUND THAT AFTER AGING FOR 6 HOURS, 95% AND 99% OF *E. COLI* IN CONTACT WITH THE CU-CONTAINING STEEL SAMPLES WERE INACTIVATED WITHIN 24 HOURS.

were found to deactivate all bacteria (*S. aureus*) within 24 hours. Note that Cu-containing stainless steels exhibit only weak antimicrobial activity after solution treatment[4], indicating the importance of having Cu-rich precipitates. Several patents on antimicrobial stainless steels developed using similar strategies also exist.

BUT IS IT REALLY SUCCESS?

As noted earlier, most studies of antimicrobial stainless steel report results of bacteria inactivation on steel samples after 24 hours of incubation time. Such a measure is too imprecise to differentiate antimicrobial performance among different alloys and aging treatments and provides little information on inactivation kinetics. Yang and Lu[5] measured *E. coli* inactivation as a function of time, giving 2.5 hours for the half-life on stainless steel 317L plus 3.8 wt% Cu. In other research, Chai et al.[7] showed that the half-lives of *E. coli* and *S. aureus* on 317L plus 4.5 wt% Cu are both about 6 hours. In contrast, the half-life of SARS-CoV-2 (the virus causing COVID-19) is 0.77 hours on pure Cu[8], and the half-life of *E. coli* on pure Cu is 0.25 hours[9].

Based on the previous discussion of these results, the half-life of these microbes on Cu-containing stainless steels is significantly longer than that on pure Cu. One possibility can be inferred from studies of the antimicrobial activity of stainless steels and other samples with coatings containing different Cu concentrations. Zhang et al.[10] found that the half-life of *E. coli* on 304 stainless steel coated with Cu-Ni alloy containing 90% Cu had a half-life of about 0.5 hours, increasing to about 2 hours when the coating contained 2.5% Cu. Efforts to increase the surface Cu concentration by increasing aging temperature to 800°C and aging time to 400 hours of 304 stainless steel plus 3.8 wt% Cu, followed by pickling, do not seem to yield antimicrobial properties any closer to Cu[11].

PRELIMINARY STUDIES

As noted in the previous discussion, it is not enough to just add Cu to stainless steels and expect things to work as well as Cu. The authors have been experimenting with Cu-precipitation-strengthened ferritic steels for the past 20 years as a new class of weathering steels for civil infrastructure applications, with markedly improved low-temperature toughness, weldability, and weathering resistance. These steels are approved as ASTM A710 Grade B bridge steels. They are low-carbon ferritic steels designed to maximize the number density of nanometer-size Cu precipitates. A typical alloy has the following composition in wt%: 0.06C-1.3Cu-0.9Ni-0.5Mn-0.4Si-0.06Nb-0.1Ti, balance Fe, with 500 MPa yield strength, 30% elongation to failure, and Charpy impact fracture energy of 160 J at -80°C. This excellent combination of strength and toughness is primarily due to the precipitation of coherent bcc nanometer-size Cu precipitates[12].

Steels with improved strength based on ASTM A710 Grade B have since been developed, mainly by adding Ni and Al to promote the co-precipitation of Cu and NiAl, producing a new series of low-carbon ferritic steels (designated CF series) with yield strength up to 1600 MPa[13,14]. It dawned on the authors that A710 Grade B and these CF steels may possess potent antimicrobial activity due to the high number density of nanometer-size Cu precipitates present in these alloys. As an example, Fig. 1 shows the atom probe tomography image obtained from one steel in this series after solution treatment at 950°C, followed by water quenching and aging at 500°C for 2 hours.

Note the high density of Cu-containing precipitates, with an average radius of 2.0 nm and interprecipitate distance of ≈ 12 nm. Antimicrobial performance of two polished Cu-containing steel samples were explored using

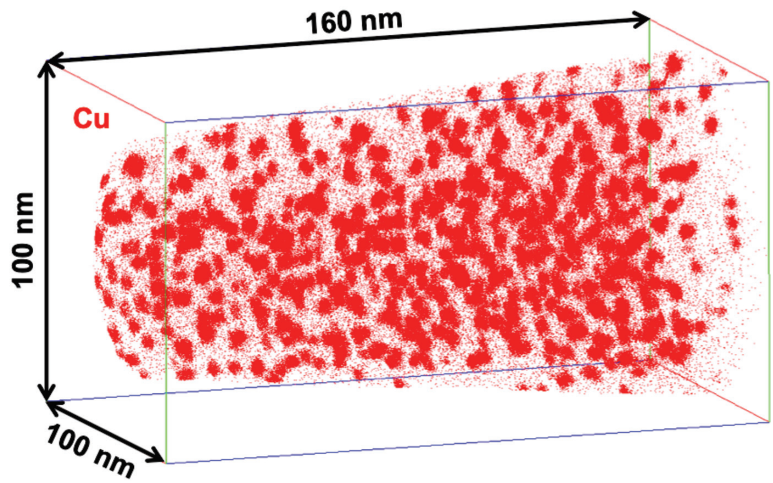

Fig. 1 — 3D copper atom map showing Cu precipitates in one of the authors' Cu-precipitation-strengthened alloys containing 2.5 wt% Cu. Sample was solution-treated at 950°C, followed by water quenching and aging at 500°C for 2 hours. Average precipitate radius is 2.0 ± 0.6 nm; precipitate number density is 68.7 ± 3.2 × $10^{22}/m^3$. Each red dot represents one Cu atom; Cu precipitates appear as regions with high density of red dots. Only Cu atoms are shown for clarity.

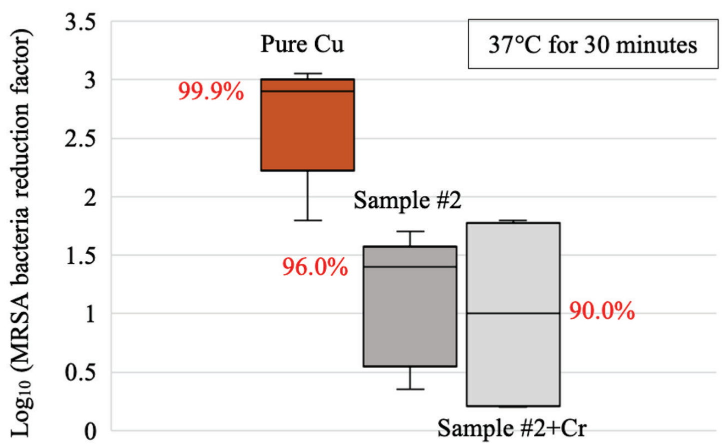

Fig. 2 — Log_{10} (reduction factor) of MRSA bacteria remaining after 30 minutes exposure at 37°C to pure Cu and two polished steel samples, one with 2.5 wt% Cu (sample #2) and the other, sample #2 with 12 wt% Cr added (sample #2+Cr), both after heat treatment to form nanometer-size copper precipitates. Median reduction percentage is noted next to each box.

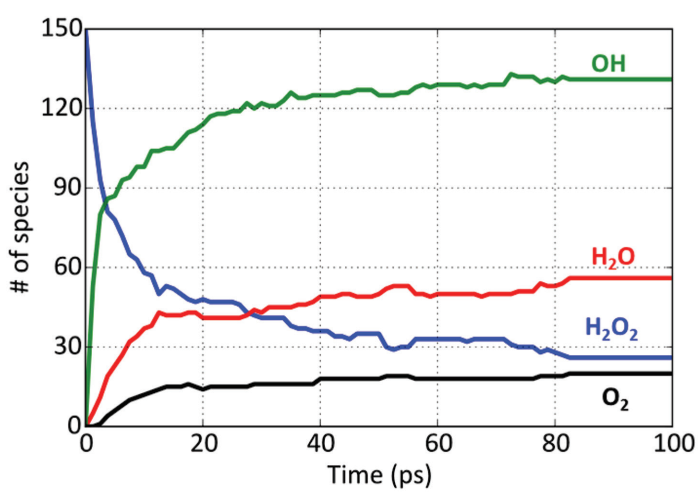

Fig. 3 — Evolution of the number of H_2O_2, hydroxyl radicals, oxygen, and water molecules as a function of time at room temperature.

MRSA bacteria, one with 2.5 wt% Cu (sample#2) and the other, sample #2 with 12 wt% Cr added (sample #2+Cr), both after heat treatment to form nanometer-size copper precipitates. Incubation at 37°C for 30 minutes is sufficient to inactivate 96% and 90%, respectively, on average for all MRSA bacteria exposed to these steel samples (Fig. 2).

The authors were curious about what might happen when Cu atoms on surfaces of these precipitates come into direct contact with microbes or active molecules in the vicinity. To explore this idea, molecular dynamics simulation using a large-scale atomic/molecular massively parallel simulator was conducted on the interaction between a bcc Cu (111) stepped surface and 150 hydrogen peroxide (H_2O_2) molecules at room temperature. H_2O_2 is produced by human cells and many bacteria species.

Figure 3 shows the evolution of the number of H_2O_2, hydroxyl radicals, molecular oxygen, and water molecules as a function of time. The fragmentation of H_2O_2 upon contact with Cu is almost immediate, producing hydroxyl radicals, oxygen, and water. These changes are accompanied by the oxidation of Cu to form Cu^+, strongly suggestive of Fenton-like chemical reactions. The process appears to reach steady state after about 60 ps, which indicates the occurrence of a back-reaction, i.e., formation of H_2O_2 from initial reaction products. Both H_2O_2 and hydroxyl radicals are reactive oxygen species that play an important role in antimicrobial action.

IS MORE COPPER BETTER?

Cu is known to cause "hot shortness" in steels—embrittlement of steel due to formation of Cu-rich liquid and its penetration into grain boundaries during hot rolling or forging. Excessive Cu amplifies this problem. Also, how adding Cu affects the corrosion performance of stainless steels must also be considered. When Cu is in solid solution, it has no detrimental effect on the stability of passivation oxide films of ferritic or austenitic stainless steels[15]. However, when present as nanometer-size precipitates after aging, Cu reduces resistance against pitting corrosion in chloride environments[16,17]. This effect is related to localized galvanic corrosion, in which pits are formed in the vicinity of Cu precipitates. Therefore, one must limit the amount of Cu introduced into stainless steels to minimize pitting corrosion.

CONCLUDING THOUGHTS

Metallurgists rarely cross into the domain of biosciences and public health. The COVID-19 pandemic may serve as a trigger for those in the field to reflect on how to contribute. Given the demonstrated antimicrobial activity of Cu, it is incumbent upon materials scientists to design potent antimicrobial copper-containing stainless steels as an economical drop-in replacement for traditional stainless steels. To achieve antimicrobial potency comparable to pure Cu, one must design the alloy to contain the maximum volume fraction of nanometer-size Cu precipitates. Doing so with as little Cu as possible will not only minimize cost, but also avoid embrittlement and boost corrosion performance. Although these conflicting requirements are daunting, the challenge can be met by employing modern computational and simulation methods along with experimental validation.

As presented in this commentary, some of these methods were used to demonstrate the chemical reactivity of Cu step atoms on surfaces of nanometer-size precipitates in generating reactive oxygen species considered to be important in antimicrobial action. Equally important, Cu-precipitation-strengthened steels were fabricated with a high number density of nanometer-size Cu precipitates at modest Cu concentrations, with promising results regarding antibacterial activity and excellent potential in numerous applications. **~AM&P**

For more information: Yip-Wah Chung, professor, Department of Materials Science and Engineering, Northwestern University, 2220 N. Campus Drive, Evanston, IL 60208; ywchung@northwestern.edu.

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Lead image: 2019-nCoV spike protein, courtesy of Jason McLellan/University of Texas at Austin.

RESIDUAL STRESS: BOTH FRIEND AND FOE

Residual stress exists in all classes of materials and significantly impacts many facets of product design and manufacturing. With the launch of a technical committee on this topic, ASM International is creating a specialized network of volunteers to advance the science of this important phenomenon.

David Furrer, FASM, Pratt & Whitney, East Hartford, Connecticut*

Residual stress is a major element of component and system design, manufacture, and application, but it represents one of the most complicated and lesser known phenomena that can greatly impact product performance. Residual stresses are relatively straightforward to understand from a high level, but as one delves deeper into the science and engineering the topic becomes more challenging.

Residual stresses are effectively locked-in stresses within a material that are a result of various prior path-dependent processing. As a whole, integration of all volumetric residual stress must equal zero to be considered in equilibrium. If these locked-in stresses are disturbed, such as by machining some volume from the material, an imbalance in residual stresses will result and the stresses will re-equilibrate causing the material to geometrically distort.

AS A WHOLE, INTEGRATION OF ALL VOLUMETRIC RESIDUAL STRESS MUST EQUAL ZERO TO BE CONSIDERED IN EQUILIBRIUM.

Similarly, material that has locked-in stresses in addition to external loads will result in local stresses that comprise a combination of internal residual stresses and externally applied stresses. The primary reason for applying various surface treatments to compressive residual stresses is to mitigate high externally applied stresses. Compressive surface residual stresses must be accompanied by an equal integrated amount of tensile stresses to reach equilibrium.

STRESS FORMATION

Residual stresses are formed in three major ways: thermally induced local plastic strains within a component, externally applied stresses that provide local plastic strains, and phase transformation-induced local plastic strains due to volume fluctuations during phase changes. The first two are closely related, with the only difference being the means by which local plastic strains are induced. Figure 1 shows how residual stresses are formed by thermally induced local plastic strains and by phase transformation-induced strains.

For the thermally induced processes, a volume of material is heated to high temperature and allowed to

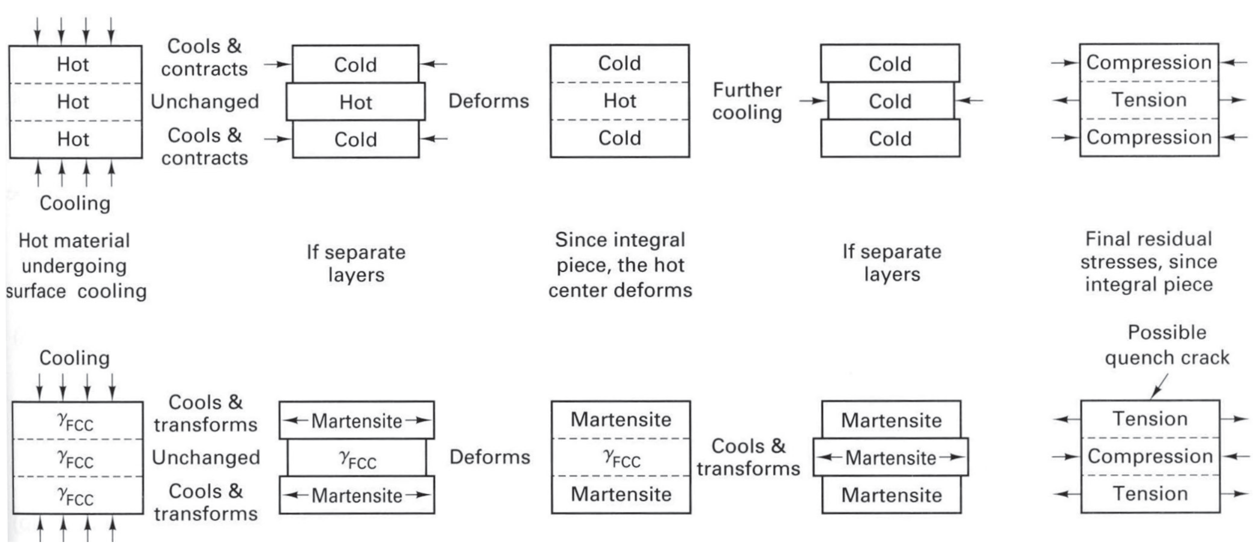

Fig. 1 — Mechanisms of generation of bulk residual stresses. Top row depicts steps in the process of thermally induced residual stress formation; bottom row depicts steps in the process for phase transformation-induced residual stress formation[1].

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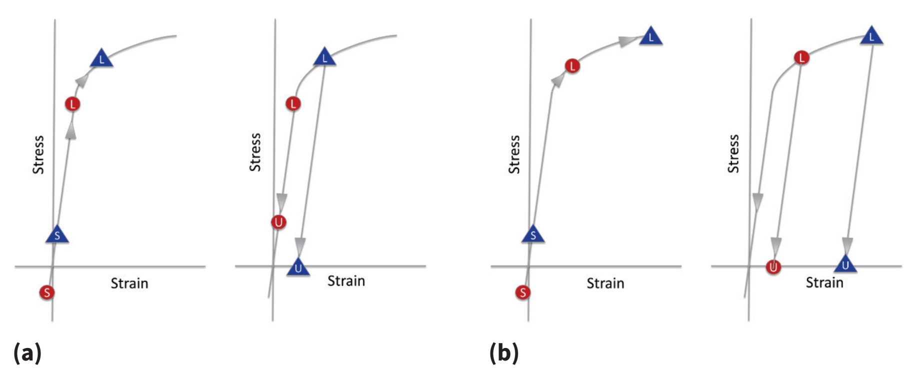
thermally equilibrate, as with solution heat treat processes. As the material is cooled rapidly from this temperature, thermal conductivity, heat capacity, and coefficient of thermal expansion behavior of the material start to play a major role. The material's outer layer will cool faster than its center. If the outer layer was not physically attached to the center material, it would contract, but it is physically connected and restrained from contracting by the internal material, which is at higher temperature. This thermal battle results in initially placing the external material in tension and the internal material in compression. If the stresses are high enough to cause local yielding, then subsequent residual stresses will follow upon further cooling the entire volume to room temperature. Formation of residual stress is due to the continued cooling, where surface material is plastically deformed in tension and/or the interior material is deformed in compression, because the internal material continues to cool and tries to contract. In this scenario, the external material restrains the internal material from contracting and as it does, it places the external material in compression and the internal material in tension. Once completely cooled to room temperature, the material will have an established internal bulk residual stress that is in equilibrium (i.e., the volumetric summation of all tensile and compressive stresses must equal zero).

For phase transformation-induced residual stresses, the method of generation is slightly different, but also relies on local strain and strain history. As seen in the lower portion of Fig. 1, a material can be heated to a high temperature and thermally equilibrated, such as a steel during an austenitizing process. Once this material is rapidly cooled and a phase change occurs within the surface material, which is accompanied by a local microstructural volume change, the outer material is placed in compression as it is being restrained from expanding by the internal material volume. An example of this may be seen in austenite to martensite reactions and the associated volume expansion. If the stresses are sufficiently high to cause local yielding, one would expect residual stresses to subsequently be formed. This is similar to the prior example, but further cooling results in the internal material transforming, expanding for the example of martensite formation. The internal material is now restrained from expanding by the already cooled external material. This places the internal material in compression and the surface material in tension once the material is thermally equilibrated at room temperature. In this case, local yielding (surface versus center) leads to the residual stresses. If the thermal cycling was performed such that the thermal gradients or extent of phase change stresses were controlled within a range where the local volumes were only elastically loaded during processing, then no residual stresses would result. This fact is the basis for many highly sophisticated and controlled heat treating processes, such as marquenching or the use of salt or polymer quenchants.

External mechanically induced residual stresses are also common, though some are intentional (i.e., peening or low-plasticity burnishing) while others are not (i.e., abusive machining). For this mechanism of residual stress formation, local volumes of material are again strained beyond their yield strength, often in tension. The surrounding material that is not yielded restrains the deformed material, which results in the locally plastic strained material being put into compression and the adjacent non-yielded material to be placed in tension. This is the exact process by which surface compressive stresses are formed by shot peening, laser shot peening, and low plasticity burnishing. If the entire volume of material was loaded past the yield point and then the stress was released, the entire volume would have no residual stress. This is the principle behind mechanical stress relieving, commonly used for aluminum material. Note that the entire volume must be strained past yield to result in complete stress relieving. This is difficult to do as metallic materials are not truly isotropic and grain level strains must be taken into account. Figure 2 illustrates how local yielding of a material will result in residual stress formation and how complete yielding of a volume can provide residual stress relieving.



S – Starting Condition
L – Loaded Condition
U – Unloaded Condition

Fig. 2 — Stress-strain curves for two regions (represented by circle and triangle points) within a volume of material. The two regions have different starting residual stresses. If the material is strained to a nominal low level (a), the region with tensile residual stress will result in local yielding, whereas the region with compressive residual stress will not. In contrast, if the material is strained to a larger amount that enables all regions to exceed the yield point (b), the material will result in no residual stress when unloaded, but each region will have experienced slightly different amounts of plastic strain. This concept can be applied to assess localized straining to induce intentional residual stress (hole expansion), for mechanical stress relieving or material/components, or analysis of test specimens or components exposed to near yield stresses in static loading or fatigue.

Residual stresses are not all the same. They are often thought of as either surface related (special processing of surfaces to create beneficial compressive stresses) or bulk (often coming from thermal processing). In addition to these major categories of residual stress, there are also various classes, including Type-1, Type-2, and Type-3 residual stresses (Fig. 3).

TYPES OF RESIDUAL STRESS

Type-1 residual stress is the most common. It is macroscopic in nature and represents average stress under local conditions. Note that residual stresses are volumetric stresses and must be described by a complete set of stress tensors. Although residual stresses are often described as a single value, this is not entirely correct and assumptions about the other orientations of stress must be made. If the entire stress state is not known, it is often best to conduct measurements and/or simulations to determine the magnitude and orientations of the residual stress state instead of simply assuming a single unidirectional stress state.

Type-2 residual stresses are more complicated in that they describe grain-level stresses. It is well known that metallic materials have grain-level property differences based on grain orientation. Systematic changes in modulus and yield strength occur as a function of crystal orientation relative to applied stresses. As a polycrystalline material is stressed, some grains will yield, while others are only elastically loaded. This is similar to the local straining of material discussed earlier, but on the grain level. The schematic in Fig. 3 shows a cluster of grains where the orientation of adjacent grains are different. After a specific loading cycle, some of the grains plastically yield and others do not, resulting in a grain-level residual stress profile that is not smooth, but discretized in regions based on the stresses within each grain.

Similar to Type-2, Type-3 residual stresses are caused by variations in strain within a grain as a result of either localized phase transformation, polygonization due to some level of annealing or nonuniform strain within grains, or strain localization near or at grain boundaries. Figure 4 shows an example of a warm-worked nickel-base superalloy microstructure exhibiting substantial sub-grain distortion and rotation. This has the potential of containing Type-3 residual stresses.

To take full advantage of their capabilities and minimize any detrimental effects to product performance, residual stresses require continuous attention and research. Key elements of this endeavor include measurement and simulation. These techniques go hand-in-hand to define, optimize, control, and understand residual stresses.

MEASUREMENT TECHNIQUES

Several methods are available for measuring residual stress. Figure 5 shows potential measurement techniques, applicable length scales, and potential sources of residual stress. Note that not all methods are equally capable of measuring the specific residual stresses for any scenario. Each method has its strengths and weaknesses. It is often beneficial to use more than one technique to gain a more complete picture of the actual stress state.

Modeling and simulation of residual stress has made significant progress and is now able to make predictions at

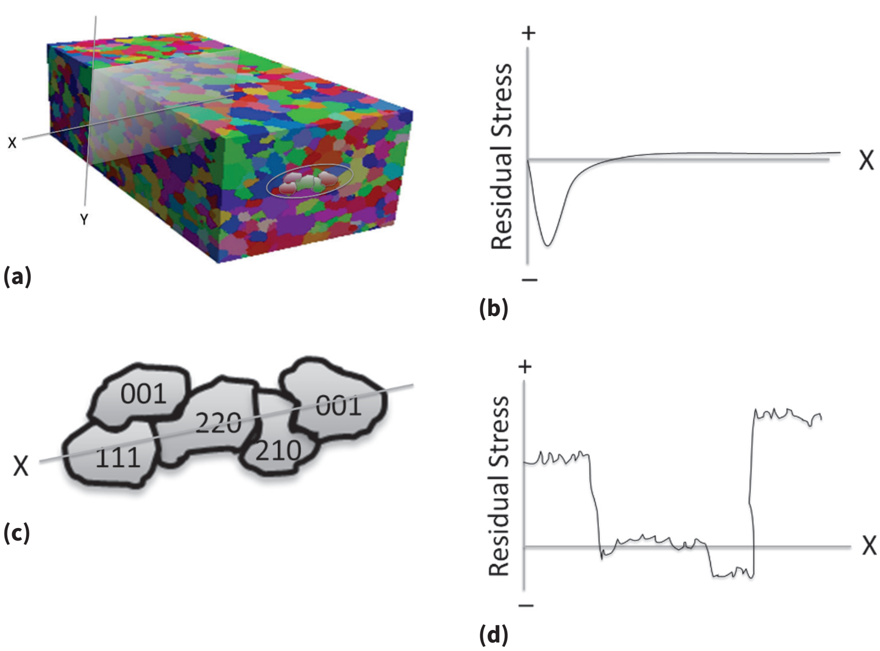


Fig. 3 — Volume of a polycrystalline alloy (a), where the sectioning plan provides reference for a surface residual stress profile produced by shot peening (b), which is an example of Type-1 residual stresses that occur over a large length scale. A sample of internal grains (c) exhibits different crystallographic orientations, resulting in varying levels of residual stress due to the anisotropic behavior of each specific grain, which is an example of Type-2 residual stresses occurring over grain size length scales.

Fig. 4 — Photomicrograph of nickel-base superalloy Waspaloy. This orientation imaging micrograph (electron backscatter diffraction pattern image) shows clear straining and polygonization within the deformed grains. Dark spots near grain and prior twin boundaries are a result of high localized strain and crystal orientation unable to be determined.

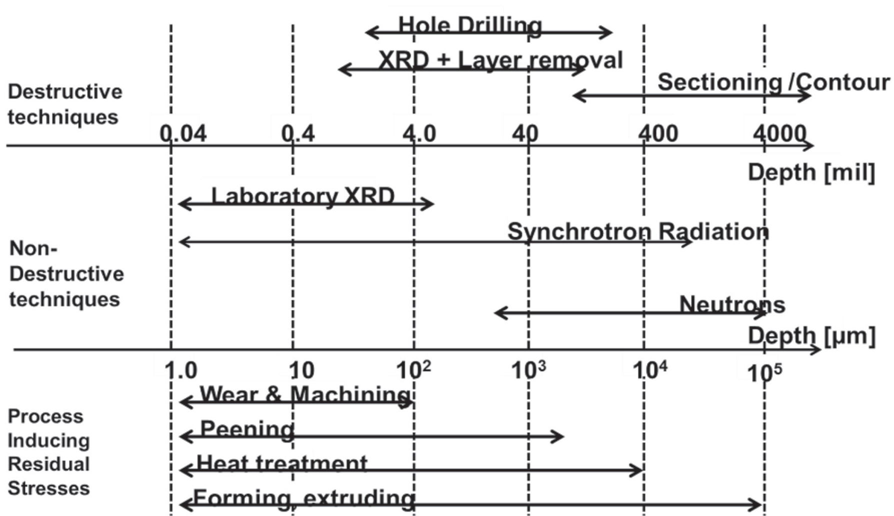


Fig. 5 — Examples of common destructive and nondestructive methods to measure residual stress and typical length scales over which each method is applicable. Additionally, examples of processes that induce residual stresses and the typical length scales over which these occur.

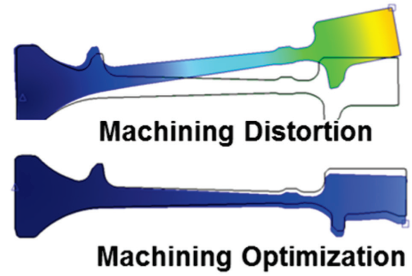


Fig. 6 — Model predictions of machining distortion for an axisymmetric disk component without prior control of bulk residual stresses (top) and for a disk where prior bulk residual stresses are optimized and specifically controlled. The predicted distortions are magnified to enable visualization and comparison.

the accuracy level required for many applications. Predicting residual stress requires a clear understanding of the processes used to manufacture the material, in addition to accurate and appropriate materials property data to describe the mechanical properties during each step of any thermomechanical process. To help with the latter, ASM International, along with the University of Connecticut, Worcester Polytechnic University, and the University of Buffalo established the Center for Materials Processing Data (CMPD) (*wp.wpi.edu/cmpd*), where projects to generate the necessary materials data for residual stress predictions are being pursued.

Residual stress plays a major role in the science and engineering of materials and products, impacting the materials, manufacturing, and product design communities, to name a few. These stresses can be either friend or foe, depending on how they are managed. Figure 6 shows a schematic of machining distortion from both a nonoptimized and optimized holistic manufacturing process sequence. It is clear that with focused effort and greater understanding and control of residual stresses, machining distortion can be readily mitigated.

TECHNICAL COMMITTEES INVITE VOLUNTEERS

ASM is currently working to restructure the society committee infrastructure to enable increased support to and involvement from ASM member volunteers. ASM has a number of long-standing content or programming committees aimed at various publication, conference, and database activities, such as the Handbook Committee, the AeroMat Organizing Committee, and the Materials Database Committee, to name a few.

One current area of focus for ASM is the ability for members to come together and conduct volunteer activities in specific technical areas. ASM is establishing a formal process for members to create “virtual communities of practice” or “special interest groups” via the ASM Connect system or through ASM Chapter efforts. These focused technical communities can be very informal as they work on local Chapter projects or international efforts in a common technical area of interest.

ASM technical committees can be formalized through proposals to the ASM Volunteerism Committee, which will oversee the creation, health, and sustainment of newly formed technical committees. The Residual Stress Technical Committee is an example of a group that provided a proposal to ASM regarding the formation of this committee and is now underway with several projects.

After technical committees are formed, they will seek out members with similar interests to further the focused topic throughout the materials community. It is critical that ASM International technical communities *link* with other standing content and programming committees to develop synergistic efforts, such as providing input to handbooks, books, journals, databases, or conference symposia.

In addition to the Residual Stress Technical Committee, there are several other technical committees that are being contemplated by ASM members, including: Material and Process Modeling Applications; Materials Data Management Tools/Methods; and Additive Manufacturing Technology. If you are interested in becoming involved in one of these topics, or would like to propose a new technical committee, visit ASM Connect’s “About Volunteerism” page at https://bit.ly/3gOCCBT. Or visit the ASM Connect home page at connect.asminternational.org.

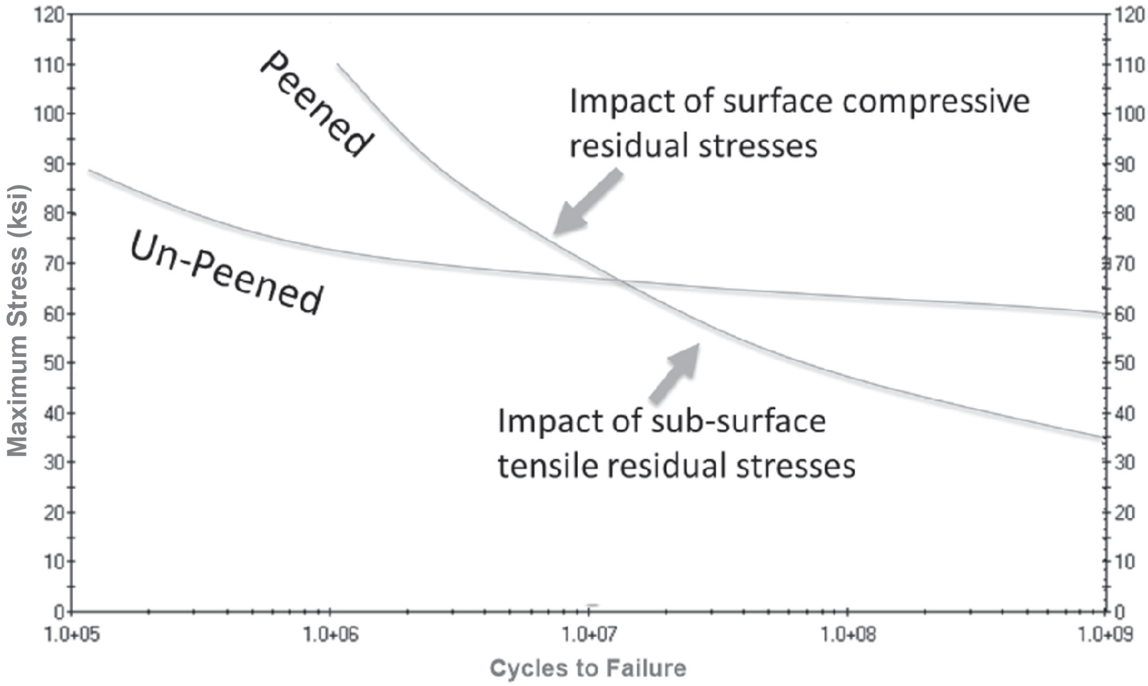


Fig. 7 — Schematic of fatigue behavior of peened and nonpeened material for a specific nominal R-ratio. Peening shows clear ability to improve LCF capabilities over nonpeened, but as stresses are lowered the HCF life of peened material can show a debit over nonpeened due to interactions of applied and internal tensile residual stresses.

It is often thought that residual stresses arising from surface treatment processes are completely beneficial. This is not always the case. For example, if a component is surface processed to produce a high level of compressive stress by peening, there will be a subsurface value that will be in tension. If the volume of material is externally loaded further in cyclic tension during service, it could lead to reduced performance and compromised component fatigue life. Figure 7 shows a schematic of such impact to the cyclic loading behavior of a material. This is a result of having a superposition of the residual and applied stresses, and local shift in R-ratio for the cyclic loading. If not adequately considered during the design, this could result in reduced product life.

TECHNICAL COMMITTEE EFFORTS

Residual stresses are not limited to metallic materials. They can exist in all classes of materials, including coatings, polymer matrix composites, and even ceramic matrix composites. Many ASM members and organizations have an interest in residual stress. To this end, ASM International recently initiated a new technical committee on the topic. The committee was formed in January with approximately 35 initial ASM members from many organizations including: Air Force Research Laboratory, ANSYS, Cummins, Curtiss-Wright Surface Technologies, General Electric, Hill Engineering LLC, Howmet, Kaiser Aluminum, Lockheed Martin, Oak Ridge National Laboratory (ORNL), Pratt & Whitney, Proto Manufacturing Inc., Quaker Houghton, Rolls-Royce Corp., TEC Materials Testing, Universal Technologies Corp., University of Connecticut (UCONN), Weber Metals, Worcester Polytechnic Institute, and ASM International.

This committee's work is aimed at furthering understanding and successful utilization of residual stresses in component and manufacturing process design, and associated assessment and control. The committee currently has three major subcommittees, focused on education (led by Jeffrey Bunn of ORNL), conference symposia (led by Lesley Frame of UCONN), and industry standards (led by Dale Ball of Lockheed Martin).

The education efforts are aimed at gathering available information that can be compiled into training programs that may include a high-level overview of residual stress, measurement methods, modeling and prediction methods, manufacturing process controls, and others. Initial elements have been assembled into an introductory presentation, where a subset is being introduced at a few ASM Chapter meetings. Further work will continue until the committee has sufficient material to allow proposing a new formalized educational program with the ASM Education Committee.

The committee had been working to develop a symposium on residual stress for IMAT 2020, which now will be targeted for IMAT 2021. The subcommittee is also looking to drive interest in focused talks at AeroMat 2021 and the International Conference on Fracture (ICF15) in 2021. The committee encourages submission of abstracts on residual stress to these upcoming conferences.

The committee is also looking to further rally the industry around the topic and develop industry standards.

One such standard currently in draft form is on "Residual Stress Classification, Metallic Structural Alloy Products, and Finished Parts." There are a number of industry specifications and standards for measurement, but there is no standard for how bulk residual stresses are defined within product requirements and definitions. Surface residual stresses are indirectly specified for surface treatment processes by means of peening intensity factors, and validation methods through use of process setup and oversight tools such as Almen strips.

For bulk residual stresses, the magnitude and spatial distribution are largely not directly or indirectly incorporated into product definitions that are provided to suppliers, but have been the focus of much research and application within the heat treating community. Bulk residual stresses are extremely important and impactful to both downstream manufacturing operations (i.e., machining and associated distortion) and component service behavior (i.e., yield behavior or fatigue life). The draft industry standard is being worked on by the Residual Stress Technical Committee in preparation for submission to the SAE standards committee for review and balloting.

This newly formed committee is just beginning, but has made significant progress on a number of fronts. The ability to develop a technical committee focused on a technical topic area of interest to a group of ASM International members enables the establishment of "home rooms" or "communities of practice" that allow members to volunteer and be active within a specific interest area. If you are interested in this topic, would like to volunteer, and want to be part of the ASM International Residual Stress Technical Committee, visit ASM Connect's "About Volunteerism" page at https://bit.ly/3gOCCB. **~AM&P**

For more information: David Furrer, FASM, senior fellow, Pratt & Whitney, 400 Main Street, Hartford, CT 06118, david.furrer@prattwhitney.com.

Reference

1. E. Paul Degarmo, et al., Materials and Processes in Manufacturing, 9th edition, John Wiley & Sons, p 97, 2003.

ISTFA/2020

THE RISE OF MEMS AND 3D FAILURE ANALYSIS

SHOW PREVIEW

46TH INTERNATIONAL SYMPOSIUM FOR TESTING AND FAILURE ANALYSIS

The 46th International Symposium for Testing and Failure Analysis (ISTFA), the premier conference and exhibition for the microelectronics failure analysis community, is scheduled for November 15 – 19 in Pasadena, California. This year's theme—The Rise of MEMS and 3D Failure Analysis—will be evident throughout the event in user group meetings, technical presentations, and keynote. The conference also includes the highly popular EDFAS video and photo contests.

ISTFA once again offers the opportunity to take an immersive half or full-day educational course. This year's tutorial program extends the learning process to a wider selection of topics. The technical sessions feature over 100 presentations of original unpublished work in areas such as sample preparation and device deprocessing, fault isolation, silicon photonics FA, scanning probe analysis, and emerging FA techniques and concepts. New this year is a student poster competition, which aims to foster exchanges between the academic world and the failure analysis engineering community.

ISTFA's keynote speaker, Dr. Tim Brosnihan, executive director of MEMS and Sensors Industry Group at SEMI, has more than 25 years of experience in the MEMS industry working in small start-ups as well as large corporations. This talk includes a history of MEMS, its fabrication technology, and how MEMS are enabling market megatrends such as autonomous driving, smart med tech, machine learning, and biometrics. The Expo features key companies showcasing the best technologies and products in the industry.

EDUCATION WORKSHOPS

- **ESD – FA**
  Instructor: Dr. Steven H. Holdman
- **Review of Scanning Probe Microscopy Methods**
  Instructor: Dr. Peter De Wolf
- **Beam-Based Defect Localization**
  Instructor: Dr. Ed Cole, Jr., FASM
- **Optical, Infrared, and FA Microscopy**
  Instructor: Mr. John McDonald

For dates, times, and full course descriptions, visit istfa.org.

TUTORIALS

An expanded tutorial program addresses 22 topics, including two new ones:

- **Microscopy:** Charged Particle Systems: Fundamentals & Opportunities
- **3D Device:** 3D Device/Package Fault Isolation and Failure Analysis

PASADENA CALIFORNIA

NOVEMBER 15-19

PASADENA CONVENTION CENTER

KEYNOTE SESSION

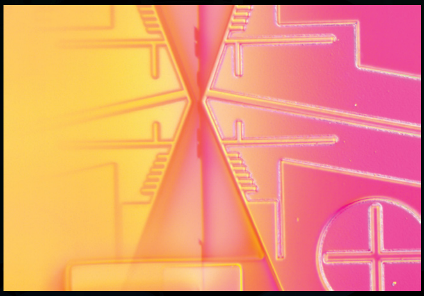
TUESDAY, NOVEMBER 17

Brosnihan

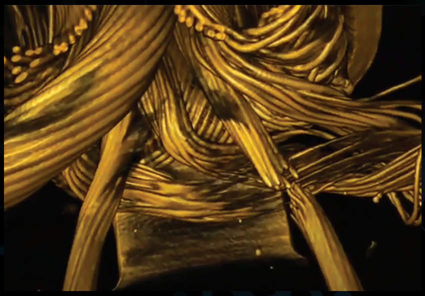
Dr. Tim Brosnihan, executive director of MEMS and Sensors Industry Group at SEMI, will talk on "Sensitization: How MEMS Technology is Enabling Our Digital World" including a brief history of MEMS, description of fabrication technology, and discussion of how MEMS are enabling market megatrends such as autonomous driving, smart med tech, machine learning, and biometrics.

SPECIAL CONTESTS

See the winners of the EDFAS Video Contest, featuring three-minute videos on failure analysis, as well as the best of the EDFAS Photo Contest, with categories in optical microscopy, SEM/TEM/x-ray/UV micrographs, and photon emissions.



First Place Winner in Color images, 2019 EDFAS Photo Contest. Courtesy of Kevin Awai, Raytheon.



First Place Winner, 2019 EDFAS Video Contest. Courtesy of Sandeep Kullar, Nordson Dage.

EXHIBIT HOURS

TUESDAY, NOVEMBER 17 | 9:30 A.M. – 6:30 P.M.

WEDNESDAY, NOVEMBER 18 | 9:30 A.M. – 4:30 P.M

TECHNICAL PROGRAM TOPICS

- 3D Device Failure Analysis
- Board and System Level FA
- FIB Circuit Analysis and Edit
- Competitive Analysis and Reverse Engineering
- Detecting Counterfeit Microelectronics
- Diagnostic Testing, Scanning, and Debug
- Emerging FA Techniques
- Electronic Device Materials Characterization
- Energy
- FA Process
- FA Techniques Addressing the Challenges of Heterogeneous Systems in Package
- Future Challenges of FA
- Metrology and In-line Device Characterization
- Microscopy
- Nanoprobing and Electrical Characterization
- Novel Memory FA
- Organic Electronic (OLED)
- Power, Discretes, and Optoelectronic Device FA
- Packaging and Assembly Level FA
- Quantum Circuit FA
- Sample Preparation and Device Deprocessing
- Scanning Probe Analysis
- Silicon Photonics FA
- Wireless, Self-Powered Sensors
- MEMS Failure Analysis
- Yield and Reliability Enhancement

EXHIBITOR LIST

Advantest Corporation
Allied High Tech Products
Angstrom Scientific, Inc.
Applied Beams
Barnett Technical Services
Bruker Corporation
BSET EQ
Checkpoint Technologies
Contech Solutions Inc.
Control Laser Corp.
CORIAL
DC - Digit Concept
EAG Laboratories
Ebatco
Electron Microscopy Sciences
Gatan EDAX
Hamamatsu Corporation
HDI Solutions - Hitachi
Herzan LLC
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JEOL USA
JIACO Instruments
Keyence Corporation
Kleindiek Inc.
LatticeGear
Leica Microsystems
MASER Engineering B.V.
Materials Analysis Technology
Mentor, A Siemens Business
MEO Engineering Company, Inc.
Microsanj LLC
MSSCORPS Co., Ltd.
Neocera LLC
Nikon Metrology
Nippon Scientific Co., Ltd.
Nisene Technology Group, Inc.
North Star Imaging
OKOS
Olympus
Oxford Instruments
Park Systems Inc.
Photothermal Spectroscopy Corp.
PIE Scientific LLC
PVA TePla America Inc.
Quantum Focus Instrument
Quartz Imaging
Raith America, Inc.
RKD Engineering
RKD Systems
Robson Technologies Inc.
SELA USA Inc.
SEMICAPS
SmarAct Inc.
Solecon Labs
SPI Supplies, Inc.
Synopsys
Ted Pella, Inc.
TeraView LTD
TESCAN USA
Thermo Fisher Scientific
Trion Technology
TSS Microscopy
ULTRA TEC
Varioscale Inc.
XEI Scientific
ZEISS
Zurich Instruments USA, Inc.

**Exhibitor list current as of August 24.*

ISTFA.ORG

Heat Treating Society
ASM INTERNATIONAL

SEPTEMBER 2020 | VOLUME 8 | ISSUE 3

HTPRO

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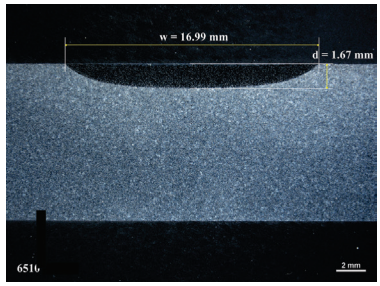
HTPRO
BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL



DEPARTMENTS

ABOUT THE COVER

Laser heat treatment of a stamping die. Courtesy of Synergy Additive Manufacturing.

EDITORIAL OPPORTUNITIES FOR *HTPro* IN 2020

The editorial focus for *HTPro* in 2020 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

November/December Atmosphere & Vacuum Heat Treating

To contribute an article to one of the upcoming issues, contact Vicki Burt at vicki.burt@asminternational.org.

To advertise, contact kelly.johanns@asminternational.org.

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CREATING AN R&D ROADMAP FOR THE HEAT TREATING INDUSTRY


Pershing

For those of us in the heat treating industry, what do we need for improved operations or to create better products? What developments are needed to improve the heat treating industry? When we talk to someone in academia, government, our industry colleagues, or our boss about the areas that need research and development in heat treatment, what do we say?

The R&D Committee of the Heat Treating Society is addressing these questions in its 2020 Heat Treat Research and Development Roadmap. The roadmap focuses on six technology areas where advances are desired. The advances must help the heat treat industry improve in the following areas:

- Cost
- Safety
- Sustainability
- Product performance

These are the improvement areas that drive the technology development desires. The committee has used prior heat treat industry input to target R&D advances in the following technology areas:

- Modeling and simulation
- Sensors and automation
- Heat generation methods
- Advanced materials
- Nondestructive evaluation
- End-product quality and performance

The HTS R&D Committee is forming a document around each of these technology areas that gives the key next developments needed to move the technology forward. The intent is to give universities, national laboratories, government agencies, industry consortiums, and even our individual companies a tangible list of where R&D development is needed.

As an example, the sensors and automation section mentions the need for expanded infrared temperature sensing in furnaces, quench oil degradation monitoring and polymer quench concentration monitoring, raw material ID and tracking, and improved gas analysis speed. It also discusses predictive maintenance methods based on sensor knowledge and data. The whole area of data, Industry 4.0, Internet of Things, and artificial intelligence comes into play when discussing these technologies. Improved use of automation is another important feature the industry must continue to advance. Specific automation developments like improved vision enables the adoption of more automation. It is easy to see that capability expansion and sensor cost reductions allow the improvement goals in cost, safety, sustainability, and product performance to occur. And so it is with each of the six technology areas. All of them have development desires explained that will impact cost, safety, sustainability, and product performance positively.

One difficulty in forming a document that purports to list all key developments needed is that some development areas, and even the correct state of the art for current technologies, may be missed. In order to minimize our "misses," we will be reaching out to more heat treating experts and asking for section reviews. We hope to make it a document that can be used and referenced by those in the industry and those that want to do purposeful research that truly makes a difference.

Michael Pershing
Chair, Heat Treating Society R&D Committee
Sr. Technology Steward, Caterpillar Inc.

HTS NAMES NEW BOARD MEMBERS FOR 2020

The Heat Treating Society (HTS) board, at the recommendation of the HTS Awards and Nominations Committee, named new board member, **Steven Ferdon** to serve on the HTS Board for the 2020-2023 term; **Chuck Faulkner** and **Marc Glasser** have been reappointed to serve for the 2020-2023 term. **Michael Brant** has been reappointed to serve as emerging professional board member for the 2020-2021 term; and **Rodolfo Canales Garcia** to serve as student board member for the 2020-2021 term. Terms begin October 1. Continuing on the board are **Eric Hutton** (president), **Lesley Frame** (vice president), **Jim Oakes** (immediate past president and finance officer), **Robert Cryderman** (secretary), **Benjamin Bernard** (member), **Fred Hamizadeh** (member), **Robert Madeira** (member), **Deidra Minerd** (member), and **Doug Puerta** (member). Leaving the board are **Thomas Wingens** (member) and **Noah Tietsort** (student board member).

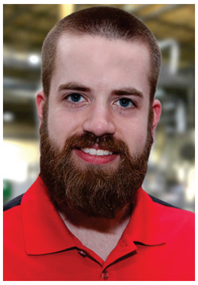
Steve Ferdon is the director of Global Engineering Technology for Cummins Electronics & Fuel Systems Business. Ferdon's team provides engineering analytical services & research in the fields of materials science, chemical technology, structural mechanics, fluid mechanics, tribology and configuration management. Ferdon worked for Duke Energy from 1982-1985, and from 1985 to 1992, he worked for Williams International, initially as a failure analyst and later as an MSE group leader, supporting the design and development of small gas turbine engines for defense and civilian aerospace applications. In 1992, he joined the new Cummins Fuel Systems Business as a technical specialist in the three-person Materials Science Engineering organization that has grown into the Global Engineering Technology organization of today.

Faulkner

Chuck Faulkner joined Quaker Houghton in 1983 and his current position is commercial development manager – heat treatment. He currently serves as ASM HTS Expo Committee co-chair, T&P Committee member, and co-chair for Heat Treat Mexico. Chuck has a B.A. in organizational management from Eastern College, St. Davids, Pa.

Glasser

Marc Glasser is the director of metallurgical services for Rolled Alloys. He has been with Rolled Alloys since 2012 and has worked in materials science and engineering for 39 years. His experience includes extensive mill metallurgy roles in processes including rolling, forging, and powder metallurgy. He also has extensive experience in customer support engineering and served as the technical manager and heat treat applications development engineer for a specialty furnace manufacturer. Glasser received his B.S. in materials engineering from Rensselaer Polytechnic Institute and his M.S. in materials science from the NYU Tanden School of Engineering.



Brant

Michael Brant is a metallurgical engineer at Contour in Indianapolis, a thermal processor and system builder that specializes in induction and nitriding heat treatment processes. Brant develops and improves heat treatment procedures for contract processing, as well as R&D applications, manages quality control for onsite metallurgical testing, and leads the development and application of magnetic particle inspection. He has achieved a Level II Magnetic Particle Qualification of Nondestructive Testing and a Six Sigma Black Belt Certification. Brant served as the emerging professional member on the HTS Board of Directors for the 2019 to 2020 term. He is accepting his 2nd appointment for the 2020 to 2021 term.

Garcia

Rodolfo Canales Garcia is a materials engineering student at Instituto Tecnologico de Morelia and vice president of the Board of Directors of the student chapter AIST-ITM. As a materials engineering student, Garcia has studied different manufacturing processes, and is particularly interested in heat treatment. He considers himself as someone passionate about steels and everything related to their processes and properties, including the use of heat treatment to modify their mechanical properties for different applications.

SOLICITING PAPERS FOR ASM HTS/BODYCOTE BEST PAPER IN HEAT TREATING CONTEST

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

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

To view rules for eligibility and paper submission, visit hts.asminternational.org, Membership & Networking, and Society Awards.

Paper submission deadline is March 1, 2021. Submissions should be sent to Mary Anne Jerson at maryanne.jerson@asminternational.org.

NOMINATIONS SOUGHT FOR GEORGE H. BODEEN HEAT TREATING ACHIEVEMENT AWARD

ASM's Heat Treating Society (HTS) is currently seeking nominations for the George H. Bodeen Heat Treating Achievement Award, which recognizes distinguished and significant contributions to the field of heat treating through leadership, management, or engineering development of substantial commercial impact. **Deadline for nominations is February 1, 2021.**

ASM HTS/SURFACE COMBUSTION EMERGING LEADER AWARD

The ASM HTS/Surface Combustion Emerging Leader Award recognizes an outstanding early-to-midcareer heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. The award was created in recognition of Surface Combustion's 100-Year Anniversary in 2015. The winning young professional will best exemplify the ethics, education, ingenuity, and future leadership of our industry. **Deadline for nominations is February 1, 2021.**

For nomination rules and forms, visit the Heat Treating Society website at hts.asminternational.org and click on Membership & Networking and Society Awards. For additional information, or to submit a nomination, contact Mary Anne Jerson by email at maryanne.jerson@asminternational.org.

HTS MEMBERS NAMED 2020 ASM AWARDEES AND FELLOWS

The Heat Treating Society is pleased to announce that several of its members have been named a recipient of a 2020 ASM Award or have joined the newest Class of Fellows. Congratulations to all!

Distinguished Life Membership


Vander Voort

Mr. George F. Vander Voort, FASM, consultant, Vander Voort Consulting LLC, Wadsworth, Ill., will receive this year's award "for being the world's leading authority and source for knowledge in the field of metallography, specimen preparation, selective etching and tint etching, interpretation and measurement of microstructures, and fractography." Distinguished Life Membership was established in 1954 and is conferred on those leaders who have devoted their time, knowledge, and abilities to the advancement of the materials industries. The award is among the most prestigious of the Society. It is expected that all nominees will be truly outstanding.

ASM Fellows


Alpay

Prof. Pamir Alpay, FASM, Executive Director, GE Professor of Advanced Manufacturing, University of Connecticut, Storrs. His citation reads, *"For exceptional contributions and leadership in materials theory, computational materials science, and multiscale materials modeling towards an understanding of aerospace alloys, functional materials, and surface properties."*


Goldstein

Mr. Robert Goldstein, FASM, Director of Engineering, Fluxtrol Inc., Auburn Hills, Mich. His citation reads, *"For seminal work on induction heat treating applications, making significant contributions to diverse areas such as human health, space exploration and materials processing."*


Grum

Dr. Janez Grum, FASM, Faculty of Mechanical Engineering – Retired, University of Ljubljana, Slovenia. His citation reads, *"For sustained contributions in metallurgical research and technologies, including nondestructive testing, failure analysis, and laser processing of steel and other engineering alloys."*


Leon

Mr. Luis Leon, FASM, Associate Technical Fellow, The Boeing Company, Seattle. His citation reads, *"For expertise as a materials technology expert and mentor who pioneered utilization of advanced materials and processes to improve the performance of high temperature commercial aircraft propulsion support systems."*


Osterman

Dr. Virginia Osterman, FASM, Senior Scientist, Solar Atmospheres Inc., Souderton, Pa. Her citation reads, *"For significant technical and educational contributions specific to vacuum heat treating processes, including use of vacuum furnaces for the embrittlement of titanium, tantalum, and other refractory metals for powder production."*

LASER HEAT TREATING CUTS COSTS AND SHORTENS SCHEDULES IN THE MANUFACTURE OF AUTOMOTIVE DIES

Automotive die OEMs throughout Europe are using laser heat treatment to deliver parts fast, with superior quality, at lower cost.

Aravind Jonnalagadda*
Synergy Additive Manufacturing, Clinton Township, Michigan

The adoption of laser heat treatment (LHT) in Europe has been universally successful, and LHT has become essentially mainstreamed there. Yet LHT is barely practiced in the U.S. for several reasons. For example, LHT as a process is still not well understood in the U.S. and there is a scarcity of reliable LHT job shops in the country. Also, data on LHT's cost, quality, and schedule improvements has not yet influenced U.S. decision makers.

The authors of this article believe LHT is poised for rapid adoption in the U.S. OEM community. This article presents a basic technical introduction to LHT and the results of a case study of LHT cost savings in automotive trimming/form dies.

DESCRIPTION OF LASER HEAT TREATING

Laser heat treating, also referred to as laser hardening, is a process in which a laser beam (with a typical spot size between 0.5 x 0.5-in. and 2 x 2-in.) illuminates the surface of a metal part for the purpose of heating it to a desired temperature, typically above the metallurgical transition temperature, for both the metal's surface and its heat affected zone (HAZ). When the laser heat source is removed, the thermal mass of the metal rapidly quenches the heated area by conduction, with the result that the treated part of the metal has the desired hardness.

The details of the laser beam's operation can be fine-tuned to exercise precise control over all aspects of the hardening process, delivering energy with great precision, and allowing for rapid quenching. Importantly, depending on geometry, LHT also allows treatment via line-of-sight for areas that are difficult to reach by other means.

Fig. 1 — Laser heat treatment of a stamping die.

*Member of ASM International

BENEFITS OF LASER HEAT TREATING

Compared to conventional heat treatment techniques, such as induction, furnace, and flame heat treatment, LHT's benefits include:

- Consistent hardness depth. By allowing precise, millisecond-level feedback control of the delivery of energy to the metal itself, LHT can produce a HAZ with exacting specifications, including consistent hardness depth.
- Minimal to zero distortion. Laser heat treatment automatically delivers the smallest possible total energy to the die under treatment for any size HAZ. This intrinsic feature of LHT automatically results in minimal to zero distortion in most large sizes of automotive dies.
- Precise application of beam energy to work spot. Flames or coils need not be in close proximity to the work area, resulting in the heat being applied only to the intended area, with minimal to zero heating of adjoining areas.
- No hard milling is required on large automotive dies. Because of LHT's low-to-zero dimensional distortion, post treatment material removal is limited to tiny amounts, which can be removed by polishing and abrasion, with no hard milling required on most automotive stamping dies.

Laser heat treating in the fabrication and maintenance of automotive dies usually results in cost savings, primarily from the complete elimination of the post hardening dimensional restoration processes.

LASER HEAT TREATABLE MATERIALS

Any steel with greater than 0.2% carbon content is treatable by LHT. The LHT treated dies are generally as hard, or harder than, conventionally treated dies.

Common laser heat treatable automotive materials include, but are not limited to:

- D6510 Ductile Iron
- D4512 Ductile Iron
- S7 Tool Steel
- S7140 Alloyed Steel
- S0030 Non-Alloyed Steel
- M2 Tool Steel
- G2500 Grey Cast Iron
- S0050A Alloyed Steel
- 4140 Alloy Steel
- G25HP Grey Cast Iron
- A2 Tool Steel
- 410 Stainless Steel
- G3500 Grey Iron
- D2 Tool Steel
- 420 Stainless Steel

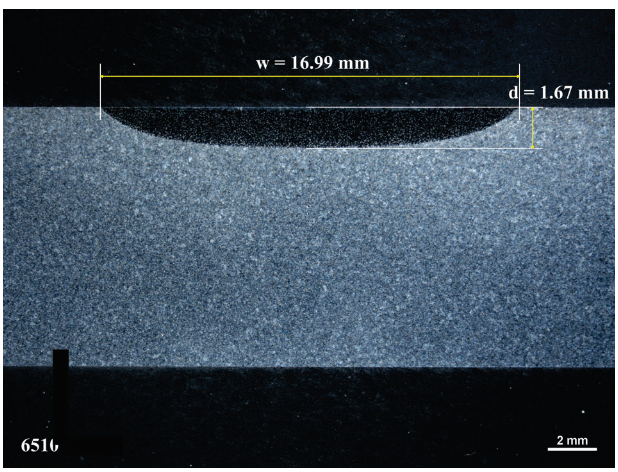


Fig. 2 — Metallurgical cross-section of laser heat treated D6510 die material.

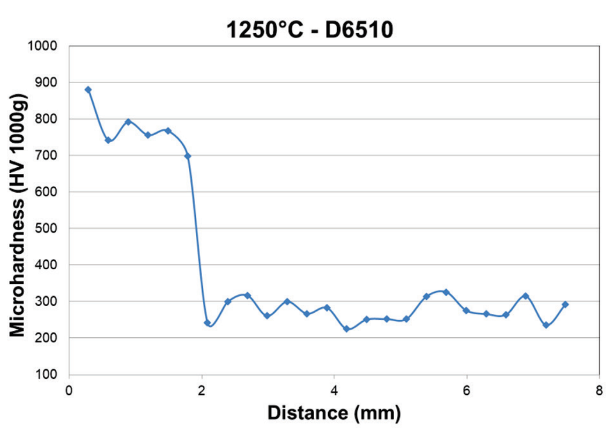


Fig. 3 — Hardness profile of laser heat treated D6510 across the depth. Average hardness of 760 HV (62.5 HRC) was recorded on the D6510 test sample shown in Fig. 2.

CASE STUDY

To illustrate the potential for LHT, consider the following case study from a U.S. domestic OEM die supplier. This study concerns new part manufacture of automotive trim/form dies. A mid-sized OEM typically produces 40 such dies in the year. For this process, both cost in hours while the product was being worked on, and also the calendar days for each step, were measured.

The results are shown pictorially in a detailed table in Fig. 4 and are summarized here:

- Laser heat treatment reduced the yearly cost for this product line from $436,000 to $312,000 at a billing rate of $50/hour, and from $697,000 to $499,200 at a billing rate of $80/hour, for a savings of 28.4%.
- Delivery time dropped from 17 to 13 days, a net speedup of 23.5%.
- Total energy reduction was significant, although not computed here. This may result in savings if carbon credits become monetized.

STEP / DESCRIPTION	COSTS AND TIMES	
	Conventional Heat Treating	Laser Heat Treating
STEP 1 – PROGRAMMING		
In this step, the various machines are programmed.	HOURS: 8 DAYS: 0	HOURS: 8 DAYS: 0
STEP 2 – 2D BASE MACHINING		
The base of the assembly is milled flat, a precursor for all other processes	HOURS: 12 DAYS: 1	HOURS: 12 DAYS: 1
STEP 3 – ROUGH / SEMI [FINISH] 3D MACHINING		
The 3D portions of the assemblies are machined. For Laser Heat Treatment, this includes finish machining, since Laser Heat Treating will not change the surface finish.	HOURS: 80 DAYS: 4	HOURS: 130 DAYS: 6
TRAVEL TO HEAT TREATING SUBCONTRACTOR		
Self explanatory	HOURS: 1 DAYS: 1	HOURS: 1 DAYS: 1
STEP 4 – HEAT TREATING [SUBCONTRACTOR DATA]		
Self explanatory	HOURS: 3 DAYS: 2	HOURS: 4 DAYS: 2
RETURN TRIP FROM HEAT TREATING SUBCONTRACTOR		
With Laser Heat Treating, parts go direct to assembly facility; with conventional heat treating, parts go to machining facility	HOURS: 1 DAYS: 1	HOURS: 1 DAYS: 1
STEP 5 – 2D BASE RE-MACHINING		
This is not required with Laser Heat Treating	HOURS: 12 DAYS: 1	HOURS: --- DAYS: ---
STEP 6 – 3D FINISH RE-MACHINING		
This is not required with Laser Heat Treating	HOURS: 80 DAYS: 4	HOURS: --- DAYS: ---
TRAVEL TO ASSEMBLY FACILITY		
This only applies to conventionally treated parts; Laser Heat Treated parts are already at the Assembly Facility	HOURS: 1 DAYS: 1	HOURS: --- DAYS: ---
STEP 7 – FINAL ASSEMBLY		
Self explanatory	HOURS: 20 DAYS: 2	HOURS: 20 DAYS: 2
TOTALS		
	HOURS: 218 DAYS: 16	HOURS: 156 DAYS: 13
Unit cost ["UC"] is computed at $50/hour. Yearly cost ["YC"] is computed for 40 dies	UC $10,900 YC $436,000	UC $7,800 YC $312,000
Yearly cost savings, LHT vs Conventional	$124,000	28.4%
Unit cost ["UC"] is computed at $80/hour. Yearly cost ["YC"] is computed for 40 dies	UC $17,440 YC $697,600	UC $12,480 YC $499,200
Yearly cost savings, LHT vs Conventional	$198,400	28.4%

Fig. 4 — Detailed table comparing cost and time involved for conventional heat treating versus laser heat treating.

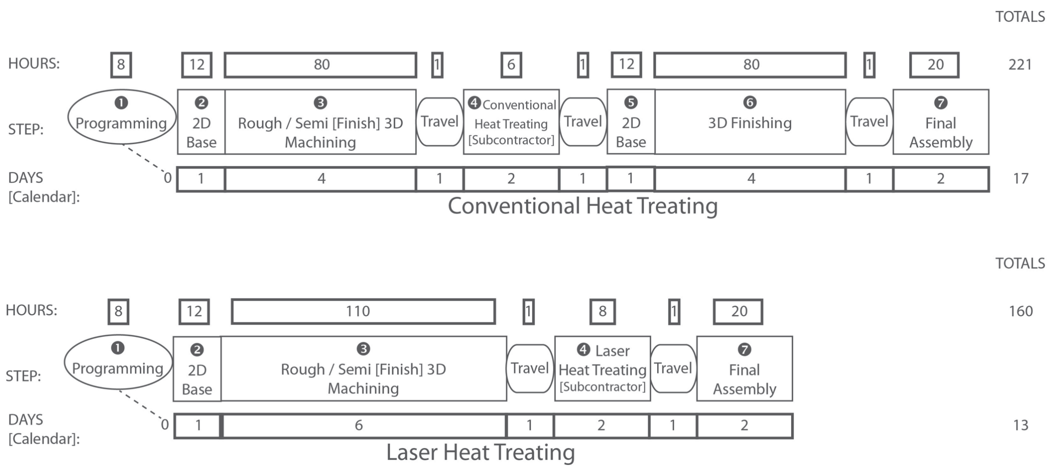


Fig. 5 —Set up of a conventional heat treating line, top, compared to a laser heat treating line, bottom.

CONCLUSIONS

Laser heat treatment is a process that is likely to expand in the automotive and other metal part manufacturing sectors. LHT faces no significant barriers to adoption, aside from the ones that are common to any emerging technology. These include lack of familiarity, lack of hard data, and a shortage of existing suppliers. The savings, measured by cost, schedule, quality, and energy reduction, are significant and are well supported. **~HTPro**

For more information: Aravind Jonnalagadda, CTO and co-founder, Synergy Additive Manufacturing LLC, 22792 Macomb Industrial Dr., Clinton Township, MI 48036, 248.719.2194, aravind@synergyadditive.com, synergyadditive.com.

PRACTICAL CONSIDERATIONS FOR VACUUM HEAT TREATMENT OF AM METALS

Temperature measurement, unvented cavities, loose powder, and direct contact of certain metals must be considered during process development of vacuum heat treatment of additively manufactured parts.

Virginia Osterman, FASM,* Solar Atmospheres Inc., Souderton, Pa.

Additive manufacturing (AM) processes vary in build method, and the path to a finished product affects the resultant microstructure and mechanical properties. In the case of fusion/melt AM processes, such as laser powder bed fusion, also called selective laser melting (SLM) and direct metal laser sintering (DMLS); and electron beam additive manufacturing (EBAM) processes, such as electron beam powder bed fusion and directed energy deposition (DED), recurrent heating and cooling of layers has a significant effect on the final microstructure and can result in anisotropy within the build itself. Additionally, each build is dependent on the starting feedstock material (powder or wire). The rate of layer deposition and cooling kinetics for each layer also has a distinct effect on the internal stress in the build and build plate. Therefore, as-built products typically must undergo a post build heat treatment to remove stresses, improve the final microstructure, and improve mechanical properties. Because many of the metal alloys used for aerospace and medical parts are highly sensitive to reactions with air at elevated temperatures, vacuum heat treatment is necessary to achieve optimum mechanical properties.

The selection of heat treatment processes depends on part geometry, properties required for the end use of the material, and the build method. The resulting microstructure has a very small grain size, which results in loss of ductility and the risk of brittle fracture. Thus, the selection of the proper thermal treatment determines the final mechanical properties of the build.

Inkjet, or binder jet (BJ) deposition, a non-melt AM bonding process, uses either liquid polymer deposition or metal-polymer matrix deposition and does not entail the strain of melt AM processes. Parts made using this process require final densification via sintering in a vacuum furnace. Binder removal becomes a major concern, especially when carried out in a cold-wall vacuum furnace.

This article discusses several practical concerns involved in using vacuum heat treatment[1], including temperature measurement, unvented cavities, loose powder, and direct contact of metals in the high-temperature vacuum[2].

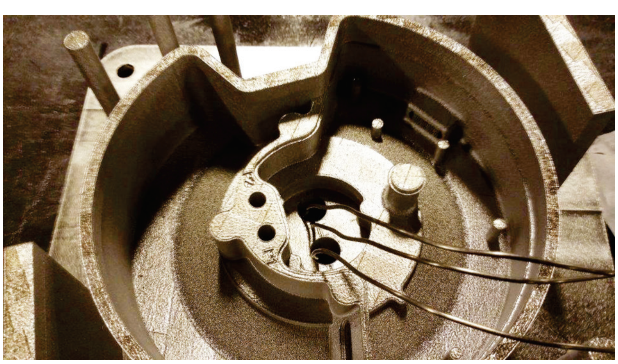


Fig. 1 — Placement of a thermocouple in a hole in an additively manufactured part provides the most accurate temperature profile during heat treatment.

Fig. 2 — Placing an external dummy block containing a thermocouple near the additively manufactured part provides a good comparative temperature profile for the part.

TEMPERATURE MEASUREMENT

Temperature uniformity and consistent temperature control are critical in all aerospace and medical heat treatment processes. Placing the thermocouple within the printed part is preferred to meet these requirements. Adding a printed hole 1.5 mm (0.0625 in.) in minimum diameter within the thickest cross section of the printed part provides the most accurate temperature profile during the heat-treating cycle (Fig. 1). If it is not possible to place a hole within the part, incorporate a dummy block (heat sink) into the build design that matches the material composition and the maximum cross section of the part. This provides a more accurate temperature profile of processed parts than placing a standard dummy block on the build plate. Avoid using the build plate for thermocouple insertion due to a mismatch with the temperature profile of the parts. If building a heat sink is not possible, then use a separate heat sink matching the thickest part cross section and material composition (Fig. 2).

UNVENTED CAVITIES

Because AM produces parts with unique geometries and uses an argon or nitrogen atmosphere, designing parts with unvented blind holes, cavities, pockets, and sealed cooling channels should be avoided. Trapped gases cause differential pressure within the part and outside the part as the vacuum pressure in the hot zone decreases. This pressure differential becomes significant during the heating process, leading to cracks and eventually part destruction. It is imperative that all printed geometries include a means to evacuation of any gases used during the vacuum pump-down process.

Fig. 3 — Damage to vacuum-furnace hot-zone components due to harmful reactions of loose powder hidden in blind holes of the build plate blown throughout the furnace during the vacuum evacuation.

LOOSE POWDER

Prior to heat treating, build plates should be inverted, and the entire build blown out using nitrogen until any free powder is fully removed from the external surfaces and, most importantly, from internal cavities such as blind holes and cooling passages. Loose powder remaining in the build is evacuated during vacuum pump-down and contaminates the furnace hot zone. Minor powder contamination might only result in the need to clean the furnace using a vacuum cleaner. However, in some high-temperature cycles, powder can cause severe reactions such as eutectic melting and diffusion bonding between the powder and furnace hot-zone components. Figure 3 shows titanium powder released from a build plate that resulted in severe diffusion bonding between the molybdenum hot-zone shields and heating elements due to incipient melting at the sintering temperature for titanium. For safety reasons, adding a slow-pump valve to the roughing line helps to avoid such powder eruptions during the vacuum pump-down.

ADVERSE REACTIONS OF METALS IN DIRECT CONTACT

The maximum thickness of the printed part should closely match the thickness of the build plate, and the build-plate composition should closely match the build material composition. Matching build-plate composition and dimensions minimizes cracking of the parts and avoids unwanted thermal reactions between the build plate and parts during post-build vacuum heat treatment.

Surface oxides on many metals prevent incipient melting between the metal and the fixture by creating asperities at the contact site. However, when heated in a vacuum, surface oxides diffuse into the bulk material or decompose at the processing temperatures, thereby eliminating such rough surfaces that limit direct surface-to-surface contact. With the two materials in direct contact, atoms can diffuse across the interface and react with similar or dissimilar atoms of the opposing material to form a new lower melting phase of the two materials. Such interactions can occur at temperatures 50 to 90% below the absolute melting point of either metal. Therefore, sticking (diffusion bonding) and melting (eutectic and incipient melting) can occur at much lower temperatures than expected. Knowledge of the temperatures at which such reactions occur is essential to avoid unexpected melting between parts, fixtures, and workbaskets.

Eutectic melting and diffusion bonding are also time and force dependent. Although the temperature might be 110°C (200°F) below the eutectic temperature if the time at temperature is extremely long or the mass of the part largely exceeds the mass of the fixture, some diffusion bonding or incipient melting could still occur.

The best way to prevent adverse reactions is to avoid heating at or near the eutectic melting point of the two materials. However, in instances where this is unavoidable, the use of a ceramic material between the part and the fixture is required. Ceramic separators can be in the form of sheet, blankets, plates, and paint. Some common stop-off paints consist of alumina, zirconia, yttria, and boron nitride. It is important to carefully select the ceramic separator based on the part or fixture material, because not all ceramic-based separator materials are inert to all metals at high temperatures. Above a temperature of 760°C (1400°F), boron nitride reacts negatively with titanium and titanium alloys. Silicon oxide, used as an additive in some ceramic compositions, reacts with some metals such as titanium and even graphite in vacuum or under reducing conditions at high temperature.

It is also important to ensure that the coating fully adheres to the graphite/metal fixture or that the sheet or fabric is intact. Over time, ceramic paints start to flake off due to continued heating and cooling. Loss of coating integrity increases the risk of failure, and ultimately eutectic or incipient melting, or solid-state diffusion reactions (diffusion bonding) between materials. Exposed material could result in unexpected melting or atomic diffusion, which changes the chemical composition of the parts at that interface, thus changing the mechanical and physical properties of the part. Continuous successful reuse of the separator can lead to a false sense of security. For example, Fig. 4 shows how the weight of the load fractured the weaves of old or overused silica fabric, resulting in direct contact between the graphite rail and Inconel sheet and, ultimately, full eutectic melting as the process temperature exceeded 1150°C (2100°F). The same precautions apply during high-temperature bake-out cycles performed periodically for maintenance purposes. All iron-base alloy workbaskets, trays, and grids should be removed from the hot zone prior to heating; otherwise, these components and the furnace itself can suffer extensive damage due to eutectic melting (Fig. 5). **~HTPro**

Fig. 4 — Damage to a graphite-metal fixture from eutectic melting enabled by deterioration of old or reused silica textiles used to separate the graphite and metal.

Fig. 5 — Damage in the area of an Inconel alloy grid from eutectic melting due to exceedance of the eutectic temperature during furnace bake-out.

Note: This article is an excerpt from "Vacuum Heat Treating Additively Manufactured Parts" in the recently published *ASM Handbook,* Volume 24: *Additive Manufacturing Processes,* available in the ASM Digital Library at dl.asminternational.org.

References

1. R. Hill, Vacuum Heat Treating of 3D-Printed Components, *Industrial Heating,* Sept. 12, 2018.

2. R. Fradette, V. Osterman, W. Jones, and J. Dossett, Vacuum Heat Treating Processes, *Heat Treating Technologies,* Vol 4B, ASM Handbook, ASM International, 2014, p 182.

For more information: Dr. Virginia Osterman, corporate chemist, Solar Atmospheres Inc., 1969 Clearview Rd, Souderton, PA 18964, 215.721.1502, ginny@solaratm.com.

ASMNEWS

ASM ANNOUNCES 2020 CLASS OF FELLOWS

In 1969, ASM established the Fellow of the Society honor to provide recognition to members for their distinguished contributions to materials science and engineering and to develop a broadly based forum of technical and professional leaders to serve as advisors to the society. Following are the members recognized by their colleagues for 2020. Additional Fellows may be elected to this distinguished body in subsequent years. The solicited guidance, which the Fellows will provide, will enhance the capability of ASM as a technical community of materials science and engineering in the years ahead.

Prof. Pamir Alpay, FASM
Board of Trustees Distinguished Professor
University of Connecticut
Storrs

For exceptional contributions and leadership in materials theory, computational materials science, and multiscale materials modeling toward an understanding of aerospace alloys, functional materials, and surface properties.

Prof. Raymundo Arróyave, FASM
Professor
Department of Materials Science and Engineering
Texas A&M University
College Station

For pioneering innovative pathways in the design of materials through a combination of fundamental materials physics, systems engineering and materials informatics, and for his service to the profession.

Prof. Kip Findley, FASM
Professor
Colorado School of Mines
Golden

For formative contributions in understanding fundamental relationships between microstructures and mechanical properties, contributions to engineering education, and enhancing research opportunities for undergraduate and graduate students.

Mr. Robert C. Goldstein, FASM
Director of Engineering
Fluxtrol Inc.
Auburn Hills, Mich.

For seminal work on induction heat treating applications, making significant contributions to diverse areas such as human health, space exploration, and materials processing.

Dr. Janez Grum, FASM
Professor
Faculty of Mechanical Engineering
Retired
University of Ljubljana
Slovenia

For sustained contributions in metallurgical research and technologies, including nondestructive testing, failure analysis, and laser processing of steel and other engineering alloys.

In This Issue

ASM INTERNATIONAL
Submit news of ASM and its members, chapters, and affiliate societies to Joanne Miller, editor, ASM News | ASM International
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Contact ASM International at 9639 Kinsman Road, Materials Park, OH 44073 | P 440.338.5151 or 800.336.5152 (toll free in U.S. and Canada) | F 440.338.4634 | E MemberServiceCenter@asminternational.org | W asminternational.org

HIGHLIGHTS 2020 CLASS OF FELLOWS

Prof. Yun Hang Hu, FASM
Charles and Carroll McArthur Endowed Chair Professor
Michigan Technological University
Houghton

For outstanding contributions to research and innovation in energy conversion materials, including application in solar cells, supercapacitors, hydrogen production, and hydrogen storage.

Prof. Shrikant Joshi, FASM
Professor
Division of Additive & Subtractive Manufacturing
University West
Trollhättan, Sweden

For sustained contributions in the fields of advanced surface engineering and laser materials processing and mentoring young professionals.

Dr. Michael R. Kessler, FASM
Dean, College of Engineering
North Dakota State University
Fargo

For contributions to the understanding and development of multifunctional materials (including the development of self-healing structural composites), bio-renewable polymers, and composites and to leadership in materials science education.

Mr. Luis R. Leon, FASM
Associate Technical Fellow
Metallurgical, Propulsion Applications
The Boeing Company
Seattle

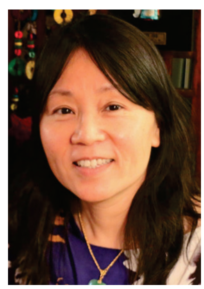
For expertise as a materials technology expert and mentor who pioneered utilization of advanced materials and processes to improve the performance of high temperature commercial aircraft propulsion support systems.

Dr. Dongjian (Don) Li, FASM
Engineering Manager
Research and Development
Howmet Aerospace
Niles, Ohio

For substantial technical achievements in titanium alloy processing development leading to improved yield and lower cost titanium processing methodologies; and activities promoting dissemination of titanium technology.

Dr. Navin Manjooran, FASM
Chairman
Solve Technology and Research Inc.
Windermere, Fla.

For driving scientific and technological advancements in nanomaterials processing techniques for energy and industry.



Dr. Guiru Nash Liu, FASM
Senior Experimental Metallurgist
Progress Rail Inc.
Chicago

For an exemplary career in practical root cause failure analysis covering a broad range of materials and manufacturing technologies.

Mr. Michael M. Niedzinski, FASM
Director of Standardization
Constellium
South Barrington, Ill.

For extraordinary contributions in implementing research and development to commercialize advanced aluminum alloy products for the aerospace and military communities.

Dr. Virginia Osterman, FASM
Corporate Chemist
Solar Atmospheres Inc.
Souderton, Pa.

For significant technical and educational contributions specific to vacuum heat treating processes, including use of vacuum furnaces for the embrittlement of titanium, tantalum, and other refractory metals for powder production.

Prof. Michael Pecht, FASM
Professor
Center for Advanced Life Cycle Engineering
University of Maryland
College Park

For technical contributions and leadership in the areas of electronics reliability, physics of failure, and sustainment.

Prof. Ma Qian, FASM
Distinguished Professor
Royal Melbourne Institute of Technology
Australia

For innovations in solidification processing, additive manufacturing, and powder metallurgy to manufacture metallic materials and products with enhanced performance and/or reduced cost or emissions.

Dr. Clare Rimnac, FASM
Wilbert J. Austin Professor of Engineering
Distinguished University Professor
Case Western Reserve University
Cleveland

For sustained research excellence in orthopedic biomechanics and biomaterials, particularly degradation of ultrahigh molecular weight polyethylene and materials performance of implants and bone.

Prof. Thomas W. Scharf, FASM
Professor
Materials Science and Engineering
University of North Texas
Denton

For significant contributions in materials tribology and surface engineering, pioneering work on solid lubricant materials and mechanisms, and distinguished service to the materials science community.

Dr. Donglu Shi, FASM
Professor
University of Cincinnati
Ohio

For pioneering contributions to superconducting materials, magnetism and magnetic materials, and novel nanostructures for photonic, biomedical, and drug delivery applications.

Mr. Jatinder P. Singh, FASM
Technical Integration Engineer-Steel
General Motors Company
Troy, Mich.

For significant advancement and implementation of advanced high strength steels for automotive body structures as a recognized leader in ferrous sheet metal, alongside a strong commitment to developing and promoting professionals in the materials engineering field.

Dr. Vasisht Venkatesh, FASM
Associate Director Materials Modeling
Pratt & Whitney
East Hartford, Conn.

For outstanding leadership in integrated computational materials engineering approaches for building process-structure-property models enabling enhanced performance and quality of Ni- and Ti-based alloys for aerospace applications.

Prof. Jingyang Wang, FASM
Division Head
Shenyang National Laboratory for Materials Science
Institute of Metal Research, Chinese Academy of Sciences
China

For pioneering contributions, global leadership, and mentoring in the field of science and technology of advanced ceramics, multifunctional coatings, and related materials and systems.

Prof. Xinghang Zhang, FASM
Professor
Purdue University
West Lafayette, Ind.

For groundbreaking discoveries in creating nanotwinned metals, control of mechanical behavior, and understanding of radiation damage in nanostructured metallic materials.

Nomination Deadline for the 2021 Class of Fellows is Fast Approaching

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

Criteria for the Fellow award include:

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

Deadline for nominations for the class of 2021 is **November 30, 2020.** To nominate someone, visit the ASM website to request a unique nomination form link. Rules and past recipients are available at asminternational.org/membership/awards/asm-fellows or by contacting Christine Hoover, 440.671.3858 or christine.hoover@asminternational.org.

ASM Nominating Committee Nominations Due

ASM International is seeking members to serve on the 2021 ASM Nominating Committee. The committee will select a nominee for 2021-2022 vice president (who will serve as president in 2022-2023) and three nominees for trustee. Candidates for this committee can only be proposed by a Chapter through its executive committee, an ASM committee or council, or an affiliate society board. **Nominations are due December 15.** For more information, contact Leslie Taylor at 440.338.5472 or leslie.taylor@asminternational.org, or visit asminternational.org/about/governance/nominating-committee.

Official ASM Annual Business Meeting Notice

The Annual Business Meeting of members of ASM International will be held virtually on:

Monday, September 14

4:00 - 5:00 p.m.

Register for the virtual meeting online at:

https://bit.ly/30R0XRZ

The purpose of the ASM Annual Business Meeting is the election of officers for the 2020-21 term and transaction of other Society business.

2021 Distinguished Lectureship in Materials & Society

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

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

Nominations may be proposed by any member of either Society by September 30.

View sample forms, rules, and past recipients at asminternational.org/membership/awards/nominate. Contact christine.hoover@asminternational.org or Deborah Hixon at TMS Headquarters, hixon@tms.org.

SMST Founders' Grant Accepting Applications

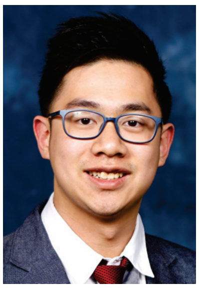
The International Organization on Shape Memory and Superelastic Technologies (SMST), an affiliate society of ASM International, is seeking applications for the 2021 SMST Founders' Grant. The intent of the SMST Founders' Grant is to provide funding for early, exploratory research related to shape memory and superelasticity. It is expected that the funds will be used as a "seed grant," used to test a concept and lay a foundation for obtaining further funding from industry or government agencies. The grant, which was endowed in 2019 by Dr. T.W. Duerig, FASM, includes a stipend up to $50,000 over two years. **Deadline to apply is January 15, 2021.** For more information visit https://bit.ly/3al1m22 or email carrie.wilson@asminternational.org.

Thermal Spray Hall of Fame Seeks Nominations

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 thermal spray. For a copy of the rules, nomination form, and list of previous recipients, visit tss.asminternational.org or contact maryanne.jerson@asminternational.org. **Nominations are due September 30, for recognition in 2021.**

Student Board Members for 2020-2021 Announced

The ASM Board of Trustees values the insights, ideas, and participation of Material Advantage students. The Student Board Member program provides the opportunity to attend four board meetings where the students will meet and work with leading technical professionals and gain leadership skills that will benefit them throughout their career. The next deadline for submissions is April 15, 2021. Details can be found on the ASM website.


Chan

Ho Lun Chan
Cal Poly Pomona

Ho Lun Chan (Lun) is pursuing a Ph.D. degree in materials engineering at the University of Virginia. He received his B.S. degree in chemical engineering at Cal Poly Pomona. Chan has a strong passion for corrosion and electrochemistry research, working with Dr. John Scully, FASM (UVA), to study the passivity of irradiated nuclear-reactor alloys in extreme environments, and with Dr. Vilupanur Ravi, FASM (CPP), to investigate the microstructural-corrosion behavior of aluminum foams and additively-manufactured steels. A materials entrepreneur, Chan has co-founded two start-up organizations during his undergraduate career. His goal is to pioneer electrochemical technologies for real-time corrosion management, extraterrestrial mining, and neurological research.


Emadi

Payam Emadi
Ryerson University

Payam Emadi is a Ph.D. candidate in the Mechanical Engineering Department at Ryerson University, Canada, under the supervision of Dr. C. Ravi Ravindran, FASM. Emadi's research involves the development of high-strength and lightweight magnesium alloys for use in the automotive and aerospace industries. Specifically, his work aims to promote uniform and finer magnesium grain structures via advanced processing methods. These include the addition of novel nucleants as well as the optimization of high-intensity ultrasonic irradiation. Emadi's research is motivated by the potential to increase magnesium usage in industry, thereby improving fuel efficiency and decreasing emissions through lightweighting.


Gilliams

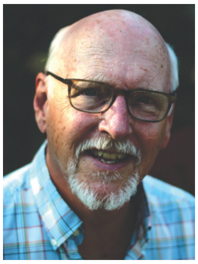
Casey Gilliams
Colorado School of Mines

Casey Gilliams is currently a fourth-year graduate student pursuing a Ph.D. in metallurgical and materials engineering with the Advanced Steel Processing and Products Research Center (ASPPRC) at the Colorado School of Mines. She graduated with her B.S. in materials science and engineering from the University of Florida in 2017. Her area of research focuses on the optimization of quench and partitioned steels, particularly with respect to processing, microstructure, and performance. She is interested in heat treatment, formability, and failure analysis.

Prof. John Ågren Named 2021 Recipient of J. Willard Gibbs Phase Equilibria Award

ASM is pleased to announce that Prof. John Ågren, FASM, Professor Emeritus, KTH Royal Institute of Technology, Stockholm, Sweden, is the 2021 J. Willard Gibbs Phase Equilibria Award recipient. His citation reads:

"For pioneering work in the field of computational thermodynamics and kinetics and their application to materials design and process improvement."


Ågren

The Gibbs 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. Originally proposed by the ASM Alloy Phase Diagram Committee, the award supports ASM's strong brand identity and reputation in the field of phase diagrams. The J. Willard Gibbs Phase Equilibria Award is endowed by QuesTek Innovations LLC.

In addition to many other contributions, Gibbs laid the thermodynamics foundations of phase equilibria with his brilliant essay, "On the Equilibrium of Heterogeneous Substances," published in 1876 and in 1878 in the *Transactions of the Connecticut Academy*.

FROM THE PRESIDENT'S DESK

Time Flies Logarithmically

Zi-Kui Liu, FASM

In materials science and engineering, we talk about fundamentals of thermodynamics, kinetics, crystallography, and defects and their correlations with chemistry, processing, microstructure, and properties. Among all of them, the kinetics and processing involve the change of materials with respect to time, such as the time-temperature-transformation (TTT) or continuous cooling transformation (CCT) diagrams. You may have noted that the time in TTT and CCT diagrams is plotted in logarithmic scale, enabling us to have a better understanding of whole processes from beginning to end. There are two interesting features: First, time has no zero as the logarithmic of time zero is negative infinite, and second, the same length at different locations on the axis of time represents the lengths of time differing in orders of magnitude, giving an impression that time gets more and more compressed when the process is moving toward its end.

This certainly applies to the process of being the ASM President. It is extremely hard to trace back to the beginning when this process started. One could argue that a single critical event triggered the process, yet there were many prior incidents that enabled such an event. That is how history is made: There is no zero of time, and every event seems accidental and random, yet so inevitable. Nevertheless, one can always select a reference point for the purpose of counting, and a convenient one would be the day that one joins ASM International as a member, with events one after another through volunteering and leadership in chapters, technical/symposium/administrative committees, and Board of Trustees. I am so grateful for everyone who believes in, encourages, supports, and pushes me to do better than my best along the way.

One can select the day that the Vice President (VP)-elect is announced as a reference point to examine the journey of VP-elect, VP, President (P), and Immediate Past President (IPP) which spans approximately 1250 days. The first 100 days count for nearly 2/3 of the total length in the logarithmic scale of time; that was exactly what all ASM Past Presidents (PP) told me: the VP/P/IPP journey flies like a breeze. So it did.

Let me bring you back to my first 100 days. In April/May 2018, I contacted ASM Presidents since 2011, i.e., Mark Smith, Christopher Berndt, Gernant Maurer, Ravi Ravindran, Sunniva Collins, John Tirpak, William Frazier, Frederick Schmidt, and David Furrer (VP at that time), and asked for their Vision Statements, their experiences, and their advice. I am so grateful to all of them for sharing their visions and insightful summaries of their experiences. Their individual in-depth views and perspectives helped me to gain a better understanding of the challenges and opportunities ASM International had been facing. I particularly liked the Board-led Task Forces initiated by David Furrer in 2017, aiming to bridge the gap between the strategic plan and operations of ASM International and engage more discussions among members of the Board of Trustees (BoT) and with volunteers and operations management team (OMT). That was an excellent initiative. My first face-to-face meeting with the BoT and OMT was at the ASM Leadership Days and Strategic Planning Meeting in July 2018. I had in-depth conversations with many ASM volunteer leaders and BoT/OMT members, both collectively and individually. One could sense the elephant in the room: the misalignment between BoT and OMT, which inevitably resulted in the change of leadership in May 2020 (Vol. 178, No. 5, p 72).

The next 100 days started at the MS&T 2018 conference in October in Columbus. In addition to the packed BoT events, I scheduled individual meetings with a number of ASM employees and OMT members and listened to their activities and thoughts. It was great to hear that ASM was moving toward a digital platform with its technical contents, which placed the society in a good position for dealing with the COVID pandemic (Vol. 178, No. 4, p 70). Another significant item was the discussion on the development of international activities. Further investigation of ASM membership demographics showed that only 20% of ASM memberships were outside of the U.S. compared with 40-50% in other materials societies and 60% in IEEE, resulting in the establishment of the BoT-led Global Network Task Force, which ultimately became one of four key initiatives of the ASM Strategic Plan discussed at the Strategic Planning Meeting in August 2019 and finalized in the Spring 2020 (Vol. 178, No. 2 p 56). ASM International has since initiated discussions with several materials societies in other countries on a broad range of potential collaborations. In a virtual meeting on July 22 with 20 PPs since 1982, I also learned about the significant international efforts that ASM made between 1985-2000. As IPP in 2020-2021 and PP in the future, I will continue promoting global partnerships and collaborations to further enhance the impact of ASM International through its memberships and technical contents. Wishing ASM all the best!

ASM President Zi-Kui Liu, FASM
zi-kui.liu@asminternational.org

MD CORNER

Providing Digital Content and Materials Data

Aderhold

For my first column as acting managing director, I'd like to thank everyone for being a member of ASM. The support we get from our members through serving on committees, participating in chapter meetings, writing articles, working with our events, contributing your thoughts and ideas and the many other ways that you volunteer is truly amazing! Thank you!

One of my jobs is to listen closely to feedback from our members. One of the recurring themes is, "You have a lot of great materials content but it's too hard to find and navigate." To respond, we launched the ASM Digital Library, a state-of-the-art platform that allows you to easily drill down or search for the content you're looking for, and even recommends content that it thinks you will like. We initially loaded the entire *ASM Handbook* series into the platform. We received a lot of positive feedback but that was just the beginning. Since the initial launch, we added more than 1000 failure analysis case studies and 50 of our most popular technical books. In the 3rd quarter, we will release *Alloy Digest,* the leading reference for materials property data on metals and alloys. Before the end of the year, we will also have the ability to search all ASM journals and over 25 years of conference proceedings.

As an ASM member, you have unlimited access to the *ASM Desk Edition.* To learn more, check out our webinar recording "Maximizing Member Benefits with the ASM Digital Library" at https://bit.ly/3ixckVd or navigate to our On-Demand Webinar Library section of the ASM Website.

Another theme we received feedback on was related to materials data. With the advent of Industry 4.0, the need for materials data and datasets has increased dramatically. High-quality data is needed to run material simulations, aid in machine learning models, and help with Integrated Computational Materials Engineering (ICME) efforts. To respond, we have kicked off the ASM Data Ecosystem Initiative. For more information on this exciting project, see the article on page 58 of this issue.

I hope these examples provide you with a better understanding of how we listen to your feedback and respond. I'd enjoy hearing from you about how ASM has added value to you or your company and what we can do to improve. Feel free to contact me at Ron.Aderhold@asminternational.org.

Ron Aderhold, Acting Managing Director,
ASM International
ron.aderhold@asminternational.org

Burke Named 2020 Sorby Lecturer

Burke

Prof. M. Grace Burke, FASM, has been named the 2020 Henry Clifton Sorby Awardee. Burke is director of the Materials Performance Centre at the University of Manchester, U.K. She is well known for her work on advanced microstructural characterization techniques and their application to address environment-sensitive materials degradation issues in nuclear power systems. She has been a lead researcher at the Bettis Atomic Power Laboratory, Westinghouse Science and Technology Center, and the University of Pittsburgh.

Prof. Burke's advice related to her knowledge and leadership in nuclear technology, has been sought by government agencies in the U.S., Canada, and the U.K. She is an internationally recognized expert in specific technique developments and groundbreaking applications, including advanced analytical electron microscopy, in-situ analytical transmission electron microscopy (ATEM) of solid and multiphase material reactions, and atom probe field-ion microscopy.

Introduction to Additive Manufacturing

Bourell

A brief video presentation by Dr. Dave Bourell, FASM, providing a practical and informative introduction to additive manufacturing (AM) was recently posted to ASM's website. Dr. Bourell, a professor of Mechanical Engineering and Materials Science and Engineering at The University of Texas at Austin, is a volume editor and author for the new *ASM Handbook,* Volume 24: *Additive Manufacturing Processes.* Dr. Bourell describes the instances in which AM is preferred over conventional manufacturing and discusses the seven current categories of AM classification, a major part of his "Introduction to Additive Manufacturing" article, written with coauthor Terry Wohlers, in *ASM Handbook,* Volume 24.

For more information, visit asminternational.org/HBVol24 or the ASM Digital Library. To view the video, visit https://bit.ly/3anQkJp.

ASM Data Ecosystem Initiative

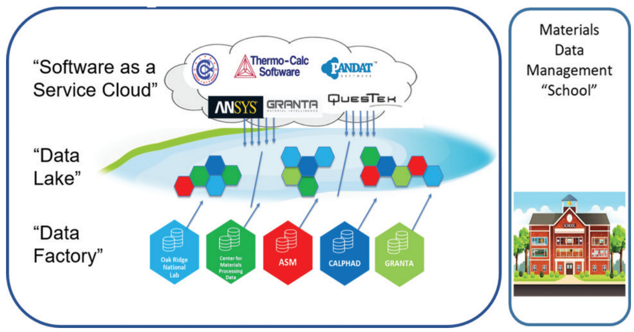
Ray Fryan, ASM Executive Director – New Product Development

ASM International has embarked on a journey to better serve members—moving us from renewal, to realization, and ultimately, to growth. The improvements we have delivered demonstrate the sound foundation of the strategic plan. As we continue on this journey, we are mindful of the rapid changes in our world. Newer technologies like artificial intelligence (AI) and machine learning (ML) are transforming design and optimization activities—beyond traditional Integrated Computational Materials Engineering (ICME), embodying the Materials 4.0 capabilities needed to serve the Industry 4.0 world. This shift impacts our members' ways of working across the product lifecycle. Think of our new reality in two interdependent buckets—models and data. These frame the ASM Data Ecosystem.

Let's start with models related to materials. George Box, a famous British statistician, is credited with the phrase "All models are wrong, and some are useful." ICME dates back into the 1980s, and as computational power has increased and storage costs for data have decreased, the sophistication of models to design materials and leverage them in design has proven to be very "useful," and by 2011, the Materials Genome Initiative became a reality. The emergence of machine learning in design and optimization has created discontinuities the market is only beginning to exploit. Combined, ICME and ML have resulted in materials design speed and efficacy that's nothing short of spectacular. That said, the industrial ecosystem's ability to deploy these new materials is advancing, albeit, at a slower pace. We're confident that pace will accelerate soon, because market pressures for optimization will require it.

So let's now consider materials data. Clive Humby has been credited with saying "data is the new oil." Only part of his point is conveyed in that often-quoted sound bite. His primary point is much more thoughtful—"data is valuable, but if unrefined, it cannot really be used." Refined materials data and related analytical tools enable digital threads spanning activities from design and R&D, to in-production, and in-service performance outcomes. Refined materials data enables a new way of working in which ASM members and stakeholders convert these data into realized value. It's more predictive and less experimental.

So what is the ASM Data Ecosystem? It's a natural extension of ASM's core mission as *the* Materials Information society. The same trusted brand—with peer-reviewed content, high quality educational products and events—will take the same approach into the world of materials data and related analytics. The Data Ecosystem architecture (see diagram, left side) shows three layers and an educational capability alongside. The top layer is the Software as a Service (SaaS) Cloud, in which vetted commercial and freeware platforms for materials and engineering simulation are securely provisioned to subscribers. This SaaS cloud will include machine learning platform tools where these subscribers can create their own models from ASM datasets or their own.



Left image: Architecture of ASM Data Ecosystem. Note, the specific tools or data sources shown are for Illustration purposes only.

The middle layer is the Data Lake, where high quality, curated datasets are stored and offered for use to subscribers. These datasets can be used with ASM provisioned tools or the user's own software. In addition, this lake will be segmented and secured in a way that the datasets are accessed only by authorized subscribers. The bottom layer—the "data factory" that feeds the lake—will be a portfolio of trusted experimentally and/or simulation-generated datasets. To wear the ASM brand, these datasets will be tested and refined via a robust, peer-reviewed curation process.

Finally, our members are already seeing the importance of thoughtfully managing this "new oil" of materials data. Accordingly, we're initiating the development of trusted, objective data management education. Our Materials Data Management School will leverage ASM's deep network of materials science and data science expertise, with trusted, objective, educational products and services.

Our members and stakeholders will greatly benefit from these new ASM capabilities. Members who want to start the Materials 4.0 journey will get access to the world of ML, ICME, Materials and Engineering Simulation, and Materials Data without a big up-front investment. All members will have the opportunity to "test drive" simulation tools before committing to longer term arrangements. Most importantly, all subscribers will benefit from a data repository built by the most trusted brand for materials information—ASM International.

Our ASM International Operations Team members are already evaluating initial simulation, data, education, and infrastructure options as we build out a prototype version of this Ecosystem. As we scale-up, we invite your input to set priorities for tools and for targeted data. Please consider helping in the coming months by serving on a volunteer focus group. Log onto the ASM Connect platform, update your profile, and review the latest volunteer opportunities. Also consider supporting our Technical Committees as a way to shape and refine these products. Your engagement will enable a smooth launch and help us prioritize the most valuable tools and data for the ASM Data Ecosystem. Thanks in advance for your willingness to serve and for your contribution of energy, knowledge, and talent.

FROM THE FOUNDATION

Great 'Lemonade' from a Team Effort

2020 has been a year like none of us have experienced. Great people and agile organizations find opportunities in the challenges, making lemonade from the lemons they are handed.

Daehn

I am beyond proud of the way the ASM Materials Education Foundation turned around what could have been a disastrous summer. Each year, the Foundation invests about one million dollars in ASM Materials Camp programs where over 700 K-12 teachers receive 40 hours of high-quality materials science education with live, interactive, hands-on instruction. ASM Materials Camps are incredibly effective in informing, inspiring, and growing the next generation of materials, engineering, and technical professionals—one of the best and most efficient investments of any organization in connecting students with needed and fulfilling careers.

COVID-19 forced change to the business model quickly and completely. Executive Director Carrie Wilson planned early on to make Camps remote. This huge undertaking was carried out by dedicated Master Teachers and ASM volunteers to largely maintain the camp format and character through interactive teleconference sessions. More than 700 supply kits were sent and new digital teaching strategies were adopted. While the Foundation saved some money on travel and other expenses of a live camp, this was more than offset in modifying content and delivery methods.

Reviews were awesome; here is just one:

Thank you for sponsoring and hosting an incredible program for teachers. The professional discussions, virtual tours of local industry, hands-on lab activities and real applications of textbook concepts embedded within the ASM Materials Camp will transform student experiences in my classrooms. The ASM Materials Camp definitely sets the bar high for future professional development, from the "why" and "how" of materials science to the "where can I get a job doing this?" Teachers and educators were encouraged to complete the tasks, engage in discussions, and process content often overlooked by pedagogy and teaching methodology. Thank you for organizing this incredible learning experience to encourage teachers and students alike to re-think, imagine, question, tinker, and discover the chemistry and physics of materials science engineering. AWESOME!

ASM Foundation now has great new tools and approaches to educate teachers about materials and show our rigorously tested hands-on labs, expanding reach into new geographies and underserved communities as well as offering new modes such as shortened, focused modules for continuing engagement.

I offer my humble thanks to ASM Foundation stakeholders who rose to this occasion. This pandemic showed how dependent we are on our manufacturing supply chain, which is fragile. The key to a robust manufacturing economy is people, from technicians to Ph.D.s. Aware and passionate middle and high-school teachers are vital to a technical talent pipeline that is smart, robust, and diverse. If you would like to learn more about or invest in these worthy programs, please go to ASMFoundation.org.

Glenn S. Daehn, FASM
Chair, ASM Materials Education Foundation

CAREERHUB
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VISIT THE CAREER HUB

Matching job seekers to employers just got easier with ASM International's CareerHub. After logging on to the ASM website, job seekers can upload a resume and do searches on hiring companies for free. Advanced searching allows filtering based on various aspects of materials science, e.g., R&D, failure analysis, lab environment, and manufacturing. Employers and suppliers can easily post jobs and set up pre-screen criteria to gain access to highly qualified, professional job seekers around the globe. For more information, visit careercenter.asminternational.org.

WOMEN IN ENGINEERING

This profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with ***Elizabeth Perepezko,*** *associate director, research at Zimmer Biomet, Warsaw, Ind.*

Perepezko

What part of your job do you like most?

My job is never boring, no day is a duplicate of the previous day, and there are always new challenges to find creative solutions. I enjoy the challenge.

What is your greatest professional achievement?

Freshman year in undergrad, I attended a seminar on orthopedic biomaterials and after that I was hooked on the topic with the goal of working at an orthopedic device manufacturer. Fifteen years ago, I moved to Indiana to start my career as a project engineer at Biomet Orthopedics, which was my dream job.

What is your engineering background?

I have a bachelor's in materials science and engineering, and a master's in biomedical engineering, orthopedic biomechanics. My first job after grad school was in the field of physical rehabilitation modalities including functional electrical stimulation (FES) and robotics for recovering stroke patients, so you could say I've covered many of the subfields of engineering with materials/chemistry, biology/medicine, mechanics, and computer programming.

What attracted you to engineering?

I have always been interested in science and how things work, and having a father who is an engineering professor provided me with an outlet to learn more about various fields of science/engineering. We would go to Chemistry is Fun and Physics is Fun public lectures at the University of Wisconsin-Madison, go to the geology department's rock drop and get to play around in his lab in the materials science department.

Did you ever consider doing something besides engineering?

Forensics. Having done a lot of failure analysis, I enjoyed the challenge of figuring out how/why a device failed from reviewing the failed components. Forensics combines many scientific fields (failure analysis, chemistry, anatomy/physiology, etc.) and would provide an interesting challenge in "reverse engineering the crime" to figure out "who done it?"

Favorite motto or quote:

"If you do the bare minimum, expect bare minimum results. You want to be great, work to be great. Nothing just happens."

Do you know someone who should be featured in an upcoming Women in Engineering profile? Contact Vicki Burt at vicki.burt@asminternational.org.

EMERGING PROFESSIONALS

Resources on ASM Connect

Andrew Frerichs, EPC Co-Chair

Without doubt, conferences provide a great number of benefits to students and Emerging Professionals, including an opportunity to showcase your work, expand your horizons, and network with members throughout the society. If you were looking forward to experiencing all the insightful, engaging, and fun activities planned for IMAT 2020 in Cleveland this year, I imagine you were sad to see it cancelled. I know I was. Society members and staff worked for years to bring this event to reality, and I know IMAT 2020 would have been a showcase of all the great parts of ASM International.

Frerichs

Each year, the Emerging Professionals Committee (EPC) hosts a symposium on important topics for individuals who are at the beginning of their careers. During this symposium and other ASM conference events, I have the honor of conversing with students and Emerging Professionals about their many joys and concerns, such as excitement about getting published, how to find a mentor, and concern for what the future brings for materials engineering. These are crucial conversations and an often undervalued, intangible benefit of in-person interaction.

The Emerging Professionals Committee recognizes how the loss of an in-person conference this year affects those just getting started with ASM. As a result, the EPC is working to provide the community with content and resources via the newly introduced ASM Connect platform. A new, student- and Emerging Professional-focused community will be introduced on ASM Connect in the very near future—one that is designed to provide content you might have missed and offer you a place to ask the questions on your mind. We want this to be a place for you, your needs, and your development in ASM. Keep an eye out for the official notice when this community opens!

While we can't meet this fall, I look forward to interacting with you soon on ASM Connect.

CHAPTERS IN THE NEWS

Canada-Wide Virtual Event

Lados

Dr. Diana Lados, FASM, current ASM Board of Trustee, was the featured speaker at the first-ever Canada-Wide Virtual Event using Ring Central/Zoom. Lados spoke on "Design of Cold-Spray 6061 Aluminum Alloys for Fatigue Crack Growth Resistance in Structural Components, Coatings, and Repairs."

Held on June 18, the event drew in participants from every ASM Canadian Chapter, as well as a few chapters in India. The session was so successful, the Canada Council is making plans to hold another in the future. Lados is the Milton Prince Higgins II Distinguished Professor at Worcester Polytechnic Institute (WPI), and the founder and director of the Integrative Materials Design Center, an industry-government-university consortium established at WPI.

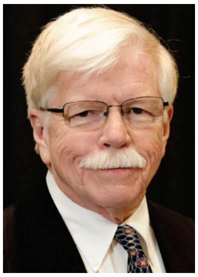
Brandywine Valley Hosts Dr. Gray

The ASM Brandywine Valley Chapter held its Annual Joint ASM-ASME April meeting virtually using the Ring Central/Zoom platform. Chapter members gathered online on April 14 to hear Dr. Paul Gray present a talk on "Ceramic Matrix Composites at GE Aviation." Gray is a senior materials engineer at the company. In discussing the growth of the ceramic matrix composite (CMC) enterprise at GE Aviation, he explained that two separate technologies, pre-preg melt infiltration and chemical vapor infiltration, merged with the acquisition of Honeywell Advanced Composites by GE Energy in 2002. In 2007, GE Aviation acquired the CMC business and matured the technology leading up to the introduction of FAA-certified CMC stationary jet engine components in 2016.

Example of CMC turbine shrouds used on passenger planes and fighter jets. Courtesy of GE Aviation.

MEMBERS IN THE NEWS

Tillack Honored by AWS



Tillack

Donald J. Tillack, FASM, was one of seven experts honored this past year as an American Welding Society Counselor. The recognition took place at the FabTech Show in Chicago in November 2019. Tillack was recognized for his original contributions to AWS and the global welding and metallurgical communities for more than fifty years. He was a founding member of AWS subcommittees G2C and G2E, which published guides for joining stainless and nickel-based alloys. Tillack developed innovative solutions for welding nickel-based alloys. Monel Filler Metal 60 and welding and heat-treating procedures for Inconel x-750 and 718 are some of his most noteworthy contributions to the industry. Tillack has been chairman of the Welding Research Council Committee on "Welding Stainless Steel and Nickel Alloys" for 15 years. He worked at Inco Alloys International for 30 years before starting his own firm, Tillack Metallurgical Consulting. He also serves as a consultant to the Nickel Institute.

Persson Heads Up Berkeley's Molecular Foundry

Persson

Kristin Persson, a senior faculty scientist in the Energy Storage & Distributed Resources Division within the Energy Technologies Area at Lawrence Berkeley National Laboratory (Berkeley Lab) and director of the Materials Project, has been named director of the Molecular Foundry. She will continue to hold an appointment as a professor of materials science and engineering at UC Berkeley. The Molecular Foundry, a Nanoscale Science Research Center national user facility, serves over 1,000 academic, industrial, and government scientists annually from all over the world through its user program. The Materials Project—which harnesses the power of supercomputers at Berkeley Lab's National Energy Research Scientific Computing Center, customized machine-learning algorithms, and state-of-the-art quantum mechanical calculation methods—has grown under her leadership to serve more than 130,000 users. Before joining Berkeley Lab in 2008 as a research chemist, Persson worked as a postdoctoral researcher at the Massachusetts Institute of Technology (MIT) after earning her doctorate in theoretical physics from the Royal Institute of Technology in Stockholm.

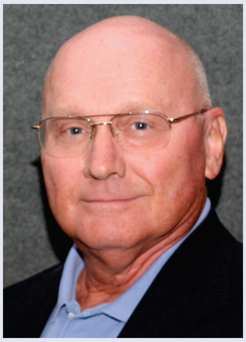
HIGHLIGHTS MEMBERS IN THE NEWS

Johnson Earns DOE Prize

Marcus Johnson, principal mechanical engineer, of Eastman Chemical Co., Kingsport, Tenn., was awarded an Individuals Taking Energy Action in Manufacturing (ITEAM) Prize by the U.S. Department of Energy (DOE) for examining boiler efficiency and finding opportunities for performance improvements. By demonstrating the value of efficiency and showing how the operation and maintenance of equipment can impact energy performance, Johnson achieved significantly lower fuel consumption and a 4% improvement in the efficiency of the facility's two large boilers. Launched in 2018, the ITEAM Prize which comes with $5,000, recognizes individuals who have implemented creative, specific, and innovative ideas and practices that led to measurable energy savings at their manufacturing facilities.

IN MEMORIAM

Edward J. Kubel, Jr., 77, died in his home in Blue Ash, Ohio, on July 23 after a short battle with cancer.



Kubel

He was born in Beaver Falls, Pa., on September 17, 1942. Kubel graduated from the University of Cincinnati with a degree in metallurgical engineering. He spent most of his career as a technical editor for ASM International, where he helped shape the editorial direction of several engineering magazines and reference handbooks from 1985 onward. Kubel became known throughout the heat treat community in his role as the editor of *Heat Treating Progress* magazine and later *HTPro.* He also served in editorial roles on *Metal Progress* and *Advanced Materials & Processes* (*AM&P*) magazine—both in its early days and later as senior editor of a relaunched version with supplements. Over the years, he served as staff liaison to various committees, including the AM&P Editorial Committee and the HTS R&D Committee. His technical advice and publishing acumen were sought by members and staff alike.

Retiring from full-time employment in 2013, Kubel continued to serve as a contributing editor for *ASM Handbooks* and *AM&P* magazine until earlier this year.

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OCTOBER 2020

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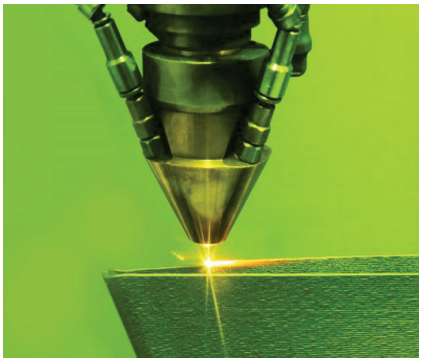
3D PRINTSHOP



In 3D printed metallic parts, Argonne scientists found a correlation between temperatures at the surface and defects that form below.

USING TEMPERATURE TO CONTROL DEFECTS

Researchers at the U.S. Department of Energy's (DOE) Argonne National Laboratory discovered a way to use temperature data at the time of production to predict the formation of subsurface defects in 3D printing so they can be addressed immediately.

For their research, the scientists used the extremely bright, high-powered x-rays at beamline 32-ID-B at Argonne's Advanced Photon Source (APS), a DOE Office of Science User Facility. They designed an experimental rig that let them capture temperature data from a standard infrared camera viewing the printing process from above, while they simultaneously used an x-ray beam taking a side-view to identify if porosity was forming below the surface.

According to Noah Paulson, computational materials scientist, this work showed that there is in fact a correlation between surface temperature and porosity formation below. "Having the top and side views at the same time is really powerful. With the side view, which is what is truly unique here with the APS setup, we could see that under certain processing conditions based on different time and temperature combinations porosity forms as the laser passes over," Paulson says.

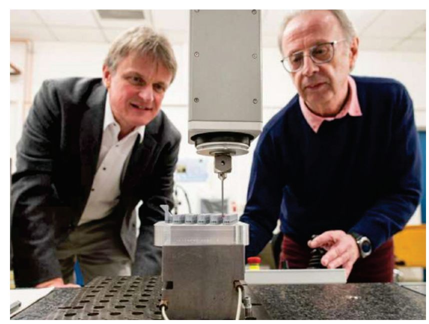
For example, they observed that thermal histories where the peak temperature is low and followed by a steady decline are likely to be correlated with low porosity. In contrast, thermal histories that start high, dip, and then later increase are more likely to indicate large porosity.

The ability to identify and correct defects at the time of printing would have important ramifications because it eliminates the need for costly and time-consuming inspections of each mass-produced component. *energy.gov/science*.

ELECTRIC PULSES SHAPE PRECISE 3D-PRINTED METAL PARTS

Saarland University researchers have developed a non-contact method of transforming metal parts fabricated by a 3D printer into high-precision technical components. The novel method combines 3D printing and electrochemical machining (ECM) to produce precision-finished components with complex geometries and small dimensional tolerances.

"Our nondestructive, non-contact manufacturing technology enables us to efficiently machine parts with intricate geometries even when made from high-strength materials," explains Professor Dirk Bähre. The workpieces, which are bathed in a flowing electrolyte solution, can be electrochemically machined to the required geometry working to tolerances of a few thousandths of a millimeter—without any mechanical contact and without imparting any mechanical stresses to the workpiece. All the engineers need is a source of electrical power. A high electric current flows between a tool (the cathode) and the conductive workpiece (the anode), which has been 3D printed. The workpiece is immersed in a conducting fluid (the electrolyte), an aqueous salt solution. The electrochemical machining process causes minute particles of metals to be removed from the surface of the workpiece. The metal atoms on the surface of the workpiece enter the solution as positively charged metal ions enabling the workpiece to very precisely attain the required geometric form. "By adjusting the duration of the current pulses and the vibration of the tool, we can remove surface material very uniformly leaving particularly smooth surfaces and achieving high dimensional precision," says Bähre. *uni-saarland.de.*



Professor Dirk Bähre, left, with Stefan Wilhelm from Saarland University, are pairing 3D printing and electrochemical machining to make intricate parts. Courtesy of Oliver Dietze.

3D PRINTING OF MICROFLUIDICS DEVICES

A team from Montana State University has developed a new method of using 3D printing to make devices for microfluidics. The researchers can 3D print directly onto glass to form thin channels, less than a millimeter wide, that contain liquid. The new process reduces manufacturing time and could allow researchers to easily produce affordable, customized prototypes of the devices, called microfluidics chips, in their labs. *montana.edu.*

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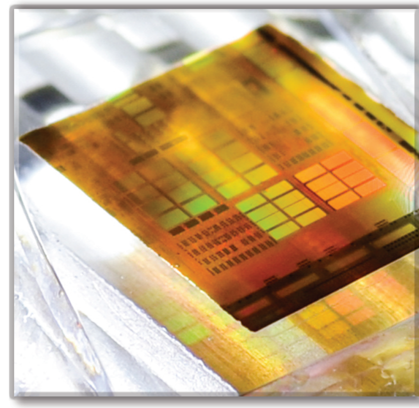
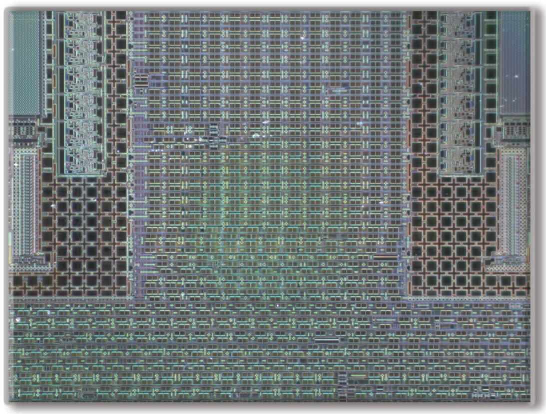
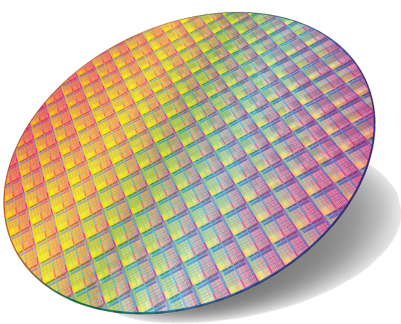
- Substrate Delayering







2376 E. Pacifica Place
Rancho Dominguez, CA 90220

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info@alliedhightech.com
www.alliedhightech.com

800.675.1118 US/Canada
310.635.2466 Worldwide