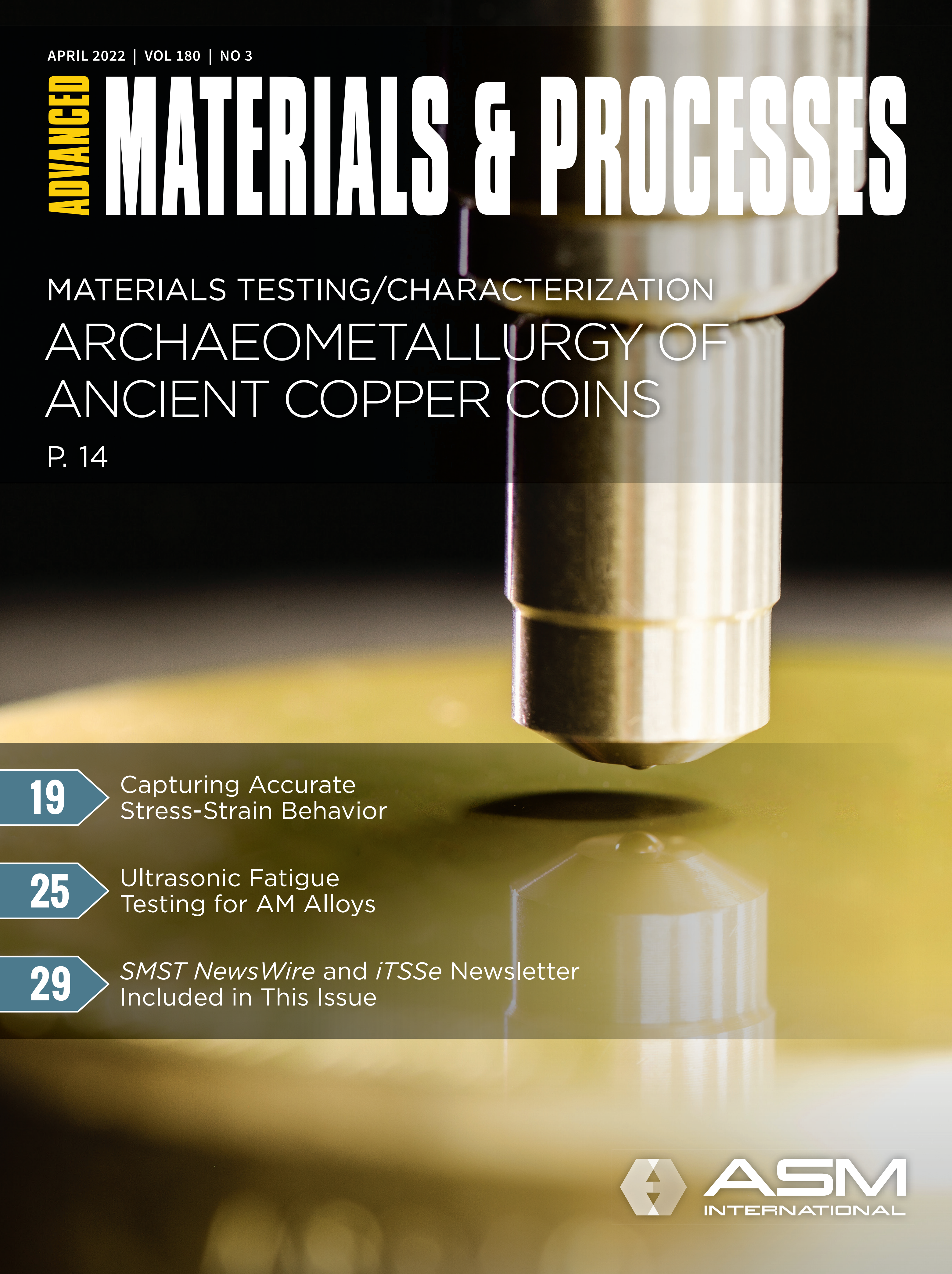
APRIL 2022 | VOL 180 | NO 3

ADVANCED MATERIALS & PROCESSES

MATERIALS TESTING/CHARACTERIZATION

ARCHAEOMETALLURGY OF ANCIENT COPPER COINS

P. 14



ASM INTERNATIONAL

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ASM INTERNATIONAL

IMAT

ASM'S ANNUAL MEETING

INTERNATIONAL MATERIALS, APPLICATIONS & TECHNOLOGIES

2022

SEPTEMBER 12–15 | ERNEST N. MORIAL CONVENTION CENTER | NEW ORLEANS, LA

NEW ORLEANS AWAITS!

The 2022 International Materials, Applications, & Technologies Conference (IMAT) will be held in the heart of New Orleans, September 12–15. The city is home to Creole cuisine, rich with history, and offers unmatched hospitality. So come for IMAT—the programming, exhibits, and networking—and stay to enjoy the culture, food, sights, and sounds of this unique cultural hub.

Jazz musicians performing in the French Quarter at Mardis Gras.

OUR MEMBERS SAY...

New Orleans Ernest N. Morial Convention Center.

"I am looking forward to returning to IMAT this fall to be a part of the presentations in the symposia of the Failure Analysis Society and the ASM Emerging Professionals Committee. These presentations are always among the most interesting and most representative of practical applications to improve safety and engineering while also being great opportunities to meet with my peers, mentors, and mentees. I am also looking forward to the Women in Engineering Breakfast, where we will honor our important innovators and leaders of the future, while striving to create and retain all engineers practicing materials science."

Erik M. Mueller, Ph.D., P.E.
Materials Engineer, National Transportation Safety Board
Graduate Student, University of the District of Columbia

"QuesTek is looking forward to attending IMAT again this year. It is a great venue for meeting our existing clients and expanding our network, across a wide range of materials-intensive industries. We anticipate identifying numerous new business opportunities for QuesTek to resolve pressing materials problems by leveraging our computational materials engineering technologies."

Jeff Grabowski
Manager of Business Development
QuesTek Innovations LLC

Bourbon Street in downtown New Orleans.

"Facilitating the DomesDay Geodesic Dome Design Competition is a highlight of our year. We use an MTS Criterion Test System to evaluate the structural integrity of student-designed domes, and it is always fun to see which designs can withstand the pressure and win the contest."

MTS Systems
IMAT Exhibitor

"To keep America competitive, we at universities must be aware of the current technologies, be able to capture the emerging ones, and be able to envision the future. IMAT meetings are an ideal venue for all three purposes, and I'm looking forward to exploring these topics with my fellow academics and researchers in New Orleans."

Hanchen Huang, FASM
Professor and Dean of Engineering
University of North Texas

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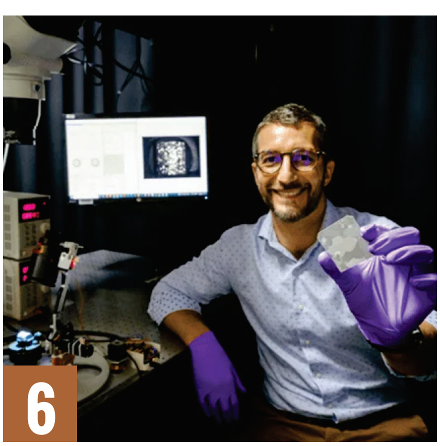
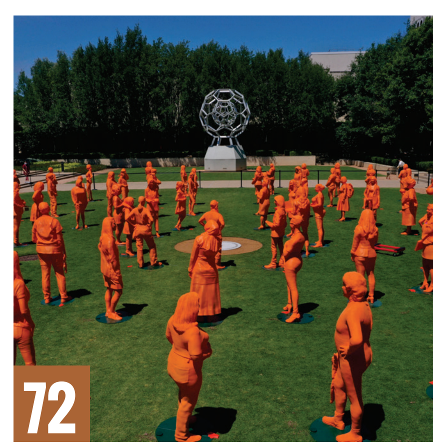
On the Cover:

Indenter for Rockwell testing with calibration block. Courtesy of Kimtaro/dreamstime.com.





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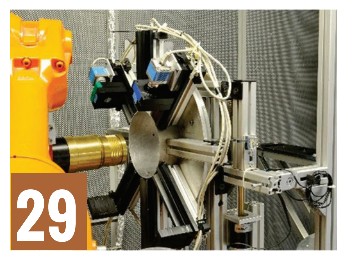
FEATURES



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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*

Madrid Tramble, *Production Manager*
madrid.tramble@asminternational.org

Press Release Editor
magazines@asminternational.org

PRESERVING CULTURE

Museum oil paintings just gained new advocates who are using novel testing methods to aid conservators in preserving these cultural treasures. Metal carboxylates knowns as "metal soaps" mysteriously form on paintings over time and damage the artwork. The phenomenon is most common with paints containing zinc and lead. Researchers at the National Institute of Standards and Technology (NIST) and the National Gallery of Art have teamed up to use infrared-light-based methods to identify the composition and distribution of the metal soaps. Various spectroscopy techniques such as photothermal induced resonance (PTIR) are used to gain a broader view of the chemical composition across various layers of paint samples. The PTIR method can provide chemical mapping to give conservators information about the initial factors causing the unusual formation and to help with preservation strategies.

"Gypsy Woman with Mandolin" by Jean-Baptiste-Camille Corot. Courtesy of National Gallery of Art, Washington, adapted by NIST.

In another example of salvaging history, see our Research Tracks page for details on how the U.K. is using materials testing to refurbish a maritime icon, the HMS Victory. The first phase of the project involves extensive control tests on the metal fasteners, caulking, and paint that could be used to restore the 18th century warship. Only the materials proven most weatherproof will be deemed worthy of this royal project.

From the British Isles we take you southwest to Chile, where our lead article offers an archaeometallurgical study of its ancient copper coins. Currency is a tangible artifact of any country's heritage. Various figureheads, flowers, buildings, and mottos are minted to commemorate and elevate the values of that government. Materials characterization can serve a vital role in analyzing coins by providing insight into the raw materials, process, and equipment used in their minting. The resulting research can paint a rich picture of the culture, the peoples, and their values that created the coinage.

Our members have been doing a bit of excavating and curating themselves lately. With the return of in-person conferences, our presenters are dusting off their travel bags. More importantly, they mined through the last two years of pandemic-stifled research and selected the gems—their own Mona Lisa's—to submit as abstracts to our ASM conferences. Many ASM members attended the successful AeroMat event in Pasadena. Next up is the International Thermal Spray Conference in Vienna followed by the International Conference on Shape Memory and Superelastic Technologies in San Diego. You can find show previews for both events in the *iTSSe* and *SMST NewsWire* supplements. And then see page 1 to get jazzed for IMAT in New Orleans this September.

Come to these events for the best-of-the-best research, reclaimed and honed from a global quarantine. Enjoy reviving your professional network. And thank your colleagues, anywhere in the world, who are applying materials science to noble conservation efforts. They are preserving culture—one coin, one ship, and one painting at a time.

Joanne Miller

joanne.miller@asminternational.org

RESEARCH TRACKS

HMS Victory in Portsmouth with HMS Queen Elizabeth behind. Courtesy of NMRN.

Researcher Nicola Symonds performs a tensile test on a wood sample. Courtesy of NMRN.

MATERIALS TESTING PRESERVES MARITIME GEM

Engineers at the University of Southampton and the National Museum of the Royal Navy (NMRN), both in the U.K., are collaborating to find the best materials to ensure the 18th century warship HMS Victory is weatherproof for another 50 years. The University's nC² Engineering Consultancy carefully designed a series of tests to assess the long-term performance of a range of paints, caulking, glues, and metal fastenings. The team is conducting a variety of tests on specially prepared samples. Tests are repeated using different combinations of products on samples that have been treated to simulate the effects of wear, rain, sunlight, and time. For example, paint is tested for adherence to wood along with flexibility and water resistance. The same tests are then conducted on samples that have been aged using UV and salt spray, and samples that have been cooled or heated to specific temperatures.

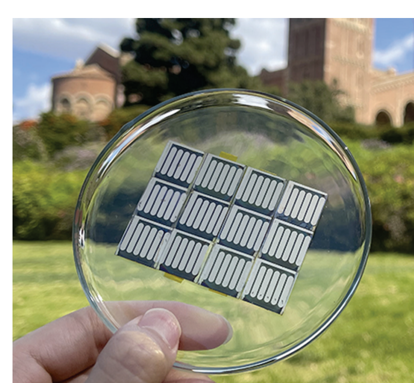
The first phase of the project is now underway. Using hundreds of oak samples prepared by NMRN's shipwrights, nC² is assessing the performance of nine different types of caulking and glue and five paint systems. A future phase will examine metal plank fastenings to see how they interact with the wood, paint, and caulking and examine any corrosion. *www.southampton.ac.uk.*

PERKING UP PEROVSKITES

Researchers at the University of California, Los Angeles along with colleagues from five other universities discovered the key reason why perovskite solar cells degrade in sunlight. Metal halide perovskites are of particular interest due to their promising application in energy-efficient, thin-film solar cells. Perovskite-based solar cells can be manufactured at much lower costs than their silicon-based counterparts, making solar energy more accessible if the widely known degradation from long exposure to illumination could be addressed.

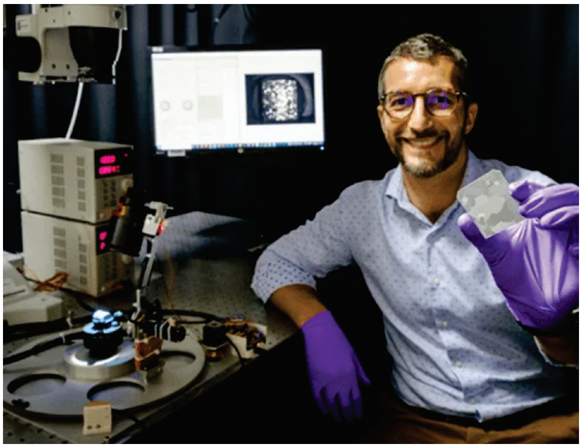
A common surface treatment used to remove solar cell defects involves depositing a layer of organic ions that makes the surface too negatively charged. The team found that while the treatment is intended to improve energy-conversion efficiency during the fabrication process of perovskite solar cells, it also unintentionally creates a more electron-rich surface—a potential trap for energy-carrying electrons. This condition destabilizes the orderly arrangement of atoms, causing perovskite solar cells to become increasingly less efficient over time and ultimately making them unattractive for commercialization.

With the new discovery, the team found a way to address the cells' long-term degradation by pairing the positively charged ions with negatively charged ones for surface treatments. The switch enables the surface to be more electron-neutral and stable, while preserving the integrity of the defect-prevention surface treatments. Researchers tested the endurance of their solar cells in a lab under accelerated aging conditions and 24/7 illumination: The cells retained 87% of their original sunlight-to-electricity conversion performance for more than 2000 hours. In the control group, solar cells manufactured without the fix dropped to 65% of their original performance over the same time and conditions. *ucla.edu.*



Thin-film perovskite solar cell produced with a manufacturing process tweak. Courtesy of UCLA.

MACHINE LEARNING | AI



A low-cost imaging system that uses an optical camera and machine learning can analyze the properties of a 3D-printed metal alloy in 15 minutes.

NEW METHOD INSPECTS 3D-PRINTED METAL PARTS

Researchers from Nanyang Technological University, Singapore developed a fast and economical imaging technique that can examine the structure of 3D-printed metal parts. Most of these alloys comprise numerous microscopic crystals, which vary in size, shape, and atomic lattice orientation. By extracting this information, the alloy's properties can be deduced. Traditionally, examining the microstructure of 3D-printed metal alloys involves time-consuming and costly measurements with scanning electron microscopes.

The technique created by assistant professor Matteo Seita and his team offers the same quality of information within minutes by using a system comprising a flashlight, an optical camera, and a laptop computer that runs machine learning software designed by the team. First, the metal surface is treated with chemicals to expose the microstructure. Next, the sample is positioned to face the camera and numerous optical images are taken as the flashlight irradiates the metal from many directions. The software then examines the patterns generated by light reflected from the surface of diverse metal crystals and infers their orientation. The whole process takes about 15 minutes.

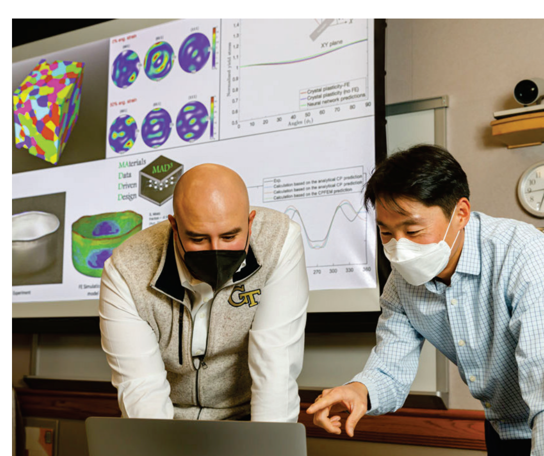
The researchers then applied machine learning to program the software by inputting hundreds of these optical images. Ultimately, the software learned how to forecast the arrangement of crystals in the metal from the images, based on variances in how light disperses off the metal surface. It was then tested to develop a full crystal orientation map. Seita believes the new imaging technique could streamline the certification and quality assessment of 3D-printed metal parts. The technology could be especially useful in applications such as aerospace manufacturing and repair. *www.ntu.edu.sg.*

PREDICTING DIRECTION-DEPENDENT PROPERTIES

A machine learning algorithm developed at Sandia National Laboratories could lead to a faster and more cost-efficient way to test bulk materials for use in automotive manufacturing, aerospace, and other industries. To screen materials such as sheet metal for formability, companies often use commercial simulation software calibrated to the results of various mechanical tests. However, these tests can take months to complete. Certain high-fidelity computer simulations can assess formability in a few weeks, but companies need access to a supercomputer to run them. The Sandia team has shown machine learning can dramatically cut the time and resources required to calibrate commercial software because the algorithm does not need information from mechanical tests—or a supercomputer.

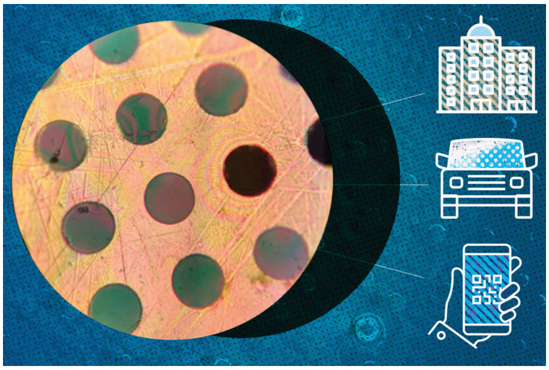
The new algorithm is called MAD^3, short for Material Data Driven Design. Researchers say the model has been trained to understand the relationship between crystallographic texture and anisotropic mechanical response. Working with The Ohio State University, Sandia trained the algorithm on the results of 54,000 simulated materials tests using a feed-forward neural network. The Sandia team then presented the algorithm with 20,000 new microstructures to test its accuracy, comparing the algorithm's calculations with data gathered from experiments and supercomputer-based simulations.

"The algorithm is about 1000 times faster compared to high-fidelity simulations. We are actively working on improving the model by incorporating advanced features to capture the evolution of the anisotropy since that is necessary to accurately predict the fracture limits of the material," says Sandia scientist Hojun Lim. *sandia.gov.*



Researchers examine data generated by a new machine learning algorithm.

PROCESS TECHNOLOGY



This new two-dimensional polymer self-assembles into sheets and could be used as a lightweight, durable coating for car parts or cell phones, or as a building material. Courtesy Christine Daniloff/MIT.

SELF-ASSEMBLING MATERIAL

A new, scalable material that is stronger than steel and as light as plastic was developed by scientists at MIT, Cambridge, Mass., using a novel polymerization process. The new material is a 2D polymer that self-assembles into sheets, unlike all other polymers, which form one-dimensional, spaghetti-like chains. Until now, scientists believed it was impossible to induce polymers to form 2D sheets. Such a material could be used as a lightweight, durable coating for car parts or cell phones, or as a building material for bridges or other structures. The researchers have filed for two patents on the process they used to generate the material.

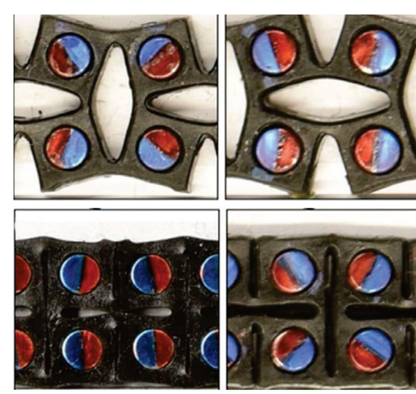
For the monomer building blocks, they use melamine, which contains a ring of carbon and nitrogen atoms. Under the right conditions, these monomers can grow in two dimensions, forming disks. These disks stack on top of each other, held together by hydrogen bonds between the layers, which make the structure very stable and strong. Because the material self-assembles in solution, it can be made in large quantities by simply increasing the quantity of the starting materials. The researchers showed that they could coat surfaces with films of the material, which they call 2DPA-1.

The researchers found that the new material's elastic modulus is between four and six times greater than that of bulletproof glass. They also found that its yield strength is twice that of steel, even though the material has only about one-sixth the density. *mit.edu.*

PROGRAMMABLE METAMATERIAL

Using metamaterials, a research team from the University of Massachusetts Amherst engineered a new rubber-like solid substance that has surprising qualities—it's programmable, and it can absorb and release very large quantities of energy. As such, this new material holds great promise for a very wide array of applications, from enabling robots to have more power without using additional energy, to new helmets and protective materials that can dissipate energy much more quickly.

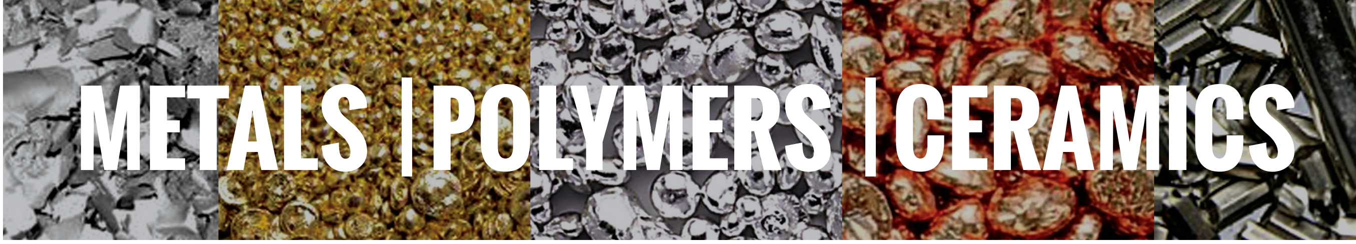
This new metamaterial combines an elastic, rubber-like substance with tiny magnets embedded in it. The new "elastomagnetic" material takes advantage of a phase shift to greatly amplify the amount of energy the material can release or absorb. To do this, scientists must engineer a new structure at the molecular or even atomic level. However, this is challenging to do and even more difficult to do in a predictable way. According to the team, by using metamaterials, they were able to overcome those challenges. They not only made new materials but also developed the design algorithms that allow these materials to be programmed with specific responses, making them predictable. This research has applications in any scenario where either high-force impacts or ultrafast responses are needed. *umass.edu.*



This elastic material is embedded with magnets whose poles are color-coded red and blue. Orienting the magnets in different directions changes the metamaterial's response. Courtesy of UMass Amherst.

BRIEF

Two cutting tool and gear tool providers, **Star SU** of Hoffman Estates, Ill., and **Louis Bélet** of Switzerland, formed a strategic partnership aimed to enhance each company's product offerings and expand their combined reach within the Americas and Europe. *star-su.com, www.louisbelet.ch.*



METALS | POLYMERS | CERAMICS

The stiffness of the high-entropy Elinvar alloy remains invariant with temperature. Courtesy of City University of Hong Kong.

SUPERELASTIC ALLOY

A research team led by the City University of Hong Kong discovered a first-of-its-kind superelastic alloy that can retain its stiffness after being heated to 1000 K (~726.85°C) or above with nearly zero energy dissipation. The high-entropy alloy reveals the Elinvar effect, where the alloy firmly retains its elastic modulus over a very wide range of temperature changes. The team believes that the alloy can be applied in manufacturing high-precision devices for space missions.

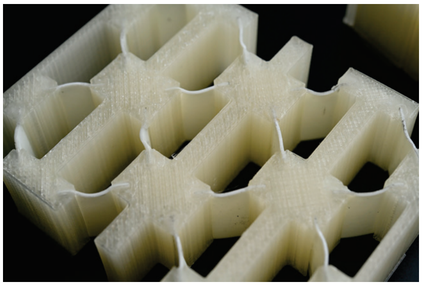
The mechanism behind the discovery is a special highly distorted lattice structure with a complex atomic-scale chemical composition. Because of the combination of unique structural features, the high-entropy Elinvar alloy has a very high energy barrier against dislocation movements. Consequently, it displays an impressive elastic strain limit and a nearly 100% energy storage capacity. The team also discovered that the alloy has an elastic limit of about 2% in bulk forms at room temperature, in sharp contrast to conventional crystalline alloys which have an elastic limit of less than 1%.

The team developed three atomic structural models for the same alloy with different distributions of the element atoms and compared the properties. They patented the discovery based on this systematic investigation. Researchers say the alloy could be used for energy storage for subsequent energy conversion, since its elasticity doesn't dissipate energy. The team envisions many applications for the alloy, particularly in aerospace engineering, in which devices and machinery are expected to undergo drastic temperature changes. *www.cityu.edu.hk.*

IMPROVING PROTECTIVE GEAR

A versatile foam-like material was created by researchers from Johns Hopkins University, Baltimore, with applications in the development of protective gear and parts for the auto and aerospace industries. The new shock-absorbing material protects like a metal, but is lighter, stronger, and reusable. The research team was able to add strength while reducing weight with high energy-absorbing liquid crystal elastomers, which have mainly been used in actuators and robotics.

During experiments to test the material's ability to withstand impact, it held up against strikes from objects weighing about four to 15 pounds, coming at speeds of up to 22 mph. The tests were restrained to this speed due to limits of the testing machines, but the team is confident the padding could safely absorb even greater impacts. The team is exploring a collaboration with a helmet company to design, fabricate, and test next-generation helmets for athletes and the military. *www.jhu.edu.*



Researchers studied the energy-absorbing capability of liquid crystal elastomers. Courtesy of Johns Hopkins University.

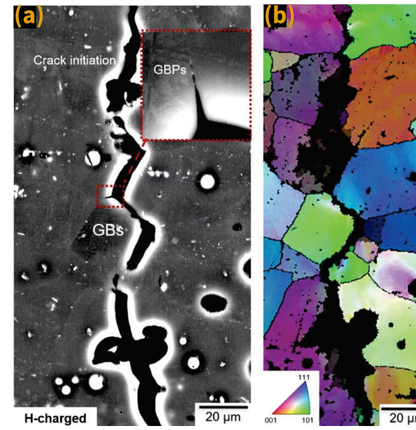
BRIEF

The private equity firm **Core Industrial Partners,** Chicago, announces the acquisition of **Haven Manufacturing** by **CGI Automated Manufacturing,** also owned by Core. Haven specializes in components for medical devices and equipment, offering design assistance, prototyping, EDM, waterjet, laser etching, blasting, grinding and passivation, and CNC machining. *havenmanufacturing.com.*

ALUMINUM ALLOY BEHAVIOR

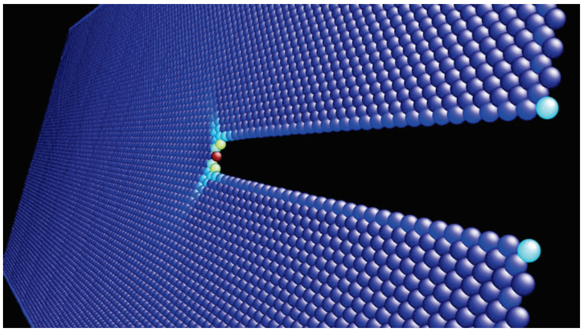
Researchers at the Max Planck Institute for Iron Research (MPIE), Germany, are studying hydrogen in aluminum alloys at the atomic level in order to more efficiently prevent hydrogen embrittlement and found first approaches to hindering this effect. The MPIE researchers used 7xxx aluminum, a high-strength aluminum class that is the primary material of choice for structural components of airplanes. They charged their samples with hydrogen and performed tensile tests showing that the ductility decreases with increasing amounts of hydrogen.

The fracture surface showed that cracks especially propagated along grain boundaries. Through cryo-transfer atom probe tomography, the scientists revealed that hydrogen gathered along those grain boundaries. They were able to show where hydrogen is located following its ingress during the material's processing or in service. Essentially unpreventable, it is important to control its trapping. The researchers recommend different strategies to prevent hydrogen embrittlement, in particular using intermetallic particles that could trap hydrogen inside the bulk material. Additionally, control of the magnesium level at grain boundaries appears critical. "Magnesium paired with hydrogen at grain boundaries increases the embrittlement," says lead researcher Huan Zhao. "At the same time, we must manipulate the correct size and volume fraction of particles in the bulk to trap hydrogen while maintaining the material's strength." The researchers are pursuing further studies on perfect particle distribution and eliminating magnesium decoration of grain boundaries to design advanced high strength, hydrogen-resistant aluminum alloys. *www.mpie.de/2281/en.*



An aluminum-based alloy with zinc, magnesium, and copper studied after aging for 24 hours at 120°C, (a) and (b) electron imaging of an intergranular crack of the hydrogen-charged alloy subjected to tensile fracture. GB: grain boundary; GBPs: grain boundary precipitates. Courtesy of *Nature.*

TESTING | CHARACTERIZATION



This graphic shows the modeled atomic configuration at the tip of a fatigue crack that is on the verge of emitting dislocation defects. Courtesy of Cornell University.

FATIGUE CRACK MECHANISMS

A team of researchers from Cornell University made advancements in better understanding how materials break. Using atomic modeling, the researchers identified the mechanism that causes fatigue cracks to grow—a defect in the structure that begins near the crack tip, moves away from it, then returns to a slightly different location. The finding could help engineers better anticipate a material's behavior and design novel alloys that resist fatigue.

The researchers set out to create a series of simulations of a structural alloy in a vacuum. Each simulation inserted a different artificial mechanism that might provoke the cracks to move forward, as they would in the real world. Some mechanisms included new sources of defects, irreversibility, and different forms of localized strain. Each time, the crack refused to budge. A fourth simulation succeeded in propagating the crack after the team realized the defects needed to interact more closely with the crack tip, such that the atomic bonds would break. While the modeling explains the mechanical mechanism at the root of fatigue cracks, there is still an open question about what role the environment plays in their growth. The group is now researching how dislocations can be steered to different locations and how loading can affect the process. This new understanding of prolonged fatigue can be applied to the design of materials, which has historically focused on how much loading a material can take before it fails. *cornell.edu.*

FUEL CELL FAILURE

Researchers from the University of Tsukuba, Japan, developed a new technique for detecting reduced efficiency in hydrogen fuel cells when enduring periods of excess or insufficient water. By using sensors that measure magnetic flux density, the amount of current generated can be monitored noninvasively, which can signal a problem. This work could lead to technology that can improve the reliability of fuel cells while also significantly reducing the carbon footprint of cars.

The new detection system is based on the magnetic flux produced by electrical currents inside the fuel cell. When the system is operating correctly, its electrical currents generate a characteristic pattern of magnetic fields that can be detected by sensors. This allows failure states to be immediately registered after changes are noted in the magnetic flux. "Our research opens the possibility for automated control systems to be integrated into future fuel cells," says lead researcher Yutaro Akimoto. This could pave the way for more efficient and practical zero-emission vehicles. *www.tsukuba.ac.jp/en.*

SOUND MEASURES ELASTICITY

Scientists from the U.K.'s University of Nottingham are measuring the speed of sound across a material's surface to determine microscopic elasticity. The innovation, referred to as spatially resolved acoustic spectroscopy (SRAS), uses high-frequency ultrasound to produce microscopic resolution images of the microstructure and maps the relationship between stresses and strains

BRIEFS

Ipsen, Cherry Valley, Ill., expanded its field service capabilities to include ultrasonic wall thickness testing for vacuum furnaces, which helps verify the integrity of the vacuum chamber and determine its remaining lifespan. The service is available anywhere in the U.S. on both Ipsen and non-Ipsen equipment. *ipsenusa.com.*

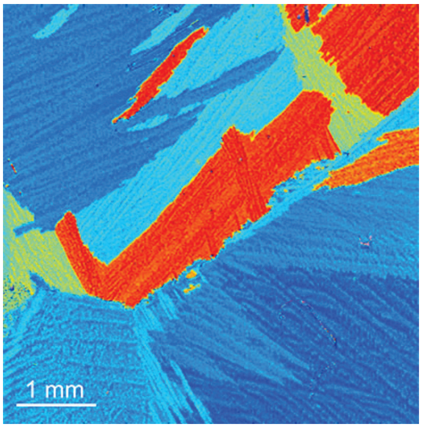
Ipsen vacuum chamber wall thickness testing.

Magnetic Analysis Corp. (MAC), Elmsford, N.Y., acquired **TacTic, a division of Laboratory Testing Inc.** The purchase expands MAC's line of NDT systems to include ultrasonic test systems that detect surface and subsurface defects in round tube, pipe, and bar. The systems enable metal producers to cost-effectively test small batches of material or frequent diameter size changes. *mac-ndt.com.*

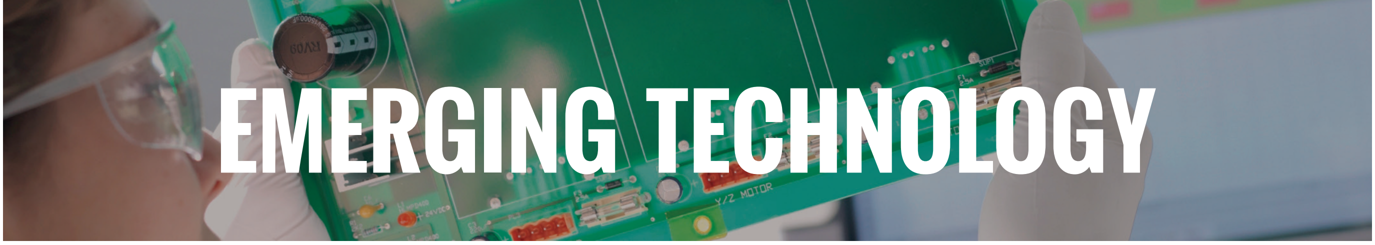
in the material—the elasticity matrix. These crystals are normally invisible to the naked eye, but by precisely measuring the speed of sound across the surface of these crystals, their orientation and the inherent elasticity of the material can be revealed.

This technology is already starting to be used in fields such as aerospace to understand the performance of new materials and manufacturing processes. According to the researchers, the technique will launch a new field of research as it's a completely new way to evaluate materials. It could be used to improve safety within systems like jet turbine blades or develop new designer alloys with tailored stiffness. For example, in medical implants, it is vital to match the stiffness of prosthetic devices to the properties of the human body to ensure harmonious operation.

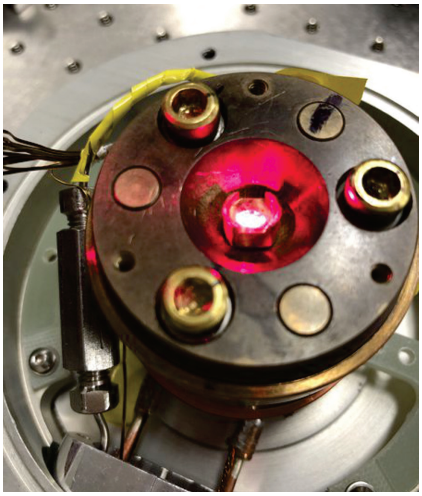
Along with the stiffness of the material, the elasticity matrix also provides insight into many important material properties that are hard to measure directly, such as how the material responds to changes in temperature. This means the rapid measurement of the elasticity matrix can be used as a roadmap to discover next-generation materials with superior properties, making SRAS++ an essential tool in the development of new materials. *www.nottingham.ac.uk.*



SRAS scan of titanium alloy. The color of the regions represents the speed of sound across the surface of that crystal. Courtesy of University of Nottingham.



EMERGING TECHNOLOGY



A strong laser is seen illuminating a material in a low-temperature chamber. Courtesy of Caltech/David Hsieh Lab.

LIGHT TRANSFORMS MATERIALS

Physics professor David Hsieh of Caltech, Pasadena, Calif., and his team recently used lasers to dramatically alter the properties of materials without producing any excess damaging heat. The researchers found an ideal material to demonstrate their method—a semiconductor called manganese phosphorus trisulphide, which naturally absorbs only a small amount of light over a broad range of infrared frequencies. The team used intense infrared laser pulses, each lasting about 10-13 seconds, to rapidly change the energy of electrons inside the material. As a result, the material shifted from a highly opaque state to a highly transparent one for certain colors of light.

The process also was found to be reversible. When the laser turns off, the material instantly goes back to its original state unscathed. The heat-free manipulation used in the new process is known as coherent optical engineering. The method works because the light alters the differences between the energy levels of electrons in the semiconductor without kicking the electrons themselves into different energy levels, which is what generates heat.

The findings, Hsieh says, mean that other researchers can now potentially use light to artificially create materials, such as exotic quantum magnets, which are difficult or impossible to create naturally. “In principle, this method can change optical, magnetic, and many other properties of materials,” say the researchers. “This is an alternative way of doing materials science. Rather than making new materials to realize different properties, we can take just one material and ultimately give it a broad range of useful properties.” *caltech.edu.*

MINERAL-BASED SEMICONDUCTORS

A research team from Missouri University of Science and Technology introduced new potential for creating advanced semiconductor devices using a naturally occurring mineral. They demonstrated a new 2D material heterostructure that has many applications in compact sensors and detectors, optical communication, optical integrated circuits, and quantum computers. The team found that flakes of lengenbachite, a mineral discovered a century ago in Switzerland, have strong anisotropic properties, meaning the flakes vary along axis lines depending on the orientation. The researchers say the characteristic could have implications for directional light-emitting devices, encrypted data transfer and signal processing, and polarization-sensitive photodetectors.

They obtain ultrathin lengenbachite flakes—around 30 nanometers thick—by mechanically exfoliating the bulk mineral using Nitto PVC tape. Lengenbachite is composed of stacks of alternating, weakly bonded layers of four-atom-thick lead sulfide and five-atom-thick arsenic trisulfide.

Notably, the researchers observed out-of-plane one-dimensional rippling structures along the lengenbachite flake surface. The ripples are caused by the periodic mechanical strain generated between the alternating atomic layers. With the help of several optical spectroscopic techniques, the researchers also found strong anisotropic optical properties in the flakes. *mst.edu.*

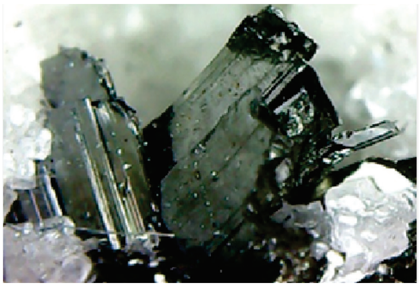
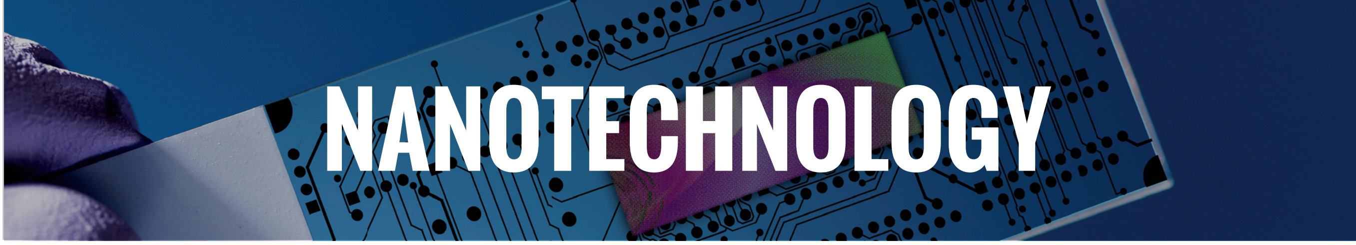


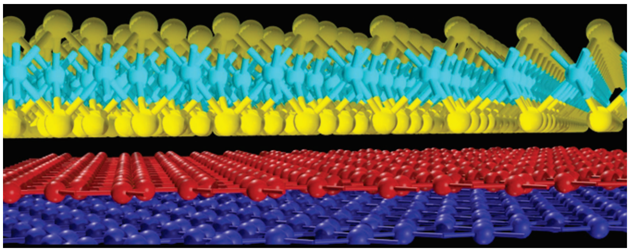
Figure is a zoomed-in view of one crystal cluster of lengenbachite mineral rock with several blade-like crystal plates.

BRIEF

Researchers from **Paragraf,** U.K., and **Queen Mary University of London** successfully fabricated organic light-emitting diodes (OLEDs) with a monolayer graphene anode instead of using indium tin oxide (ITO). The team says the graphene OLEDs achieve identical performance to ITO OLEDs, which are widely used in mobile phone touchscreens and require the rare earth element indium. *www.qmul.ac.uk.*



NANOTECHNOLOGY



When layers of "magic-angle" graphene (bottom) encounter layers of certain transitions metals, it induces a phenomenon called spin-orbit coupling in the graphene layers. Courtesy of Li lab/Brown University.

FERROMAGNETIC GRAPHENE

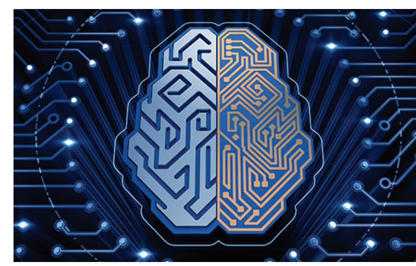
Surprising feats of physics can arise by stacking two sheets of the carbon nanomaterial graphene at a particular angle—an arrangement known as "magic-angle" graphene. Now, a research team from Brown University, Providence, R.I., discovered another mechanism to add to graphene's impressive list. By inducing a phenomenon known as spin-orbit coupling, magic-angle graphene becomes a powerful ferromagnet. Previously, scientists found that when cooled to near absolute zero, magic-angle graphene transforms into a superconductor.

"Magnetism and superconductivity are usually at opposite ends of the spectrum in condensed matter physics, and it's rare for them to appear in the same material platform," says lead researcher Jia Li. "Yet we've shown that we can create magnetism in a system that originally hosts superconductivity." Li and his team interfaced magic-angle graphene with a block of tungsten diselenide, a material that has strong spin-orbit coupling. Aligning the stack precisely induces spin-orbit coupling in the graphene.

The team found that the magnetic properties of magic-angle graphene can be controlled with both external magnetic fields and electric fields, which would make this 2D system an ideal candidate for a magnetic memory device with flexible reading and writing options. Another potential application is in quantum computing, the researchers say. An interface between a ferromagnet and a superconductor has been proposed as a potential building block for quantum computers. The problem, however, is that such an interface is difficult to create because magnets are generally destructive to superconductivity. "We are working on using the atomic interface to stabilize superconductivity and ferromagnetism at the same time," Li says. "The coexistence of these two phenomena is rare in physics, and it will certainly unlock more excitement." *brown.edu.*

NEUROMORPHIC SPINTRONICS

An international team of collaborators from Tohoku University, Japan, and the University of Gothenburg, Sweden, achieved a breakthrough in neuromorphic spintronics resulting in new technology for brain-inspired computing. Researchers demonstrated the first integration of a cognitive computing nano-element, the memristor, into another—a spintronic oscillator. Arrays of these memristor-controlled oscillators combine the non-volatile local storage of the memristor function with the microwave frequency computation of the nano-oscillator networks and can closely imitate the non-linear oscillatory neural networks of the human brain.



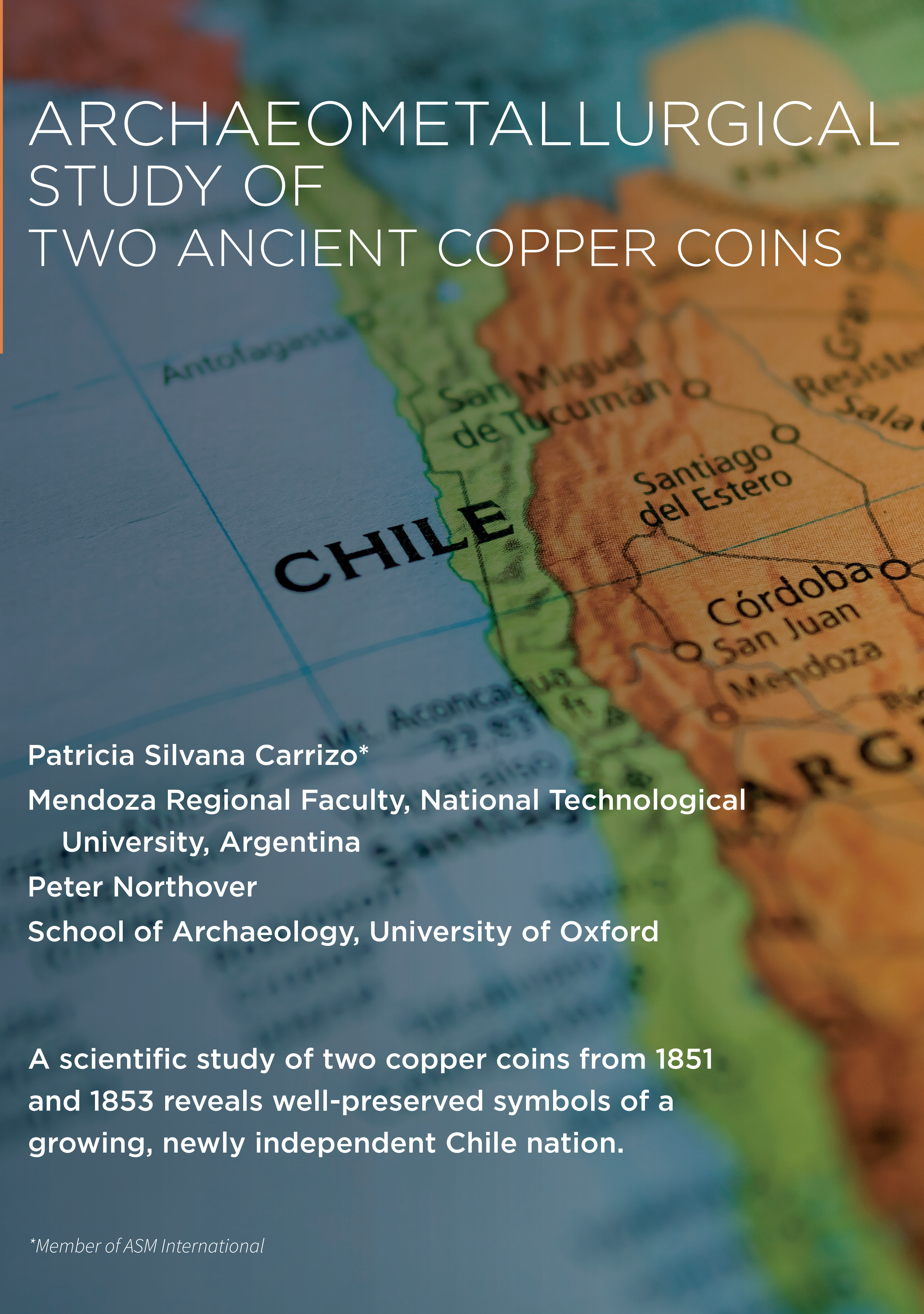
Researchers are making progress on the development of energy-efficient artificial neurons capable of emulating brain-inspired processes.

Researchers examined the operation of a test device comprising one oscillator and one memristor. Resistance of the memristor changed with the voltage hysteresis applied to the top electrode. Upon voltage application to the electrode, an electric field was applied at the high-resistance state, compared to electric current flows for the low-resistance state. The effects of electric field and current on the oscillator differed from each other, offering various controls of oscillation and synchronization properties. *www.tohoku.ac.jp/en, www.gu.se/en.*

BRIEF

In this award-winning image taken with a scanning electron microscope, the green spots are a surface coating developed to limit transmission of SARS-CoV-2. The flower was added. Ph.D. candidate Mohsen Hosseini and chemical engineering professor William Ducker, **Virginia Tech,** won the "most whimsical" category in the National Nanotechnology Coordinated Infrastructure image contest, held annually in celebration of **National Nano Day.** *vt.edu.*

Contest-winning image titled "Lotus on Anti-SARS-CoV-2 Coating."



ARCHAEOMETALLURGICAL STUDY OF TWO ANCIENT COPPER COINS

Patricia Silvana Carrizo*
Mendoza Regional Faculty, National Technological University, Argentina
Peter Northover
School of Archaeology, University of Oxford

A scientific study of two copper coins from 1851 and 1853 reveals well-preserved symbols of a growing, newly independent Chile nation.

**Member of ASM International*

A set of coins created in the mid-19th century for the Republic of Chile was studied to confirm its composition and manufacturing method. A one-cent coin from 1851 belongs to a private collector and a half-cent coin from 1853 was rescued from the Historical Fort May 25 Village archaeological site and is currently exhibited in the Narciso Sosa Morales Museum in Argentina. Through the study of currencies, the relationship between money and nations can be observed; they are a material testimony of the identity of a people, of an era, and of the monetary policies that have animated the economy. Engravers and craftsmen have shaped in metal many of the most significant characteristics of the history of a nation, as well as its artistic development. The rich iconographic heritage shows the historical symbols of these countries and gives a sense of identity. For example, the relatively new (at the time) nations of the Americas used new symbols such as erupting volcanoes, the sun, eagles, condors, Andean camelids, hands swearing on the constitution, and the figures of the Republic and Minerva as representations of freedom, among others.

In the country of Chile, through the enactment of the law of January 9, 1851, the Chilean monetary system was transformed, going from reales and escudos to pesos and centavos, with the following equivalence 1 peso = 8 reales. The aforementioned law, in article 4 said, “There will be two kinds of copper coins, called cents and half a cent of refined copper without mixing any other metal.” The law of March 19, 1851 established that, “The copper coins will bear on the obverse the central star of the shield with the inscription: “Republic of Chile” and year of issue; and on the reverse the expression of its value, a bouquet of circular laurel, and the motto: “Economy is wealth.” Throughout the numismatic history of Chile different versions of the coat of arms have been used on coins. Initially, when Chile was a Spanish colony, the coats of arms of Spain were used. Later, when independence came, Chile’s coat of arms represented the Earth on a pillar. There were more simplified versions in which only the central flat star is shown, as in the case of the 1851 coin. The 1853 coin shows the coat with a five-pointed star with additional relief.

CHILEAN AND ENGLISH MINTS

To comply with this law, copper was commissioned from the Carlos Lambert smelter in Coquimbo (Chile). The plates produced were taken to Santiago where they were minted at the Casa de Moneda. Unfortunately, defects in the plates resulted in coins that were inconsistent in weight, which ranged between 8.388 and 9.400 g. This added to the technical deficiencies of the Mint in making of copper coins, being the first time such large quantities were produced, and led to the end of production of these coins in the country.

The Birmingham Mint, a coining mint, originally known as Heaton’s Mint or Ralph Heaton & Son’s Mint, in Birmingham, England, started producing tokens and coins in 1850 as a private enterprise, separate from, but in cooperation with the Royal Mint. In 1851 coins were minted for Chile. The same year copper plates were made for the Royal Mint to convert

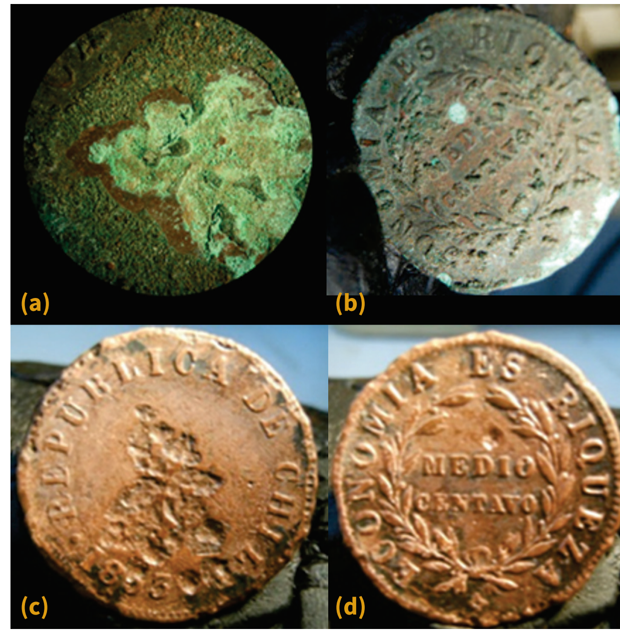


Fig. 1 — The 1853 copper coin before (a and b) and after (c and d) electrolytic cleaning.

Fig. 2 — Obverse and reverse of 1851 historical coin, after electrolytic cleaning.

Fig. 3 — Example of the 1853 half-cent coin in good condition.

TABLE 1 – COIN CHEMISTRY COMPOSITION

Coin	% Zn	% Ni	% Fe	% Mn	% Cu	% Pb	% Si	% As	% Bi
1853, Half cent	0.076	0.099	0.090	0.015	96.2	0.10	0.26	0.091	0.11
1851, One cent	0.063	0.069	0.062	0.016	80.0	0.066	0.48	0.10	0.079

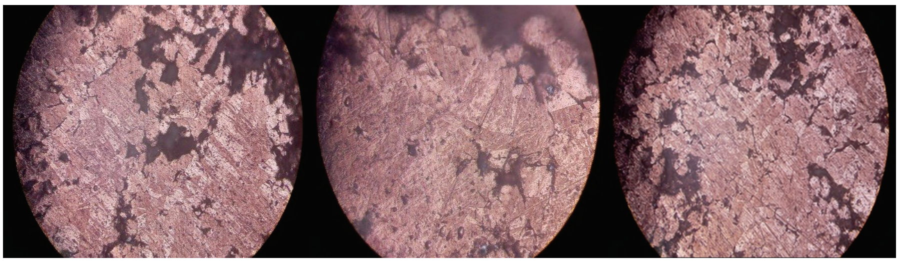


Fig. 4 — Micrograph of the 1853 historical copper coin showing corrosion from pitting. Reagent: Alcoholic solution of 2% ferric chloride ($FeCl_3$). Magnification: 100x.

Fig. 5 — Example of the 1851 one-cent coin in good condition.

into pennies, halfpennies, farthings, half farthings, and quarter farthings. In 1852, the Mint won a contract to produce a new series of coins for France. In this, the Mint was a pioneer in the minting of bronze. In 1853, the Royal Mint was overwhelmed with the production of gold and silver coins. They even re-minted copper coins for Chile. The Birmingham Mint won its first contract to mint finished coins for Great Britain: 500 tons of copper, minted between August 1853 and August 1855, with another contract in 1856. During the peak of operation, the four presses of hit around 110,000 coins a day.

CLEANING BY ELECTROLYTIC REDUCTION

The two copper coins in this study were in good condition, having a well-preserved metallic core and an original surface that was covered with non-deforming corrosion products that could be reduced back to the metallic state. The researchers decided to use electrochemistry to clean the coins by electrolytic reduction[1]. This treatment creates a galvanic battery in which the metallic object to be treated acts as a cathode and a galvanized steel sheet (zinc) or an aluminum sheet acts as an anode, with a 1% M sodium hydroxide as the electrolyte. When the galvanic reaction takes place, the less noble metal, in this case the aluminum or zinc, loses electrons in favor of the most noble (copper), producing a reduction of some corrosion products back to the metallic state. At the same time, the reaction produces hydrogen, which when released in the form of bubbles mechanically removes some corrosion products from the metal surface.

The results were achieved in 2 hours, a fraction of the typical time for metal cleaning, and with a degree of cleanliness that revealed all the details of the copper coin surface. Different results can be obtained depending on the intensity of the applied current, and can affect the rate of reduction of corrosion products to the metallic state and mechanical cleaning by the action of bubbles of hydrogen on the surface. In general, it is advisable not to work with very high currents due to the complexity of the chemical reactions that could affect the cleaning process[2].

Figures 1a and b show the state in which the 1853 copper coin was received and Figs. 1c and d show the coin after electrolytic cleaning. Figure 2 shows the 1851 coin after cleaning. The clean and polished coins show their origin, year of issue, monetary value, legend, and two laurels. The material is primarily copper with alloying elements that do not play a major role in the chemical composition (Table 1). The calamine formed (green) patina on its surface behaved as a protective barrier over time preventing corrosion; that is why the coin has an almost perfect state of preservation.

METALLOGRAPHIC OBSERVATIONS OF THE 1853 HALF CENT COIN

Figure 3 shows an example of the half cent 1853 Chilean coin as listed in the Standard Catalog of World Coins, also known as the Krause catalogs. The obverse side says “REPUBLICA DE CHILE” with the five-pointed star in relief, and year of minting 1853 between two points. The reverse side says “ECONOMIA ES RIQUEZA” (in English: economy is wealth), and the denomination in words is surrounded by laurels with a four-pointed star on the bottom. Note than in the 1853 coin from the study, the letter Q of “RIQUEZA” has a short outer tilde.

The coin’s microstructure was investigated after etching with an alcoholic solution of 2% ferric chloride

($FeCl_3$). The 1853 coin shows a grain structure typical of hot working and annealed with some visible twin grains, variable grain size, and some porosity seen as dark holes due to corrosion (Fig. 4) There is no evidence of second phase. Some intracrystalline cracks have also occurred due to copper corrosion.

METALLOGRAPHIC OBSERVATIONS OF THE 1851 CENT COIN

Figure 5 shows an example of the one cent 1851 Chilean coin as listed in the Standard Catalog of World Coins. Similar to the 1853 coin, the obverse side says "REPUBLICA DE CHILE" with the five-pointed star in relief, and year of minting 1851 between two smaller stars. The reverse side says "ECONOMIA ES RIQUEZA," the denomination in words is surrounded by laurels united with a double loop. There are variants regarding the shape of the letter Q in the word RIQUEZA (Fig. 6). The first type has the Q tilde outside of the letter (most common) and in the second type the tilde crosses the letter (rare). There is another variant, even rarer still, with the accent similar to that of the letter (Ñ). The 1851 coin from the study is quite worn due to the passage of time, but when looking at the letter Q, it is seen that the tilde crosses toward the inside of the letter[3] (Fig. 7).

For the 1851 coin, the 2% alcoholic ferric chloride solution ($FeCl_3$) was also used as the etching reagent, which shows a structure with a well-formed recrystallized grain matrix with straight twin lines, and very little porosity (Fig 8). There is no evidence of a second phase. X-ray fluorescence analysis of both coins confirms that only minor, trace-type alloy components are involved, with copper being the main component. Chemical composition and metallographic evidence indicate that the alloy is of a single phase and aligns with the aforementioned decree of January 9, 1851, which said coins were to be made of refined copper without mixing any other metal. Table 2 lists hardness values for both coins.

Fig. 6 — Three images of 1851 one-cent coins for the morphological comparison of the letter Q.

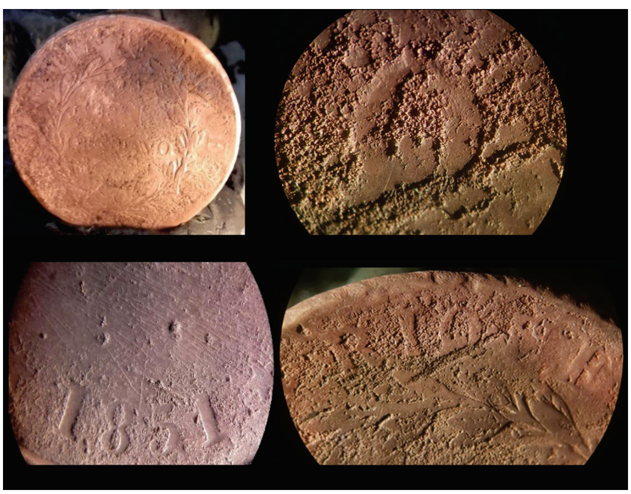


Fig. 7 — Historical coin macroscopy of 1851 one-cent coin.

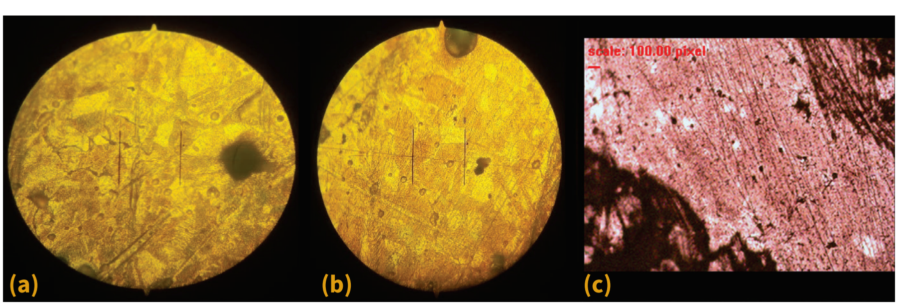


Fig. 8 — Micrograph of the 1851 historical copper coin. Corrosion at the grain edge and detail of slight porosity. Reagent: Alcoholic solution of 2% ferric chloride ($FeCl_3$). Magnification: 400x (a, b) and 100x (c).

TABLE 2 – COIN VICKERS MICROHARDNESS

	1853 half-cent coin		1851 one-cent coin	
1º	146 HV	138.7 HB	137 HV	130.15 HB
2º	132 HV	125.4 HB	109 HV	103.55 HB
3º	121 HV	115.0 HB	101 HV	95.95 HB
AVERAGE	133 HV	126.36 HB	116 HV	109.88 HB

MINTING PROCESS

According to the manufacturing method used at that time, metal was melted in crucibles in a coal furnace, and poured into prepared rails to form solid ingots. Ingots that did not meet the required thickness were passed between two rollers that pressed the metal strip, stretching it to the desired thickness. When the rail hardened it was necessary to anneal it to relaminate it. If the rail was too long, it was cut into smaller pieces.

After the rails were a thickness equal to the blanks, they were annealed to make them more workable. To protect against oxidation from annealing, the rails were put in ovens in sealed boxes.

Automated machines were used to drill the rail and obtain the blanks. These machines were manually fed, and the operator had to move the metal strip forward to the rhythm of the machine. The cut blanks then went through the press, creating a pre-listel, a rim or raised border, which, among other things, helped protect the engraved pattern. The press was formed by a conduit through which the flange passed while the coin was pressed in its edge, raising it and creating its pre-listel and eliminating the burrs left by the cut of the coin. Afterward, the coin was annealed to soften it, eliminating internal tensions. The annealing of the blanks was followed by washing to eliminate any rust formed during annealing. They were washed first in a chemical solution and then with a bath of soap and water that left its surface shiny. The coins were dried initially on trays with hot sawdust, and years later in drying machines[4].

SUMMARY

Chile in the 1850s, as a growing nation, adopted emblems and symbols in line with new concepts of freedom, union, force, and independence. One way the country demonstrated these new images was in its currency, with a law passed in 1851 directing the minting of copper coins.

Two Chilean copper coins from this time period were studied. Knowing these coins were virtually pure copper, electrolytic cleaning using sodium hydroxide was used to clean them, though it is not recommended for copper alloys and silver alloys. All the products of corrosion (greenish layer of malachite) were separated in around 60 minutes. The entire surface could be seen and studied in detail. In addition, the good state of preservation of these ancient coins was verified. Coin-collector catalogs verified that the currencies are legitimate and confirmed where and how the coins were minted. **~AM&P**

For more information: Patricia S. Carrizo, chemical engineering and archaeometallurgy specialist, National Technological University, Argentina, patricia.carrizo@frm.htn.edu.ar.

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1. A. Aldaz, et al., A Simple Tool for the Electrolytic Restoration of Archaeological Metallic Objects with Localized Corrosion, *Studies in Conservation,* Vol 31, 1986.

2. C.E. Birchenall and R.A. Meussner, Principles of Gaseous Reduction of Corrosion Products, National Bureau of Standards Special Publication, No 479, p 39-57, 1977.

3. Images used for comparison: First type: courtesy of Classical Numismatic Group St. James's Auctions LLC and Second type: courtesy of Heritage Auctions (www.ha.com).

4. B. Muñiz García, Fabricación de la moneda a través de los tiempos (Manufacture of Coins through the Ages), Revised version October 2005-2008.

HEATON'S MINT

An interesting part of this study was the research done into the history of where and how the coins were made. Because they were minted in England, news stories and other documentation are available to tell a fuller story.

Ralph Heaton II (1794–1862) was the son of Ralph Heaton I, an engineer, inventor, and businessman in England. Ralph Heaton II was a die sinker operating independently of his father. In December 1817 Ralph I conveyed to his son land and buildings to enable him to develop a separate company. Ralph II engaged in brass founding, stamping, and piercing. Brass chandeliers were made for the newly invented gas lighting and he patented a "bats wing" burner.

At an auction In April 1850, Ralph Heaton II bought four steam screw presses and six plate presses for making blanks from metal strapping from the defunct Soho Mint, created by Matthew Boulton around 1788.

A newspaper of the time also reported that the complete set of presses, pneumatic pumps, and other machinery for minting, were acquired by Ralph Heaton and Son, with the intention to take over Soho's contracts. Unlike the government-owned Royal Mint, Heaton was able to get permission to produce coins for foreign powers. In 1851 Heaton and Son began producing currency for other nations including Chile, as well as minting coins outsourced by the Royal Mint.

GET ENGAGED, GET INVOLVED, GET CONNECTED

The ASM Online Community on ASM Connect, at connect.asminternational.org, is a platform where experts and knowledge seekers can connect and communicate. ASM Members can get the ball rolling by posting questions and information briefs about technical areas of interest. For topics of sustained interest, dedicated communities can form; these can evolve into ASM technical committees if the members wish to collaborate on projects for the benefit of the ASM community.

The ASM Archaeometallurgy Committee was recently launched and ASM members with interest and experience in the study and characterization of historic metals and artifacts are welcome to join. A planned special issue of the International Metallographic Society journal *Metallography, Microstructure, and Analysis* is just one of the projects underway. For more information, contact committee chair Patricia Silvana Carrizo or staff liaison Scott Henry, scott.henry@asminternational.org.

PROFILOMETRY-BASED INDENTATION PLASTOMETRY BRINGS SPEED AND ACCURACY TO METALLURGICAL R&D

This unique testing method offers economic benefits, sustainability advantages, and the potential to slash the time required to develop new alloys and processing recipes.

Bryer C. Sousa and Danielle L. Cote**
Worcester Polytechnic Institute, Massachusetts
Matthew A. Priddy
Mississippi State University
*Victor K. Champagne, Jr.**
U.S. Army Research Laboratory, Maryland

Profilometry-based indentation plastometry (PIP) was developed and commercialized by Plastometrex in the U.K. This unique testing method offers the materials science, engineering, and processing community a paradigm shift in the mechanical characterization of metal systems. Rooted in indentation, PIP testing gives metallurgical and mechanical engineers a simple way to determine nominal stress-strain curves up to the ultimate tensile strength (the point at which the onset of plastic instability arises), as well as true stress-strain curves, Voce plasticity parameters, yield strength, and simulated Brinell hardness values in less than five minutes.

Another notable feature is that PIP testing only requires a sample thickness of roughly 2 mm, and length and width dimensions of just 6 mm. This can lead to significant cost savings compared with sample requirements for uniaxial tensile testing, specimen machining, and component manufacturing. For example, assuming a rectangular specimen geometry, the volume of material required for PIP testing per stress-strain curve is 72 mm^3, whereas an ASTM E8 sub-size specimen (prior to machining to test coupon geometry) requires a volume of 2100 mm^3 per stress-strain curve. The result is a reduction in material costs of approximately 97% when using PIP testing and plasticity analysis.

PIP THEORY AND PRACTICE

PIP is performed using an indentation plastometer (Fig. 1). As noted by Tang et al., PIP-obtained tensile stress-strain curves are derived by loading a hard spherical tip into a given specimen until reaching a known force[1]. This is followed by measuring the resultant indent profile and performing an iterative finite element model (FEM) simulation of the same test until best-fit plasticity parameters are achieved. More details regarding the process of obtaining tensile stress-strain curves via PIP analysis will be discussed shortly; the true stress-strain relationship (metallic plasticity behavior) and deformation response of the material are formulated via the Voce plasticity model, as far as an analytical framework for PIP testing of strain hardening material systems is concerned[2].

Numerous constitutive plasticity laws and analytical expressions are found in the literature, such as those presented by Hollomon, Swift, Ludwik, Harley and Srinivasan, Ludwigson, and Baragar[3]. However, the implementation of a Voce plasticity framework within PIP testing centers on the observation that the Voce model was capable of characterizing the plasticity response of metallic material systems with true strain hardening rates that approach zero. Further, the Voce model was also the most adept plasticity model for effectively capturing accurate, true stress-strain behaviors across a range of alloys and metals.

In contrast with the Ludwik-Hollomon plasticity model, which is expressed as:

$$\sigma = \sigma_y + K\varepsilon^n$$

wherein σ represents the von Mises applied stress, σ_y represents the von Mises yield stress, ε represents the von Mises plastic strain, K represents the strain

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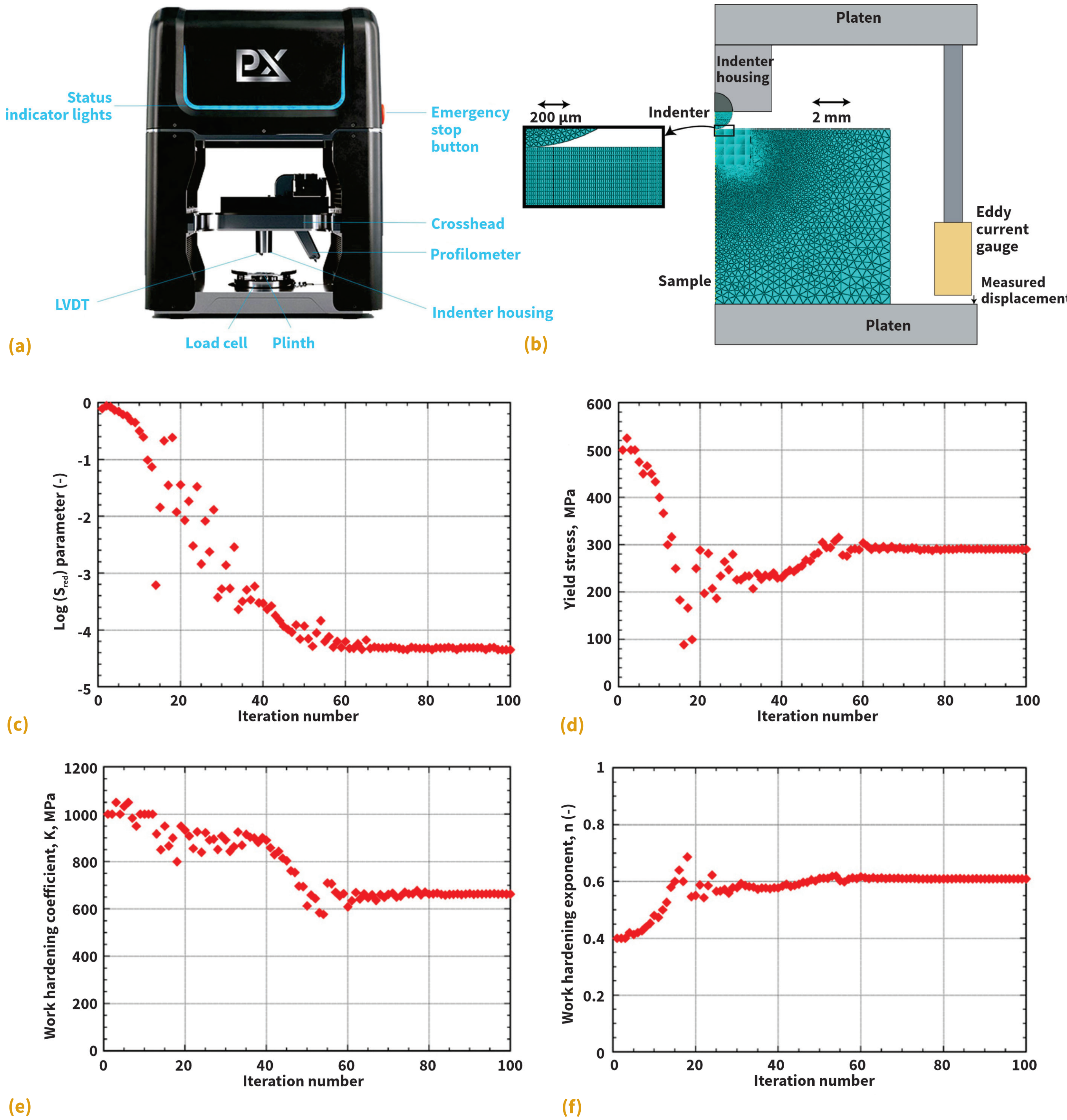

Fig. 1 — (a) Indentation plastometer from Plastometrex; (b) FEM-based schematic of a plastometer for PIP testing; and (c, d, e, and f), the convergence process underpinning PIP data analysis[2].

hardening coefficient, and *n* represents the strain hardening exponent, the Voce plasticity model is expressed as:

$$\sigma = \sigma_s - \left(\sigma_s - \sigma_y\right) \exp\left(\frac{-\varepsilon}{\varepsilon_o}\right)$$

wherein σ, σ_y, and ε are the same variables found in the Ludwik-Hollomon plasticity model expression, σ_s is the saturation stress, and ε_o is the characteristic strain. Reference 3 is a valuable resource for more information related to PIP testing.

USING PIP IN MATERIALS PROCESSING

The streamlined PIP testing method could benefit a wide range of applications within the advanced materials and processing community. For example, consider the case of capturing plasticity parameters and intrinsic mechanical properties as a function of thermomechanical processing times and temperatures along with standard aging curves, which traditionally rely on indentation hardness or tensile test data as a function of processing parameters. In contrast, PIP testing can more easily identify optimal processing parameters in a high-throughput manner.

As such, heat treatment optimization and tuning for application-specific performance requirements are well suited for PIP testing and analysis integration. This is especially relevant for the aluminum, steel, nickel, titanium, cobalt, and copper-centric domains of expertise. Accordingly, the Cote Research Laboratory at Worcester Polytechnic Institute (WPI) is actively working with Solvus Global, also located in Worcester, Mass., the U.S. Army Research Laboratory, the University of Massachusetts Amherst, the Metals Processing Institute, Florida International University, Mississippi State University, and others to utilize PIP in this way further. For example, the thermal post-processing optimization of wire arc additive manufacturing (WAAM)-based maraging 250 steel systems is underway. Beyond heat treatment optimization, advanced processing parameters are being evaluated for cold spray additive manufacturing (CSAM), WAAM, photopolymer additive manufacturing (PAM), directed energy deposition (DED), and additional materials processing methods.

CASE STUDY 1: COMPARISON OF PROCESSING TECHNIQUES

To demonstrate the utility of PIP testing within the realm of processing method selection, Al 6xxx specimens were produced via high-pressure nitrogen CSAM, a hybrid combination of shot peening and high-pressure nitrogen CSAM, arc melting, and extrusion. The CSAM-based Al 6xxx consolidations were processed using a 0071 polybenzimidazole nozzle, a cold spray system from VRC Metal Systems, Box Elder, S.D., an inertly gas-atomized Al 6061 feedstock powder, and a wrought Al 6061-T651 build plate. The arc melted specimen was produced using wrought Al 6061-T651 and an electric arc as a thermal energy source.

As for the hybrid combination of shot peening and high-pressure nitrogen CSAM consolidations, the same processing parameters, feedstock, hardware, and system were used; however, shot peening was introduced at constant intervals of deposited layers. Further, while a roughness of approximately 3 µm or less is best for PIP testing, specimens were compression mounted using phenolic mounting material and a SimpliMet 4000 system from Buehler, Lake Bluff, Ill. This was followed by grinding and polishing for metallographic preparation using a Buehler EcoMet 300 automatic polisher until a mirror finish was achieved using a 0.02 µm colloidal silica suspension. After that, PIP testing was performed per prescribed protocols, execution of the tests via CORSICA 2.0, and analysis via SEMPID (software for extracting material properties from indentation data). Figure 2 shows testing results and analysis.

In addition to the nominal or engineering stress-strain curves obtained and presented for the arc melted, hybrid CSAM and shot-peened, high-pressure CSAM deposited, and extruded Al 6xxx specimens, one can identify that the processing technique achieves the desired

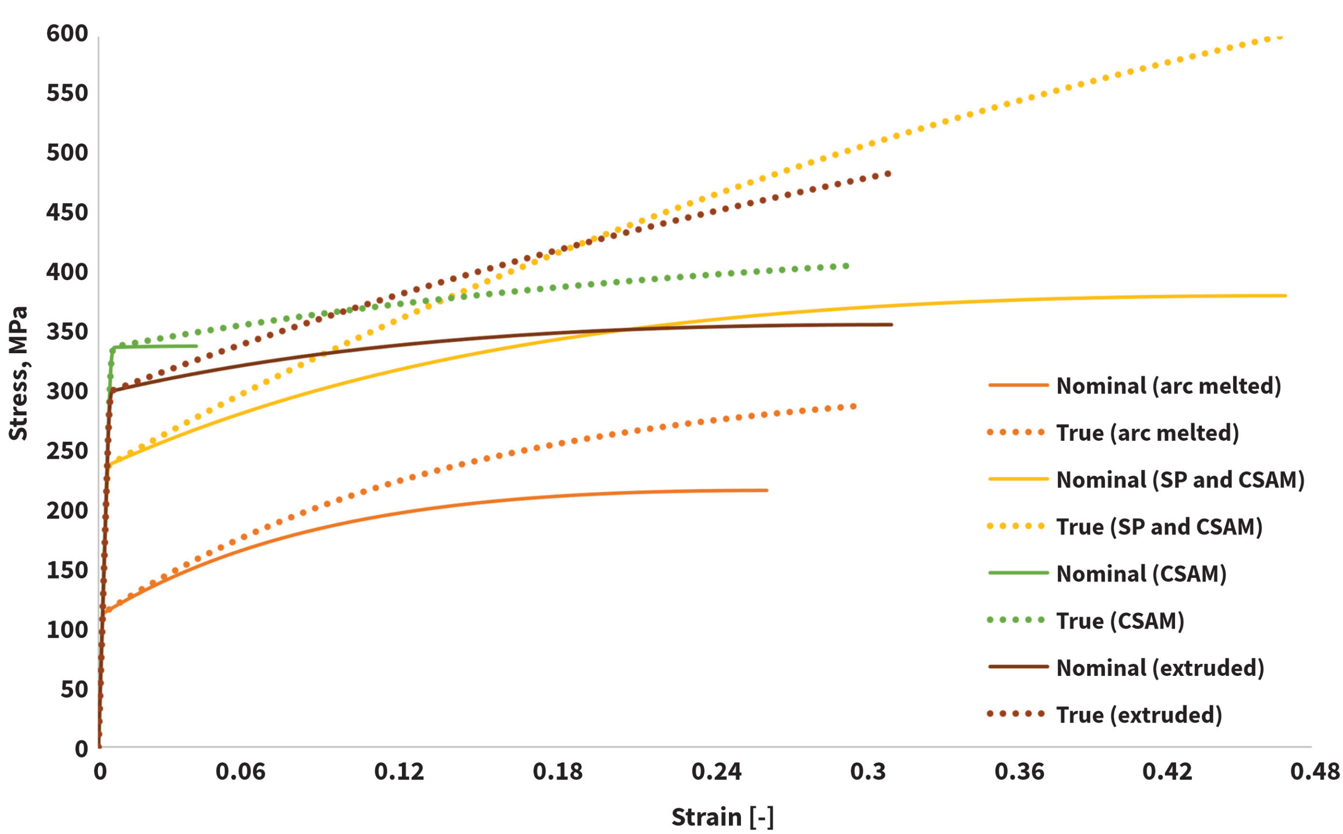

Fig. 2 — Nominal and true stress-strain curves for the four uniquely processed Al 6xxx series studied here.

strength-to-ultimate tensile strain ratios for a given application. The arc melted material was found to have the lowest yield strength (113 MPa) and lowest ultimate tensile strength (217 MPa). Regarding yield strengths (excluding the arc melted specimen discussed above), the hybrid CSAM and shot-peened, extruded, and CSAM processed Al 6xxx specimens were found to be 238, 300, and 338 MPa, respectively. At the same time, the ultimate tensile strengths (excluding the arc melted specimen) for the hybrid CSAM and shot-peened, extruded, and CSAM processed Al 6xxx specimens were found to be 381, 356, and 339 MPa, respectively.

By coupling these insights regarding strength with implications for ductility from the nominal stress-strain curves obtained via PIP testing and analysis, hybrid CSAM and shot-peened processed Al 6061 resulted in the most pronounced balance between strength and ultimate tensile strain, i.e., the strain at which the onset of plastic instability initializes, followed by necking until critical failure occurs. Interestingly, one can demonstrate the value of using the Voce plasticity constitutive law parameters obtained from PIP testing to define the mechanical characteristics within FEA and affiliated models to obtain insights surrounding specimen-specific deformation behaviors. For example, SEMPID contains a tool for PIP users that provides operators with the ability to model Brinell indentation as a function of the Voce plasticity parameters garnered from PIP analysis (Fig. 3).

Specifically, this built-in feature within SEMPID models a Brinell indentation test wherein the simulated Brinell indenter tip radius is 5 mm and the max indentation load applied is 3000 kg. Thus, Fig. 3 captures the final effective plastic strain fields and von Mises stress fields for the hybrid CSAM and shot-peened, extruded, and CSAM processed Al 6xxx specimens at the maximal external load applied. Concurrently, those interested can also obtain similar plots at various stages of external loading and plot displacement fields and Brinell residual indent profiles. In any case, for the extruded Al 6xxx, CSAM processed, and hybridized CSAM and intermittently shot-peened specimens, Brinell test simulations recorded Brinell hardness values and indent diameters of 123.9 kg/mm^2 and 5.333 mm, 121.1 kg/mm^2 and 5.389 mm, and 113.3 kg/mm^2 and 5.556 mm, respectively. SEMPID software also enables users to model spherical indentation and uniaxial tensile tests using the plasticity parameters measured and the axisymmetric tensile coupon geometries and measured ductility. Note that the user must define both of these latter variables prior to performing computational analysis.

CASE STUDY 2: WAAM APPLICATIONS

This case study focuses on wire arc additive manufacturing (WAAM) and highlights PIP within the context of post-processing influence on strength. The research involved applying PIP testing to a WAAM-processed maraging 250 steel material system. More specifically, the as-printed and stress relieved WAAM-processed maraging 250 steel systems were produced using constant processing parameters and build plate compositions. Stress relief thermal post-processing was first performed on the WAAM-processed consolidations attached to the build plate. Accordingly, PIP testing enabled insights into the stress-strain behavioral evolution induced by thermal post-processing compared to the as-processed counterpart. The two WAAM-processed specimens are shown in Fig. 4 before metallographic preparation and PIP testing. Nominal and true stress-strain data for both

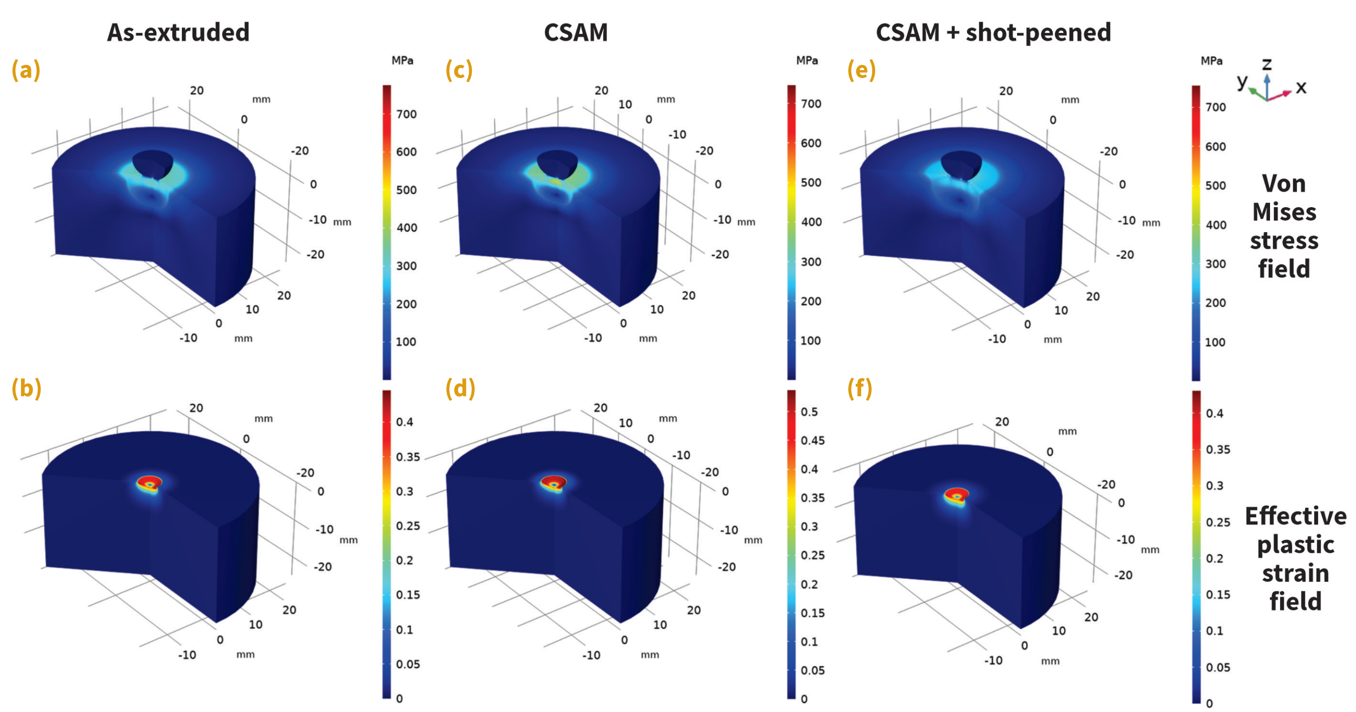

Fig. 3 — PIP and SEMPID-enabled FEA of simulated Brinell indentation testing of three uniquely processed Al 6xxx materials.

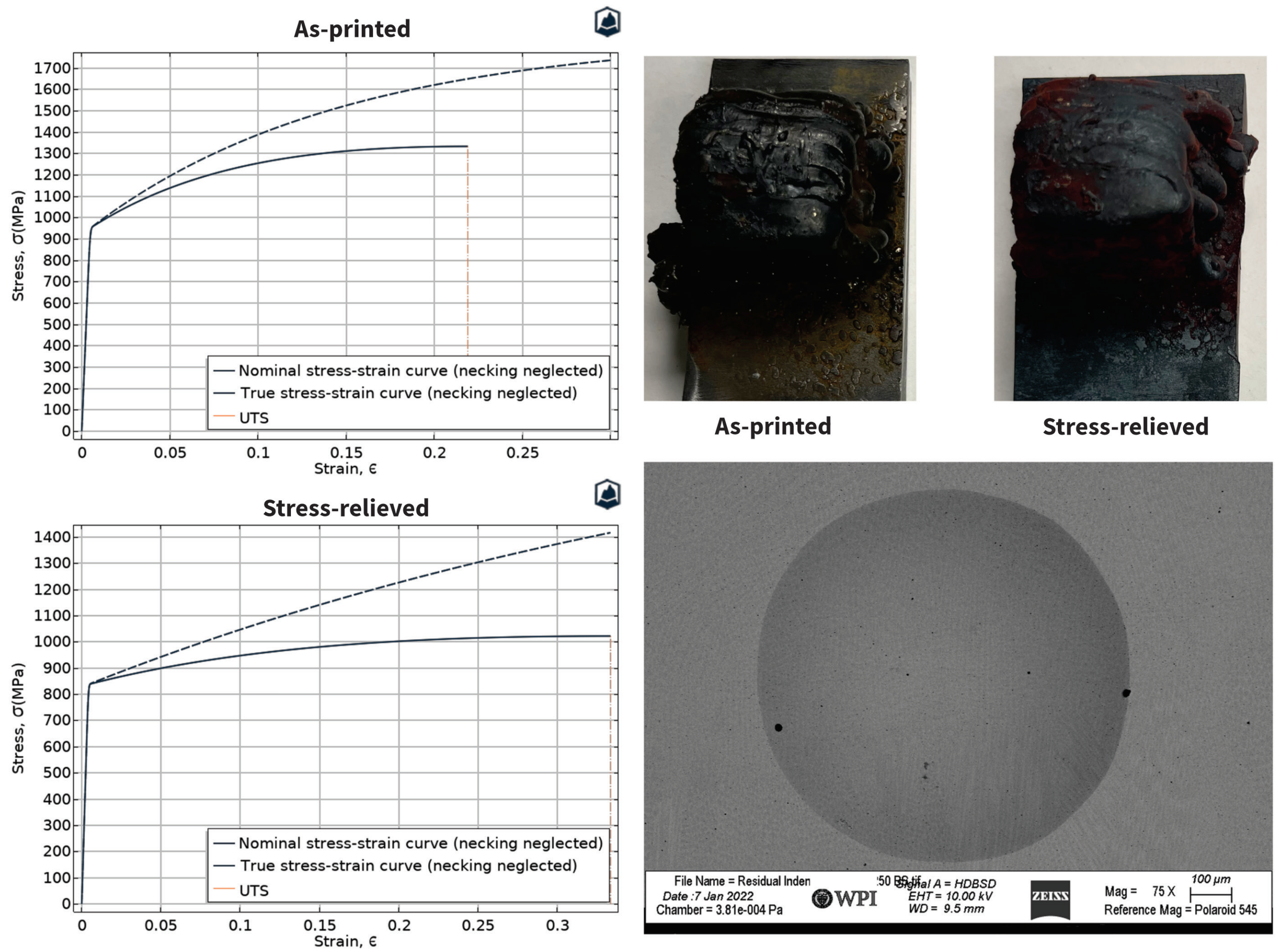

Fig. 4 — PIP analysis of as-printed and stress-relieved WAAM-processed maraging 250 steel systems.

conditions are presented alongside a scanning electron micrograph of a residual PIP indent applied to a WAAM-processed maraging 250 steel system.

PIP testing and analysis found the yield strength, ultimate tensile strength, and characteristic strain for both the as-printed and heat treated conditions to be 950 and 838 MPa, 1333 and 1022 MPa, and 13% and 50%, respectively. Testing was conducted parallel to the build direction and equidistant from the deposit-substrate interface and specimen surface. Soon, the degree of information obtained via PIP testing and analysis of the WAAM-processed steels discussed here will be enhanced. PIP line scans are currently being measured for region-specific property insights; multiple orientations relative to the build, traverse, and step directions are being characterized; substrate-free WAAM-processed and thermally post-processed specimens are being characterized to explore the relationship between residual stress states and resultant PIP behavior.

CONSTRAINTS AND LIMITATIONS

Like all materials characterization methods, PIP has its limitations. For example, PIP testing should not be performed within 3 mm of a specimen's given edge. In addition, one must avoid near-edge measurements to ensure that the presence of both free edges and the edge of the specimen in contact with the mounting matrix material will not influence the plastic deformation field formed during testing. This could reduce PIP test accuracy due to the potential for deviations from radial symmetry, which would violate the underlying principles within the indentation models.

For high-fidelity PIP testing and analysis, one must also consider specimen curvature and surface roughness variation boundaries. Currently, the maximal radius of curvature is 1 m, and the maximal surface roughness is 10 µm; however, surface roughness of 3 µm or less, or surfaces that have been polished using P1200-P2400 grit polishing paper, is ideal for PIP applications. To date, materials that can be tested via PIP include pure and alloyed aluminum, steel, titanium, nickel, copper, and cobalt systems. Note that materials with yield strengths well above 2000-3000 MPa are also currently out of range.

RECENT PROGRESS

PIP testing and analysis are steadily gaining wider adoption and further integration within various sectors of the metallurgical and materials engineering communities. Recent advancements have resulted in the application of PIP testing and analysis to the following metallic materials:

- Brazed and nonbrazed Hardox steels used for mining applications[4]
- Forged aluminum systems[5]
- Fusion welds[6]
- Residual stress quantification and effects upon PIP data[7,8]
- Quantification of creep characteristics[9]

With the extensive PIP testing and analysis capabilities, the advanced materials and processing community is well positioned to benefit from this novel characterization method. **~AM&P**

For more information: Bryer C. Sousa, doctoral candidate, Department of Mechanical and Materials Engineering, Worcester Polytechnic Institute, 100 Institute Rd., Worcester, MA 01609, bcsousa@wpi.edu.

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TECHNICAL SPOTLIGHT

ULTRASONIC FATIGUE TESTING FOR ADDITIVELY MANUFACTURED METAL ALLOYS

Compared with traditional fatigue testing, the ultrasonic method achieves much speedier results along with the ability to run extremely high test cycles in a reasonable time frame.

Fatigue testing that employs sample resonance at ultrasonic frequencies is a relatively underutilized technique that is attracting increased interest as a tool to rapidly assess the suitability of alloys for 3D printing. This testing method is especially useful for applications in aerospace, automotive, medical device, and other industries that require high reliability and extremely long performance life. Compared with conventional fatigue tests, ultrasonic testing provides both faster test speeds and the unique ability to test to extremely high cycle numbers in a practical time frame. Very high cycle fatigue (VHCF) testing can reveal material failure modes that would remain undetected under lower cycle fatigue test conditions. Gigacycle fatigue tests, which would take years using traditional test methods, can be performed in about six days with ultrasonic testing, as shown in Fig. 1. This article provides a simple introduction to ultrasonic fatigue testing along with examples of its utility in the characterization of metals including 3D-printed alloys.

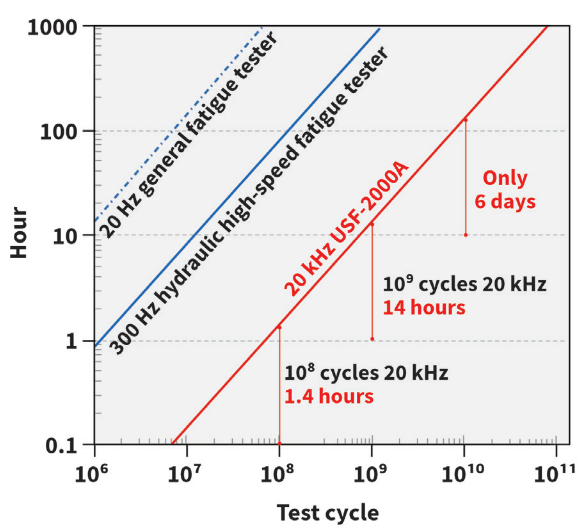

Fig. 1 — Gigacycle fatigue tests that require years of testing using conventional techniques only take about six days with ultrasonic testing.

TESTING BASICS

Fatigue testing involves the periodic stressing of materials below their yield strength to produce plots of applied stress versus the number of test cycles to failure. These S-N plots are used to estimate the expected lifetime of materials for intended design applications.

With traditional fatigue instrumentation, samples are stressed by cyclic external loads generated by a servo-hydraulic or electromechanical mechanism and easily measured with a load cell. Uniaxial fatigue testing methods are well established and thoroughly documented in ASTM publications such as STP 566-EB Handbook of Fatigue Testing, as well as ASTM standards E466-21 and E606, which describe force-controlled and strain-controlled procedures, respectively. ASTM standard E467 describes procedures for dynamic load verification.

Conventional fatigue machines can generate maximum cycle frequencies of about 100 Hz. Consequently, fatigue tests are typically restricted to a

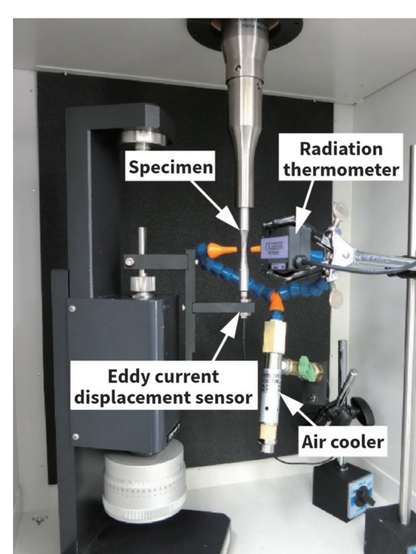

Fig. 2 — Shimadzu USF-2000A ultrasonic fatigue testing system.

■ Principles

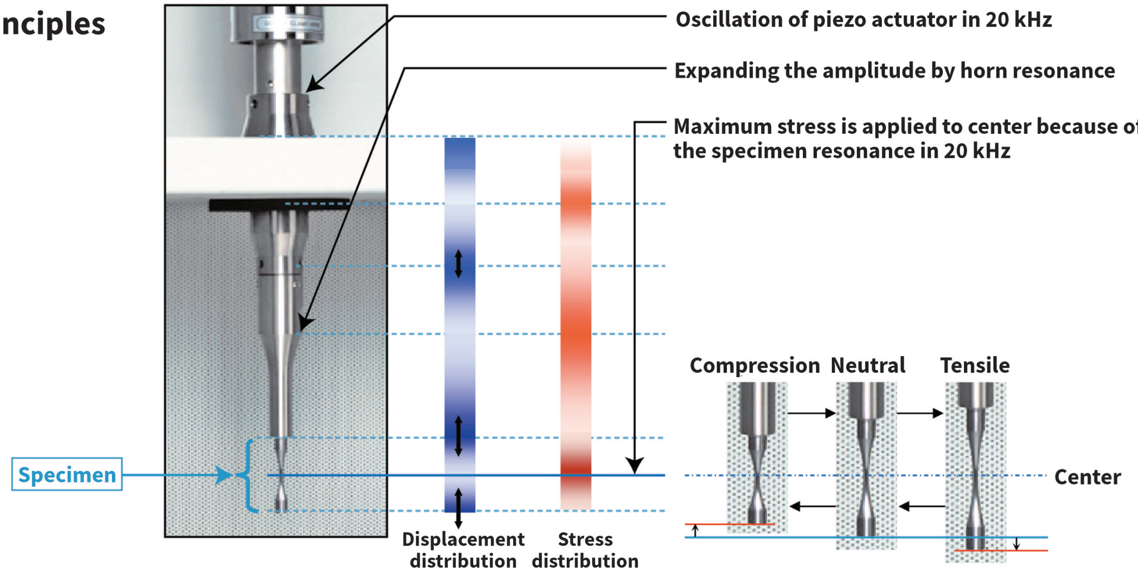

Fig. 3 — Illustration of the principles of a piezoelectric oscillator as wave vibrations move through a sample.

maximum of 10^6 or 10^7 cycles. However, many applications require component fatigue life in excess of 10^7 cycles. Testing in the very high cycle regime in excess of 10^7 cycles has shown that failure can initiate due to internal inclusions rather than surface defects commonly observed in lower cycle testing.

The basic components of an ultrasonic fatigue system are shown in Fig. 2.

A piezoelectric oscillator operating at 20 kHz is connected to a booster and amplification horn, which magnify the displacement of the oscillator. One end of the sample is connected to the horn while the other end is free to oscillate. A longitudinal wave vibration travels through the sample, which then stretches and compresses in resonance with the oscillator. For a resonating sample, maximum displacement occurs at the sample ends while maximum stress occurs at the sample midpoint, as shown in Fig. 3. The amplitude of the displacement is controlled by the power input to the piezoelectric oscillator. The load is not measured directly. System software allows stress to be calculated from sample dimensions and displacement of the free edge of the sample, which is measured using a noncontact eddy current displacement sensor.

The ultrasonic fatigue test can be designed to exert a mean stress on the sample by attaching the entire acoustic wave train to a universal testing machine (UTM) and connecting the sample to a second horn, which is fixed to the base of the UTM frame (Figs. 4 and 5). In this case, the sample displacement used to calculate the sample stress is measured using a strain gauge attached to the sample, as there is no oscillating free end to observe.

The sample shape and length are chosen to allow resonance at 20 kHz. Tapered cylindrical, rod, or notched type samples are used. System software enables the correct sample length for resonance at 20 kHz to be calculated from inputs of the test material's density and Young's modulus.

Fig. 4 — External view of the mean stress loading jig.

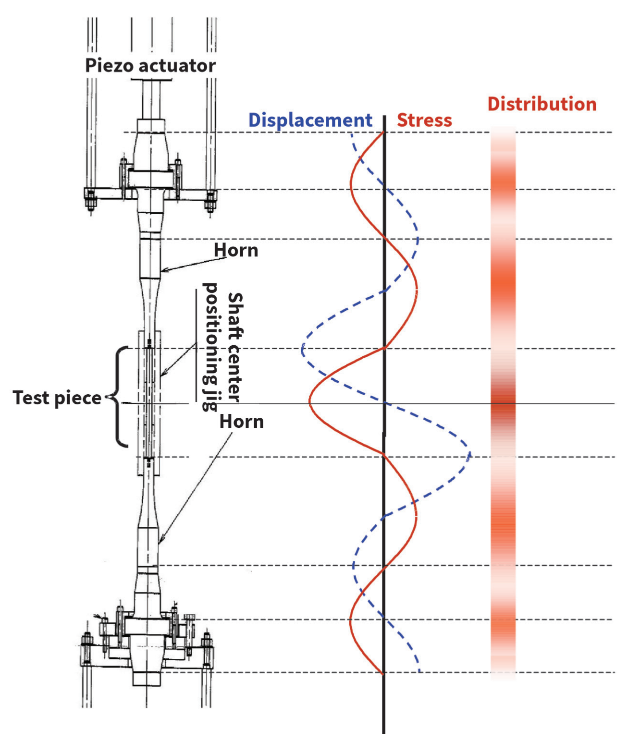

Fig. 5 — The acoustic wave train can be mounted to a universal test machine with the sample connected to a second horn at the base of the frame to apply a mean stress.

The technique is limited to materials that can resonate at 20 kHz without excessive heating. Consequently, this method has been primarily used to test metal samples, although recent studies have successfully employed the technique to test carbon fiber reinforced plastics[1]. To prevent excessive heating of samples, the system is configured with a forced-air cooling mechanism. In addition, the computer control system allows the oscillations to be regularly halted during the experiment to let the sample cool during the test. During testing, sample temperature is monitored using a radiative temperature measuring device.

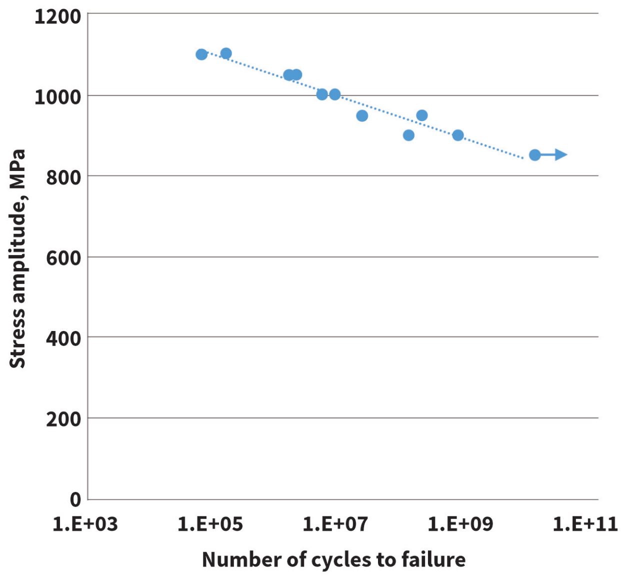

Fig. 6 — S-N curve for SNCM439 steel sample.

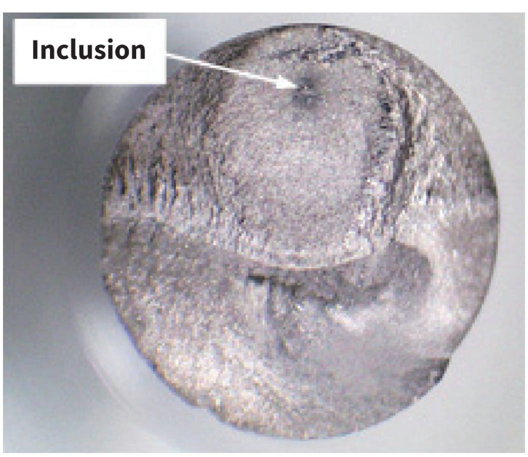

Fig. 7 — Fracture surface of SNCM439 sample.

A more thorough description of the basics of ultrasonic fatigue testing may be found in the *ASM Handbook* published in 2000[2]. In 2017, The Japan Welding Engineering Society published a standard test method for ultrasonic fatigue testing of metals (WES 1112:2017), which describes the theory and testing procedures in detail[3].

EXAMPLES

To demonstrate the technique, the staff of the Global Applications Development Laboratory of Shimadzu Corporation in Kyoto, Japan, tested SNCM439 steel according to WES 1112:2017 using a Shimadzu USF-2000A system[4,5]. Intermittent operation and forced-air cooling were employed to maintain the sample temperature of 30°C or less as mandated by the standard.

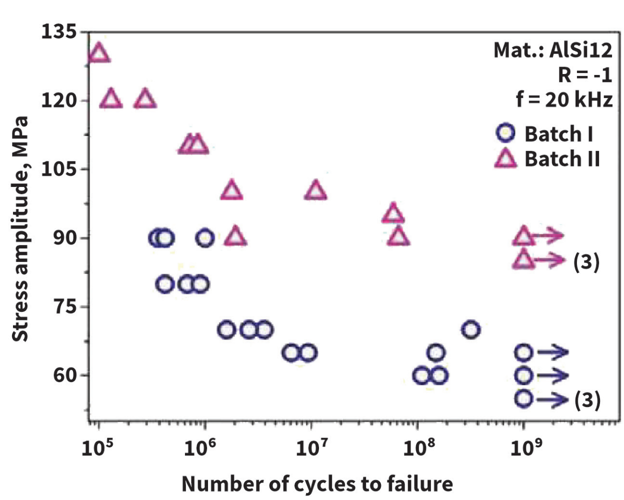

Fig. 8 — Two batches of AlSi12 alloy samples tested to failure. Batch II has base plate heating, while Batch I does not.

Figure 6 shows how fatigue failure occurred at 10^8 to 10^9 cycles for low-stress magnitudes. Figure 7 shows an optical micrograph of the fracture surface of an SNCM439 sample, indicating that failure initiated at the site of an inclusion.

These data show the importance of fatigue testing at 10^7 cycles and beyond for materials intended for long-lifetime, high-reliability applications. Such testing can reveal failure mechanisms due to internal defects that may go undetected with lower cycle testing. Therefore, ultrasonic fatigue testing can be a powerful technique to characterize alloys intended for additive manufacturing (AM) applications where the effects of AM process parameters on internal microstructure and material performance are not fully understood.

An example of how AM processing parameters can affect VHCF performance is shown in Fig. 8. AlSi12 alloy samples were manufactured using selective laser melting with and without heating of the base[6]. Both samples failed beyond 10^7 cycles. Base plate heating (Batch II) resulted in significantly higher fatigue strength due to a reduction in gas pore size.

Additional examples of ultrasonic fatigue testing of AM materials may be found in the review prepared by Andrea Tridello and Davide Paolino[7]. A comprehensive AM VHCF review article was authored recently by Maryam Avateffazeli and Meysam Haghshenas[8].

ASTM Committee E08 has established a group to discuss the nuances of this technique and develop a best practices guide[9]. **~AM&P**

For more information: Christopher J. Macey, business development group leader, Shimadzu Scientific Instruments, 7102 Riverwood Drive, Columbia, MD 21046, 410.381.1227, cjmacey@shimadzu.com, www.ssi.shimadzu.com.

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Thermal Spray Society
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iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

25 YEARS OF THE CENTER FOR THERMAL SPRAY RESEARCH

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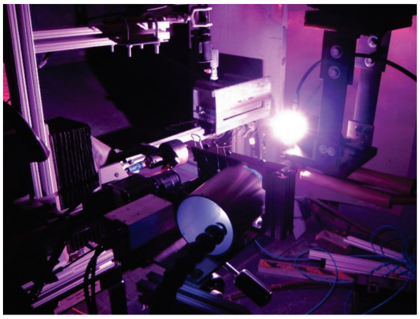
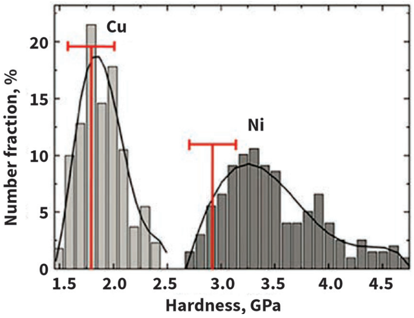




EDITORIAL OPPORTUNITIES FOR *iTSSe* IN 2022

The editorial focus for iTSSe in 2022 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

July/August:
Energy and Power Generation

To advertise, contact Kelly Johanns at kelly.johanns@asminternational.org.

DEPARTMENTS

ABOUT THE COVER

Photograph of controlled, high heat flux, transient, thermal gradient testing using high velocity oxy-fuel thermal spray set-up at Stony Brook Center for Thermal Spray Research that allows rapid exposure of advanced alloys, additively manufactured components and coatings at heat fluxes exceeding 1MW/m^2 and heating rates of thousands of degrees per min.

MUSINGS ON MICROGRAPHS

Viewing and characterizing a micrograph brings to mind the excitement of looking through a kaleidoscope for the very first time. Most of us likely experienced the fascination of a kaleidoscope as a child. We were intrigued by the endless shapes, shades, and colors, all feeding our imagination and spurring our curiosity to find out how it works. Then we would hesitantly pass the scope to the next viewer.

In our professional studies, the way we use thermal spray to engineer surfaces for countless applications makes me think of the relationships within our professional association—the **ASM Thermal Spray Society.** Our resources include this very magazine *(iTSSe),* the *Journal of Thermal Spray Technology,* the International Thermal Spray Conference (ITSC), and focused topical events. All of these contribute to our continuously expanding knowledge base and enrich our interactions with hardworking colleagues deserving of many accolades. Therefore, sharing the kaleidoscope is of the utmost importance as we grow professionally.

So what does the symbolic kaleidoscope have to do with the Thermal Spray Society? Specifically, we can think about:

- Micrographs—density, particle size, bond line, surface roughness, and more when looking at the *Journal of Thermal Spray Technology*, *AM&P, iTSSe,* online ASM resources, and numerous technical books
- Visually identifying part wear and considering different options in order to choose the best surface technology to apply
- The heat source for various processes, from plasma plume to HVOF shock diamonds to twin wire arc, or the optical particle distribution of cold spray
- A clean and proper surface for optimal coating application
- A diamond superfinish polish to obtain a chatter-free surface
- Engaging with other attendees at conferences, where silver-haired colleagues continue to contribute to the science and pass knowledge to the next generation
- Interacting with professors and students to see the sincerity in facial expressions


Kay

Some upcoming kaleidoscope opportunities will occur at ITSC in May in the historic and beautiful city of Vienna. See the Show Preview in this issue for more details. And more chances for these connections will be available at Cold Spray and NEMS, taking place during IMAT in September in New Orleans, and during the ongoing OpenMic series based on helping students meet thermal spray notables. We hope you will participate in one or more of these events.

These opportunities exist because of a truly international group of people who are not only sincere and hardworking, but willing to offer mentorship. Each of these volunteers adds color and richness to the kaleidoscope of our society.

Thank you to all of the readers of *iTSSe,* to the ASM staff at Materials Park who bring us all together, and to all of my many mentors.

Charles M. Kay, FASM
President, Hannecard Roller Coatings/ASB Industries
TSS Past President and Volunteer *iTSSe* Editor

SEEKING NOMINATIONS FOR THERMAL SPRAY HALL OF FAME

The Thermal Spray Hall of Fame, established in 1993 by the Thermal Spray Society of ASM International, recognizes and honors outstanding leaders who have made significant contributions to the science, technology, practice, education, management, and advancement of 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.

CENTER FOR THERMAL SPRAY RESEARCH COMPLETES SUCCESSFUL 25 YEARS

Stony Brook celebrates a milestone by reflecting on its Center for Thermal Spray Research from the early years of growth and expansion to the development of an industrial consortium.

Sanjay Sampath, FASM, TSS-HoF, Center for Thermal Spray Research, Stony Brook, New York*

In August 1996, following a year long, multi-stage competition, the National Science Foundation (NSF) awarded a multi-year Center grant under the auspices of the Division of Materials Research's Materials Research Science and Engineering Center (MRSEC) program to a team led by Stony Brook faculty. The Center, directed by Prof. Herbert Herman, FASM, TSS-HoF, along with Profs. Christopher Berndt, FASM, TSS-HoF, and Sanjay Sampath, FASM, TSS-HoF, converted a fledgling but successful academic exercise in thermal spray materials processing into a major multidisciplinary materials program. The premise of the Stony Brook proposal was that thermal spray allows materials to be synthesized from extreme conditions with novel microstructures, which enables important functionalities in engineering systems.

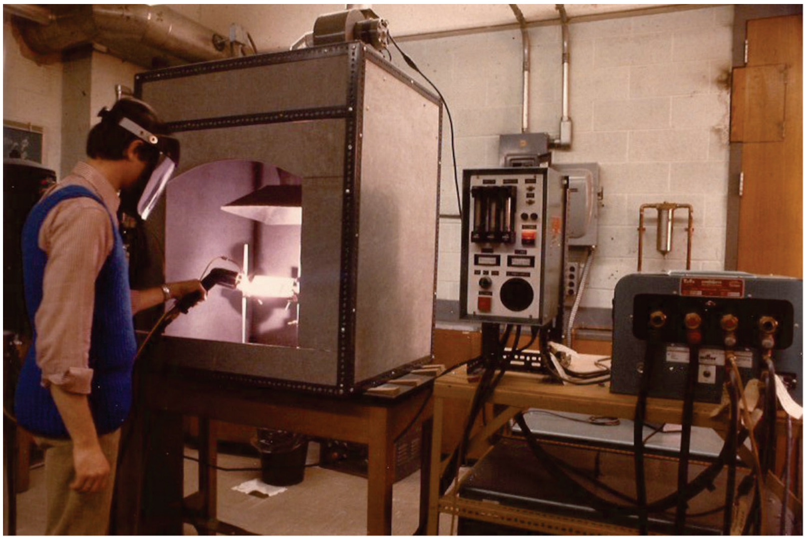


Fig. 1 — A "glove box" plasma spray set-up at Stony Brook used by the late Dr. Volker Wilms in the 1970s.

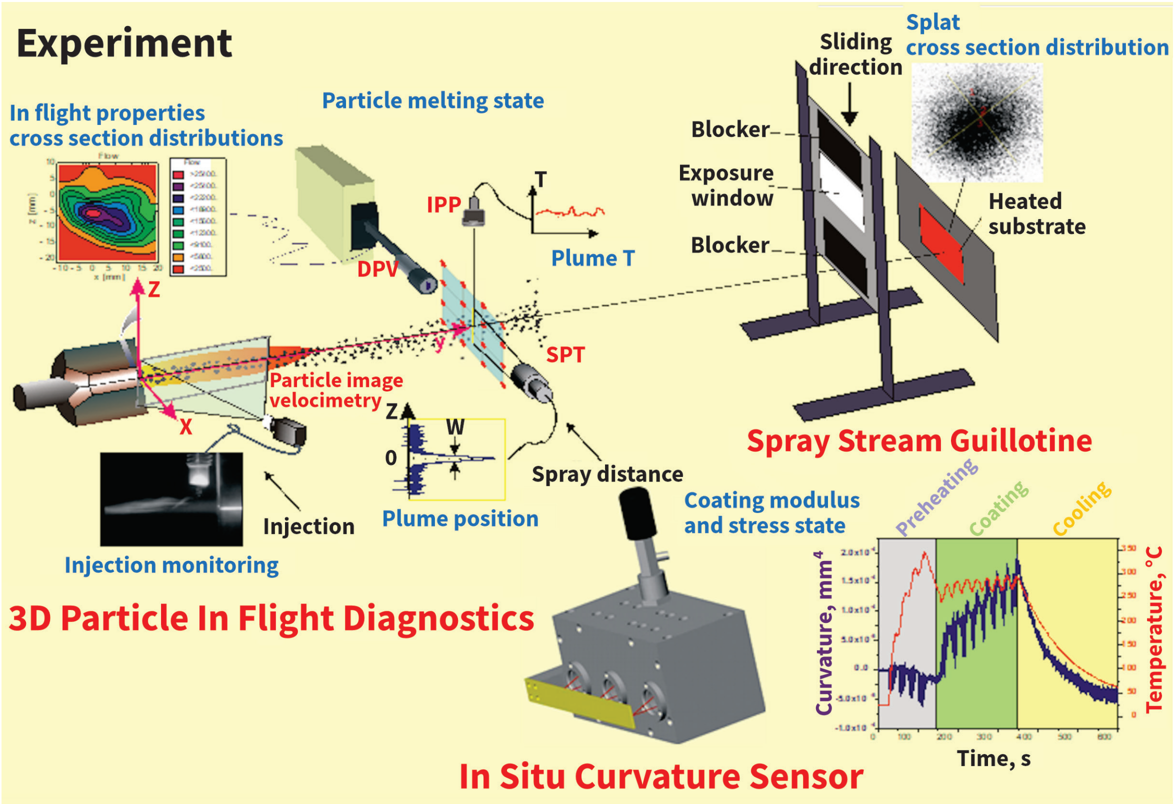
THE EARLY YEARS

The roots of the thermal spray program at Stony Brook date back to the mid-1970s, when then graduate student, the late Volker Wilms, suggested to his advisor Prof. Herman that plasma spray technology would be a great way to rapidly quench oxides to explore metastability. This led to establishment of the "glove box" plasma spray equipment in the basement of the engineering building shown in Fig. 1. Numerous students followed exploring the fascinating world of rapidly quenched "splats and coatings," developing unique scientific insights that even today are considered landmark publications. In the mid-1980s, with a major donation from the Swiss-entrepreneur, Herbert Nussbaum of Plasma Technik AG (now part of Oerlikon Metco), a state-of-the-art atmospheric and vacuum plasma spray facility was established. This brought attention to academic thermal spray programs in the U.S. Throughout the 1980s and early 1990s, research and industrial projects expanded, exposing the technology to the broader materials engineering community. In fact, it was during the mid-1980s that Prof. Herman along with industrial visionaries, developed the framework for ASM Thermal Spray Division (Thermal Spray Society today) with Prof. Herman serving as the founding president.

In the mid-1990s, as coatings started to become mainstream in automotive, aerospace, energy, heavy machinery, and orthopedic implants, there was a clear recognition that this platform technology needed an integrated scientific approach to propel the knowledge and capability. The academic team in partnership with industry and other collaborators, focused their attention on establishing a National Center of excellence through the NSF MRSEC.

An initial four-year, $4M grant allowed the core team to bring in fresh perspectives for tackling this complex problem of an existing industrial materials technology. The interdisciplinary thrusts included contributions from scientists at the National Institute of Standards and Technology to apply small-angle x-ray and neutron scattering to study porosity and interfaces in these layered materials. A parallel effort also used neutrons to conduct depth profile of residual stresses. Working with colleagues at the Massachusetts Institute of Technology, mechanics of these layered, defected materials has enabled new insights on the mechanical behavior of non-traditional materials systems. A unique partnership with the Stony Brook Geoscience Department allowed examining the role of the high pressures generated

**Member of ASM International*



(a)

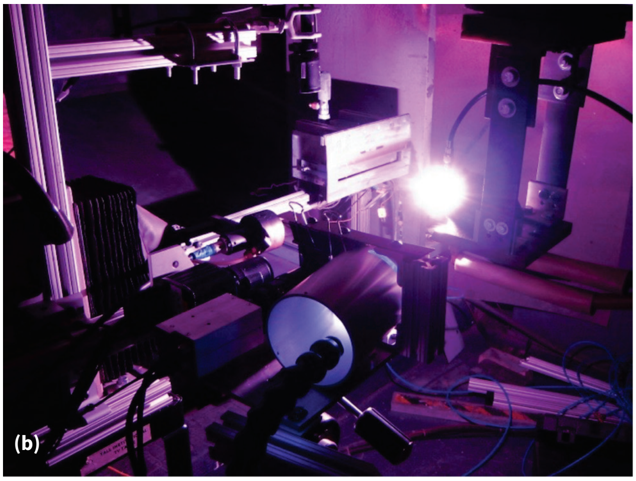

(b)

Fig. 2 — An integrated multi-sensor process diagnostics and in situ coating monitoring approach developed at CTSR in the early 2000s allowed rapid assessment of process parameters and its effects on coating formation dynamics. This set up (illustration (a) and actual image (b)) is now routinely used by both undergraduate and graduate students for both training and research. Numerous publications have resulted offering significant insights into science of thermal sprays[1].

during impact formation of metastable materials. Along the way, the program enabled introducing robustness into the process through study of particle dynamics both during the melting and deposition phases.

PHASE TWO: EXPANSION

Following a successful first phase, the program was renewed for a second five-year iteration with a promised expansion into new strategies. This included studies of liquid feedstock to synthesize novel chemistries and applications of thermal spray in electronic, magnetic, and sensor functions (Fig. 2). The Center benefited through a significant, complementary program funded by the Defense Advanced Research Projects Agency (DARPA) to examine the ability of thermal spray for direct writing of functional thick films and sensor devices (Fig. 3). In this effort, Prof. Sampath led a large group of scientists and engineers to extend the boundaries of thermal spray technologies to create functional surfaces and multilayers. Together, these programs dramatically expanded research and knowledge-transfer activities of the Center for the much of the early to mid-2000s. Along the way, through support from state and industrial partners, a new state-of-the-art industrial scale laboratory was established, which continues to serve as a unique facility in the U.S. The Center is home to five plasma spray cells, two HVOF cell with multiple torches, a recently updated VPS system and newly introduced cold spray facility. Wide ranging characterization facilities were also set up.

INDUSTRIAL CONSORTIUM

As the program approached the end of its lifecycle, the Center pivoted to seek industrial support to continue the developments in research and human resources. An industrial

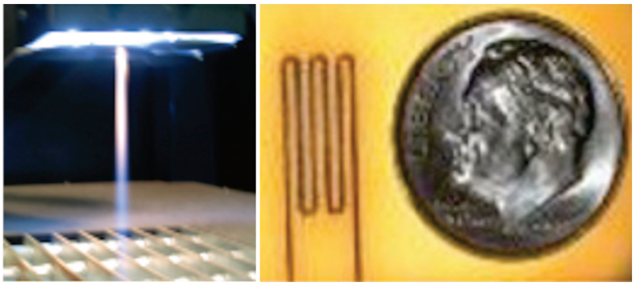


Fig. 3 — Under the auspices of DARPA, CTSR developed and commercialized direct write thermal spray technology that allows fine feature deposition of thick film electronics and sensors[2,3].

Consortium for Thermal Spray Technology was established in 2002 with 10 leading companies. It allowed for the initiation of knowledge transfer from fundamental research to industrial practice. The Consortium continues to thrive today with 30 contributing members with a host of new initiatives in science, technology, and development of trained graduates in this unique field of materials enquiry (Fig. 4).

The Center's output is significant by all measures. Some 50 Ph.D. students, 40 M.S. students, and 30 post-docs were trained across different disciplines (Fig. 5). Hundreds of undergraduates participated and continue to participate in the Center activities learning to handle complex materials processing equipment and characterization methods. More than 500 K-12 students participated through the field-trip program. On the intellectual front, the Center output was significant with over 400 referenced publications, 12 book chapters, and seven patents, including three licenses. Acknowledgment has come in the form of several best paper awards, student prizes, and faculty recognitions. New scientific methodologies and technologies were transitioned for industrial use through collaborative projects, field trip demonstrations, student internships, and spin-offs. Also notable are many of the Center participants and graduates who continue to contribute to the field, bringing scientific perspectives into everyday engineering.

Over the last decade, the Center has continued to push both fundamental boundaries as well as expand engineering opportunities. Prominent areas of

Fig. 4 — Current membership of the industrial Consortium for Thermal Spray Technology enabling knowledge transfer from fundamental research to industrial practice.

Fig. 5 — A Center for Thermal Spray Research alumni reunion.

continued scientific enquiry include mechanics and physics of layered structures, hybrid architectures, combining ceramics with metals and polymers for damage tolerance, functional oxides with unique functionalities allowing processing with concomitant application examples, and methodologies and metrologies to characterize unique multiscale structures resulting from the process.

A celebratory workshop is planned in 2022 to mark this important milestone and coincide with the 20th anniversary of the Consortium partnership. **~iTSSe**

For more information: Prof. Sanjay Sampath, director, Center for Thermal Spray Research, Stony Brook University, N.Y., 11794, 631.632.8480, sanjay.sampath@stonybrook.edu, www.stonybrook.edu/ctsr.

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COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—MICROHARDNESS AND NANOINDENTATION

This article series explores the indispensable role of characterization in the development of cold spray coatings and illustrates some of the common processes used during coating development.

Dheepa Srinivasan

A quick screening of the mechanical properties of a cold spray coating can be achieved by examining the microhardness—another ubiquitous tool for coating characterization to assist in optimizing the coating for a given set of parameters. Because cold spray coating thickness ranges from 0.25 to 12 mm (0.01 to 0.5 in.), Knoop and Vickers hardnesses are typically used to characterize the coating hardness, the latter being more suitable for thicker (>25 µm) coatings. Vickers microhardness is measured using loads ranging from 50 g to 1 kg (2 to 35 oz), depending on the expected coating hardness.

An average of 10 measurements is recommended to span the thickness of the coating, as shown in Fig. 1a. It is also recommended that substrate hardness should be measured at a location away from the vicinity of the interface. The dwell time of the indent is typically 10 to 15 s. In the case of a softer coating, and especially a softer substrate such as pure aluminum, a lower load is used, i.e., <50 g. For harder substrates, a higher load is typically used, i.e., >100 to 500 g (3.5 to 18 oz). Vickers microhardness is calculated by using the standard formula:

$$HV = 1.854\, F/d^2$$

where d is the mean of the two diagonals of the impression on the sample, and F is the applied force in kilogram force.

It is standard practice to correlate the coating process parameters, extent of porosity, and other properties by using the coating microhardness. Due to the severe deformation that takes place in the cold spray process, a complex strain hardening is expected. Therefore, nearly all cold spray coatings tend to have 20-40% higher hardness in the as-sprayed condition than their wrought counterparts. A study on load sensitivity reveals that these coatings exhibit a behavior that is invariant under the applied load, as shown in Fig. 1b for NiCr coatings on AISI 4130 steel. Hardness does not usually vary much with coating thickness, as shown in Fig. 2a for an IN625 coating on an AISI 4130 steel substrate. Dotted lines indicate substrate hardness.

With heat treatment, the hardness of many cold spray coatings increases, sometimes reaching as much as 30-40% higher than in their as-sprayed condition. This is contrary to what happens in most work-hardened materials, in which recovery processes tend to decrease the final hardness. An example is shown in Fig. 2b, taken from the IN625/NiCr cold spray coating, which shows a steady increase in hardness up to a certain temperature, above which it drops to a lower value. Coating hardness with time is shown in Fig. 2c for the same IN625 coating.

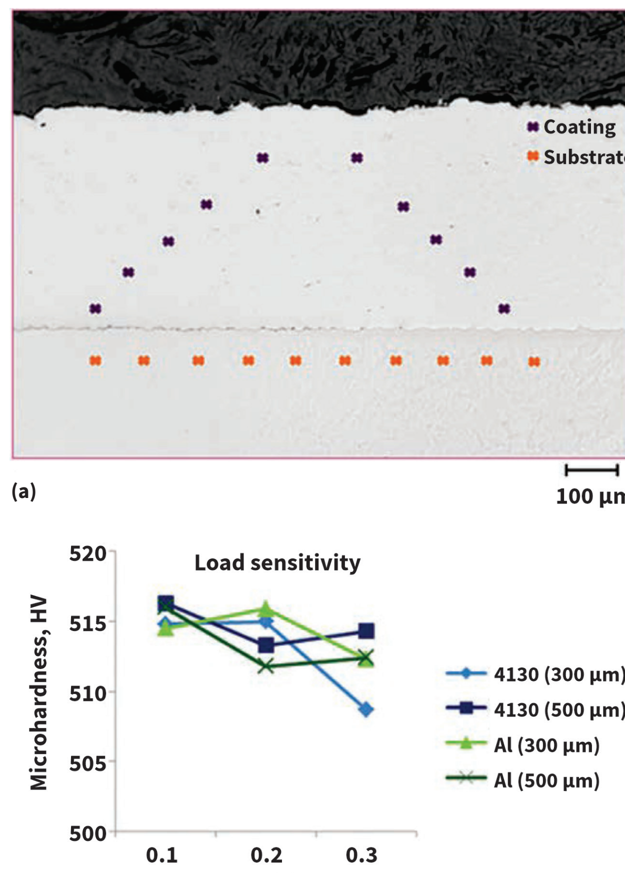

Fig. 1 — (a) Schematic showing a possible method for hardness measurement in the cold spray coating and substrate; and (b) load sensitivity analysis of coating microhardness.

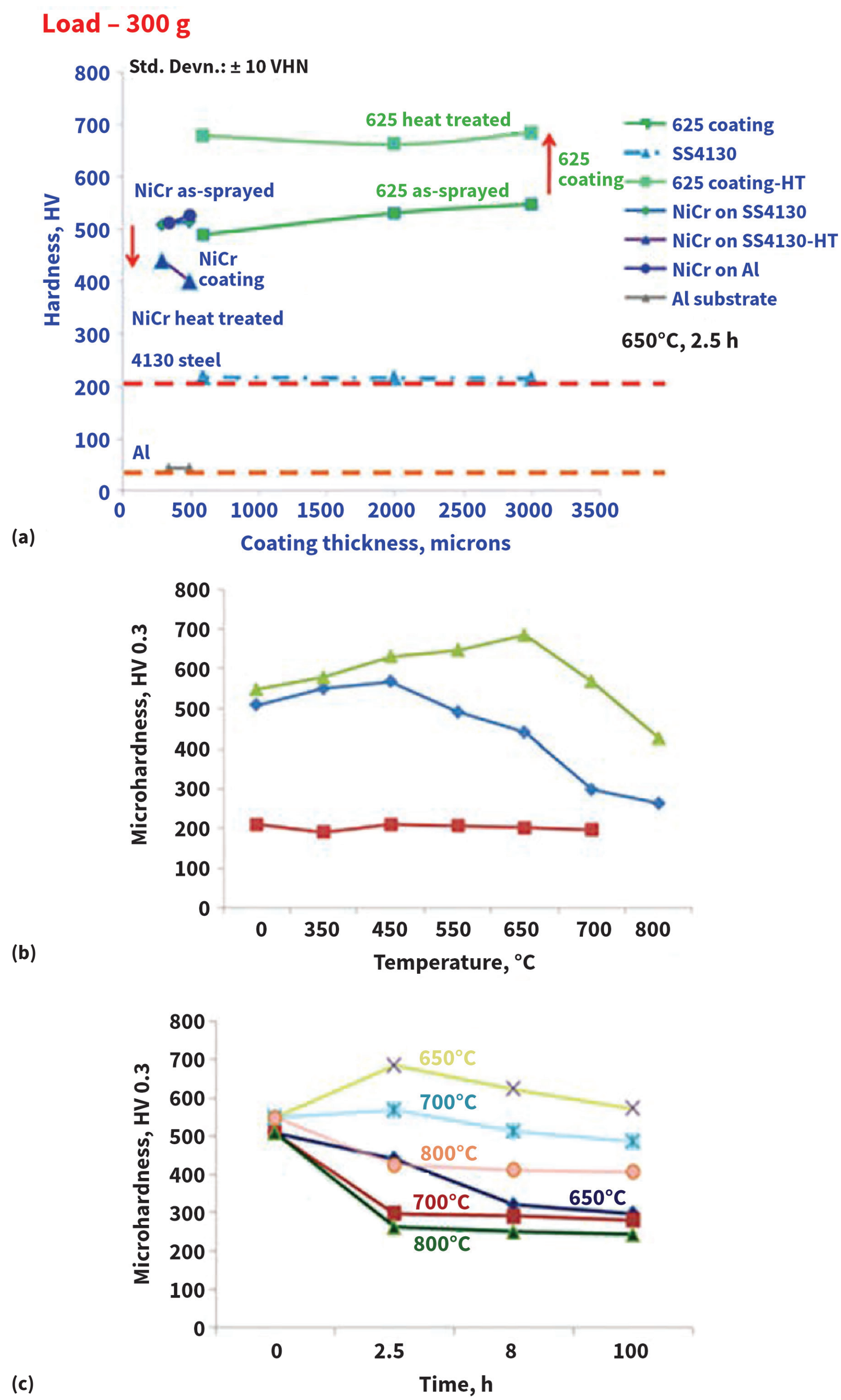

Fig. 2 — Microhardness as a function of (a) coating thickness, (b) temperature, and (c) time for an IN625 coating on an AISI steel substrate.

NANOINDENTATION

Nanoindentation is mainly used to determine the hardness and elastic modulus of the coating. Conventional indentation techniques, including standard microhardness tests, involve measurement of the size of a residual plastic impression in the specimen as a function of the indenter load. From the area of contact, the hardness of the material is inferred. In a nanoindentation test, the size of the residual impression is often only a few micrometers, so direct imaging becomes difficult. Here, the depth of penetration beneath the specimen surface is measured as the load is applied to the indenter. From the known geometry of the indenter, the size of the area of contact is determined.

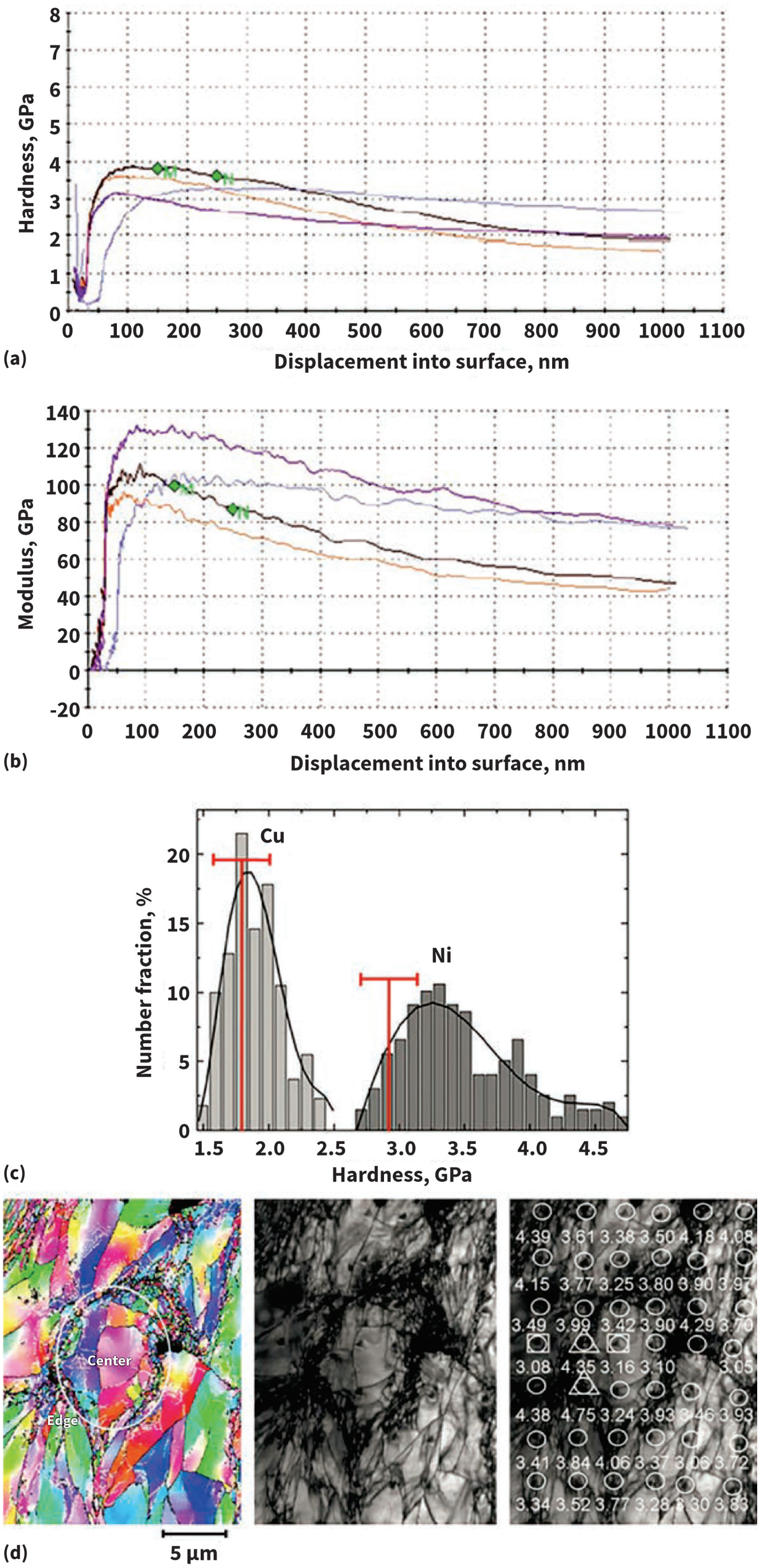

Fig. 3 — Nanoindentation of cryomilled Cu-10Zn cold spray coating showing (a) hardness and (b) modulus of elasticity; (c) nanohardness of as-sprayed copper and nickel coatings, with hardness (superimposed red line) of the feedstock powders; and (d) EBSD characterization of the cross section of a nickel coating after nanoindentation.

A nanoindentation test is usually performed as a depth-sensing indentation test using a diamond Berkovich indenter with a nominal edge radius of 100 nm. Hardness and elastic modulus are measured at loads ranging between 1 and 500 mN, at a loading/unloading rate of 200 µN/s. Data are analyzed using the Oliver-Pharr method. Figure 3a shows an example of the hardness-versus-displacement curve. Figure 3b shows a modulus displacement curve after a series of nanoindentation tests were made on a Cu-10wt%Zn cold spray coating.

Nanoindentation testing is a valuable tool to characterize the extent of plastic deformation and recovery in cold spray coatings. Figure 3c is a plot of the nanohardness of a copper-nickel composite coating that makes it possible to distinguish the relative fractions. Figure 3d is an image quality map taken using electron backscatter diffraction (EBSD), combined with corresponding nanohardness, to help deduce that static recrystallization takes place in cold sprayed copper. The sample surface must be absolutely flat and polished prior to carrying out nanoindentation tests. **~iTSSe**

For more information: This article series is adapted from *Chapter 5, Cold Spray—Advanced Characterization* authored by Dheepa Srinivasan in "High Pressure Cold Spray—Principles and Applications," edited by Charles M. Kay and J. Karthikeyan (ASM, 2016). Complete references are included in this volume. The author may be reached at dheepasrinivasan6@gmail.com.

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

NEW PROCESS IMPLEMENTATION TO ENHANCE COLD SPRAY-BASED ADDITIVE MANUFACTURING

Hongjian Wu, Shaowu Liu, Yicha Zhang, Hanlin Liao, Rija-Nirina Raoelison, and Sihao Deng

Cold spraying (CS) is a solid-state coating technique that has been applied as a novel additive manufacturing (AM) method to fabricate freestanding metal components. Recent advances in cold spray additive manufacturing (CSAM) technology call for new process implementation to improve manufacturing accuracy and flexibility. In this study, a concept of modular systems is presented to design and implement a new CSAM framework. The current CSAM system is an open framework system composed of different modules. The flow of the proposed CSAM system is explained to understand the physical and functional relationships between the key elements of the entire system. This physical and functional modularity is useful to promote hybrid AM processes. In addition, based on the smart manufacturing concept of Industry 4.0, a novel approach is proposed to bring the perception and the decision-making abilities into the traditional CS system. (Fig. 1)

Fig. 1 — Schematic representation of CS+milling process.

FACTORS AFFECTING ADHESION IN METAL/CERAMIC INTERFACES CREATED BY COLD SPRAY

Sara I. Imbriglio and Richard R. Chromik

Increasingly, due to their interesting applications, research on metal/ceramic interfaces created by cold spray is being undertaken. For metal/ceramic interfaces, where the ceramic is not expected to plastically deform, adhesion is poorly understood. This review article provides an overview of the current state of knowledge regarding the deposition of metal on ceramic. This review includes a summary of the materials tested, the testing methodology and findings as well as an overview on the effect of deposition parameters on adhesion, the role of jetting in the interface and outlook regarding potential local changes occurring at the interface promoting adhesion. (Fig. 2)

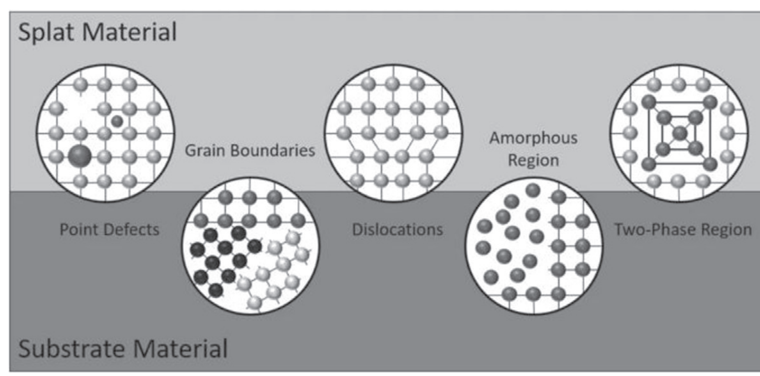

Fig. 2 — Schematic of defects formed at the interface in the splat and/or substrate materials under mechanical work leading to mechanical activation.

NUMERICAL MODELING OF BOND FORMATION IN POLYMER SURFACE METALLIZATION USING COLD SPRAY

Asghar Heydari Astaraee, Chiara Colombo, and Sara Bagherifard

Surface metallization of polymeric materials using cold spray technology has gained increasing attention in the past decade. Experimental studies have evidenced multiple challenges of this process regarding continuity and homogeneity of the metallic deposits on polymer substrates. Modeling and simulation tools could be very helpful to assess the efficiency of different strategies suggested for improved deposition at a considerably reduced cost; nevertheless, the efforts to use numerical modeling in this sector have been less successful. Here, we develop a detailed finite element model for the cold spray deposition of metal particles on polymeric substrates to shed light on the underlying deposition mechanisms. The simulation results are compared with the literature experiments to establish the effectiveness of the proposed model. (Fig. 3)

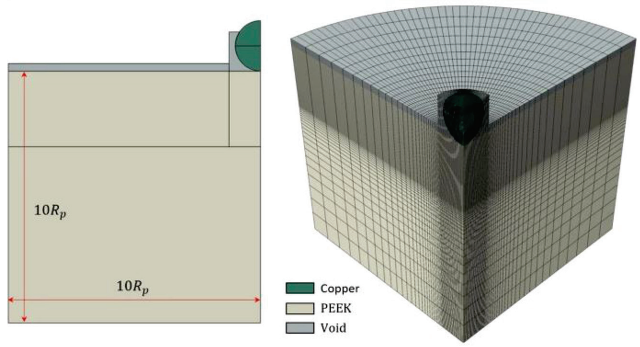

Fig. 3 — Model geometry and mesh details (R_p: particle radius).

COLUMNAR THERMAL BARRIER COATINGS PRODUCED BY DIFFERENT THERMAL SPRAY PROCESSES

Nitish Kumar, Mohit Gupta, Daniel E. Mack, Georg Mauer, and Robert Vaßen

Suspension plasma spraying (SPS) and plasma spray-physical vapor deposition (PS-PVD) are the only thermal spray technologies shown to be capable of producing TBCs with columnar microstructures similar to the electron beam-physical vapor deposition (EB-PVD) process but at higher deposition rates and relatively lower costs. The objective of this study was to achieve a fundamental understanding of the effect of different columnar microstructures produced by these two thermal spray processes on their insulation and lifetime performance and propose an optimized columnar microstructure. Characterization of TBCs in terms of microstructure, thermal conductivity, thermal cyclic fatigue lifetime and burner rig lifetime was performed. (Fig. 4)

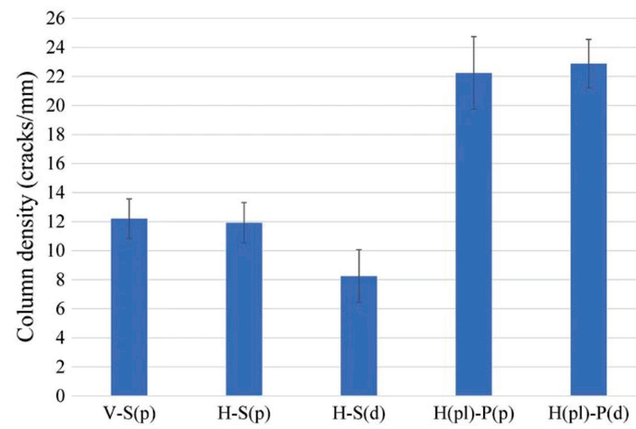

Fig. 4 — Column density of the SPS- and PS-PVD-sprayed topcoats (TCs).

CHARACTERIZATION OF AN AXIAL-INJECTION PLASMA SPRAY TORCH

Stephan Zimmermann, Georg Mauer, Karl-Heinz Rauwald, and Jochen Schein

The Axial III torch is a multiple-arc plasma generator with a set of three single cathode–anode units, which is still of significant importance, especially in the field of suspension plasma spraying. The division of the plasma generator into three spatially separated systems allows for central feedstock injection with improved deposition rates and efficiencies. In this work, several diagnostic methods were applied to characterize the plasma jet of an Axial III spray torch to further the understanding of this spray system. (Fig. 5)

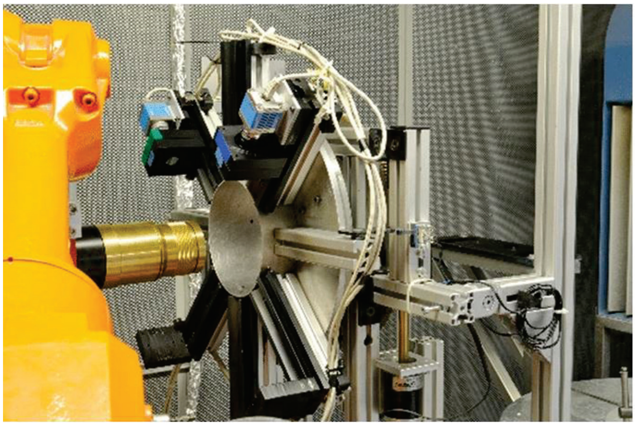

Fig. 5 — Tomography setup to determine the shape of the plasma jet and the temperature distribution.

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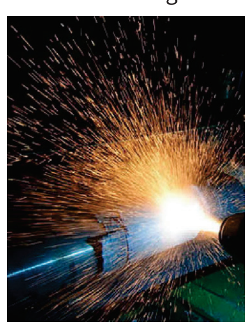

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Shape Memory & Superelastic Technologies
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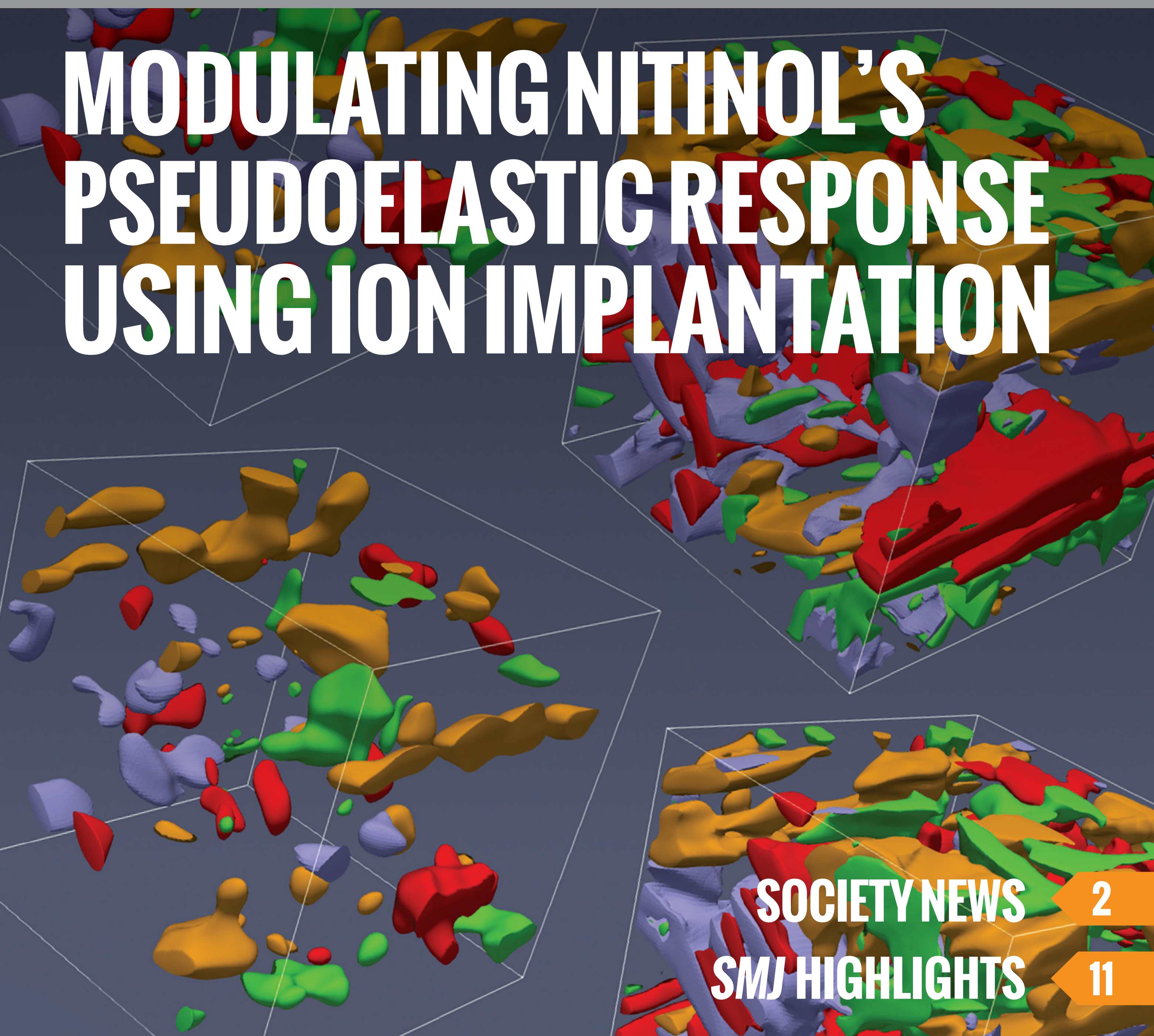
APRIL 2022 | VOL. 4 | ISSUE 1

SMST NEWSWIRE

THE OFFICIAL NEWSLETTER OF THE INTERNATIONAL ORGANIZATION ON SHAPE MEMORY AND SUPERELASTIC TECHNOLOGIES

MODULATING NITINOL'S PSEUDOELASTIC RESPONSE USING ION IMPLANTATION



SMST Shape Memory & Superelastic Technologies ASM INTERNATIONAL

APRIL 2022 | VOL. 4 | ISSUE 1

SMST NEWSWIRE

AN OFFICIAL PUBLICATION OF THE INTERNATIONAL ORGANIZATION ON SHAPE MEMORY AND SUPERELASTIC TECHNOLOGIES

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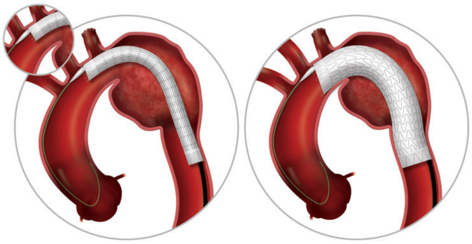

DEPARTMENTS

ABOUT THE COVER

Close ups of a few phase field simulations of the B2-B19' transformation in a single B2 crystal without an amorphous structure.

EDITORIAL OPPORTUNITIES FOR *SMST NEWSWIRE* IN 2022

The editorial focus for the *SMST NewsWire* in 2022 reflects shape memory and superelasticity technologies for biomedical, actuator applications, and emerging markets.

April | October

To contribute an article, contact Joanne Miller at joanne.miller@asminternational.org.

To advertise, contact Kelly Johanns at kelly.johanns@asminternational.org.

SMST'22: COMMEMORATING 60 YEARS OF NITINOL

Benafan

I want to share my excitement in welcoming you to the beautiful coastal getaway of Carlsbad, California, home of SMST 2022. It surely has been a few abnormal years of pandemic life, where we cancelled events and postponed meetings. Personally, I am "Webexed-," "Teamed-," and "Zoomed-out." But we are now ready to cautiously welcome you back to the SMST premier conference and exhibition. This year's SMST event commemorates the 60th year of Nitinol, and with it we usher in invigorating programming. We bring panel discussions that feature medical and aerospace key stakeholders who will discuss current trends and challenges facing our industry. We will introduce the new SMST William J. Buehler Award to recognize excellence in shape memory or superelastic technical innovation. To help us announce the first awardee, we invited a very special group of people who may know a thing or two about the birth of Nitinol. It will be a very special event! Above all, the technical program looks splendid, thanks to you, the presenters. We will learn about traditional exciting topics while infusing new shape memory categories like ceramics and elastocalorics.

Our mission does not stop at advancing science and technology, as we also are determined to cultivate SMST's future leaders. For our students and emerging professionals, we offer exciting programming, competitions, and social events. Don't miss the highly recommended educational workshop on Nitinol led by none other than Dr. Alan Pelton, FASM, along with some very passionate instructors. We will get to hear from our recent Founders' Grant awardee, and will also host the CASMART 5th Student Design Challenge. Our networking receptions and social events provide ideal venues for striking up conversations. Also, we made sure to include some free time during the conference to explore the area, visit LEGOLAND, go for a swim, or play golf at The Crossings at Carlsbad course.

Need to hear more about some recent developments? In this issue of the *SMST NewsWire,* we bring you selected articles to expose new works. Speaking of exposure, have you known that exposing Nitinol to irradiation can improve its properties? Our featured article discusses a method of using ion implantation to modulate the pseudoelastic response of Nitinol. This can be the answer to your Nitinol near-surface alterations. See for yourself. At a device level, our Technical Spotlight touches on a new thoracic endovascular aortic repair (TEVAR) delivery system. Make sure to check out its unique features.

Finally, don't forget to review the SMST'22 technical program found online at smstevent.org, and get those questions ready. To both the veteran SMST attendees and the newcomers, thank you for your contributions and I look forward to meeting you in "3D" soon!

Othmane Benafan, Ph.D.
SMST'22 Chair
President, International Organization on
Shape Memory and Superelastic Technologies

DONATE NOW TO CASMART'S STUDENT DESIGN CHALLENGE

The Shape Memory and Superelastic Technologies Society (SMST) is teaming with CASMART, the Consortium for the Advancement of Shape Memory Alloy Research and Technology, at SMST 2022 Conference & Exposition in San Diego, for their 5th Student Design Challenge.

The Student Design Challenge is intended for undergraduate and/or graduate students to consider innovative approaches to developing new materials and hardware using shape memory alloy (SMA) technology. Students will have the opportunity to showcase and present their creativity during the CASMART Student Design Challenge.

SMST believes in inspiring young minds to pursue science, math and technology education and careers. These subjects are critical in our economy, so let's work together to raise money to excite students and drive them to fulfilling and productive career paths! For more information visit, https://bit.ly/35WvvXN. Teams (finalists) include:

1. Team "**SMArt Clamp**" (Saarland University, Germany): Joshua Mayer, Tom Weisgerber, Yannik Goergen (Advisors: Dominik Scholtes, Dr.-Ing. Paul Motzki)
2. Team "**NiTiMore Temperature**" (Georgia Institute of Technology): Alexa Brammer, Patrick Bravo, Katherine Cauffiel, Ryan Peacock (Advisors: Nathaniel Lies, Dr. Aaron Stebner)
3. Team "**SMArtians**" (IIT Madras, India): Aayush Raghuraman, Aayush Rath, Aditya Ravindran, Rishab Sharma, Kartik Deepak Ruikar (Advisor: Sivakumar M. Srinivasan)
4. Team "**Nitinauts**" (Georgia Institute of Technology): Phoebe Ellison, Heeyong Huang, Austin Love, Ethan Ray (Advisors: Tyler Knapp, Dr. Aaron Stebner)

MODULATING THE PSEUDOELASTIC RESPONSE OF NiTi USING ION IMPLANTATION

Ni-ion irradiated NiTi is observed to be nearly 50% harder, retains 85% recoverable deformation, and has reduced hysteresis.

Alejandro Hinojos, Daniel Hong,* Longsheng Feng, X. Gao, Yunzhi Wang, FASM,* Michael J. Mills, FASM,* and Peter M. Anderson, FASM,* The Ohio State University, Columbus, Ohio*

Chao Yang and Janelle P. Wharry, Purdue University, West Lafayette, Indiana

Khalid Hattar, Sandia National Laboratories, Albuquerque, New Mexico*

Nan Li, Los Alamos National Laboratory, New Mexico

Jeremy E. Schaffer, Fort Wayne Metals Research Products LLC, Fort Wayne, Indiana*

This work explores whether ion beam modification can be used to modulate the austenite to martensite phase transformation in Nickel-Titanium (NiTi), thereby achieving novel or localized transformation properties in near-surface regions. This could provide alternatives to laser shot peening or other surface treatment methods and possibly expand applications in biomedical, aerospace, and other fields[1-5]. Irradiation induces defects and internal stress that can serve as nucleation and/or pinning sites for the phase transformation. Thus, it can augment more conventional approaches, including alloying[6-11], severe mechanical work[12-14], grain size reduction[15], and precipitation of coherent precipitates[15,16]. A range of outcomes is possible in principle, including a shift of the critical stress or temperature for onset of the transformation, linearization, reduction of hysteresis, stabilization, and extent of transformation strain.

Because prior studies show irradiation amorphization of NiTi-based intermetallics[17-24], this work employs lower doses of irradiation (< 0.1 DPA, displacements per atom) to retain a large volume fraction of ordered phase, and then uses nanoindentation and structural analysis to probe submicron and nanoscale features that are not accessible with conventional or micron-scale pillar testing[25-29]. Nanoindentation has the capacity to clearly identify the austenite-martensite phase transformation[30] as well as tension-compression asymmetry and anisotropy[31-33].

APPROACH

A combined experimental-computational approach was used to study the hypothesis that irradiation defects can modulate the phase transformation. First, cross-sectioned samples of drawn $Ti\text{-}Ni_{50.5\%at}$ 3.2 mm diameter wire (Ft. Wayne Metals) with a <111> axial texture were metallographically prepared and irradiated into the top axial surface with 30 MeV Ni^{6+} ions to achieve a fluence of 5 x 10^{13} cm^{-2} using the Tandem Accelerator Facility at the Center for Integrated Nanotechnology at Sandia National Labs[34]. SRIM software[35] was used to specify this fluence to achieve < 0.1 DPA, the critical threshold for amorphization[19].

Next, Berkovich indentation to 250 nm depth on polished side facets was performed with a Hysitron TI950 TriboIndenter at the Center for Integrated Nanotechnologies at Los Alamos National Laboratory[36], to sample submicron volumes $V_{ind} \approx 0.125\ \mu m^3$ at positions z = 0 to 8 µm below the implanted surface. For reference, ~70 indents in unirradiated drawn $Ti\text{-}Ni_{50.5\%at}$ wire were performed perpendicular to the <111> axial texture. Both scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used for structural characterization. Two simulation methods were used to explore the influence of possible irradiation defects on the martensitic phase transformation. At the submicron scale, phase field (PF) modeling following Zhu et al.[36] and at the atomistic scale molecular dynamics (MD) simulations were used to study stress-induced transformation in 170 nm and 21 nm cubes, respectively, with and without irradiation type defects. The PF simulations applied a compressive stress of 700 MPa along the <100> B2 direction and solved the time-dependent Ginzburg-Landau equation[37] on a 128 × 128 × 128 grid. The MD simulations applied a tensile strain of 0.1 at a rate of 0.001 ps^{-1} and used LAMMPS[38] and Ko and coworkers'[39] modified embedded atom method (MEAM) potential, which accurately captures the B2-B19′ transformation, and OVITO[40] for phase identification and common neighbor analysis.

RESULTS

The indentation results (Fig. 1) show that at z ≈ 3.6 µm below the implantation surface, the irradiated material exhibits an indentation load P_{250nm} = 8.5 mN, ~46% larger than for unirradiated material, yet the recoverable displacement δ_{rec} upon unloading is comparable to unirradiated material. The cycle 2 indentation curves—where the material is reindented at the same site—show that the irradi-

*Member of ASM International

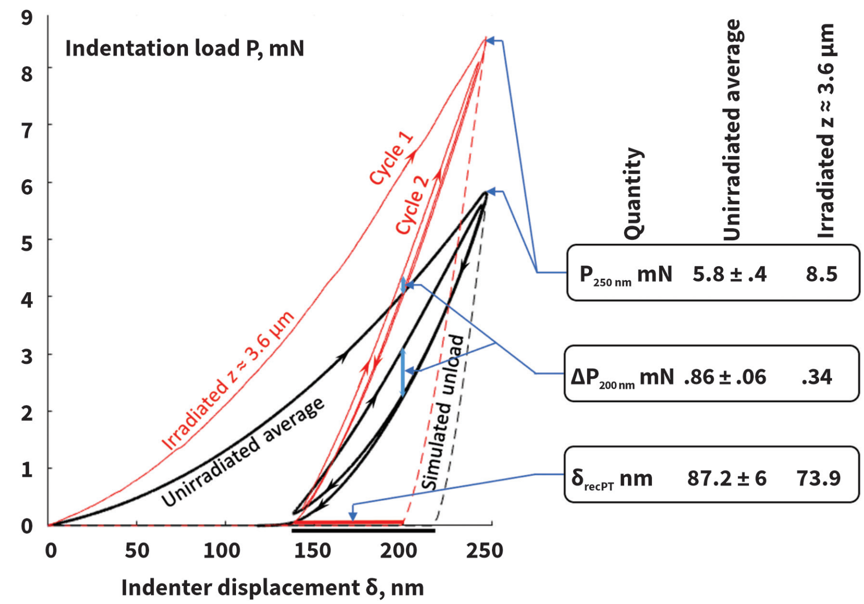

Fig. 1 — Nanoindentation response in unirradiated (averaged over ~70 indentations) and irradiated (single indent location at z ≈ 3.6 μm below the implanted surface) drawn Ti-$Ni_{50.5at\%}$ wire.

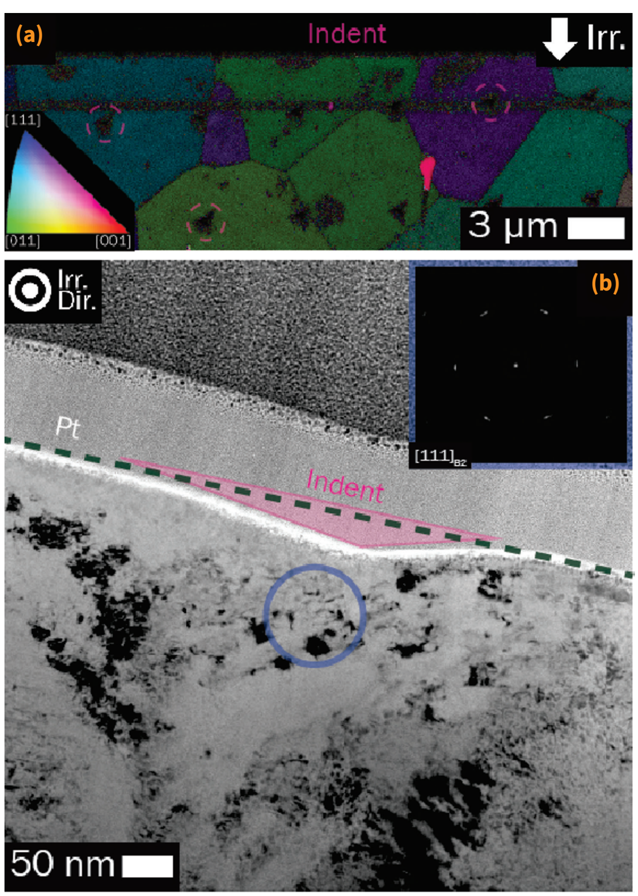

Fig. 2 — (a) EBSD IPF map normal to wire axis; (b) TEM bright field image, cross section of an indent located above the damage band in (a).

ated material has smaller hysteresis and is more stable, with negligible plasticity, compared to the unirradiated material. Simulated unloading curves for an elastic-plastic material with an elastic modulus of austenite (90 GPa)[41] and a plastic flow strength that is adjusted to match the cycle 1 loading response are computed using a finite element model. The difference, δ_{recPT}, between the simulated and experimental curves denotes the recoverable displacement attributable to the phase transformation. The irradiated material has ≈85% of the recoverable displacement of unirradiated material.

The SEM electron backscatter diffraction (EBSD) inverse pole figure (IPF) map (Fig. 2a) reveals equiaxed grains and a dark band at ~3 μm below the implantation surface, as well as indentation sites in the vicinity of the band. The inability to properly index the band and indentation sites signify damage that could be caused by amorphous regions and other defects cited in prior work. The regions outside the band are still indexed as crystalline B2 phase but are likely to contain some amorphous damage. Additional evidence from enhanced contrast in backscattered electron (BSE)[42] imaging (not shown) supports the presence of a damage distribution consistent with implantation in other alloys[43-45]. The TEM bright field image (Fig. 2b) shows a cross-section near one of the indents. The faint traces of defects immediately beneath the indent are likely dislocations generated by indentation. The diffraction pattern inset of the $<111>_{B2}$ reveals azimuthal elongation of the $<110>_{B2}$ spots showing signs of crystal rotation[22] from plasticity or retained internal stresses[46]. Characterization using scanning TEM (STEM) bright field imaging (not shown) suggests that pre-existing defects near the damage band can be destroyed, setting the stage for investigation of dislocations in amorphous regions and whether amorphization in the B2 phase is continuous[19,22].

The phase field simulations (Figs. 3a-e) predict that a B2+amorphous composite with a morphology approximated by STEM observations (white = amorphous, black = B2) does not transform to martensite (variants v1-v4 as indicated by colors) as readily as the B2-only case (Figs. 3f-j). The B2 phase in the composite is interconnected but the channels cannot be filled fully by self-accommodating martensitic variants. The stark contrast between Figs. 3e and j clearly indicate that the autocatalysis of the martensitic transformation has been suppressed by the elastic but non-transforming amorphous phase. This is consistent with the significantly larger nanoindentation load for irradiated NiTi (Fig. 1).

The MD simulations (Fig. 4) predict that point defects and defect clusters also hinder the B2-B19′ martensitic phase transformation. At a total strain of 0.08 (loading), the pristine B2 structure (Fig. 4a) forms an internally twinned B19′ martensite structure while the simulations with interstitials (Fig. 4b) and vacancies (Fig. 4c) form the twinned B19′

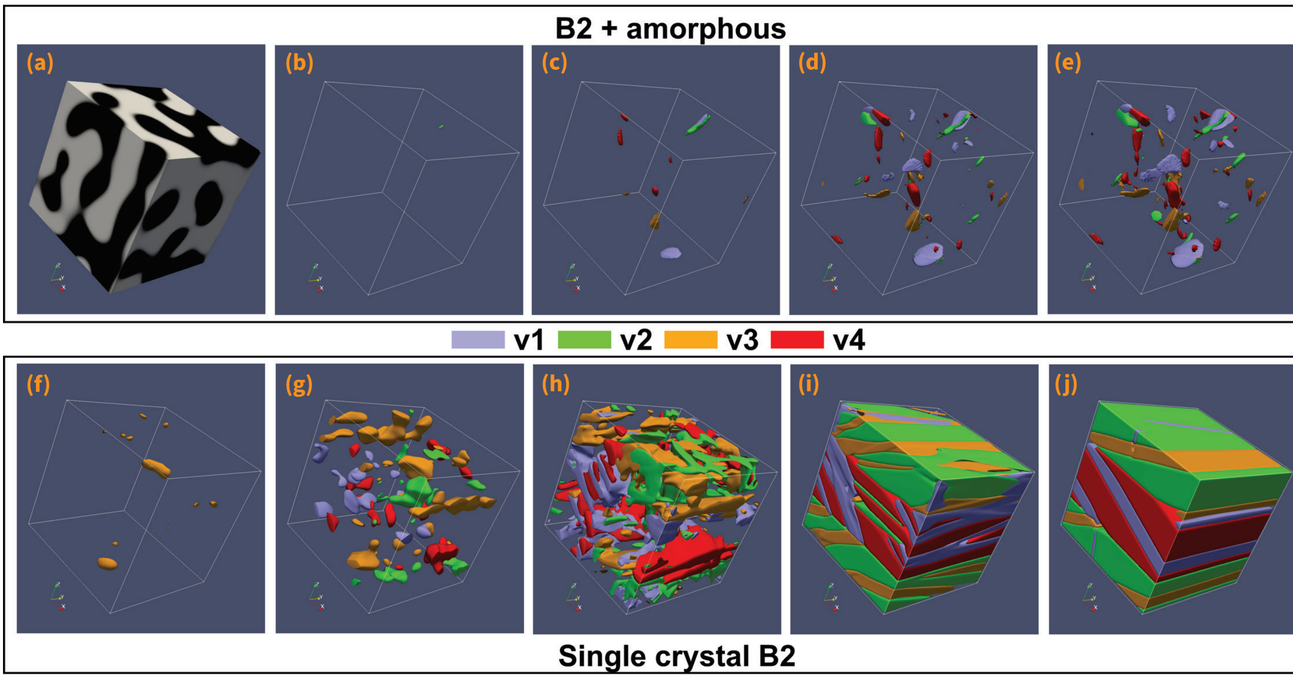

Fig. 3 — Phase field simulations of the B2-B19′ transformation in (a-e) a B2(black)+amorphous(white) composite and (f-j) a single B2 crystal without an amorphous structure. The four martensite variants v1, v2, v3, and v4 (see color key) can form self-accommodating herringbone microstructures.

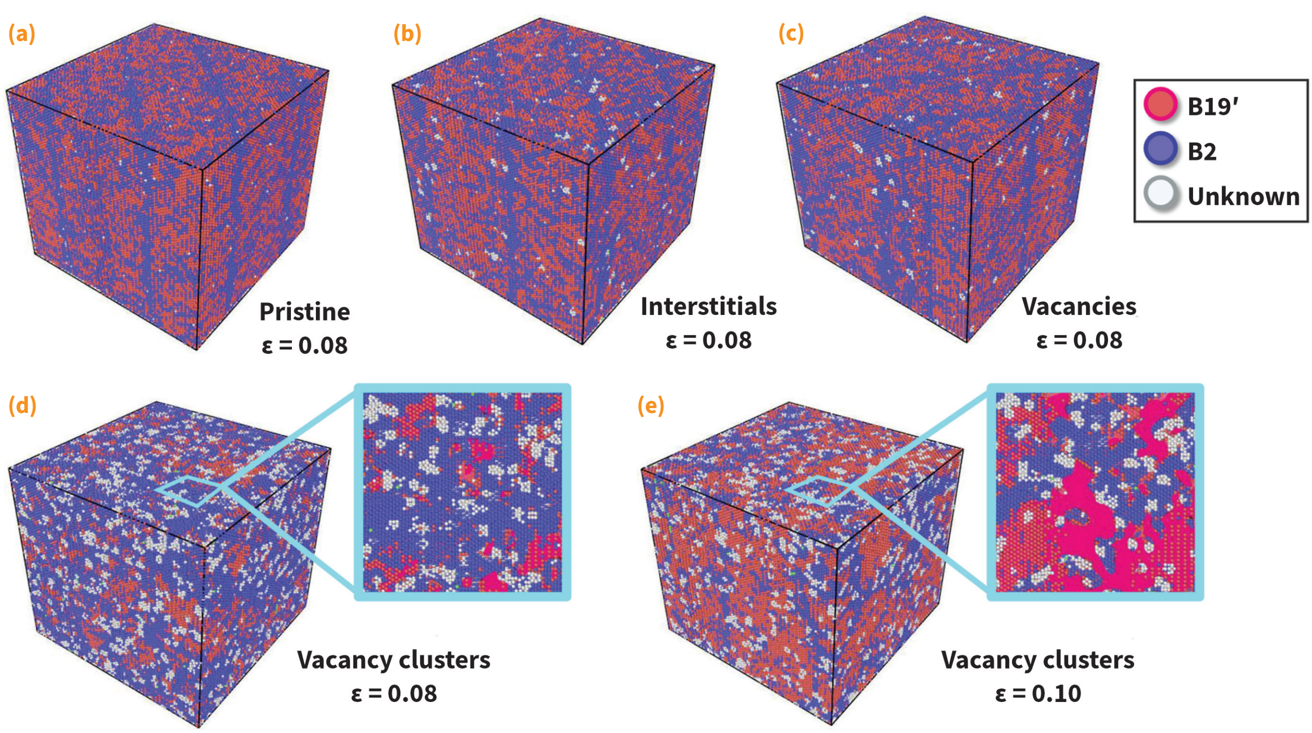

Fig. 4 — Molecular dynamic simulations of the B2-B19′ transformation in equiatomic NiTi for (a) pristine (b) interstitials (10^{-4} at.%), (c) vacancies (10^{-4} at.%), and (d) vacancy clusters (10^{-3} at.%) at 0.08 strain and (e) vacancy clusters (10^{-3} at.%) at 0.1 strain. See key for color of lattice sites.

structure with fewer B19′ transformed lattice sites. The vacancy cluster case (Fig. 4d) shows even greater defect-mediated suppression of the transformation and at greater strain (Fig. 4e), the vacancy clusters appear to constrain the growth of B19′ martensite (compare insets, Figs. 4d and e). The MD results, like the PF counterparts, are consistent with the larger indentation load required for irradiated NiTi. The detailed defect structures are ultimately determined by a balance of free energy, which drives the maintenance of short-range order, and irradiation-induced ballistic disordering of lattice atoms[47].

CONCLUSIONS

Ni ion beam modification of $Ti\text{-}Ni_{50.5\%at}$ wire at <0.1 DPA is shown to increase the indentation load in implanted regions by as much as ~50%, yet retain ~85% of recoverable displacement while achieving ~60% reduction in hysteresis, greater stability, and more linear behavior. Electron microscopy reveals inhomogeneously distributed damage consisting of a mixture of amorphous and crystalline B2 phases in the implanted region. The increased hardness is supported by phase field and molecular dynamics simulations that predict defects at multiple scales to require increased load to achieve the B2-B19′ martensitic transformation. The results suggest the potential for Ni ion beam modification to achieve functional surface modification of NiTi. **~SMST**

For more information: Peter Anderson, professor, Department of Materials Science and Engineering, The Ohio State University, 140 W. 19th Ave., Columbus, OH 43210, 614.688.3050, anderson.1@osu.edu.

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THORACIC STENT GRAFT DELIVERY SYSTEM ADAPTS TO PATIENT'S ANATOMY

A new TEVAR delivery system allows staged, predictable endograft deployment and in situ angulation control, while avoiding windsocking and bird-beaking.

The introduction of thoracic endovascular aortic repair (TEVAR) has completely changed clinicians' attitudes and approaches in the treatment of thoracic aortic pathologies[1]. Since the advent of TEVAR, the use of endovascular repair to treat increasingly complicated disease states in challenging aortic anatomies has grown. Thoracic endografting provides a therapeutic option to a rising number of patients who are not good candidates for open repair or who prefer a minimally invasive approach[2].

Fig. 1 — The GORE TAG Conformable Thoracic Stent Graft with Active Control System and associated accessory devices. The stent graft design remains the same as the previous-generation Conformable GORE TAG Device.

Fig. 2 — The nested handle of the TEVAR system enables stepwise deployment and optional angulation of the device. This figure shows the device deployed to its intermediate diameter after removal.

Over the years, much progress has been made to improve TEVAR in terms of the design of both the stent graft and the delivery system. However, despite recent advancements, TEVAR is not free from complications, and challenges with bird-beaking and windsocking continue to be a problem, especially in the aortic arch. Failure to conform to arch anatomy may increase the risk of type I endoleak, which, if left untreated, can result in aortic rupture and possibly death. Windsocking due to high blood flow velocity and pressure in the aortic arch can lead to difficulties with precise deployment. This is especially true with deployment mechanisms where the proximal end opens while the distal end remains constrained. Predictability of deployment is also important at the level of the distal landing zone to avoid covering of the visceral arteries. To overcome these challenges, a conformable thoracic stent graft with delivery system from GORE introduces novel features that help to enhance deployment accuracy and stent graft apposition and to fully take advantage of the stent graft's conformability.

TECHNICAL CONSIDERATIONS

The GORE® TAG® Conformable Thoracic Stent Graft with ACTIVE CONTROL System combines the company's conformable GORE® TAG® Device with a novel nested handle delivery system. The stent graft therefore has the same conformable stent graft design with sutureless graft attachment, oversizing windows that enable optimized radial fit, and indications and anatomic requirements. The principle of operation is also maintained, with a fiber deployment mechanism that is actuated to release the self-expanding stent graft from a constraining sleeve.

The delivery system features a nested handle that separates stent graft expansion into two deployment steps, each requiring actuation of a separate handle component (Fig. 1). Deployment consists of four required steps and two optional angulation steps. Removal of the primary deployment handle deploys the stent graft to its intermediate diameter, initiating device opening from the leading to the trailing ends (Fig. 2). At this intermediate stage, the angulation control dial is now accessible and the user has the first opportunity for optional angulation of the proximal end of the stent graft by rotating this dial. Removal of the secondary deployment handle deploys the stent graft to its full diameter, initiating deployment from the trailing to leading ends. The angulation control dial remains accessible even after full expansion, and the user has a second opportunity for optional angulation at full diameter. Throughout the deployment, the stent graft is secured onto the catheter via a lock wire. This ensures control of device positioning throughout the procedure until removal of the lock wire handle. Finally, the angulation assembly handle is removed to withdraw the angulation fiber mechanism.

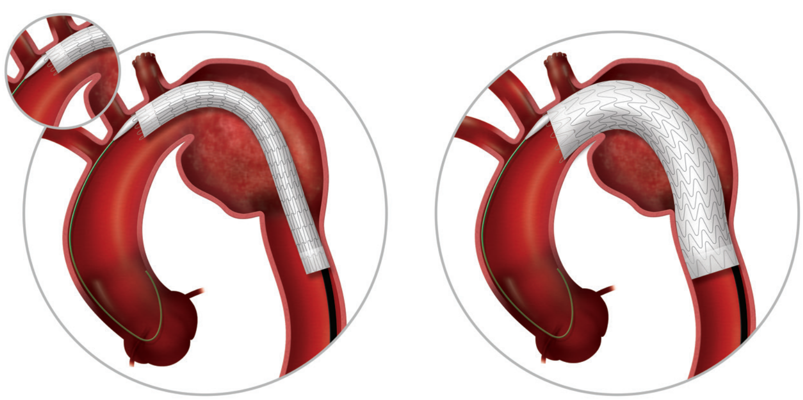

Fig. 3 — (a) Staged deployment allows the device to first be opened to an intermediate diameter along its entire length while ensuring continuous blood flow. (b) A separate deployment step expands the device to its full diameter.

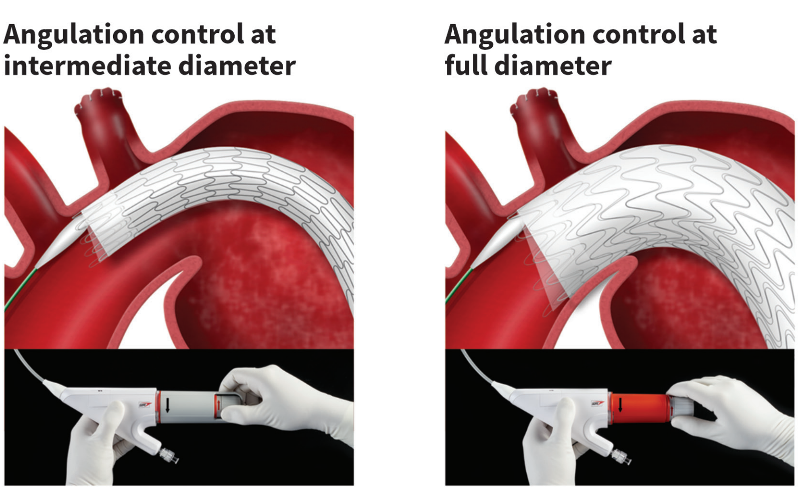

Fig. 4 — The optional angulation feature can be used at both intermediate (a) and full (b) diameter stages. By nesting the stent rows along the inner aortic curve, angulation helps to achieve orthogonal device placement in tight arches.

The GORE® DEVICE has two important features to improve deployment predictability through accuracy and control: staged deployment and in situ angulation control of the proximal end of the stent graft. With staged deployment, the nested handle delivery system design enables the stent graft to deploy in two distinct steps (Fig. 3). Removal and actuation of the first primary deployment handle opens the device along its entire length to its intermediate diameter, which is approximately 50% of its nominal diameter. Importantly, this deployment to intermediate diameter is designed to allow continuous blood flow both through the lumen of the stent graft and around the device. This feature ensures hemodynamic stability throughout the procedure, even in the aortic arch with its characteristic high blood flow pressure and velocity. A unique advantage of this design is that blood pressure does not have to be aggressively reduced because the blood flow into the distal aorta is not compromised. The lack of windsocking forces that tend to push the device distally during device opening helps to ensure precise positioning of the stent graft in the aorta. Because there is little or no wall apposition at this intermediate diameter, it is possible to make refinements in the stent graft positioning. If required, it is also possible to modify the C-arm gantry angle to remove device parallax and maximize every millimeter of the landing zone. Removal and actuation of the secondary deployment handle opens the device to its full diameter. A lock wire secures the stent graft to the catheter, ensuring that the user maintains control of the device and its positioning throughout the procedure until the lock wire is removed as one of the final deployment steps.

Angulation of the proximal end of the stent graft is an optional feature that allows for more orthogonal placement of the stent graft. The benefit of angulation becomes evident in angulated aortic arch anatomies, where the wall apposition along the inner aortic curvature can sometimes lead to the formation of a bird beak. The GORE® ACTIVE CONTROL System allows the user to adjust the angulation and orthogonal placement of the proximal end of the stent graft in situ, depending on the individual anatomic needs of the patient. Angulation control is possible during the two phases of deployment, at intermediate diameter and after the stent graft has expanded to its full diameter (Fig. 4). Because this is an optional feature, the clinician can decide during deployment whether and to what degree angulation is beneficial in that specific anatomy.

This ability to optimize proximal device apposition may help to avoid complications such as type Ia endoleak.

CONCLUSION

The Conformable GORE® TAG® Endoprosthesis was already widely recognized for its conformable stent graft design and its proven history across broad indications. With the new features of staged deployment and angulation control, the GORE® TAG® Conformable Thoracic Stent Graft with ACTIVE CONTROL System represents a new development in TEVAR device design that enables in situ adjustments in stent graft positioning and apposition and sets a new standard for the conformability and control that can be expected of a TEVAR device. ~SMST

Note: Co-authors include Giovanni B. Torello and Martin Austermann, St. Franziskus Hospital, University of Münster; and Giovanni F. Torsello, Charité Universitätsmedizin Berlin.

For more information: Jill Skoczen, thoracic strategic marketing, W. L. Gore & Associates, jskoczen@wlgore.com.

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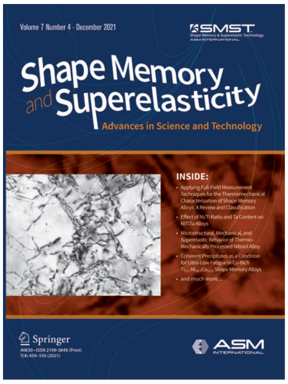
Additional author information:

Giovanni B. Torsello, MD Chief of Vascular Surgery Department St. Franziskus Hospital Professor of Vascular Surgery University of Münster Münster, Germany Principal Investigator of the SURPASS Registry +49.251.935.3933; giovanni.torsello@sfh-muenster.de Disclosures: None.

Martin Austermann, MD Vascular Surgery Department St. Franziskus Hospital Assistant Professor of Vascular Surgery University of Münster Münster, Germany; martin.austermann@sfh-muenster.de Disclosures: None.

Giovanni F. Torsello, MD, BA Radiology Department Charité Universitätsmedizin Berlin Berlin, Germany; giovanni.f.torsello@gmail.com Disclosures: None.



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December 2021

EFFECT OF Ni/Ti RATIO AND Ta CONTENT ON NiTiTa ALLOYS

S. Cai, J.E. Schaffer, and Y. Ren

Influences of Ta and Ni/Ti ratio on transformation temperatures, microstructures, and superelastic properties of NiTiTa alloys were investigated. It is found that: (1) increasing Ni/Ti ratio increases the solubility limit of Ta in NiTi matrix and suppresses the formation of Ta-rich secondary phases. 4 at.% Ta can be dissolved in alloys with Ni/Ti ratio of ~1.1; (2) high Ni/Ti ratio promotes the formation of Ti_2Ni_3 phase, which is suppressed by increasing Ta additions; (3) phase transformation temperatures increase with Ta content at a rate of ~70–80°C/at.% Ta, but rapidly decrease with increasing Ni/Ti ratio; (4) super-elastic properties of NiTiTa alloys can be optimized by adjusting residual cold work, Ta content, and Ni/Ti ratio; and finally, (5) phase transformation temperatures of NiTiTa alloys decrease with increasing valence electron concentration in general (Fig. 1).

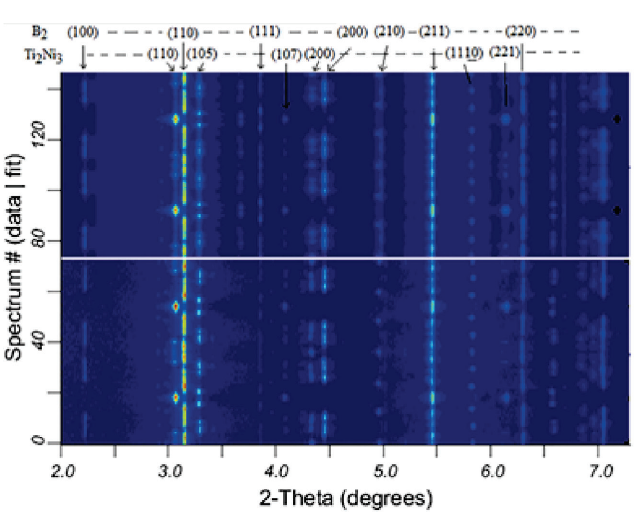


Fig. 1 — Comparison between experimental results and modeling results of alloy A4 confirms the presence of Ti_2Ni_3 precipitates. The upper half of the figure shows modeling results, and the lower half figure is experimental data.

December 2021

COHERENT PRECIPITATES AS A CONDITION FOR ULTRA-LOW FATIGUE IN CU-RICH $TI_{53.7}NI_{24.7}CU_{21.6}$ SHAPE MEMORY ALLOYS

L. Bumke, E. Quandt, N. Wolff, C. Chluba, T. Dankwort, and L. Kienle

Sputtered Ti–rich TiNiCu alloys are known to show excellent cyclic stability. Reversibility is mostly influenced by grain size, crystallographic compatibility, and precipitates. Isolating their impact on cyclic stability is difficult. Ti_2Cu precipitates for instance are believed to enhance reversibility by showing a dual epitaxy with the B2 and B19 lattice. Their influence on the functional fatigue, if they partly lose the coherency, is still unknown. In this study, sputtered $Ti_{53.7}Ni_{24.7}Cu_{21.6}$ films have been annealed at different temperatures leading to a similar compatibility (λ^2 ~ 0.99), grain size and thermal cyclic stability. Films annealed at 550°C (referred to as LT) exhibit a superior superelastic fatigue resistance but with reduced transformation temperatures and enthalpies. TEM investigations suggest the formation of Guinier–Preston (GP) zone-like plate precipitates and point towards a coherency relation of the B2 phase and finely distributed Ti_2Cu precipitates (~60 nm). Films annealed at 700°C (referred to as HT) result in the growth of Ti_2Cu precipitates

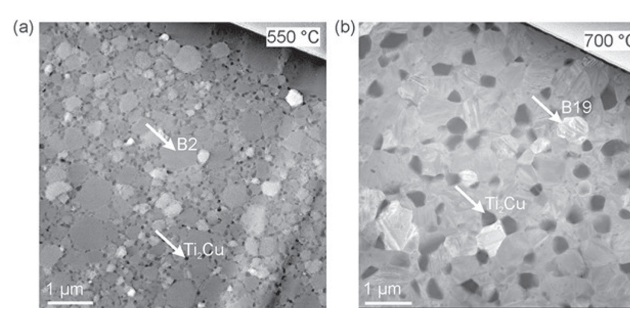


Fig. 2 — STEM-HAADF images of the LT (a) and the HT sample (b) at room temperature reveal a similar grain size of TiNiCu for both samples, but a large difference in the sizes and arrangement of Ti_2Cu precipitates (dark contrast). The sizes of the precipitates is approx. 60 nm for the LT sample and 280 nm for the HT sample, respectively.

(~280 nm) with an irregular distribution and a partial loss of their coherency. Thus, GP zones are assumed to cause the reduction of transformation temperatures and enthalpies due to increased internal stresses, whereas the coherency relation of both, Ti_2Cu and GP zones, help to increase the superelastic stability, well beyond 10^7 cycles (Fig. 2).

March 2022

FUNCTIONAL PROPERTIES OF THE MULTILAYER NiTi ALLOY PRODUCED BY WIRE ARC ADDITIVE MANUFACTURING

N. Resnina, I.A. Palani, S. Belyaev, S. Singh, A. Kumar, R. Bikbaev, and A. Sahu

This paper studies the functional properties in a layered NiTi sample produced by wire arc additive manufacturing (WAAM). The experimental studies were carried out using two types of samples: including the Ti–rich and Ni-rich layers or including Ni-rich layers only. The obtained results showed that the existence of the Ti–rich NiTi layer affected the two-way shape memory effect, which was two times higher than the sample including the Ni-rich NiTi layers only. This was due to the additional internal stress formed during preliminary deformation on the border between the Ti–rich and Ni-rich NiTi layers. It was found that the existence of the Ti–rich NiTi layer suppressed the initiation of superelastic response because the stress-induced martensite remained stable on unloading. It was observed that excluding the Ti–rich NiTi layer from the deformation allowed to reveal the superelasticity effect. It was also noticed that the value of the maximum recoverable strain did not exceed 4%, which was 2–2.5 times less than in the NiTi samples produced by conventional technologies. It was assumed that a small recoverable strain was caused by the texture and a small strain up to failure (Fig. 3).

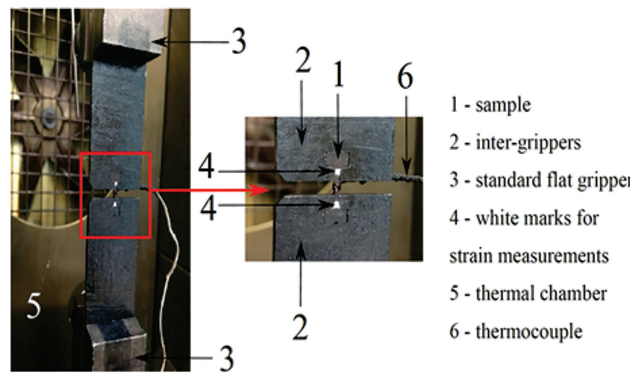


Fig. 3 — Image of the sample installation to the standard testing machine grippers.

SMST2022
Shape Memory and Superelastic Technologies Conference and Exposition

MAY 16–20 | SAN DIEGO, CALIFORNIA
THE WESTIN CARLSBAD RESORT

KEYNOTE PRESENTERS

TUESDAY, MAY 17 | 8:10 – 9:00 a.m.

Dr. Riki Banerjee
Synchron
Endovascular Brain Computer Interface (BCI) for Severe Paralysis: First in Human Experience

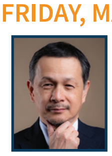
WEDNESDAY, MAY 18 | 8:00 – 9:30 a.m.

Prof. Aaron Stebner
Georgia Institute of Technology
3D Printing Nitinol: The Past, Present, and Future

THURSDAY, MAY 19 | 8:00 – 9:00 a.m.

Prof. Ichiro Takeuchi
University of Maryland
Development of Compression-based Elastocaloric Cooling Systems based on Superelastic Shape Memory Alloys

FRIDAY, MAY 20 | 8:10 – 9:00 a.m.



Prof. Koichi Tsuchiya
National Institute for Materials Science
Research and Activities on Shape Memory Alloys in Japan

NITINOL EDUCATION WORKSHOP

MONDAY, MAY 16 • 9:00 a.m. – 5:00 p.m.
Organized by Dr. Alan R. Pelton, FASM

This workshop will provide participants with a thorough introduction to Nitinol technology for those wishing to gain a more fundamental understanding of shape memory and superelasticity. **Sponsored by Norman Noble Inc.**

Course topics include:

- **How Nitinol Works:** Basic thermal and mechanical properties
- **Medical Applications of Nitinol:** Design, processing, and properties to optimize in vivo performance of medical devices
- **Actuator Applications of Nitinol:** Design, processing, and properties optimize the performance of actuators
- **Advanced Nitinol Topics:** Additive manufacturing, thin films, elastocaloric, and magnetostriction applications with processing and properties

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Note: Exhibitors list current as of March 14.

Scenic view of the Carlsbad coast.

EXHIBITION HOURS*

TUESDAY, MAY 17
9:30 a.m. – 7:00 p.m.

WELCOME RECEPTION WITH EXHIBITORS
TUESDAY, MAY 17
5:30 – 7:00 p.m.

WEDNESDAY, MAY 18
9:30 a.m. – 1:00 p.m.

**Times are subject to change.*

ASM International's main priority is to ensure the safety of our members, speakers, attendees, exhibitors, and staff as we continue to monitor all relevant information on the COVID-19 virus and its impact on hosting events in public spaces. For up-to-date information, visit smstevent.org or contact: events@asminternational.org.

FOR EVENT DETAILS AND TO REGISTER, VISIT SMSTEVENT.ORG

SMST 2022 EXHIBITOR SHOWCASE

VISIT THESE KEY EXHIBITORS AND MORE AT SMST IN SAN DIEGO, CALIFORNIA

EXHIBITION HOURS

The Westin Carlsbad Resort

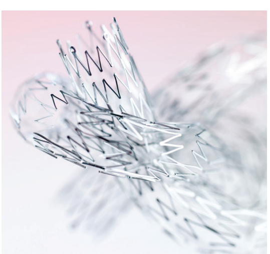
Tuesday, May 17 • 9:30 a.m. – 7:00 p.m.

Wednesday, May 18 • 9:30 a.m. – 1:00 p.m.

ADMEDES

IDEAS. EXPERTISE. PASSION.

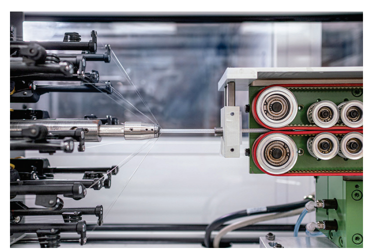
ADMEDES is the leading global provider of Nitinol and other metallic components to the medical device industry for 25+ years. Our diverse product applications include heart valve frames, vascular and gastroenterology stents, orthopedic and ophthalmologic devices, and more. From rapid response prototyping to laser technology, micromachining, wire technology, microassembly, and test lab services, we are dedicated to the highest quality standards. In Germany, California, and Costa Rica—we're here to help you every step of the way. Ideas. Expertise. Passion. This is **ADMEDES.**



admedes.com – Booth 205

CONFLUENT

Confluent Medical Technologies applies material science to MedTech innovation. Confluent specializes in expert design and development of large scale manufacturing specializing in interventional catheter based devices and implants. Our key capabilities include Nitinol components, balloon and complex catheters, high precision polymer tuning, and implantable textiles. **Confluent Medical** now employs over 1700 people with eight state-of-the-art facilities across the United States and Costa Rica.



confluentmedical.com – Booth 105

EUROFLEX®

WE CREATE SOLUTIONS

EUROFLEX offers high-grade semi-finished products and components from a variety of materials for medical applications. Many years of experience in the metallurgy, the special features of the materials as well as the requirements of medical technology are the basis for continuous expansion of the **EUROFLEX** product range.

Fast sample production, customer support from the sample to serial production, as well as extensive analysis and investigation methods are part of the services of the company.

euroflex.de – Booth 304

laserlinc

Using laser and ultrasonic-based technologies, **LaserLinc** helps you solve your in-process and off-line non-contact measurement, and visualization needs through product innovation, software expertise, and deep application knowledge. **LaserLinc** offers you the most dependable non-contact measurement solutions available. Our professional team of experts makes it easy for you to implement a range of robust and flexible solutions to enhance your production environment and improve your yield.

laserlinc.com – Booth 211

SMST 2022 EXHIBITOR SHOWCASE

(continued from page 61)

Norman Noble, Inc.

Microprecision Medtech Manufacturing

Established over 75 years ago, **Norman Noble** remains committed to leading the development of advanced manufacturing processes required for our medical OEM customers. **Norman Noble's** exclusive STEALTH athermal laser technology enables the manufacturing of next-gen medical implants made from thin and thick wall Nitinol without producing any heat affected zone (HAZ). Please contact us to learn more about our new Rapid Prototyping services.

nnoble.com – Booth 204

Vascotube

A Cirtec Company

Cirtec MEDICAL GMBH

Vascotube, a Cirtec Company, focuses on custom manufacturing tubing exclusively for medical devices. Simply: we do not do anything else. We are dedicated to quality medical implantable tubing and the specific requirements of working and forming Nitinol and other demanding materials. Our tubing is used in medical devices including replacement heart valves and stents. We specialize in large outer diameters, high surface smoothness, tight wall tolerances, and tight concentricity.

vascotube.com – Booth 106

Nitinol for Medical Devices

October 24-26, 2022 | 2.0 CEUs | ASM Headquarters & Virtual Classroom

The unique properties of the shape memory alloy Nitinol have led to many transformational medical device innovations including self-expanding stents, percutaneously delivered heart valves, kink-resistant guidewires, and self-locking orthopedic devices. Its superelastic qualities allow the alloy to withstand large amounts of recoverable strain, and its potential for excellent biocompatibility and fatigue resistance make it the material of choice for some of the most demanding medical device applications.

Upon completion of this course, students can successfully:

- Identify the reasons for Nitinol's unique properties
- Describe how Nitinol performs in a variety of conditions
- Understand basic Nitinol device manufacturing principles
- Recognize how to apply the benefits of Nitinol's properties to real-world applications

Register for this course by visiting bit.ly/EDUNitinol

asminternational.org/exploreeducation

ASM INTERNATIONAL | Education

ASMNEWS

TECHNICAL COMMITTEES UPDATE

ASM Technical Committees Foster Member Collaboration and Networking

ASM recently reimagined its volunteer committee structure to make it even easier for members to connect and collaborate with others who share the same technical interests. The graphic shows the current slate of ASM technical committees and new committees on the way.

The ASM Core and Emerging Technologies Council, chaired by **Steven M. Arnold, FASM,** NASA, provides oversight on behalf of the ASM Board of Trustees and helps foster the organization and startup of new committees. Several new technical committees have launched within the past two years.

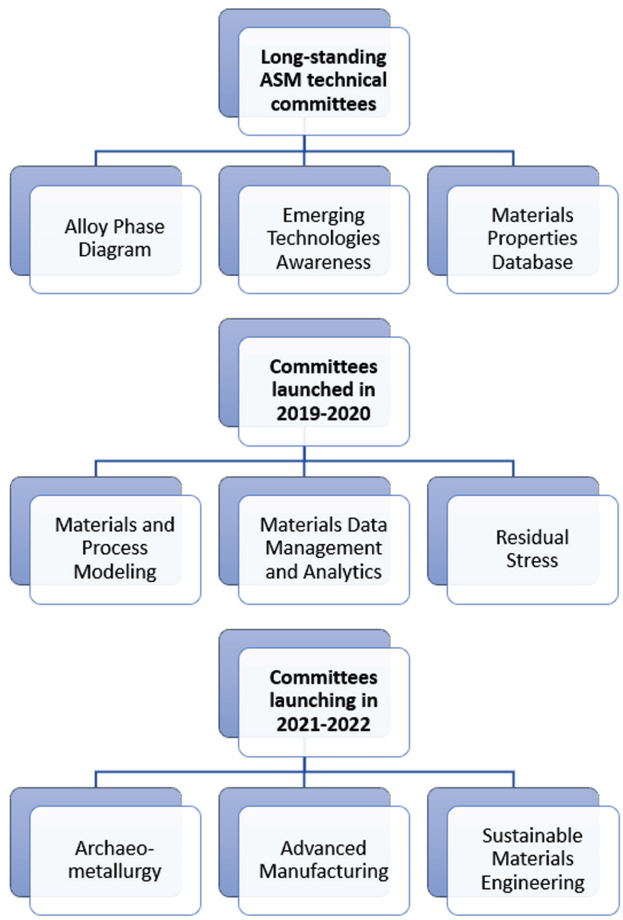
Two new committees are being organized. If you are interested in joining an existing ASM technical committee or starting a new one, contact Scott Henry, scott.henry@asminternational.org.

Advanced Manufacturing

ASM Past President **William Frazier, FASM,** Pilgrim Consulting LLC, is leading the organizing efforts for this committee, which will focus on new and enhanced materials process technologies needed to realize the promise of Industry 4.0. It will address crosscutting issues such as materials mechanisms that tailor material properties and performance characteristics; processing path dependency of microstructure and properties; availability and use of data and analytics; and issues related to the development, acceptance, and broad-based application of new processing technologies. The committee will work to expand ASM conference programming, education courses, publications, and datasets and will seek to coordinate with U.S. and international advanced manufacturing institutes.

Sustainable Materials Engineering

John Wolodko, FASM, University of Alberta, has proposed a committee to respond to the growing global interest in sustainability driven by changes in government policy, consumer demand, and corporations rethinking their strategic direction. The materials sector will play a critical role over the next decade in providing material solutions to reduce a variety of environmental and socioeconomic impacts including the reduction of carbon emissions, improvement of renewable energy platforms for electricity generation, storage, and transportation (e.g., electric vehicles), and reduction of materials waste (improved recycling/reuse/biodegradability). The committee will work on conference programming and education offerings, and support student outreach in coordination with the ASM Materials Education Foundation.



In This Issue

Submit news of ASM and its members, chapters, and affiliate societies to Joanne Miller, editor, ASM News | ASM International 9639 Kinsman Road | Materials Park, OH 44073 | P 440.338.5455 | F 440.338.4634 | E joanne.miller@asminternational.org
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

ASMNEWS

FROM THE PRESIDENT'S DESK

Materials Innovation for a Decade of Opportunity


Todd

The first quarter of 2022 has been a busy one for ASM. The ASM Data Ecosystem launched on February 15 and is attracting significant member interest. The first webinar, *Enhancing Materials Performance for Industry 4.0,* was held on March 29 and is archived for members who were unable to attend the live event. On February 18, in response to an invitation, ASM sent "Recommendations to the National Academies of Sciences, Engineering, and Medicine (NASEM)," a document advising the National Science Foundation (NSF) on furthering the vision of the Materials Genome Initiative through the NSF Design of Materials to Revolutionize and Engineer our Future (NSF DMREF) program. The NASEM committee will "*evaluate the goals, progress, and scientific accomplishments of the program within the context of similar efforts both within the United States and abroad. High-level, strategic recommendations will be provided for aligning the program to take full advantage of existing and future opportunities for accelerating the progression of materials research.*" ASM's response can be found by visiting https://bit.ly/3D2ZEAL. We will keep you posted with updates.

On the interdisciplinary front, ASM's AeroMat teamed up with SAE's AeroTech on March 15-17 for our first co-located event in Pasadena, Calif. Members of both societies enjoyed access to enhanced technical programming, additional learning opportunities dedicated exclusively to advanced aerospace materials, and expanded industry exhibits. This is the beginning of a new long-term partnership designed to bring added value to our members.

On the global front, congratulations to the Pune Chapter for recently hosting a highly successful International Women's Day celebration. ASM Vice President Dave Williams represented ASM at this year's event. Read highlights of the event in the Chapters in the News section of this issue.

Our new Executive Director, Sandy Robert, continues to come up to speed through her outreach into our community and through resources and connections provided to her by ASM's officers and board. She is meeting with the officers weekly to discuss operational progress and is getting to know the staff and the organization's lines of business. She is working closely with key members of the team to ensure close financial monitoring and management as we emerge from the pandemic. Sandy is also holding introductory meetings with the Board of Trustees to benefit from their perspectives, and is meeting with various member committees and task forces to understand our governance model. Certainly, advancement of our members is ASM's number one priority.

Speaking of our members, one of the highlights of this year so far was my visit to the Milwaukee Chapter on March 8—my first in-person chapter visit since COVID-19 began. This was a very positive experience. Led by Chris Misorski, I met a very enthusiastic group of volunteers who were focused on reinvigorating post-COVID, in-person meetings, particularly as their regular meeting venue had closed during the pandemic. The chapter is in great health, the Material Advantage Chapter at the University of Wisconsin-Madison is growing, and there is strong sentiment that ASM should concentrate on membership growth at all levels while remaining focused on core materials education. Integrated Computational Materials Engineering (ICME) was a featured program as was a future ASM education course. Strong representation of local industry and the University of Marquette, among others, was present. Thank you for making me so welcome.

These are just a few highlights of ASM's many initiatives. More to come next issue!

ASM President Judith Todd, FASM
judith.todd@asminternational.org


ASM presidential visit to the Milwaukee Chapter in March.

National Volunteer Week

In recognition of National Volunteer Week, April 17-23, ASM International thanks all of the many volunteers who are the lifeblood of the Society's programs and services. Volunteers serve as chapter officers, event organizers, committee chairs and members, Materials Camp mentors, publication reviewers, and more. Thank you for all you do year round!

Canada Council Award Nominations due April 30

ASM's Canada Council is seeking nominations for its 2022 awards program. These prestigious awards include:

G. MacDonald Young Award–The ASM Canada Council established this award in 1988 to recognize distinguished and significant contributions by an ASM member in Canada. This award consists of a plaque and a piece of Canadian native soapstone sculpture.

M. Brian Ives Lectureship–This award was established in 1971 by the ASM Canada Council to identify a distinguished lecturer who will present a technical talk at a regular monthly meeting of each Canadian ASM Chapter who elects to participate. The winner receives a $1000 honorarium and travels to each ASM Canada Chapter throughout the year to give their presentation with expenses covered by the ASM Canada Council.

John Convey Innovation Awards–In 1977, the Canada Council created a new award to recognize sustaining member companies that contribute to development of the Canadian materials engineering industry. The award considers a new product and/or service directed at the Canadian or international marketplace. Two awards are presented each year, one to a company with annual sales in excess of $5 million, and the other to a company with annual sales below $5 million.

Place your nominations for the 2022 awards! Award rules, past recipients, and sample nomination forms can be found at asminternational.org/membership/awards/nominate.

International Metallographic Contest at IMAT

Deadline: September 2

The International Metallographic Contest (IMC), an annual contest cosponsored by the International Metallographic Society (IMS) and ASM International to advance the science of microstructural analysis, will be held at IMAT 2022 in New Orleans, September 12-15. Six different classes of competition—including a new video class—cover all fields of optical and electron microscopy:

Class 1: Light Microscopy—All Materials

Class 2: Electron Microscopy—All Materials

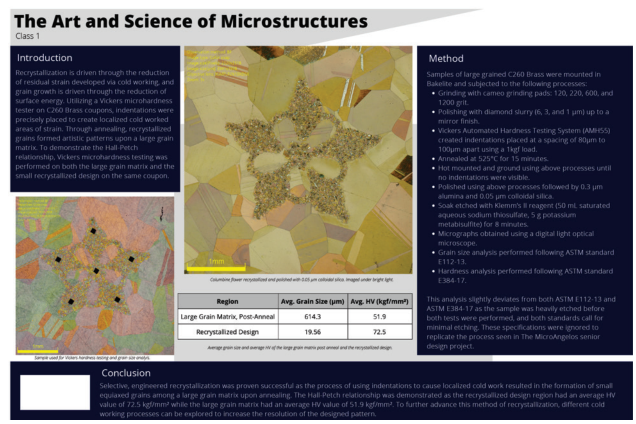
Class 3: Student Entries—All Materials (Undergraduate Students Only)

Class 4: Artistic Microscopy (Color)—All Materials

Class 5: Artistic Microscopy (Black & White)—All Materials

Class 6: Video Entry—Topic of Choice involving defined problem (Undergraduate Students Only)

Best-In-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of $3000. For a complete description of the rules, tips for creating a winning entry, and judging guidelines, visit asminternational.org/web/ims/membership/imc or contact IMC chair, Ellen Rabenberg, at ellen.m.rabenberg@nasa.gov.



IMC 2021 Jacquet -Lucas winning poster by Gerald Bourne from Colorado School of Mines.

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

The ASM Heat Treating Society established the Best Paper in Heat Treating Award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advantage in managing the business of heat treating. The award, endowed by **Bodycote Thermal Process-North America,** is open to all full-time or part-time students enrolled at universities (or their equivalent) or colleges. The winner will receive a plaque and a check for $2500. Paper submission deadline is **April 15.**

For nomination rules and forms for the award, visit the Heat Treating Society website at hts.asminternational.org and click on Membership and Networking and then Society Awards. For additional information or to submit a nomination, contact Mary Anne Jerson at 440.671.3877 or email maryanne.jerson@asminternational.org.

FROM THE FOUNDATION

Extending Our Reach


Keough

Nothing makes me happier than seeing a student's face light up at their first sight of molten metal or other materials phenomena. I love being part of the ASM Materials Education Foundation, so I can see firsthand more students experiencing these joys. Our foundation offers top-notch programming and activities to inspire and encourage students to enter the fields of materials science, engineering, and manufacturing.

Although the ASM Foundation loves providing programming directly to students, we know that even more students can experience that excitement if we reach teachers and help them share their enthusiasm with their students—every student they teach, every year. We reach an exponentially greater number of students through the ASM Materials Camps for Teachers than we ever could with our student camps.

That is why as chair of the ASM Foundation, I am working hard with the board and staff to be sure we can expand our reach to more teachers each year. Not just teachers of elite private schools, but teachers at urban public schools, rural schools, and schools that are teaching a diverse body of students. We want to cast the materials science and engineering net wide to include students who have never heard of the field, never thought of themselves as scientists, and never thought they could be engineers.

Our goals are to increase our current number of teachers and students in our ASM Materials Camps and expand access to resources and content that encourage interest in STEM opportunities and ignite passion in the next-generation workforce. We need resources and support to build on the base of the ASM Materials Education Foundation. Let's continue to work together to improve the knowledge and skills of our teachers, which will translate to their students becoming leaders in the materials field.

The ASM Foundation curriculum provides hands-on, minds-on activities that bring critical concepts to life for all students and helps encourage them to pursue career paths they may never have imagined. This passion begins with attending ASM Materials Education Foundation programming and activities, conducted by our teachers. With your support, we will continue to light a spark in students and deliver the next generation of enthusiastic talent to the materials field.

John "Chip" Keough, FASM

Chair, ASM Materials Education Foundation

ASM Scanning Electron Microscopy: Online Course with Lab Option

Zeiss EVO 15 SEM.

In collaboration with Zeiss, ASM presents the new online course *Scanning Electron Microscopy* (SEM). The class presents basic SEM theory and operating principles along with imaging and analytical techniques. This online tutorial is designed for new users who want to become familiar with basic scanning electron microscope operation.

Participants have the option to choose the online course only or to pair it with a live one-day session at ASM's laboratory with lab manager and instructor John Peppler. The lab sessions will be held in small groups in the ASM Microscopy Lab with several 2022 dates offered. Attendees are encouraged to bring their own samples. For more information, visit https://bit.ly/3I9IjqK.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer


Drake

Dana Drake, Lab Manager, Metals, EOS of North America

"I get to share my enthusiasm for this immense world! Everything is made of something. I help students think critically about the lifespan of a part—and I get exposure to rock stars in the industry." That's why Dana Drake volunteers with ASM as a mentor to high school students, serving for the past 10 years at the Eisenman Materials Camp.

Drake attended Colorado School of Mines for her bachelor's degree in metallurgical and materials engineering, then worked in failure analysis for Tinker Air Force Base before returning to pursue a master's in materials science. She now works as a metals lab engineer for EOS, a company specializing in additive manufacturing machines. Her days include running powder testing to determine feedstock quality and evaluating parts printed by the system.

In 2011, Drake took an ASM class at the dome from metallographer Frauke Hogue, FASM, a beloved teacher and high school camp mentor. She inspired Drake to volunteer as a mentor, a role she has been committed to since 2012. Drake loves working with high school students, and at age 35 describes herself as "a kid at heart" who enjoys relating her common interests in music, theater, or pop culture to the technical lessons.

"It brings me joy to help students develop critical thinking skills and show them how beautiful and interconnected everything is," says Drake. "It refreshes your energy. Any career can become mundane. So it's fun to see things with new eyes. It's rejuvenating to pass on something that is important to me."

The camps are also an opportunity to learn from other mentors with vast professional experience. "They all have rigorous and diverse backgrounds. We teach each other. So whenever I have questions or need recommendations, I have this vast network," says Drake. "It's been a great opportunity to grow technically and make connections with people who are also very passionate about materials science. There are so many ways to give, even if you can't commit to a leadership role. You can find roles that match your interests and availability on ASM Connect."

WOMEN IN ENGINEERING

*This profile series introduces materials scientists from around the world who happen to be females. Here we speak with **Mary O'Brien,** Glenn T. Seaborg Postdoctoral Fellow at Los Alamos National Laboratory (LANL), New Mexico.*

O'Brien

What does your typical workday look like?

Probably half of my day is administrative, emailing the right person to get paperwork through. The connections you make with all of your coworkers is the most important thing when it comes to getting stuff done. So I spend a small amount of time each day fostering those connections. A quarter of my day may be spent doing experiments in the lab, and the other quarter is analyzing that data, making experimental plans, reading literature, considering proposals for future work, and writing publications. Some days are more thrilling and science-y than others, but overall, I love my job.

What part of your job do you like most?

I love having access to cutting-edge equipment and conducting research on a wide variety of fascinating materials. But the real asset at a national lab like LANL is access to some truly brilliant minds. If you have a question outside of your expertise, it's guaranteed there is someone on this campus who can give you the answer. I am regularly in awe of the abilities and intellect of the people around me, which keeps me excited to come to work every day.

Did you ever consider doing something else with your life besides engineering?

The last couple of years finishing my Ph.D. were miserable. Graduate school takes a serious mental health toll that I don't think we talk about enough, but needs to be addressed urgently. During that time, I became so insecure about my abilities in science that I seriously considered walking away and becoming a professional ski patroller. I know many of my female colleagues and peers from under-represented minorities often similarly consider leaving science, and a healthy percentage make the decision to leave. I consider it part of my life's purpose to make STEM more welcoming and accessible for future generations.

Best career advice, given or received:

My dad always used to say, "Don't sweat the petty things and don't pet the sweaty things." I'm not always good at following this advice, but I do try to keep things light. After all, scientists are ultimately just big curious kids who get to play with expensive toys for a living.

What are you working on now?

Hydrogen embrittlement is a serious problem in many industries ranging from oil and gas to nuclear power, and its mechanism is poorly understood. I hope to shed light on some fundamental mechanisms of hydrogen interaction with metallic systems and am currently making efforts in that realm.

Tell us about your involvement with ASM International. Why are you a member?

Every year since 2017, I have been a mentor for the Eisenman Materials Camp. I cannot think of a more positive experience than working with those kids and my fellow mentors each year. We even managed to transition to multiple virtual camps during the height of COVID-19. At Eisenman, I get to teach and hopefully inspire young minds, and also learn an incredible amount of new information from my fellow mentors about materials systems I don't usually work in. It is definitely the most rewarding and fun outreach activity I could think of, and it has kept me hooked on ASM.

Women in materials engineering are…

A force to be reckoned with.

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

CHAPTERS IN THE NEWS

Pune Chapter Celebrates International Women's Day

ASM International's Pune Chapter celebrated International Women's Day on March 5 in the auditorium of MKSSS's Cummins College of Engineering for Women (CCOEW). Collaborating with the college in organizing the event were The Institution of Engineers, the Pune Local Centre, and ASM International. The celebration was conducted both in-person and online. More than 100 participants attended the event including engineering students from CCOEW at Nagpur and Pune.

The program began with a traditional lamp lighting ceremony led by dignitaries including Dr. Madhuri Khambete (principal), Dr. Gautam Chandekar (HoD Mech. from CCOEW), Udayan Pathak, FASM, (chair, ASM Pune Chapter), and Ruta Barve, FASM, (joint secretary, ASM Pune Chapter). The honor of lighting the lamp was given to two students, Rajeshwari and Abha.

During the event, the Mentoring Program for Women Materials Engineers was launched jointly by Deepa Deshpande (director, Precicut) and Pradeep Goyal, FASM, (ASM India mentor and founder chairman of Pradeep Metals). Ruta Barve elaborated on the structure of the program. This exclusive mentoring program was designed in consultation with Dr. Rajiv Narvekar (senior practice leader, Tata Management Training Centre & Group Innovation Centre). He also agreed to serve as the program's chief mentor.

Traditional lamp lighting, symbolizing knowledge removing ignorance. Clockwise from top left: Ruta Barve, FASM, Madhuri Khambete, Udayan Pathak, FASM, and Rajeshwari.

The program started out with an inspirational talk by Sanhita Karmakar from Kolkata and an interview with Prof. Fahmida Gulshan, Bangladesh University of Engineering and Technology (BUET), Dhaka, conducted by Dr. Sarika Verma of CSIR-AMPRI.

There was a panel discussion on "Career Opportunities for Materials Engineers in Current Global Technology Disruption." The panelists included Dr. David Williams, FASM, (VP, ASM International and professor of materials science and engineering, The Ohio State University), Dr. Anne-Claire Christiaen, (director, Advance Design Center, Emerson Electric, Ohio), Jill Long, (VP HR, North America & Asia, Bodycote Thermal Processing PLC), Sachin Ghanpathi, (retired director, manufacturing engineering, Cummins India Ltd. & Industry 4.0 Expert), and Shruti Dubey, (ASM student board member and chair, Material Advantage, IIT Kanpur). The session was moderated by Jaswandi Gotmare of Emerson Innovation Center-Pune.

Williams emphasized the need for acquiring numerical and data analytics skills for materials engineers. Christiaen mentioned the tremendous career opportunities arising from a circular economy, which will change the entire design approach from low cost, lightweight materials to a carbon footprint approach for environmental sustainability.

Long shared the criticality of acquiring new skills like data analytics and machine learning, along with soft skills such as resourcefulness and problem solving. Ghanpathi highlighted that adopting Industry 4.0 is helping manufacturing value chains to become more agile. He also added that collaboration is the key, but basic engineering knowledge will be advantageous. Dubey drew everyone's attention to the valid point that material is omnipresent. Hence, along with core subjects of materials science and engineering, there is a need to include machine learning and coding in engineering programs.

The panel discussion was a highlight of the Pune Chapter's International Women's Day event.

Pathak and Barve welcomed guests and shared the activities of the ASM Pune Chapter, while Nita Gaykar expressed thanks. Gotmare, Gaykar, and Barve from the Pune Chapter organized the event. Pournima Barve and Tannu Kanojia co-anchored the program.

This program was an example of true diversity and inclusion. #breakthebias2022.

Special thanks to Amanjeet Kaur, student of CCOEW, Nagpur, for compiling this report.

Hartford and UConn Host Joint Event

The ASM Hartford Chapter, working with assistant professor Lesley Frame of the University of Connecticut (UConn), held a joint event on March 8, in recognition of International Women's Day. The program was titled, "The Balancing Act: Pursuing Professional Advancement (through Graduate School, Continuing Education, Volunteerism) while Working." A total of 30 people attended the event at UConn including 20 undergraduate and graduate materials science and engineering (MSE) students. Jennifer Williams of Collins Aerospace hosted a panel that included Alexandra Merkouriou, Ph.D. student, UConn; Jackie Garofano, CTO, Connecticut Center for Advanced Technology; and Ruchika Jain, graduate student and employee, Novo Precision.

Albuquerque Hears about Spaceflights

On March 9, astronaut John "Danny" Olivas was the featured speaker at an ASM Albuquerque Chapter virtual meeting. His talk was titled "The Overview Effect: A Materials Scientist Perspective." Olivas, a veteran of two space shuttle flights and five spacewalks, relayed his 12-year experience in the profession. He discussed how being a materials scientist provided NASA with unique insight into materials-related spaceflight challenges, from failure analysis on NASA's T-38 fleet to forensic work on the Columbia disaster. Olivas is the only astronaut to carry the ASM flag on board the space shuttle to the International Space Station.

MEMBERS IN THE NEWS

National Academy of Engineering Honors ASM Members

In February, the National Academy of Engineering (NAE) elected 111 new members and 22 international members. Among the inductees are several ASM members:

Michele Viola Manuel, FASM, department chair and Rolf E. Hummel Professor, department of materials science and engineering, University of Florida, Gainesville, for contributions to research, implementation, and teaching of computational materials design of biomimetic self-healing metals and high-performance lightweight alloys.

Julie Mae Schoenung, FASM, department chair and professor, materials science and engineering, University of California, Irvine, for innovative and interdisciplinary applications of materials engineering in trimodal composites, coatings, additive manufacturing, and green engineering.

James A. Yurko, director, Materials Engineering, Apple Inc., Cupertino, Calif., for innovation, leadership, and the accelerated development of materials applied to consumer electronic products.

Election to NAE is among the highest professional distinctions accorded to an engineer. Academy membership honors those who have made outstanding contributions to engineering research, practice, or education. An induction ceremony for the NAE Class of 2022 will be held on October 2 at the Academy's annual meeting in Washington.

McDonald Named Associate VP at U of A

André McDonald, FASM, professor in the department of mechanical engineering, University of Alberta (U of A), was appointed to the role of associate vice president (Strategic Research Initiatives and Performance). He will support strategic research initiatives, planning, and performance measurement; identify research and innovation trends; develop interdisciplinary institutional research initiatives; and steward large-scale institutional research grant applications. McDonald will continue his member engagement with ASM through his research in thermal spray, work with the Thermal Spray Society, and service on the ASM Task Force on Academic Engagement. He currently leads the Experiential Learning in Innovation, Technology, and Entrepreneurship (ELITE) Program for Black Youth, which supports hands-on learning and work-integrated training in STEM fields.

McDonald

Smithsonian Exhibit Honors Elliott

Amy Elliott, Oak Ridge National Laboratory (ORNL) scientist, was one of 120 women featured in a new exhibit, IfThenSheCan, at the Smithsonian to commemorate Women's History Month. A life-size 3D-printed statue of Elliott, a manufacturing scientist, was on display in the Smithsonian Castle in Washington in March. The statues recognize women who have excelled in STEM fields and is the largest collection of women statues ever assembled. Elliott, who leads ORNL's robotics and intelligent systems group, specializes in ink-jet-based 3D printing of metals and ceramics. Her inventions have been licensed by industry and have won prestigious awards including two R&D 100 Awards. She also holds several patents and licenses including a method for 3D metal printing of aluminum boron carbide metal composites. Now a STEM mom, she was honored to be 3D scanned for the statue while expecting her first child. For more on these unique STEM statues, see the 3D PrintShop on page 72.

Elliott and son John Luke next to her statue.

Agarwal Elected AAAS Fellow

Agarwal

Arvind Agarwal, FASM, professor and chair of Florida International University's department of mechanical and materials engineering and director of the Advanced Materials Engineering Research Institute, was elected Fellow of the American Association for the Advancement of Science (AAAS). "Agarwal was elected for his distinguished contributions to advanced materials, plasma spraying and carbon nanotube composites, biomechanics, bioengineering, nanotechnology and graphene foam reinforced advanced materials for deicing, which is of great benefit to aerodynamics," said Sudip Parikh, CEO and executive publisher of the AAAS *Science* family of journals. Agarwal obtained his Ph.D. in MSE from the University of Tennessee at Knoxville in 1999, then worked as a materials scientist at Plasma Processes Inc. in Huntsville, Alabama, for three years before becoming an academic. He has authored more than 350 publications, edited four books and co-authored three, and holds 10 U.S. patents. Agarwal serves on editorial boards of six journals and has organized numerous symposiums on surface engineering and nanomaterials.

IN MEMORIAM

Prewo

Karl M. Prewo, FASM, of Vernon Rockville, Conn., passed away on February 9. He was born and spent his early childhood in the predominantly German speaking Yorkville section of New York City. Prewo pursued studies at Rensselaer Polytechnic Institute and the Polytechnic Institute of Brooklyn, and received a doctorate from Columbia University. He had a 30-year career at United Technologies Research Center, during which time he was awarded 56 patents, two George Mead medals for engineering achievement, and the Horner Citation. He became a Fellow of both the American Ceramic Society and ASM International and authored over 80 technical papers and four chapters in materials science books. Prewo also taught extension courses at UCLA, University of Maryland, and the University of Surrey, U.K. For many years, he participated in an advisory capacity to the U.S. Air Force and the National Materials Advisory Board. For his work with global, cooperative scientific programs, he was awarded the Ishikawa Carbon Prize for International Collaboration in Tokyo and the Medal of Excellence in Composite Materials at the University of Delaware. After retiring from United Technologies, he helped secure National Science Foundation funding to create the Regional Center for Next Generation Manufacturing in Connecticut's community college system. Prewo participated in establishing the Connecticut Center for Advanced Technology and creating a multi-state National Aerospace Leadership Initiative for the U.S. Air Force to ensure that U.S. workers and companies were leaders in applying advanced manufacturing technologies. He was elected to the Connecticut Academy of Science and Engineering where he chaired the Economic Development Board.

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3D PRINTSHOP

Part of the "#IfThenSheCan-The Exhibit" on display at the Smithsonian in Washington.

LIFE-SIZE 3D-PRINTED STATUES CELEBRATE WOMEN IN STEM

The largest collection of statues of women were on display in Washington in March to help the Smithsonian commemorate Women's History Month. Each of the 120 life-size sculptures included a QR code with information about the women, who are all modern STEM innovators and role models from various fields. The statues have been previously displayed in Dallas, and a handful of them were in New York's Central Park Zoo.

Titled "#IfThenSheCan—The Exhibit," each statue was 3D printed in acrylic, cured with UV light, and then painted with a bright neon orange weather-resistant paint. Ellen Stofan, the Smithsonian's under secretary for science and research, said in a statement that the exhibit, "provides the perfect opportunity for us to show that women have successfully thrived in STEM for decades, while also illustrating the innumerable role models young women can find in every field." *ifthenexhibit.org.*

A MORE SUSTAINABLE CONCRETE FROM RECYCLED GLASS

By replacing sand with glass as the aggregate in concrete mix and then 3D printing the material, researchers hope to reduce the environmental impact in the construction industry. The scientists at Brunel University London and West Pomeranian University of Technology in Szczecin also note the 3D printed concrete can be used to produce previously unattainable shapes and forms.

They started with brown soda-lime beverage glass obtained from a local recycling company. The glass bottles were first crushed using a crushing machine and then the crushed pieces were washed, dried, milled, and sieved. The resulting particles were smaller than a millimeter square. The crushed glass was then used to make concrete in the same way that sand would be. They used this concrete to 3D print wall elements and prefabricated building blocks that could be fitted together to make a whole building.

The presence of glass not only solves the problem of waste but also contributes to the development of a concrete with superior properties than that containing natural sand. The thermal conductivity of soda-lime glass—the most common type of glass, found in windows and bottles—is more than three times lower than that of quartz aggregate, which is used extensively in concrete. This means that concrete containing recycled glass has better insulation properties and could substantially decrease the costs required for cooling or heating during summer or winter.

Researchers made other changes to the concrete mixture to make it more sustainable as a building material, including replacing some of the Portland cement with limestone powder. They found it can be used in 3D printing without a reduction in the quality of the printing mixture. *brunel.ac.uk.*

A building envelope prefabricated using 3D printing. Courtesy of Mehdi Chougan.

BRIEF

Desktop Metal, Boston, has launched ETEC, a new 3D printing brand that will enable EnvisionTEC, the original inventor of digital light processing (DLP) technology, to better connect with industrial customers. Desktop Metal acquired EnvisionTEC in 2021. ETEC will focus on bringing its high-speed, photopolymer 3D printing solutions to volume manufacturers of consumer and industrial products. *desktopmetal.com.*