FEBRUARY/MARCH 2021 | VOL 179 | NO 2

ADVANCED MATERIALS & PROCESSES

METALLOGRAPHY/MATERIALS CHARACTERIZATION

COMPUTER VISION AND MACHINE LEARNING TO QUANTIFY MICROSTRUCTURE

P. 13

ASM INTERNATIONAL

FEBRUARY/MARCH 2021 | VOL 179 | NO 2

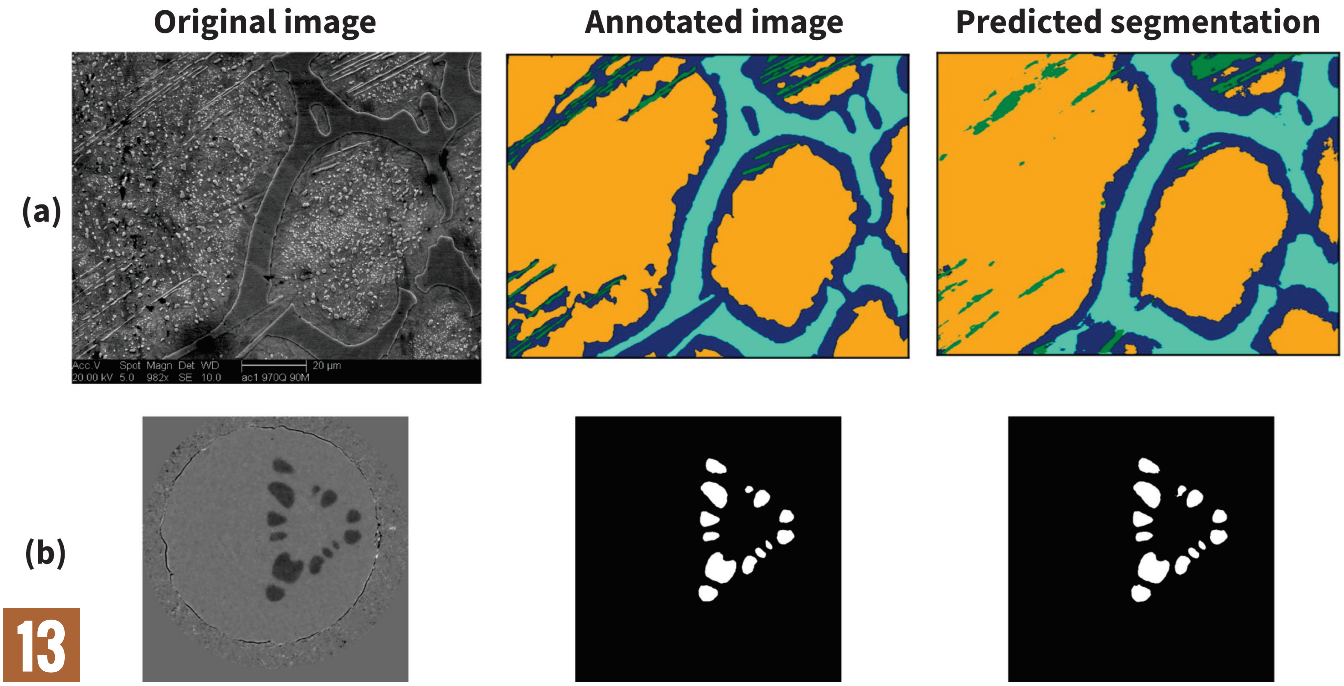
ADVANCED MATERIALS & PROCESSES

METALLOGRAPHY/MATERIALS CHARACTERIZATION

COMPUTER VISION AND MACHINE LEARNING TO QUANTIFY MICROSTRUCTURE

P. 13

ASM INTERNATIONAL



13

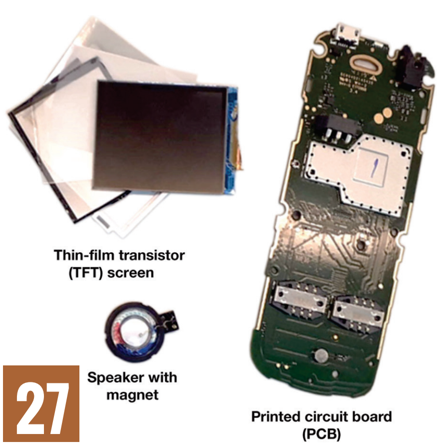
COMPUTER VISION AND MACHING LEARNING TO QUANTIFY MICROSTRUCTURE

Elizabeth A. Holm, Ryan Cohn, Nan Gao, Andrew R. Kitahara, Bo Lei, Srujana Rao Yarasi, and Thomas P. Matson

Computer vision and machine learning systems for microstructural characterization and analysis are used for a variety of image analysis tasks, including image classification, semantic segmentation, object detection, and instance segmentation.

On the Cover:

In this tiled image, an ultrahigh carbon steel microstructure with three carbide morphologies is segmented into spheroidite (green), Widmanstatten carbide (magenta), network carbide (teal), and ferrite (dark blue) using computer vision and machine learning. Courtesy of CMU Holm Group.



27

TECHNICAL SPOTLIGHT ADVANCED ICP-OES FOR RARE EARTH ELEMENT DETECTION

The latest advancements in ICP-OES systems are changing the landscape for rare earth element analysis.

34

ASM NEWS

The latest news about ASM members, chapters, events, awards, conferences, affiliates, and other Society activities.

40

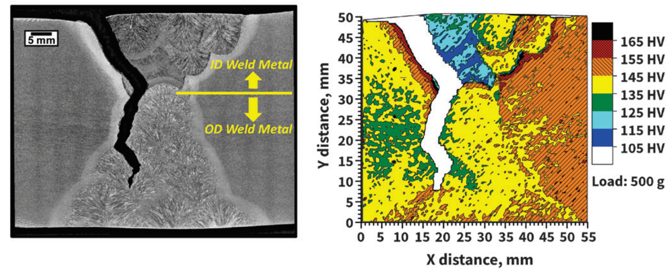
GEORGE DIETER REMEMBERED

ASM members share tributes to Dr. George E. Dieter, Jr., FASM, 1928-2020.

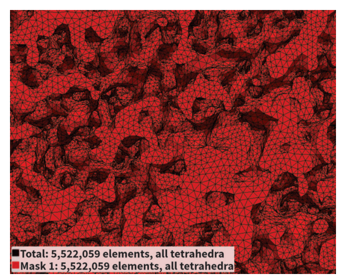
ADVANCED MATERIALS & PROCESSES

FEBRUARY/MARCH 2021 | VOL 179 | NO 2

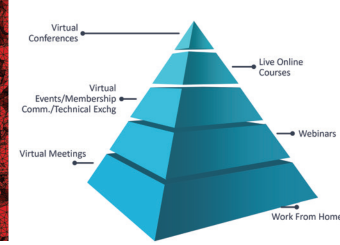
FEATURES



19



23



31

TRENDS

INDUSTRY NEWS

DEPARTMENTS

Advanced Materials & Processes (ISSN 0882-7958, USPS 762080) publishes eight issues per year: January, February/March, April, May/June, July/August, September, October, and November/December, by ASM International, 9639 Kinsman Road, Materials Park, OH 44073-0002; tel: 440.338.5151; fax: 440.338.4634. Periodicals postage paid at Novelty, Ohio, and additional mailing offices.
Vol. 179, No. 2, FEBRUARY/MARCH 2021. Distributed at no charge to ASM members in the United States, Canada, and Mexico. International members can pay a $30 per year surcharge to receive printed issues. Subscriptions: $499. Single copies: $54. POSTMASTER: Send 3579 forms to ASM International, Materials Park, OH 44073-0002.
Change of address: Request for change should include old address of the subscriber. Missing numbers due to "change of address" cannot be replaced. Claims for nondelivery must be made within 60 days of issue.
Canada Post Publications Mail Agreement No. 40732105. Return undeliverable Canadian addresses to: 700 Dowd Ave., Elizabeth, NJ 07201. Printed by Publishers Press Inc., Shepherdsville, Ky.

Check out the Digital Edition online at asminternational.org/news/magazines/am-p

ADVANCED MATERIALS & PROCESSES

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

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

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

Frances Richards and Corinne Richards
Contributing Editors

Jan Nejedlik, *Layout and Design*

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

Press Release Editor
magazines@asminternational.org

INSPIRING LEGACY

As the materials world mourns the recent passing of George Dieter, Jr., FASM, professor emeritus at the University of Maryland, his ASM family remembers the impact the industry legend had on so many lives, careers, and multiple disciplines.

Referencing his fundamental book *Mechanical Metallurgy,* Peg Jones, FASM, recalls, "We used a text simply referred to as 'Dieter' in one of my foundational undergrad courses that helped to establish the compass heading for my career." More tributes are shared on pages 40-41 and Dieter's illustrious career is described on the In Memoriam page in *ASM News.* It is obvious that his connection with an ASM network of friends and colleagues was an important part of his career and life and vice versa.

It is also striking that Professor Dieter's impact was not limited to metallurgical or mechanical engineering. With his keen intellect and intuitiveness, Dieter saw the need for designers to have access to materials and processing information to do their jobs well. As a result, he built a bridge between materials science and design with his text *Engineering Design* and through his leadership role in the development of *ASM Handbook,* Vol. 20, *Materials Selection and Design.* The link he formed between those disciplines continues to this day.

Now our field is seeing another bridge erected—this one between materials science and data—with ASM and its members playing a key role in this emerging area. In our lead article, Elizabeth Holm, FASM, and team detail how computer vision (CV) and machine learning (ML) can be used in tandem to provide detailed data about micrographs. The resulting data provides a complete analysis including image classification and other characterization information. Starting on page 13, read how the use of CV and ML complements traditional image analysis methods.

In related news, our Society already has several data ecosystem projects that are rapidly moving forward to respond to member and industry needs in this growing area. Other Societal initiatives are described in the "ASM Progress Report" in this issue, provided by Diana Essock, FASM. Our current ASM president walks us through the organization's response to the COVID-19 pandemic, including changes to staff operations, membership interactions, and delivery of products and services. The focus involves a switch to virtual offerings initially, followed by a transition to hybrid models. She also outlines the Board-led Task Forces that are key to advancing ASM's strategic goals in this new environment.

Directly related to the Task Force on Diversity/Equity/Inclusion is the newly formed IDEA Committee. You can read an update on their activities and future plans in the *ASM News* section. Immediately following that column is a message showing how you can "Get Engaged, Get Involved, Get Connected." You may see similar messages throughout the year as a welcoming invitation to participate in your Society. We hope you will join in and help move ASM forward.

It's one of the many ways we can carry on George Dieter's legacy: by getting engaged, involved, and connected; by working with passion and excellence; by mentoring and coaching the next generation of engineers; and by continuing work that bridges materials science to other disciplines.

joanne.miller@asminternational.org

Introducing the LEXT™ OLS5100

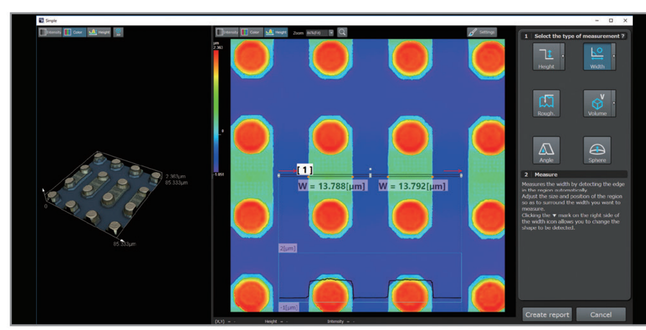
3D Measuring Laser Confocal Microscope

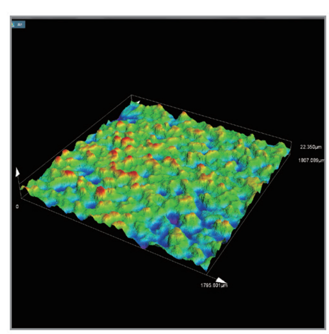
Design of Experiments Just Became Easier

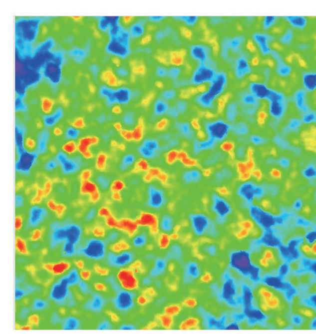
The new LEXT OLS5100 microscope's Smart Experiment Manager tool simplifies your workflow by automating time-consuming tasks.

With guaranteed accuracy, outstanding optical performance, and smart tools that make the system easy to use, the OLS5100 microscope makes precisely measuring shape and surface roughness at the submicron level fast and efficient, simplifying your workflow and delivering high-quality data you can trust.*

- Automatically create your experiment plans with ease
- Auto populate data to your experiment plan matrix, reducing the chance of input errors
- Clear data trend visualization tools



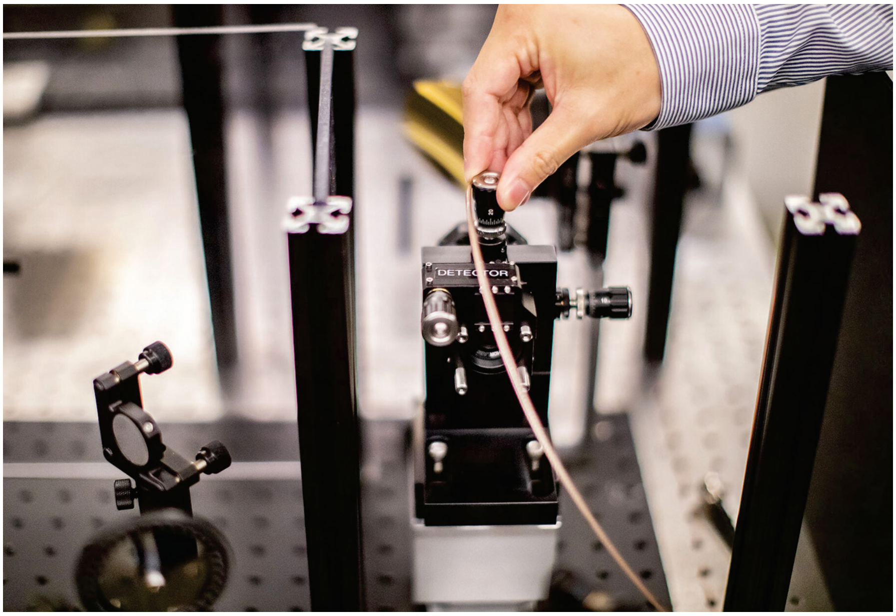




To learn more about the OLS5100 microscope, visit:
https://www.olympus-ims.com/microscopes/laser-confocal/ols5100

*To guarantee XY accuracy, calibration work must be undertaken by an Olympus service technician.

RESEARCH TRACKS



New research demonstrates that two metal alloys are able to efficiently convert light into electricity. Courtesy of University of Pennsylvania.

ANALYZING TOPOLOGICAL MATERIALS

Two recent studies, one on rhodium monosilicide and the other on cobalt monosilicide, could provide a new approach for developing devices such as photodetectors and solar cells. Both studies demonstrate that there is a topological origin to the ability of two related metal alloys to convert light into electrical current. Both studies were led by assistant professor Liang Wu of the University of Pennsylvania and involved collaborators from the University of Fribourg, French National Centre for Scientific Research, Max Planck Institute for Chemical Physics of Solids, Donostia International Physics Center, University of Maryland, Instituto de Ciencia de Materiales de Madrid, and University of Grenoble.

Wu and his lab are working on a number of projects involving topological materials for use in new applications and devices. The team's most recent findings are focused on ways to convert light into electric current through a better understanding of the relationship between photocurrent and topology. Their research uses terahertz emission spectroscopy to gain new insights into the material. The researchers found that both CoSi and RhSi's photocurrents were purely topological in origin, although in RhSi this response was less pronounced. The conclusion in RhSi applies at much lower photon energy than previous theories predicted, which could be due to the presence of more defects in this compound. By using a combination of both experiment and theory, these results also have further implications for improving topological materials for more widespread use in the future.

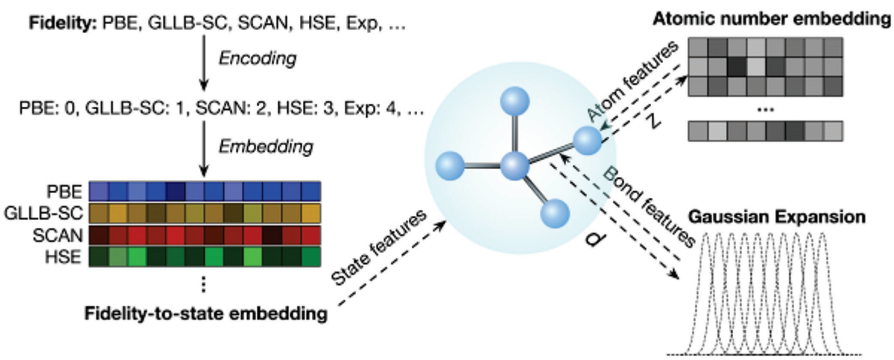
"This study will potentially enable new electronic device concepts based on these emerging topological materials that consume less power, are more energy efficient, and ultimately lead to new electronic systems with improved size, weight, and power for the U.S. Army," says Joe Qiu, program manager at the Army Research Office, which funded the research. *upenn.edu.*

USING AI IN MANUFACTURING

The Alan Turing Institute and the University of Sheffield Advanced Manufacturing Research Center (AMRC), both in the U.K., will work together toward three specific goals: identifying opportunities for artificial intelligence (AI) adoption in manufacturing, accelerating research collaboration, and boosting skills development. The two organizations signed a memorandum of understanding that will take advantage of their combined research and development skills across manufacturing, data science, machine learning, and AI. Researchers from Turing and AMRC plan to find solutions to some of the grand challenges facing the manufacturing sector, such as how to meet increasing demand and how to best respond to COVID-19. The AMRC is comprised of a network of leading research and innovation centers that work with manufacturing companies of all sizes around the globe. The Alan Turing Institute is the U.K.'s national institute for data science and artificial intelligence, with headquarters at the British Library in London. *www.amrc.co.uk.*

Researchers at The Alan Turing Institute are working on AI approaches to manufacturing.

MACHINE LEARNING | AI



Schematic of a multi-fidelity graph networks approach to more accurately predicting material properties. Courtesy of the Materials Virtual Lab at UC San Diego.

IMPROVING MATERIAL PROPERTY PREDICTIONS

By combining large quantities of low-fidelity data with smaller amounts of high-fidelity data, nanoengineers at the University of California San Diego developed a new machine learning method to more accurately predict material properties. The team believes their approach is also the first to predict the properties of disordered materials. Researchers looked at the band gaps of various materials as proof of concept. Their multi-fidelity graph networks led to a 22-45% decrease in the mean absolute errors of experimental band gap predictions, compared to a traditional single-fidelity approach.

"There is no fundamental limitation as to what properties this can be applied to," says Professor Shyue Ping Ong, whose team plans to use the new method to develop better materials for energy storage, photovoltaic cells, and semiconductor devices. "What we show in this work is you can actually adapt a machine learning algorithm to predict the properties of disordered materials. In other words, now we are able to do materials discovery and prediction across the entire space of both ordered and disordered materials rather than just ordered materials. As far as we know, that is a first." *ucsd.edu.*

DEVELOPING SUPERHARD MATERIALS

A machine learning model developed at the University of Houston (UH) and Manhattan College, Riverdale, N.Y., can accurately predict the hardness of new materials. Superhard materials—defined as having a hardness value exceeding 40 gigapascals on the Vickers scale—are rare, which makes identifying new materials challenging, according to UH professor Jakoah Brgoch. One of the complicating factors is that the hardness of a material may vary depending on the amount of pressure exerted, known as load dependence. That makes testing a material experimentally complex and using available computational modeling methods almost impossible.

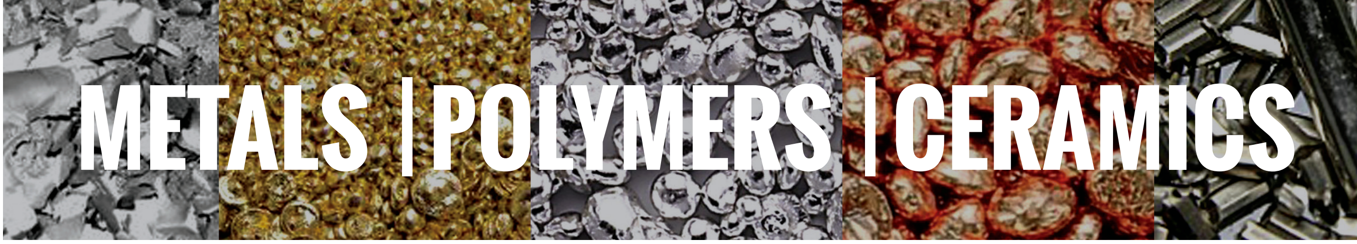
The new model overcomes this hurdle by predicting the load-dependent Vickers hardness based solely on chemical composition. The team says the accuracy of their new model is 97%. "The idea of using machine learning isn't to say, 'Here is the next greatest material,' but to help guide our experimental search," says Brgoch. The researchers report finding more than 10 new and promising stable borocarbide phases with work now underway to produce the materials for lab testing. *uh.edu.*

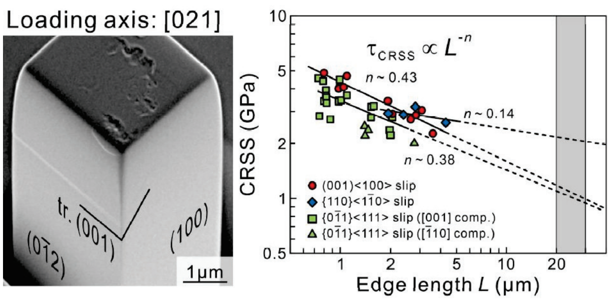
New machine learning model accurately predicts the hardness of new materials. Courtesy of University of Houston.

BRIEF

A multi-institutional team including researchers from the **National Institute of Standards and Technology,** Gaithersburg, Md., developed an artificial intelligence algorithm called CAMEO (Closed-Loop Autonomous System for Materials Exploration) that discovered a potentially useful new material without needing help from scientists. CAMEO determines which experiment to run on a material, conducts the experiment, and collects the data. It can also ask for more information such as crystal structure before running the next iteration. *nist.gov.*

METALS | POLYMERS | CERAMICS





Scientists measured the plastic deformation that occurred when a tiny probe exerted force on the micropillar specimens with various loading axis orientations. Courtesy of National Institute for Materials Science.

HEAT-TOLERANT ALLOYS UNDER PRESSURE

Scientists at Kyoto University in Japan are studying atomic-level measurements to develop more heat-tolerant components in gas turbines. Metals containing niobium silicide are promising materials that can withstand high temperatures and improve efficiency of power plant aircraft turbines, but it has been difficult to accurately determine their mechanical properties due to their complex crystal structures. The new microlevel approach could help scientists obtain the accurate measurements needed to understand the atomic-level behavior of complex crystals under pressure.

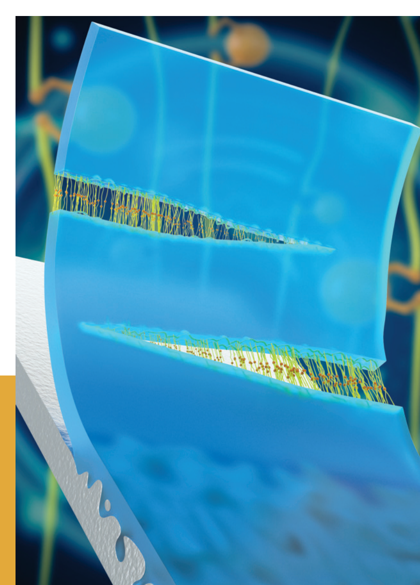
"Our results demonstrate the cutting edge of research into plastic deformation behavior in crystalline materials," researcher Kyosuke Kishida says. In the work, scientists measured plastic deformation in a niobium silicide called α-Nb5Si3. Tiny micropillars of these crystals were exposed to very small amounts of stress using a machine with a flat-punch indenter at its end. The stress was applied to different faces of the sample to determine where and how plastic deformation occurs within the crystal. By using scanning electron microscopy on the samples before and after the test, they were able to detect the planes and directions in which deformation occurred. This was followed by simulation studies based on theoretical calculations to further understand what was happening at the atomic level. Finally, the team compared the results with those of a boron-containing molybdenum silicide they had previously examined. The team plans to use their approach to study mechanical properties of other crystalline materials with complex structures. *www.kyoto-u.ac.jp/en.*

REPURPOSING WHEAT FOR FOAMS

University of Córdoba, Spain, researchers found a new way to repurpose wheat straw by using it as the foundation to manufacture polyurethane foams. Until now, this agricultural excess material had no well-defined use and produced exorbitant amounts of waste. Plastic "foam rubber" material, often manufactured from petroleum by-products, is extremely versatile and has multiple uses in the construction and automobile sectors as a sealant as well as a thermal and acoustic insulator.

To date, castor oil has been one of the main candidates in the race to obtain sustainable polyurethane foam that does not require petroleum. One of the challenges is that this vegetable-based oil does not offer complete hardness and dryness once exposed to air, one of the keys to proper rubber foam formation, according to researchers. For this reason, the new research proposed substituting 50% of this castor oil for wheat straw, with results that offer similar characteristics to those generated by traditional manufacturing processes that use nonrenewable compounds. "We were able to obtain very desirable parameters in the manufacturing of foam, converting 96% of the wheat used with an almost maximum performance," explain researchers. In addition, they obtained higher levels of biodegradability than those reached by the products currently on the market.

After the wheat waste is liquefied, polyols are obtained. These polyols are one of the key compounds that play a



ORNL's tough elastomers have uses in the automotive and electronics industries.

BRIEF

Researchers from the DOE's **Oak Ridge National Laboratory,** Tenn., used a blend of a self-healing polymer with curable elastomers to produce a series of self-healable and highly adhesive materials. The elastomers can self-repair in ambient temperatures and conditions, as well as underwater, with their adhesive force only minimally impacted by surface dust. *ornl.org.*

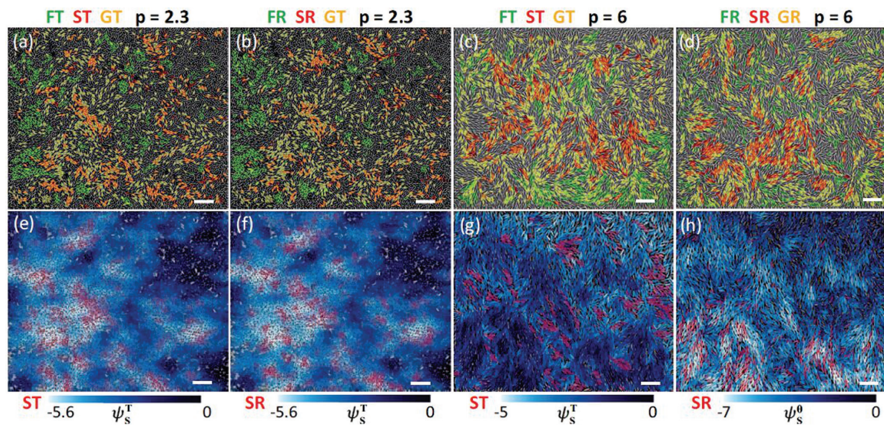
role in the chemical reaction that makes polyurethane foams. While these new polyurethane foams could have myriad applications and even be manufactured with other kinds of biomass, the research group, in the second stage of their study, will use them in plant nurseries to help with plant growth. *www.uco.es.*

FORMING GLASS MATERIALS

Researchers from the Institute of Mechanics of the Chinese Academy of Sciences and Hong Kong University of Science and Technology recently conducted experimental studies for the first time on glassy systems composed of nonspherical particles. They found the monolayers of monodisperse ellipsoids are good glass formers and do not form local crystalline structures. Thus, they provide an ideal and general system for detecting the structural origin of slowing dynamics as the glass transition is approached.

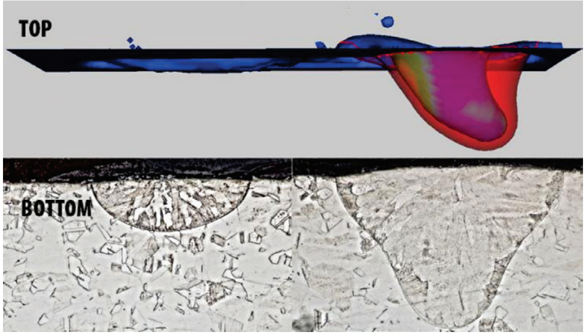
Glass formers have strong dynamic heterogeneities—some regions move fast while others move slow. These results show that structures with low structural entropy correspond well with slow dynamics, whereas fast relaxing regions have high structural entropy. The low structural entropy is a general structural feature of slow dynamics in glassy matter, which holds in systems composed of spheres and non-spheres.

According to the researchers, "The observation of critical behaviors in ellipsoid glasses provides much more solid quantitative evidence of the thermodynamic nature of glass transition. The results shed new light on both the mysteries of glass theory and designing materials with high stability and glass forming ability." *www.english.imech.cas.cn.*



Spatial correlations between slow-dynamics (red ellipses) and low-structural-entropy (light blue) regions in translational and rotational motion of colloidal ellipsoids with different aspect ratios. Courtesy of Yuren Wang.

TESTING | CHARACTERIZATION



Top: multi-physics simulation of laser-induced melting of stainless steel, showing the electron emission signal primarily produced at the front of the surface depression. Bottom: cross sections of laser tracks produced in stainless steel. Courtesy of Aiden Martin/LLNL.

METAL 3D PRINTING

Lawrence Livermore National Laboratory, Calif., researchers are measuring the emission of electrons from the surface of stainless steel during laser processing to improve the reliability of laser-based metal 3D-printing techniques. They collected thermionic emission signals from 316L stainless steel under laser powder bed fusion (LPBF) conditions using a custom testbed system and a current preamplifier that measured the flow of electrons between the metal surface and the chamber. Then, they used the generated thermionic emission to identify dynamics caused by laser-metal interactions.

The results illustrate the potential for thermionic emission sensing to detect laser-driven phenomena that can cause defects in parts, optimize build parameters, and improve knowledge of the LPBF process while complementing existing diagnostic capabilities. The ability to capture thermal emission of electrons will help advance basic understanding of the laser-material interaction dynamics involved in the LPBF process and support the broader technology maturation community in building confidence in parts created using the technique.

By observing and analyzing the electrons emitted during laser processing, lab researchers demonstrated they could tie increases in thermionic emission to surface temperature and laser scanning conditions that cause pore formation and part defects. The work represents an important step toward establishing effective in situ monitoring capabilities that can accelerate qualification and certification of LPBF components, the researchers say. *llnl.org.*

NONDESTRUCTIVE IMAGING WITH PHOTONS

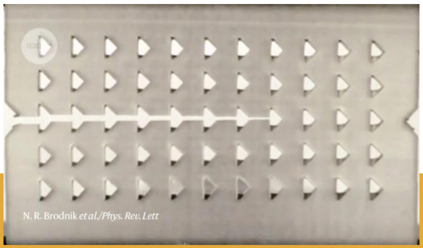
A collaborative research team from Humboldt-Universität zu Berlin and the Research Center for Non-Destructive Testing GmbH, Austria, showed that entangled photons can be used to improve the penetration depth of optical coherence tomography (OCT) in highly scattering materials. The method, as published in *Optica,* represents a way to perform OCT with mid-infrared wavelengths and could be useful for nondestructive testing and analysis of materials such as ceramics and paint samples.

Researchers demonstrated their proof-of-concept experiment for mid-infrared OCT based on ultrabroadband entangled photon pairs. They showed that this approach can produce high quality 2D and 3D images of scattering samples using a relatively compact, straightforward optical setup. This method eliminates the need for broadband mid-infrared sources or detectors, which have made it challenging to develop practical OCT systems that work at these wavelengths. The technique could be useful for many applications including analyzing the complex paint layers used on airplanes and cars or monitoring pharmaceutical coatings. It can also provide detailed 3D images that could be useful for art conservation.

For their technique, the researchers developed and patented a nonlinear crystal that creates broadband photon pairs with varying wavelengths. They tested the setup on a range of real-world samples, including highly scattering paint samples. The team is now working with industry partners and other research institutes to develop a compact OCT sensor head and full system for a pilot commercial application. *www.osa.org/en-us.*

BRIEF

Katherine Faber, FASM, and her colleagues at the **California Institute of Technology,** 3D-printed rectangular plates with a regular array of triangular holes. Overall, the holes made the material tougher than it would have been without them. But when pulled from its edges, the material tended to break in a specific pattern—if the triangles pointed right, a crack first formed on the left and propagated rightwards. This cracking sequence revealed that the patterning caused an asymmetrical improvement in toughness. The researchers say their technique could help steer cracks in a prescribed direction and help protect critical components when a failure is inevitable. *nature.com.*

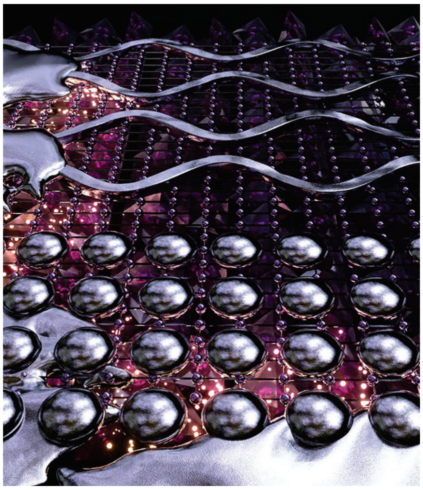


Triangular holes make this material more likely to crack from left to right. Courtesy of N.R. Brodnik et al./*Phys. Rev. Lett.*

DEFYING CONVENTIONAL METALLURGY

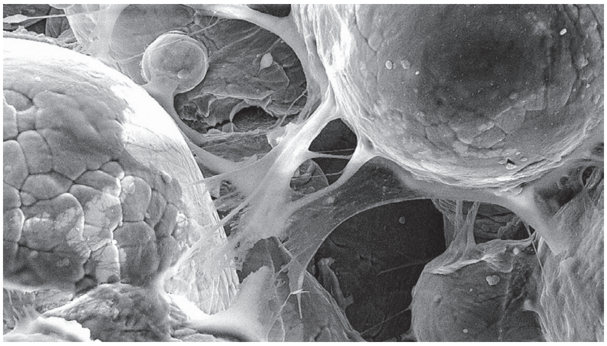
Researchers from the University of New South Wales, Sydney, along with international collaborators, discovered that diverse types of patterns occur at the surface of solidified metal alloys. The team used two-component metallic mixes, such as gallium-based alloys containing small amounts of bismuth. With electron microscopy, they were able to observe a kaleidoscope of highly ordered patterns including alternating stripes, curved fibers, dot arrays, and some exotic stripe-dot hybrids on the metallic surfaces. The team found that, when these patterns are formed, the abundance of the low-concentration element bismuth at the surface region was notably increased. Such surface enrichment found in this study defies conventional metallurgical understandings.

The researchers related the magic behind this newly observed solidification phenomenon to the unique surface structures of liquid metals. "This previously ignored surface solidification phenomenon improves our fundamental understanding of liquid metal alloys and their phase transition processes. In addition, this autonomous surface process can be used as a patterning tool for designing metallic structures and creating devices for advanced applications in future electronics and optics," says Prof. Kourosh Kalantar-Zadeh, corresponding author. *www.unsw.edu.au.*



Stripes, dots, and other exotic patterns on the surface of liquid metal after solidification. Courtesy of Jialuo Han/UNSW.

SURFACE ENGINEERING



This image shows cells adhering to a titanium alloy created by cold-spray 3D printing, which demonstrates the material's biocompatibility. Courtesy of Cornell University.

3D PRINTING WITH COLD SPRAY

A collaboration led by Cornell University recently developed a 3D-printing technique that creates cellular metallic materials by using cold spray. According to the researchers, the materials have applications in thermal management, energy absorption, and biomedicine. The new method uses a nozzle of compressed gas to fire titanium alloy particles at a substrate. During testing, the particles were between 45-106 microns in diameter and traveled at roughly 600 meters per second, faster than the speed of sound. Researchers used computational fluid dynamics to calibrate the alloy's ideal speed. When launched at a slightly slower rate, the particles created a more porous structure, which is ideal for biomedical applications.

Once the particles collided and bonded together, the researchers heated the metal so the components would diffuse into each other and settle like a homogeneous material. "We only focused on titanium alloys and biomedical applications, but the applicability of this process could be beyond that," they say. "Essentially, any metallic material that can endure plastic deformation could benefit from this process. And it opens up a lot of opportunities for larger-scale industrial applications, like construction, transportation, and energy." *cornell.edu.*

NEW ATOMIC LAYER DEPOSITION METHOD

Scientists at The University of Alabama in Huntsville (UAH) found a new way to deposit thin layers of atoms as a coating onto a substrate material at near room temperatures. Researchers applied ultrasonic atomization technology to evaporate chemicals used in atomic layer deposition (ALD), a technique central to microelectronics manufacturing.

Each ALD cycle deposits a layer a few atoms deep. The ALD process then repeats the deposition cycle hundreds or thousands of times. ALD processes typically rely on heated gas-phase molecules that are evaporated from their solid or liquid form, like room humidifiers that use heat to vaporize water. However, in that particular ALD process, some chemical precursors are not stable and can decompose before reaching a sufficient vapor pressure for ALD. The UAH ultrasound invention makes it possible to use a wide range of reactive chemicals that are thermally unstable and not suitable for direct heating.

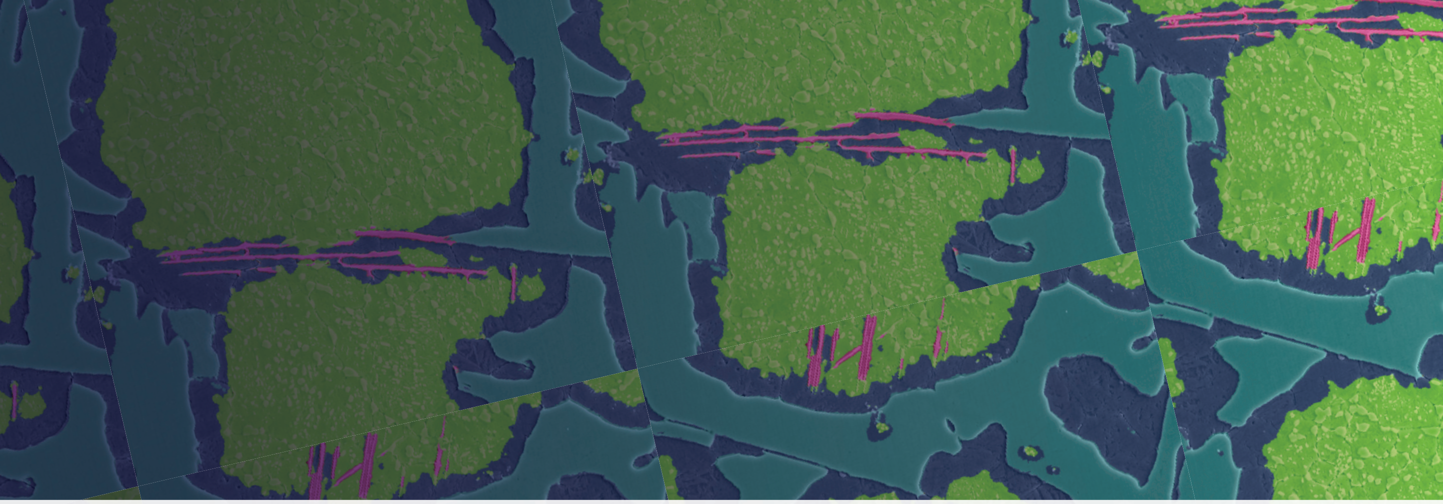
"Ultrasonic atomization, as developed by our research group, supplies low vapor pressure precursors because the evaporation of precursors was made through ultrasonic vibrating of the module," explains associate professor Yu Lei. "Like the household humidifier, ultrasonic atomization generates a mist consisting of saturated vapor and micro-sized droplets. The droplets continuously evaporate when the mist is delivered to the substrates by a carrier gas."

The new process uses a piezoelectric ultrasonic transducer placed in a liquid chemical precursor. Once started, the transducer begins to vibrate a few hundred thousand times per second and generates a mist of the chemical precursor. The small liquid droplets in the mist are quickly evaporated in the gas manifold under vacuum and mild heat treatment, leaving behind an even coat of the deposition material. "Using the room-temperature ultrasonic atomization, new ALD processes could be developed using low volatility and unstable precursors," says Lei. *uah.edu.*

BRIEF

ASB Industries, Barberton, Ohio, added a new thermal spray ABB robot manipulator to its equipment lineup. The new robot, with its small footprint, gives ASB the flexibility to use customized process fixtures that can adapt to its clients' parts processing. The robot arm fits a variety of thermal spray guns. *asbindustries.com.*

Recent addition to ASB's robot family.



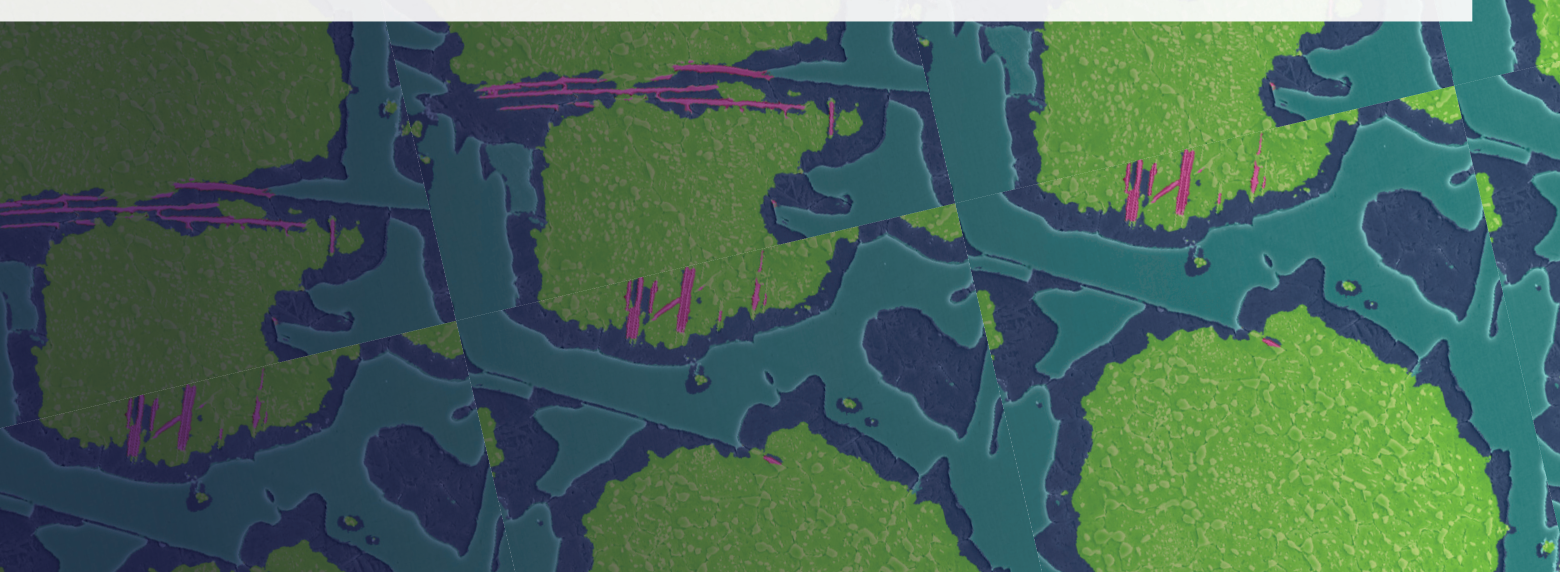
COMPUTER VISION AND MACHINE LEARNING TO QUANTIFY MICROSTRUCTURE

Elizabeth A. Holm, FASM,* Ryan Cohn,* Nan Gao,* Andrew R. Kitahara,* Bo Lei,* and Srujana Rao Yarasi*
Carnegie Mellon University, Pittsburgh

Thomas P. Matson, Carnegie Mellon University, Pittsburgh and MIT, Cambridge, Massachusetts

Computer vision and machine learning systems for microstructural characterization and analysis are used for a variety of image analysis tasks, including image classification, semantic segmentation, object detection, and instance segmentation, leading to accurate, autonomous, objective, repeatable results in an indefatigable and permanently available manner.

*Member of ASM International



Quantitative representation of microstructure is the foundational tool of microstructural science, connecting the material's structure to its composition, process history, and properties. Microstructural quantification traditionally involves a human deciding *a priori* what to measure and then devising a purpose-built method for doing so. However, recent advances in data science, including computer vision (CV) and machine learning (ML), offer new approaches to extracting information from microstructural images[1-7]. The objective of CV is to represent the visual content of an image in numerical form, and ML makes use of these representations to accomplish a given goal. Given a microstructural image, a CV/ML system can perform a variety of analysis objectives, including image classification (e.g., ferritic, austenitic, martensitic), property prediction (e.g., yield strength), feature measurement (e.g., grain size), constituent identification (e.g., phase identification), or a host of other characterization tasks. The CV/ML approach is not a single solution that addresses every microstructural science challenge, but it offers a path toward objective, repeatable, generalizable, and scalable methods that complement the traditional materials characterization workflow.

...THE MOST VALUABLE MICROSTRUCTURAL DATA SETS INCLUDE METADATA THAT ENRICHES THEIR INFORMATION CONTENT.

COMPUTER VISION AND MACHINE LEARNING

Computer vision encompasses an array of methods for creating a numerical representation of a visual image, termed the feature vector[8]. Machine learning methods then extract quantitative visual information from the high-dimensional feature vector[9]. Most high-performance CV/ML systems currently use convolutional neural networks (CNNs), which take an image as input, apply a variety of signal processing operations to it in order to encode it as a vector, and then utilize an artificial neural network or other ML method to draw a conclusion about the visual content of the image[10,11]. The first part of the CNN pipeline—encoding the image as a feature vector—is termed the feature learning stage, and the second part—drawing a conclusion—is the classification stage.

Designing and training a CNN requires deep expertise and a large data set (typically millions of images), making it impractical for most microstructural data sets. However, CNNs that have been optimized and trained on a large set of natural images have been successfully used with other kinds of images, including microstructures. This transfer learning[12] approach enables using pre-trained CNNs (such as the VGG16 network[13] trained on the ImageNet data set[14]) for microstructural representation. However, because the goal is not to classify microstructural images into the ImageNet categories (broccoli, bucket, bassoon), the network is truncated before the classification stage. Instead, the CNN layers themselves are used as the image representations for ML tasks.

Machine learning methods are either supervised (trained using known correct answers, termed ground truth) or unsupervised (finding patterns without knowledge of a ground truth), and there are important roles for each approach. Supervised ML methods make predictions about new data based on information learned from training data with known ground truth answers[10,11,15]. In contrast, unsupervised ML algorithms find relationships between images without ground truth data or human intervention, typically by generating clusters of related images[6,16]. The choice of ML modality and model depends on the nature of the input data and the desired outcome. In this process, it is helpful to include a domain expert in ML algorithms because the best-in-class solutions are ever-evolving.

MICROSTRUCTURAL IMAGE DATA

When assembling an image data set for CV/ML analysis, image quality is less important than exposing the ML system to the full scope of the data space. This is not a recommendation to ignore good microscopy practices, but rather a suggestion that many acceptable images are better than one perfect image. Data collection practices that increase the performance of CV/ML systems include taking redundant images of a sample with non-overlapping fields of view, standardizing imaging conditions (such as instrument, settings, magnification, and orientation), and data augmentation via subsampling or affine transformations such as translation or rotation[17]. Moreover, the most valuable microstructural data sets include metadata that enriches their information content. Metadata may include multiple imaging modalities (e.g., EBSD and backscatter data for the same field of view), as well as information on material system, composition, imaging information, processing history, property measurements, and any other data available related to the image.

Data size is often assumed to be the limiting factor in developing CV/ML methods, and in some cases it is. However, excellent results have been achieved with very small numbers of original micrographs (sometimes fewer than 10). This has to do with the data-richness of microstructural images. The upshot is that a relatively modest investment in data may yield a successful CV/ML system.

IMAGE CLASSIFICATION AND CHARACTERIZATION

Image classification may not seem important, because microstructures are usually known. However, classification of images underlies a host of critical archiving and analysis tasks. Classification relies on the fact that the CV feature vector is a numerical representation of the visual information contained in an image. As such, similarities in the feature vector should correspond to visual similarities. Thus, the distance between two feature vectors can be used to perform visual search, clustering, and classification. For example, for a database of 961 ultrahigh carbon steel (UHCS) microstructures[18] Fig. 1 shows the three

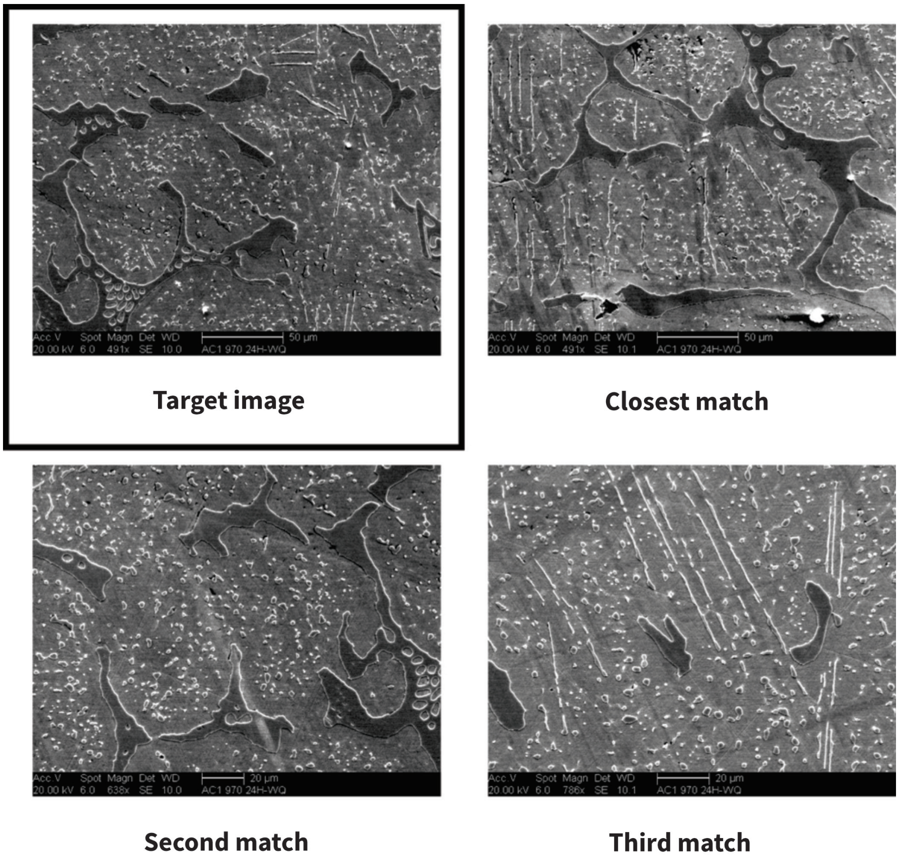


Fig. 1 — Visual search for images with similar feature vectors in a database of 961 ultrahigh carbon steel micrographs[18]. Visually similar micrographs contain similar microstructural constituents, here comprised of a mix of network, Widmanstatten, and spheroidite carbides.

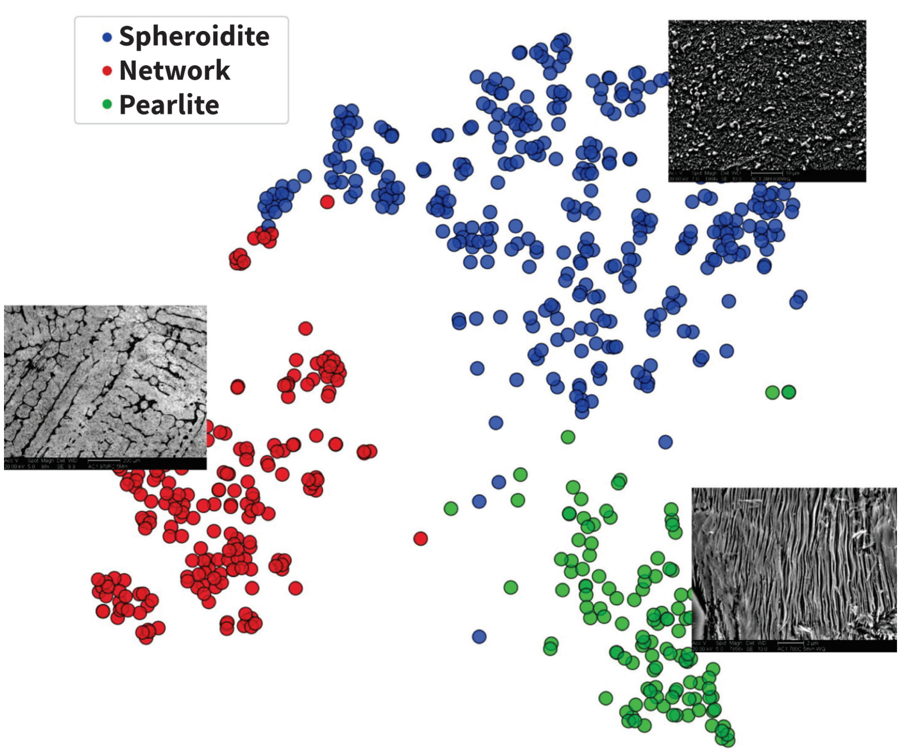


Fig. 2 — Visual clustering plot in which micrographs cluster according to their primary microconstituent: spheroidite (blue), network carbide (red), or pearlite (green)[2]. Example microstructures for each cluster are shown in the insets.

images with feature vectors closest to that of a given target image; obviously, feature vector similarity is reflected in visual similarity. This makes it easy to search an image database for related microstructures. For the same set of UHCS micrographs, Fig. 2 shows a visual clustering map where each point represents an image; point color corresponds to the primary microstructural constituent in each micrograph. Clearly, similar images cluster, which illustrates the visual structure of the data set.

Feature vectors can also be used to quantify microstructural information directly. Figure 3 shows an example that uses the feature vector to measure average grain size in polycrystalline microstructures; the results are within a standard error of 2.3%. Finally, the feature vector can contain visual information that is not perceptible to humans. For instance, chemical composition is not usually measured visually, but rather with specialized tools such as energy dispersive spectroscopy (EDS). Figure 4 shows the results of a ML approach that achieves 76% total accuracy in classifying the composition of inclusions in steel from backscattered SEM images. This demonstrates the ability of the CV/ML system to sense subtle visual details like feature size, shape, contrast, and color distribution with a fidelity that exceeds human perception.

SEMANTIC SEGMENTATION

Quantitative measurement of materials microstructure typically requires the image to be segmented, where each pixel in the image is assigned to a microstructural constituent. Conventional segmentation algorithms, such as those incorporated in ImageJ[19], can work well on suitable microstructures, but become less effective for complex or non-ideal images and often require considerable human intervention. Therefore, we turn to CV/ML methods to address these challenges.

Image segmentation has important applications in robotics and medical imaging among others, so there is considerable research activity in developing segmentation methods. These methods can be adapted to microstructural images via transfer learning. For example, the PixelNet CNN[20] trained on the ImageNet database of natural images[14] has been used to classify pixels according to their microstructural constituent as shown in Fig. 5. In Fig. 5a, the system was trained using 20 hand-annotated images from the UHCS micrograph database[3], and in Fig. 5b, the system was trained on 30 hand-annotated images from a set of tomographic slices of an Al-Zn solidification dendrite[21]. In both cases, the predicted segmentations are arguably equal in quality to the human annotations, and certainly adequate for quantitative analysis. Besides the excellent performance, the CV/ML system is also fast, autonomous, objective, and repeatable, enabling the high throughput necessary for applications such as 3D reconstruction or quality control.

An additional benefit of this approach is the ability to capture human-like judgments about image features. For instance, in Fig. 5a, the spheroidite matrix constituent, comprised of spheroidite particles in a ferrite matrix, is segmented as a single constituent (orange). Likewise, in Fig. 5b, the system learns to ignore sample preparation artifacts such as the sample edge, pores, and the circular beam spot at the center of the image. Conventional segmentation methods would be challenged to handle these complex features. It is this capacity for learning what to look for and what to ignore that distinguishes the CV/ML approach to semantic segmentation.

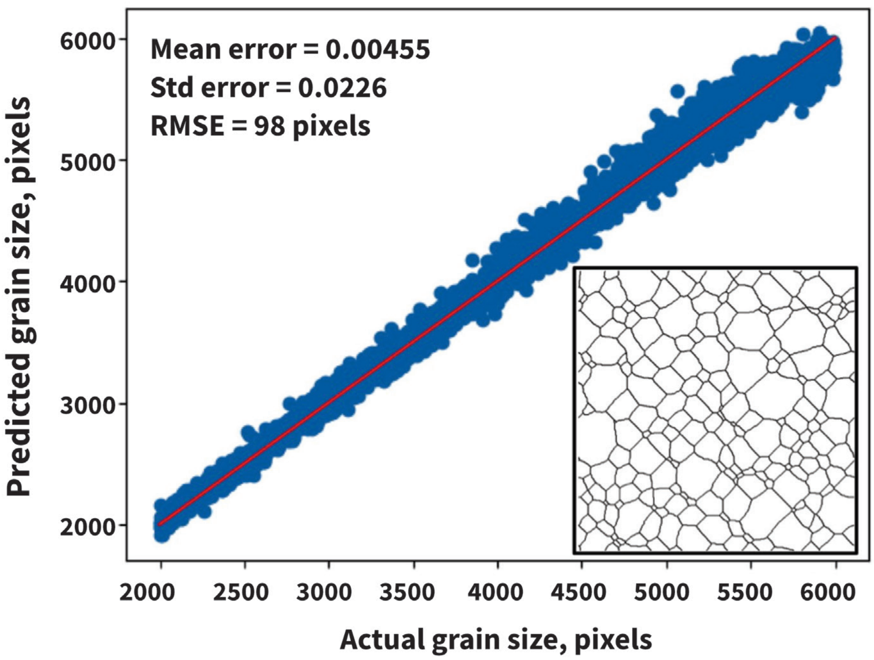


Fig. 3 — Measurement of average grain size from a database of 15,213 synthetic polycrystalline microstructures using deep regression. The red line corresponds to perfect accuracy. Inset shows an example microstructure.

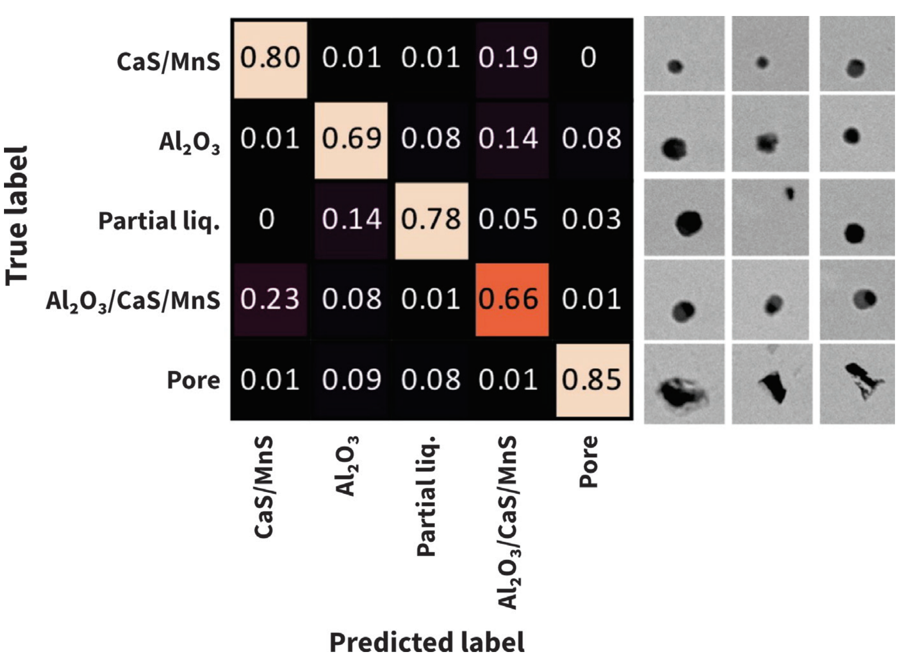


Fig. 4 — Classification results for steel inclusion composition from a database of 2543 backscattered SEM image patches (example images are shown to the right). The prediction accuracy for each inclusion type is shown along the diagonal; overall accuracy is about 76%.

OBJECT DETECTION AND INSTANCE SEGMENTATION

Object detection entails locating each unique object of its kind in an image, i.e., finding each individual precipitate in a micrograph. Instance segmentation extends this technique to also generate segmentation masks for each individual object. Specialized CNNs have been developed for object detection and instance segmentation[22]. As in the case of semantic segmentation, transfer learning allows models trained on natural images to be adapted to materials science applications.

For example, the presence of small satellite particles is known to affect the flowability of metal powders used in additive manufacturing. A CV/ML approach utilizing object detection and instance segmentation demonstrated the ability to identify individual powder particles and their satellites in dense powder images. Tedious manual annotation yielded five and ten labeled images for powder particles and satellites, respectively. The CV/ML system was trained on these images, and sample predictions are shown in Fig. 6. The powder particle masks showed very good agreement

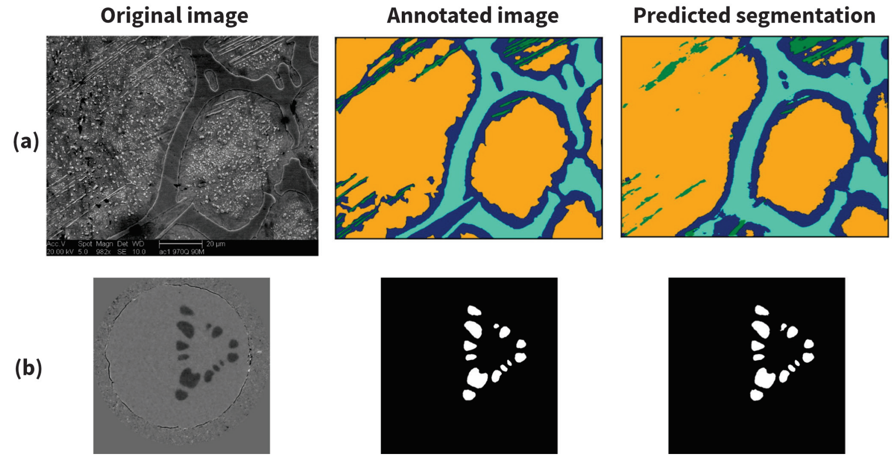


Fig. 5 — Semantic segmentation of microstructural images using a CV/ML system. (a) Segmentation of microstructural constituents in an SEM micrograph of ultrahigh carbon steel. Constituents include network carbide (light blue), ferritic denuded zone (dark blue), Widmanstatten carbide (green), and spheroidite matrix (gold). (b) Segmentation of a tomographic section of an Al-Zn alloy. The solidification dendrite is shown in white on a black background.

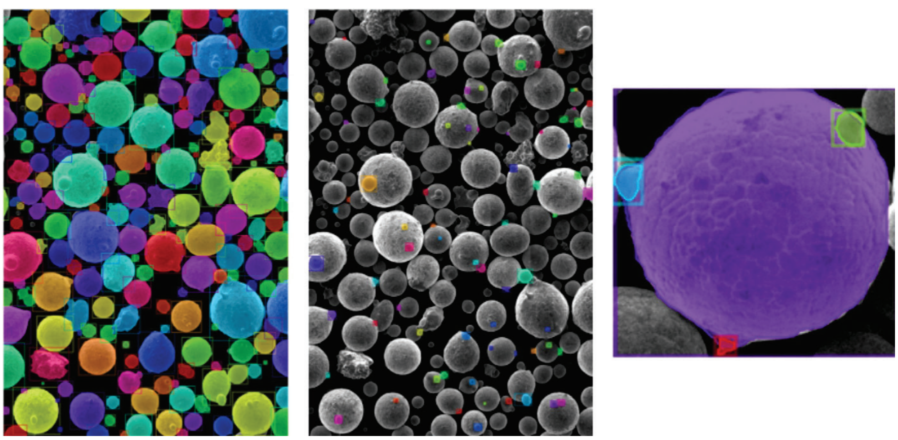


Fig. 6 — Predicted powder particle (left) and satellite (middle) segmentation masks for SEM images of metal powders used in additive manufacturing. Colors are randomly assigned for visual clarity and do not have physical significance. Sample satellited powder particle (right) detected by overlaying the powder particle and satellite masks.

with the manual annotations and indicated that the model approached human-level performance for identifying individual particles. Detecting satellites is a much harder problem, resulting in lower model performance. However, most of the predictions still matched with the annotations, indicating that satellites can consistently be detected in these images. Overlaying the particle and satellite masks to determine the fraction of particles that contain satellites provided a new, objective, and self-consistent method of characterizing the satellite content of powder samples that showed good agreement with the expected trends for images of different powder samples.

CONCLUSIONS

The key function of CV is to numerically encode the visual information contained in a microstructural image for ML algorithms to find associations and trends. CV/ML systems for microstructural characterization and analysis span the gamut of image analysis tasks, including image classification, semantic segmentation, object detection, and instance segmentation. Applications include:

- Visual search, sort, and classification of micrographs via feature vector similarity.
- Extracting information not readily visible to humans, such as chemical composition in SEM micrographs.
- Performing semantic segmentation of microstructural constituents with a high accuracy and human-like judgment about what to look for and what to ignore.
- Finding all instances of individual objects, even when they impinge and overlap.
- Segmenting individual objects to enable new capabilities in microstructural image analysis.

A common characteristic among all of these applications is that they capitalize on the ability of computational systems to produce accurate, autonomous, objective, and repeatable results in an indefatigable and permanently available manner. **~AM&P**

Acknowledgments

This work was supported by the National Science Foundation under grant CMMI-1826218 and the Air Force D3OM2S Center of Excellence under agreement FA8650-19-2-5209.

For more information: Elizabeth Holm, professor, Carnegie Mellon University, 5000 Forbes Ave., Pittsburgh, PA 15213, eaholm@andrew.cmu.edu, cmu.edu.

References

1. E.A. Holm, et al., Overview: Computer Vision and Machine Learning for Microstructural Characterization and Analysis, *Materials and Metallurgical Transactions A, 51*(12), p 5985-5999, 2020.

2. B.L. DeCost, T. Francis, and E.A. Holm, Exploring the Microstructure Manifold: Image Texture Representations Applied to Ultrahigh Carbon Steel Microstructures, *Acta Materialia, 133,* p 30-40, 2017.

3. B.L. DeCost, T. Francis, and E.A. Holm, High Throughput Quantitative Metallography for Complex Microstructures using Deep Learning: A Case Study in Ultrahigh Carbon Steel, *Microscopy and Microanalysis, 25*, p 21-29, 2019.

4. B.L. DeCost, E.A. Holm, Vision-based Methods in Microstructure Analysis, *Statistical Methods for Materials Science: The Data Science of Micro-*

structure Characterization, CRC Press, p 241-258, 2019.

5. B.L. DeCost, et al., Computer Vision and Machine Learning for Autonomous Characterization of AM Powder Feedstocks, *JOM, 69,* p 456-465, 2017.

6. A.R. Kitahara and E.A. Holm, Microstructure Cluster Analysis with Transfer Learning and Unsupervised Learning, *Integrated Materials and Manufacturing Innovation, 7,* p 148-156, 2018.

7. J. Ling, et al., Building Data-driven Models with Microstructural Images: Generalization and Interpretability, *Materials Discovery, 10,* p 19-28, 2017.

8. R. Szeliski, *Computer Vision: Algorithms and Applications,* Springer, New York, 2010.

9. P. Flach, *Machine Learning: The Art and Science of Algorithms that Make Sense of Data,* Cambridge University Press, 2012.

10. Y. LeCun, Y. Bengio, and G. Hinton, Deep Learning, *Nature, 521,* p 436-444, 2015.

11. I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning,* MIT Press, 2016.

12. G. Csurka, et al., Visual Categorization with Bags of Keypoints, Workshop on Statistical Learning in Computer Vision, ECCV 1, p 1-16, 2014.

13. K. Simonyan and A. Zisserman, Very Deep Convolutional Networks for Large-scale Image Recognition, International Conference on Learning Representations, arXiv:1409.1556, p 1-14, 2015.

14. O. Russakovsky, et al., Imagenet Large Scale Visual Recognition Challenge, *International Journal of Computer Vision, 115,* p 211-252, 2015.

15. T.M. Mitchell, *Machine Learning,* McGraw-Hill, 1997.

16. S. Lloyd, Least Squares Quantization in PCM, *IEEE Transactions on Information Theory, 28,* p 129-137, 1982.

17. C. Shorten and T.M. Khoshgoftaar, A survey on Image Data Augmentation for Deep Learning, *Journal of Big Data, 6,* p 60, 2019.

18. B.L. DeCost, et al., UHCSDB: UltraHigh Carbon Steel Micrograph DataBase, *Integrated Materials and Manufacturing Innovation, 6,* p 197-205, 2017.

19. C.A. Schneider, W.S. Rasband, and K.W. Eliceiri, NIH Image to ImageJ: 25 Years of Image Analysis, *Nature Methods, 9,* p 671-675, 2012.

20. A. Bansal, et al., PixelNet: Representation of the Pixels, by the Pixels, and for the Pixels, arXiv:1702.06506 [cs.CV], p 1-17, 2016.

21. T. Stan, Z. Thompson, and P. Voorhees, Optimizing Convolutional Neural Networks to Perform Semantic Segmentation on Large Materials Imaging Datasets: X-ray Tomography and Serial Sectioning, *Materials Characterization, 160,* 110119, 2020.

22. L. Liu, et al., Deep Learning for Generic Object Detection: A Survey, *International Journal of Computer Vision, 128,* p 261-318, 2020.

APPLICATION OF MICRO-XRF MAPPING: POWER GENERATION INDUSTRY CASE STUDIES

Through a series of case studies, the benefits of micro x-ray fluorescence (XRF) over traditional XRF are demonstrated in the power generation industry for informing weld procedures, identifying root cause, and providing materials or component specifications.

Tapasvi Lolla and John Siefert, Electric Power Research Institute, Charlotte, North Carolina

Geoff West, WMG, University of Warwick, Coventry, England

Tina Hill, Bruker AXS Inc., Madison, Wisconsin

X-ray fluorescence (XRF) is a well established analytical tool that is used for determining the elemental composition of materials. It is a quantitative microanalysis technique in which x-rays from a primary source are impinged on a material of interest to cause emission of secondary x-rays from the material. The energies of these secondary x-rays are characteristic to the material, and this can be used to determine the relative amounts of elements present in the material.

Over the years, XRF has found a wide range of applications across many industries. Some examples where it is used include: positive materials identification of metals and alloys, quality control in materials fabrication and component manufacturing, geological and environmental analysis, drug manufacturing in the pharmaceutical industry, and as a diagnostic tool in the medical industry. XRF units come in various forms, and with varying elemental sensitivity and quantification capability—from a portable handheld unit for quick, semi-quantitative analysis to benchtop analyzers capable of high spatial resolution elemental mapping, to a wavelength dispersive XRF system for high sensitivity and quantification capability.

Micro-XRF (μ-XRF) operates under the same principles as conventional XRF. An important difference between conventional XRF analysis and μ-XRF is that in conventional XRF, large sample areas of several millimeters are usually analyzed with a broad beam size ranging from hundreds of micrometers to several millimeters with the purpose of quantification. Wider beam size results in difficulties analyzing the compositions of smaller regions within a material (such as dilution effects in welds) or to distinguish spatial heterogeneities in chemical compositions at closely spaced sites (e.g., segregation). On the other hand, μ-XRF uses a small spot created by polycapillary x-ray optics to excite a much smaller, predefined sample location. The resulting beam spot size measures in the tens of microns for the same depth of penetration as a conventional XRF. In addition, samples for conventional XRF are prepared to optimize the conditions for quantification and preparation steps often involve homogenization, among other modifications. Such a preparation procedure ensures a standardized sample evaluation routine and high reproducibility of results. However, inhomogeneity of the sample can be an important aspect of the analytical question. The improved spatial resolution achieved in μ-XRF, with the option for little to no sample preparation, can play a key role in establishing local compositional variations for many applications. When this capability is coupled with a large, motorized stage having precise control in the XYZ directions, it becomes possible to collect maps by reproducibly traversing the stage across the defined area of interest. The results from such an analysis are displayed as elemental distribution plots that allow for the interrogation of elemental changes and/or selected locations.

The outcomes are similar to elemental distribution mapping performed using energy dispersive spectroscopy (EDS) in a scanning electron microscope (SEM), although there are some key differences regarding sensitivity and spatial resolution. The sensitivity of μ-XRF for many elements is, in principle, higher than what can be achieved in SEM-EDS due in part to the lack of background of Bremsstrahlung radiation in the former. This leads to manufacturers of μ-XRF specifying higher detectability limits for elements with $Z > 20$ than in SEM-EDS, for a given matrix composition. These theoretical improvements in sensitivity for coarse grained crystalline materials can be off-set by diffraction effects, which introduce small peaks into the spectra. Furthermore, the depth from which information can be obtained from a material is an important factor to consider for elemental analysis. The photon source of µ-XRF will have a higher depth of penetration than the electron source of SEM-EDS. Hence, the information depth is larger in µ-XRF for a given matrix material. This makes it possible to examine thicker layers such as coatings and multiple layered structures using µ-XRF without destructive sample preparation. Because the penetration depth is larger, the interaction volume is much larger in µ-XRF than SEM-EDS and although it results in reduced spatial resolution, this provides a number of key advantages for large area compositional mapping of materials. First, because the interaction volume is often closely matched with the pixel size in µ-XRF, the whole area is analyzed, not just a central point of each area as in SEM-EDS. Secondly, the increased depth of penetration and interaction volume means the specimen preparation requirements are much less stringent in µ-XRF than in SEM-EDS to the point where is it possible to analyze samples in µ-XRF with minimal preparation/cleaning. Finally, because µ-XRF uses x-rays the technique does not suffer from charging effects. Samples may be analyzed with or without vacuum or stigmation effects, which can be significant in large steel samples. All of these factors make µ-XRF a versatile tool for elemental quantification and mapping.

At the Electric Power Research Institute's (EPRI) laboratories in Charlotte, North Carolina, a benchtop Bruker M4 TornadoPlus µ-XRF unit with light element detection capabilities is routinely employed to study elemental distribution in power plant components over large-area material cross sections. This unit uses a Rh x-ray source and two light element large-area silicon drift detectors to map the distribution of elements in a material. Apart from compositional analysis, results from such studies are also used to identify areas of interest for further in-depth electron microscopy-based investigations. This technique has been used in several unique investigations, a few of which are presented in the following case studies.

CASE STUDY 1: WELD PROCEDURE DEVELOPMENT FOR CLADDING A CARBON STEEL IN WET FLUE GAS DESULFURIZATION SYSTEM

There are multiple examples of applications across different industries where a layer of alloy is deposited on a substrate material using a welding process, either to provide a protective layer of coating in corrosive environments or to enhance the wear/erosion resistance of a component. Common examples in the power generation industry include nickel alloy-based weld overlays on dissimilar metal welds (DMWs) and pipes to prevent stress corrosion cracking in nuclear power plants, cladding of carbon-steel pipes using stainless steel or nickel alloy-weld coating material to mitigate corrosion in wet flue gas desulfurization systems, or the deposition of cobalt-based alloys for wear resistance in valve mating surfaces or stems. In such overlays, there is always a concern of metallurgical issues arising from mixing of the substrate and overlay material that occurs during welding resulting in dilution. Inadequate awareness about the dilution zone characteristics could lead to costly failures during service. Well-documented industry-wide failures were observed in valve components of fossil-fired power plants due to the detrimental microstructure formed in the dilution layer of cobalt-based hardfacing overlay welds made on mainstay power generation steels like 2¼Cr-1Mo (e.g., Grade 22) or 9Cr-1Mo-VNbN (e.g., Grade 91)[1].

A common practice for determining the amount of dilution is to use bulk (area) SEM-EDS analysis to find the approximate amounts of major alloying elements in the deposited weld as a means to determine the extent of the dilution zone. This would typically involve a sampling strategy where the composition is measured in a specified number of positions across multiple imaging fields (the field of view in an SEM is typically in the few mm range). In the presented case study, the weld specimen is a corner (fillet) weld between the vertical wall and the horizontal base plate (both SA-516 Grade 70 material) of the absorber vessel of a wet flue-gas desulfurization unit. The corner weld was made using C-276 nickel alloy filler metal and two layers of weld overlay were also deposited on the plates near the weld region as shown in Fig. 1. A single field µ-XRF scan across the entire weld joint was generated and the distribution maps of major alloying elements (i.e., Fe, Cr, and Ni) are shown in Fig. 2.

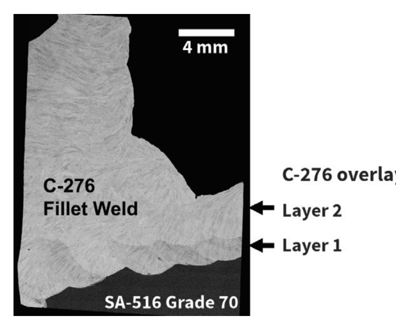


Fig. 1 — SEM backscattered electron image montage showing the cross section of a corner joint weld of two SA-516 Grade 70 base plates along with two layers of weld overlays made using C-276 weld.

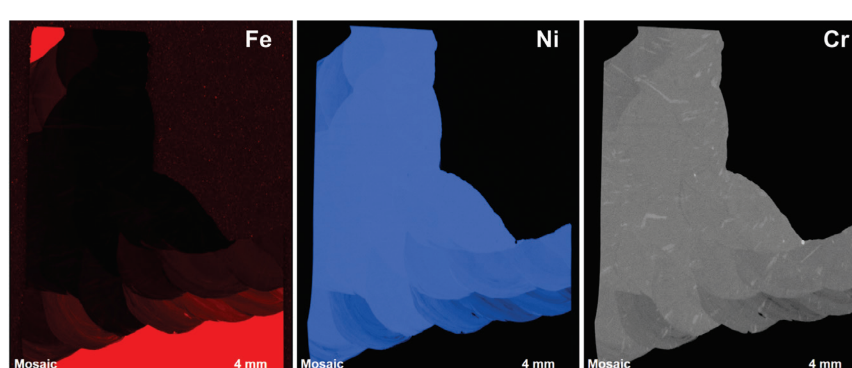


Fig. 2 — M4 Tornado µ-XRF elemental distribution maps of Fe, Ni, and Cr of the weld cross section shown in Fig. 1.

The elemental distribution maps show that, due to dilution of the Ni-rich C-276 weld with Fe-rich base plate, there is an increase in the amount of Fe and a corresponding decrease in the Ni and Cr content in the first weld overlay layer. There is also evidence of dilution, albeit to a lesser extent, in the second overlay layer of deposited C-276. The µ-XRF results further show that dilution is not uniform and there could be elemental variation even within an individual weld bead. Elemental analysis using both SEM-EDS and XRF in the first layer of weld provided Fe values ranging from 15 to 25 wt%, the second layer of weld ~8 wt%, and the fillet weld region ~1.25 wt%. Although it would be possible to replicate the XRF analysis in the SEM using SEM-EDS mapping, it would be much slower to cover the area shown and less accurate. Hence, µ-XRF provides a rapid way of performing single field chemical distribution mapping of large areas. It should also be emphasized that bulk analysis using EDS as a screening method will not provide perspective on local maximum values in elements of interest within an individual weld bead. This could be an important criterion for long-term, in-service performance (depending on the weld metal exposure to the environment). It is thus the case that future methods of quality assurance or enhanced weld procedure development may need to consider reporting of maximum, mean, and minimum percent of dilution. The value of mapping the distribution of elements for such assessments using µ-XRF is that it can take such complexities into account that would otherwise not be possible by means of a bulk EDS measurement.

CASE STUDY 2: LONG-SEAM WELD FAILURE IN A HOT REHEAT SYSTEM

In power plants, welds play a crucial role in maintaining the structural integrity of pressure-retaining parts that operate at high temperatures. Welds can also represent locations of inherent increased susceptibility to damage development due to a range of concerns linked to design, fabrication, operation, construction scope changes, and other complexities. For the power generation industry, a particular concern at elevated temperature is the introduction of time-dependent damage (e.g., creep).

In one recent example, a long seam welded Grade 22 hot reheat system operating at ~1000°F (540°C), experienced a leak during normal operation after ~270,000 hours[2]. Figure 3 (left) shows an etched cross-sectional image of the seam weld along with a crack that initiated at the pipe inner diameter (ID) near the weld and traveled over half the thickness of the wall. Also shown is a micro-hardness map (right) displaying the distribution of hardness across the double V-groove seam weld. Prominent in this map is a region of significantly lower hardness (105 HV0.5 to 125 HV0.5, in blue) within the weld region, immediately adjacent to the crack at the tube ID. Note that this same region exhibits a marked difference in etching response in the macrograph.

To inform the failure analysis investigation and provide contributing factors for the root cause evaluation, a large-area µ-XRF scan was performed on the weld cross section. Distribution maps of key elements are shown in Fig. 4. The µ-XRF scan revealed that the zone with lower hardness has lower Cr and Ni (and correspondingly higher Fe) content compared to the adjacent parent material and other regions of the weld near the outer diameter. This finding suggests that the long seam weld had been fabricated and/or repaired during the fabrication stage with a filler material that was consistent with a carbon steel composition rather than a matching AWS-type B3 consumable. In this example, µ-XRF mapping was key in establishing that off-specification filler material (so-called "rogue filler metal") was used to make the long seam weld and this likely contributed to the accelerated nature of the observed failure.

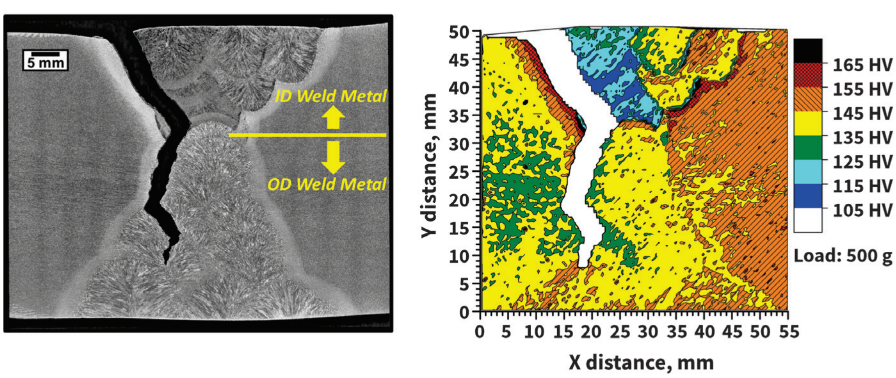


Fig. 3 — Cross section of a long-seam weld in a high energy pipe, showing a crack near the weld (left) and a hardness distribution map of this weld showing region of lower hardness near the ID.

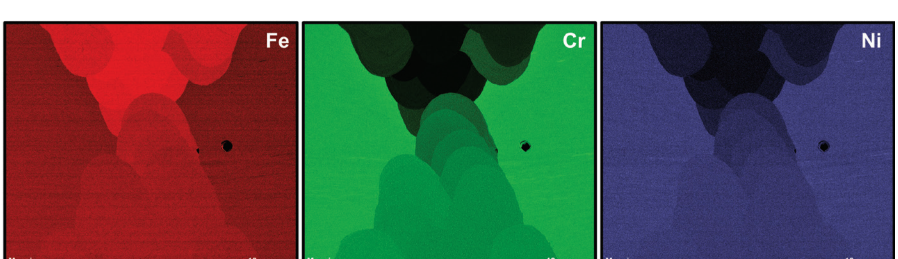


Fig. 4 — Micro-XRF elemental distribution maps of Fe, Cr, and Ni from an uncracked section of weld in Fig. 3.

CASE STUDY 3: ELEMENTAL SEGREGATION IN FINAL PRODUCT FORMS

Segregation of alloying elements is commonly observed in engineering alloys[3]. Heterogeneity in such alloys is a consequence of the many steps required to make the final product,

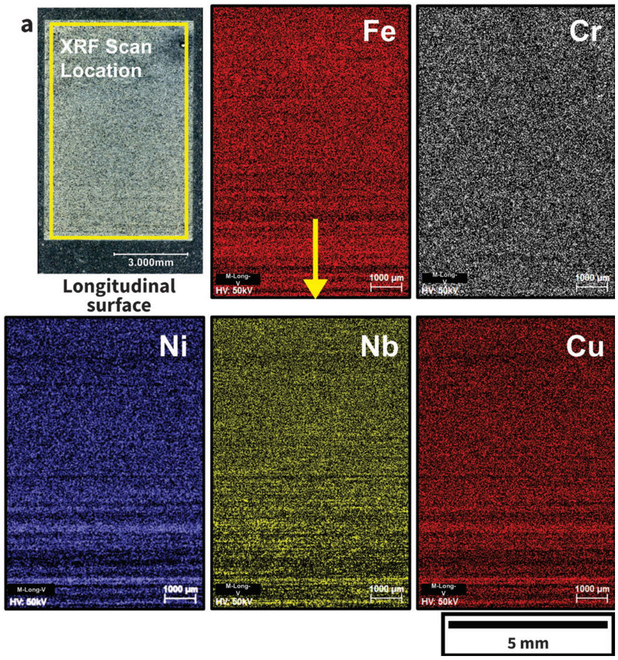


Fig. 5 — Through-thickness µ-XRF elemental distribution maps from region "a" of longitudinal tube section.

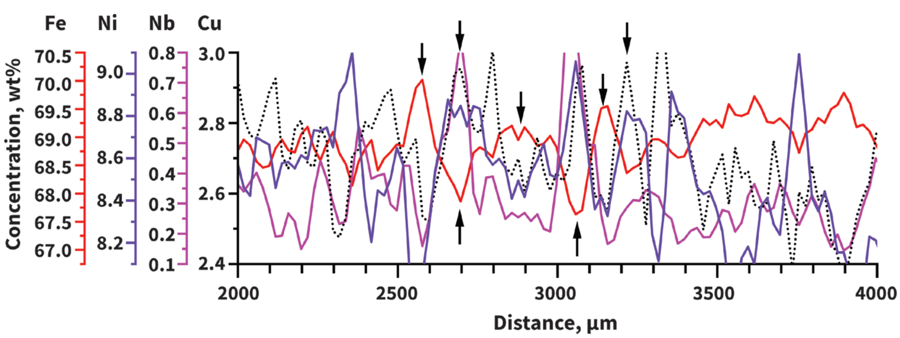


Fig. 6 — Line scan results showing variation in alloying elements with distance of scan.

which include casting the molten metal in a workable form, followed by the necessary hot and/or cold work processes. The resulting compositional variations could influence steel characteristics such as precipitation behavior, phase transformation temperature and rates. In extreme environmental conditions such as in power plants, segregation of elements may negatively affect local corrosion properties or enhance the development of creep damage.

Micro-XRF mapping is an ideal tool for investigating segregation of elements at a macro-scale. Figure 5 shows a longitudinal cross section of tube of an advanced austenitic 18Cr-9Ni-CuNbN steel (e.g., Super 304H) and results from µ-XRF analysis. Results from the scan show Ni, Nb, and Cu rich bands formed along the tube axis. Using a µ-XRF line-scan performed perpendicular to these bands (location identified by the yellow arrow), the distribution of elements at these bands are plotted in Fig. 6. The plot suggests that bands with lower concentration of Fe appear to correspondingly have higher Ni, Nb, and Cu concentrations (marked by black arrows for convenience). In this example, µ-XRF mapping was used to determine regions with significant elemental segregation and line scan was then used to determine the concentration of alloying elements at such sites. Because local variation in compositions could influence formation and/or stabilization of specific phases, these results highlight the need to seek representations of the actual composition range instead of simply the average (or bulk) composition for reliable thermodynamic predictions.

Micro-XRF is an invaluable tool in the current suite of macro-based laboratory characterization. As briefly described in this article, the results obtained from this technology are routinely used to:

- Perform quality assurance or optimize welding procedures where dilution can be a significant, long-term concern to corrosion and/or high temperature performance
- Inform failure analysis investigations
- Assess the potential heterogeneity in final product forms commonly used in the fabrication of complex components

EPRI and its extended network of collaborative organizations are taking advantage of µ-XRF to better inform weld procedures, root cause, and improve materials or component specifications. In a research setting, the routine use of µ-XRF provides a practical means to interrogate a large library of samples and determine those which are most relevant for a more rigorous evaluation. Tools like µ-XRF may be invaluable well into the future as they continue to supplement existing microscopy equipment with semi-quantitative results in the quest to solve the power generation industry's most complex materials challenges. **~AM&P**

For more information: Tapasvi Lolla, technical leader, Electric Power Research Institute, 1300 West W.T. Harris Blvd., Charlotte, NC 28262, tlolla@epri.com.

References

1. T. Lolla, et al., Delamination Failures of Stellite Hardfacing in Power Plants: A Microstructural Characterisation Study, *Science and Technology of Welding and Joining, 19*(6), p 476- 486, 2014.

2. 30-Plus Years of Long-Seam Weld Failures in the Power Generation Industry—Perspective and Continuing Challenges with Life Management. EPRI, Palo Alto, CA, 3002011587, 2017.

3. S. Jabar, et al., The Effect of Micro-Segregation on the Quantification of Microstructural Parameters in Grade 91 Steel, *Metallurgical and Materials Transactions A, 52,* p 426- 437, 2021.

OPTIMIZING 3D-PRINTED, REUSABLE METAL N95 FILTERS BY 3D CHARACTERIZATION AND MODELING

As N95 masks are in short supply and high demand, reusable, sterilizable metal filters for masks built using 3D microstructural characterization and simulation methods are a promising alternative.

Aaron Acierno, Erica Stevens,* Teddi Sedlar, Katerina Kimes,* and Markus Chmielus,**
Department of Mechanical and Materials Science Engineering, University of Pittsburgh
Kurt Svihla and Steve Pilz, Ansys Inc., Canonsburg, Pennsylvania
Patrick Dougherty, The ExOne Company, North Huntingdon, Pennsylvania
Thomas Spirka, Synopsys Inc., Mountain View, California

By the end of 2020, the novel coronavirus disease (COVID-19) had infected over 60 million individuals worldwide and caused over 1.5 million deaths[1]. As wide distribution of vaccines rolls out, research on disease transmission rates[2,3] and mitigation efforts[4] have concluded that mask wearing is an effective measure for reducing transmission, and public health recommendations follow accordingly[5]. With all sectors of the population advised to wear masks, highly effective N95 masks are in short supply and high demand. Breathable, accessible, reusable, highly effective respiratory protection from outside the current supply chain is desirable to meet demand and protect the populace. Additionally, beyond this current pandemic, reusable masks would not only stabilize stocks at healthcare centers, ensuring that staff are immediately and sufficiently protected in the event of a future airborne virus public health emergency, but also reduce the environmental impact of billions of single-use masks.

**Member of ASM International*

One materials class alternative for producing reusable, sterilizable N95-quality filters is metals: copper or stainless steel. Copper has been shown to exhibit antimicrobial properties[6], and stainless steel has established cleaning procedures within hospitals and clinics. Thus, metal reusable filters for masks could be sterilized and reused while also meeting N95 filtration requirements after optimizing geometry and permeability to balance breathability and efficacy.

Design freedom for geometry and permeability can be found in the additive manufacturing method of binder jet 3D printing, a technique that selectively deposits a liquid binding agent onto each successive layer in a powder bed and presents unique advantages for filter fabrication: (1) material compatibility includes both copper and stainless steel[7], (2) high printing speed[8], (3) fabrication at room temperature prevents ready oxidation[9], and (4) customized post-processing can be used to tailor porosity levels[10].

Aiming to leverage the potential for effective and reusable metal filters produced outside of the current supply chain, a collaboration of researchers from the University of Pittsburgh, ExOne, Synopsys, and Ansys fabricated, characterized, and modeled binder jet 3D-printed copper and stainless-steel metal mask filters. This article describes the 3D microstructural characterization, simulation, and modeling of final binder jetted parts, developing an iterative process framework for the streamlined development and assessment of 3D-printed, porous, metal N95-filters (Fig. 1).

Using feedstock powder from three separate suppliers per composition, 316L stainless steel and copper samples were binder jet 3D printed and sintered by ExOne using an ExOne Innovent. Various amounts of connected porosity were generated through partial sintering at specific temperatures: 800, 850, and 900°C for copper; and 900, 1000, and 1100°C for stainless steel. 3D porosity analysis by micro computed

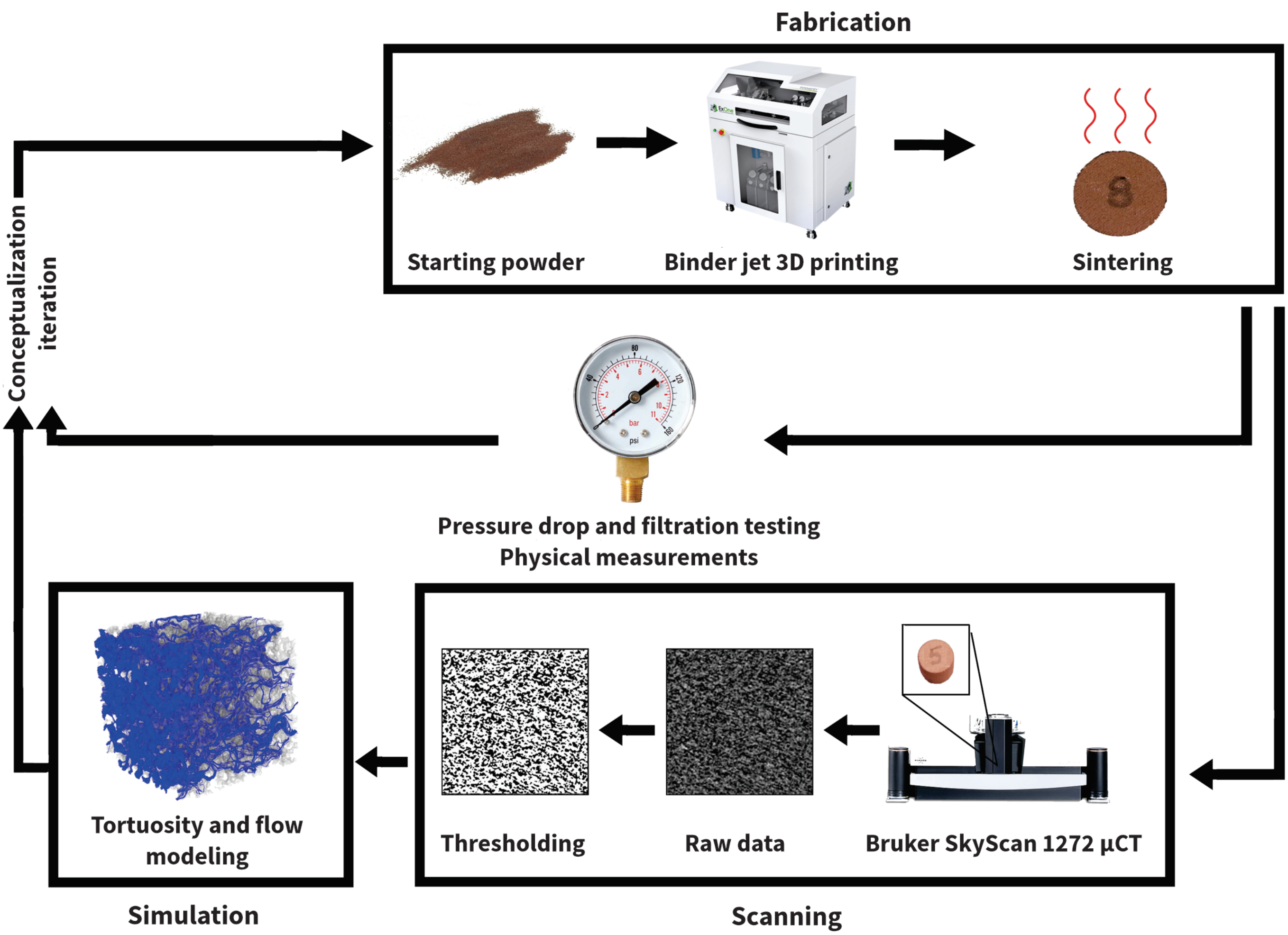


Fig. 1 — Flow chart describing the process steps and procedures for iterative conceptualization and fabrication of metal filters with integrated characterization and simulation.

tomography (µCT) was performed on cut sections from the centers of printed and partially sintered samples.

UNDERSTANDING PORE NETWORKS

Filter performance can be inferred by evaluating critical aspects of the flow channels. In the studied metal parts, the flow channels consist of large, connected networks of porosity, which are tortuous—full of twists and turns. This tortuous nature of the pore network can be quantified using tortuosity, a media transport descriptor to describe flow behavior[11]. For a permeable binder jetted sample intended for use as a filter, the tortuosity describes the flow pathway for air through the pore network. Quantitatively, tortuosity is the ratio of the distance a real particle would travel through the network from one point to another over the shortest direct distance between those two points. High tortuosity means more twists and turns for the example particle to traverse, while a tortuosity of unity represents a theoretical, fully porous sample with the lowest possible tortuosity.

Image sequences reconstructed using µCT data were thresholded and binarized before import to a Perl-based tortuosity calculator developed by Nakashima and Kamiya[12]. As anticipated, increased sintering temperatures generally resulted in an increase in tortuosity, seen in Fig. 2. Densification kinetics accelerate with higher sintering temperatures, more quickly pinching off and isolating pore networks and increasing the tortuosity as ease of travel decreases for the fluid. Continuing work is focused on developing a MATLAB program that, in addition to tortuosity, will calculate the pore volume fraction of the bulk sample and percentage of total porosity that contributes to the largest pore network.

SIMULATING PRESSURE DROP, FLOW AND FILTRATION

To accurately model flow and filtration characteristics using computational fluid dynamics (CFD), an accurate digital representation of the porous microstructure with fine details is required. This digital representation was created by first importing a µCT image stack into the Synopsys Simpleware ScanIP module, which segmented voxels associated with solid material to create a 3D model of the porous structure. CFD meshes consisting of tetrahedral elements (between 8.9 million and 15.8 million depending on resolution and scan size) were then formed with-

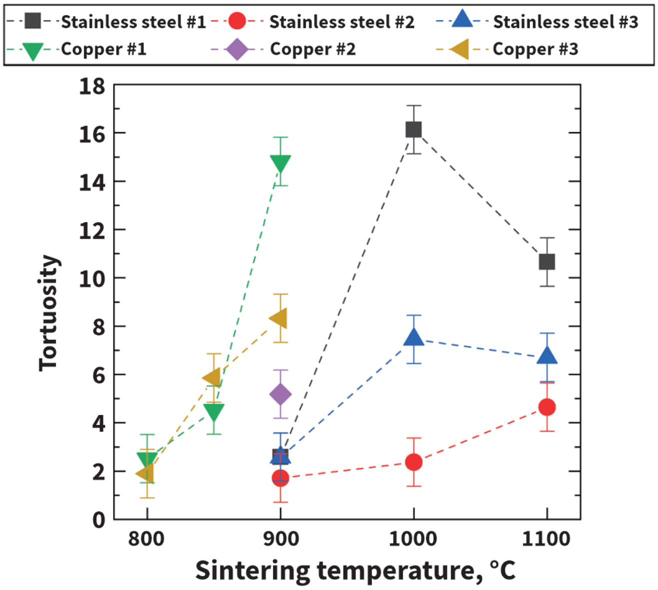


Fig. 2 — Tortuosity plotted against the sintering temperatures for samples from three different stainless steel and copper powder suppliers.

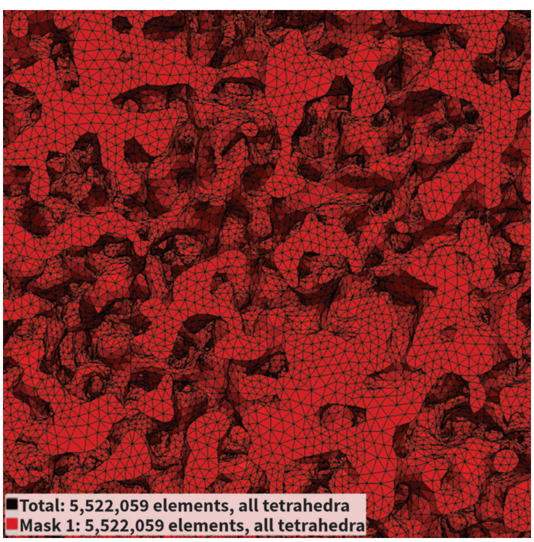


Fig. 3 — Example tetrahedral mesh created from µCT data of the porous microstructure for CFD simulation.

in the segmented solid structures using the Synopsys Simpleware FE module (e.g., Fig. 3).

The tetrahedral meshes represented the bases for single-phase flow and pressure drop simulations that assumed steady, laminar flow with pressure specified boundaries and flow rates, which spanned the range expected for N95 masks in normal operation. Pressure drop (∇P) versus velocity characteristics (v) were used to determine a porous resistance (R) corresponding to a simple viscous relationship of the form:

$$-\nabla P = Rv \quad \text{(Eq 1)}$$

Flow resistance ranged from 4.0-5.0 x 10^7 kg/m^{3}s for the various 3D-printed and partially sintered filters. These values were used as simulation inputs for the full mask geometry with the filter modeled as a porous region in Ansys Fluent.

Particle filtration simulations were performed for meshes refined by eight times (a factor of two in the three spatial directions) relative to the original mesh count using Lagrangian particle tracking for discrete phase particles ranging in size from 0.6 to 5 µm. The percentage of particles trapped as a function of particle size and air flow rate were compared to NIOSH guidelines for N95 masks to determine which metal powder/sintering combination adheres to acceptable filtration standards. Results of a typical particle filtration simulation are shown in Fig. 4a where the trajectories of 1 µm particles are superimposed on the computational mesh and show a 57.6% filtration efficiency.

Finally, the air flow velocities were simulated for full mask models consisting of a porous media (i.e., the porous metal structure) with resistances determined from the resolved pore simulations. In Fig. 4b, the uniformity of flow velocity is shown for a candidate mask model with pins to increase the surface area, reducing the overall flow resistance and improving the breathability characteristics of the mask. The information about high and low flow regions of the mask can inform further design iterations to improve filtration efficiency and breathability characteristics.

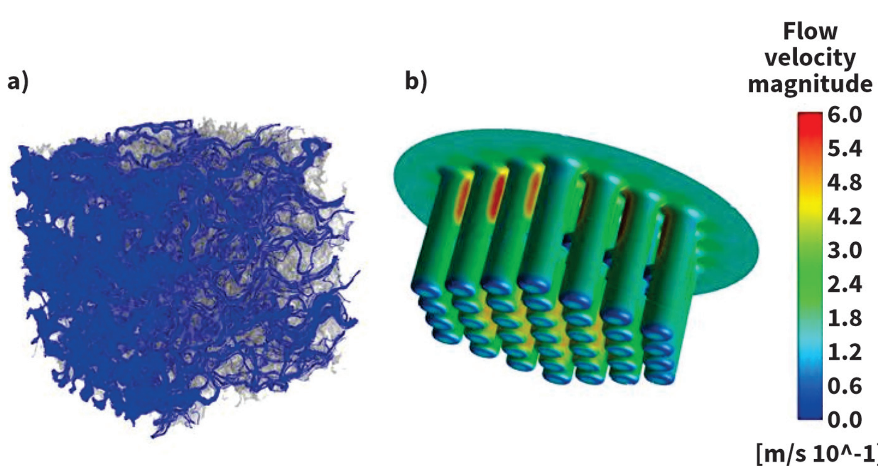


Fig. 4 — (a) Trajectories of 1 µm particles for a typical sample powder (57.6% efficiency). (b) Velocity contours for a candidate pin filter design.

OUTLOOK

The use of binder jetting technology and iterative optimization of printing and post-processing parameters to produce reusable, sterilizable metal N95 filters for masks is promising. The filter design, characterization, and optimization loop can be expedited by using the 3D microstructural characterization and subsequent flow and filtration characteristics simulation methods presented here. Continuing work is focused on developing the MATLAB program for an expanded view of tortuosity and related parameters, as well as optimizing filter geometry for a balance of breathability and particle filtration. As the fight against COVID-19 evolves or even disappears, the need for effective, reusable mask filters remains. 3D-printed metal filters can be an alternative to currently used unwoven or woven masks, and 3D characterization and modeling can help accelerate their development and design. **~AM&P**

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

For more information: Markus Chmielus, professor, Mechanical Engineering and Materials Science, University of Pittsburgh, Benedum Hall #636, Pittsburgh, PA 15261, chmielus@pitt.edu, engineering.pitt.edu, chmieluslab.org.

Acknowledgment

This project was financed in part by a grant from the Commonwealth of Pennsylvania, Department of Community and Economic Development.

References

1. COVID-19 Map - Johns Hopkins Coronavirus Resource Center, Johns Hopkins University and Medicine. [Online]. Available: coronavirus.jhu.edu/map.html. [Accessed: 18-Dec-2020].

2. A. Ozygit, *Infection, Disease & Health, 25*(4), p 233-238, 2020.

3. H. Zhu, et al., *Applied Mathematical Modelling, 89*(2), p 1983-1998, 2021.

4. Y.B. de Bruin, et al., *Safety Science, 128,* p 104773, 2020.

5. How to Select, Wear, and Clean Your Mask, Centers for Disease Control and Prevention, [Online]. Available: cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/about-face-coverings.html. [Accessed: 18-Dec-2020].

6. N.V. Doremalen, et al., *New England Journal of Medicine, 382*(16), p 1564-1567, 2020. doi:10.1056/nejmc2004973.

7. M. Ziaee and N B. Crane, *Additive Manufacturing, 28,* p 781-801, 2019.

8. Y. Ba and C.B. Williams, *Rapid Prototyping Journal, 21*(2), p 793-814, 2015.

9. A. Mostafaei, et al., *Progress in Materials Science,* doi: 10.1016/j.pmatsci.2020.100707.

10. A. Mostafaei, et al., *Data in Brief, 10,* p 116-121, 2017.

11. J. Fu, H.R. Thomas, and C. Li, *Earth-Science Reviews, 212,* p 103439, 2012.

12. Y. Nakashima and S. Kamiya, *Journal of Nuclear Science and Technology, 44,* p 1233-1247, 2007.

TECHNICAL SPOTLIGHT

ADVANCED ICP-OES LEADS THE WAY TO FAST AND EFFICIENT RARE EARTH ELEMENT DETECTION

The latest advancements in ICP-OES systems are changing the landscape for rare earth element analysis.

Highly sought after for use in the electronics industry, rare earth elements (REEs) and their alloys are critical to the functionality of a wide range of devices, from smartphones to medical imaging equipment and wind turbines. Global demand for REEs has exploded in recent decades, a trend that shows no sign of abating. A recent Adamas Intelligence report predicts a five-fold increase in demand for REEs in the magnet industry alone by 2030[1], a growth that the organization describes as unfathomable.

REEs, unlike the name suggests, are not rare in nature; however, they are a finite resource and hard to locate in economically extractable formats. Moreover, REE mining is fraught with high costs, geopolitical conflict, and environmental damage. Add to this the rise in electronics waste (e-waste) and pollution from the disposal of obsolete technology, and the result is an attitudinal shift around how REEs are extracted, but more importantly, how they are recovered and recycled back into the manufacturing process.

To support global demand for REE recycling and reuse, laboratories require solutions that can detect and characterize trace and ultra-trace quantities of REEs in e-waste. Reliable and robust technology is needed to generate the high throughputs required to make the process both practical and profitable. For many years, inductively coupled plasma mass spectrometry (ICP-MS) has been used to detect REEs. This highly sensitive technology can deliver outstanding results, but the methods can be time-consuming and require stringent cleanroom conditions. With restricted matrix robustness and manual workflows, the throughput achievable using this technique has limitations.

New advances in inductively coupled plasma optical emission spectrometry (ICP-OES) are now challenging the status quo when it comes to analyzing REEs, even in ultra-trace quantities. With advanced ICP-OES systems able to achieve the same sensitivity as ICP-MS, ICP-OES also offers improved matrix robustness, simpler operation, and higher sample throughputs. The accelerated detection provided by ICP-OES allows laboratories to more efficiently characterize REEs in e-waste and environmental samples. This shift supports the sustainability ambitions of an industry working to change an age-old linear economy to a circular manufacturing model, recycling e-waste and reducing its dependency on natural resources.

CHALLENGES IN RARE EARTH ELEMENT DETECTION

The REEs are classified as the 15 elements in the lanthanide series, lanthanum (La) to lutecium (Lu), plus scandium (Sc) and yttrium (Y), which have close geological occurrence with the lanthanides. The high demand for these elements, added to extraction issues and limited accessibility, makes them a highly valued commodity. The environmental impact of extracting and processing REE ores, coupled with the damaging effects of e-waste, has led the electronics industry to evaluate its entire manufacturing supply chain.

A major challenge to widespread REE reuse and recycling has been limitations in the accurate and efficient detection and extraction of these elements. Samples often contain multiple REEs, and the interelement spectral interference mounts a significant challenge because REEs emit similar spectral lines (see Fig. 1). In complex matrices, such as those seen in e-waste, further interference can also be generated from other metals, especially base metals such as iron and nickel. Techniques must be selective and sensitive enough to detect trace amounts in complex matrices while accounting for the interference generated by overlapping wavelengths.

REEs are usually analyzed using techniques such as x-ray fluorescence spectrometry, ICP-MS, and ICP-OES. ICP-MS has long been the method of choice due to the high levels of sensitivity that can be achieved. For this technique, samples must be prepared in a liquid form, usually through digestion to produce an aqueous solution in an acidified matrix. The sample is then ionized to reduce it to its constituent elements and the elements are then separated and detected based on mass-to-charge ratio. The required dynamic range of linearity is captured effectively by ICP-MS but interference is difficult to elucidate during analysis. For this reason, ICP-MS is commonly used for discrete mass detection, to analyze each element in isolation from the others; the more complex the matrix becomes, the more elements are included, and the more interference is encountered. Sample dilution reduces interference levels but also reduces sensitivity, diminishing the key driver behind ICP-MS technology.

ICP-MS has several other drawbacks too. First, sample preparation requires expensive high-purity diluting acids. In addition, the highly sensitive technique means that the smallest level of contamination can invalidate results meaning that the equipment needs to be cleaned and tests re-run. Furthermore, cleanroom conditions and strict cleaning protocols are a must, adding time and cost to each analysis. In a commercial laboratory requiring high throughputs with optimal reproducibility and accuracy, labor-intensive, expensive, and specialist processes can have substantial, negative impacts.

For a sustainable future, where REEs are detected and recovered quickly and effectively, the manual and costly processes of the past must be challenged. New techniques must be explored to increase throughput while maintaining high sensitivity and quality standards. Reproducibility and accuracy are key criteria needed for reuse and recycling to become a viable alternative to mining virgin ore.

ICP-OES: A SIMPLE ALTERNATIVE

Recent advances in ICP-OES technology are providing an alternative analytical option to ICP-MS at a lower capital outlay. Advanced instruments such as the Thermo Scientific iCAP PRO XP ICP-OES Duo can now provide similar detection rates and sample throughputs when compared to ICP-MS, along with a high linearity range and very good spectral resolution, even in complex matrices. This new breed of ICP-OES takes the high matrix tolerance of radial ICP-OES systems and combines it with the sensitivity of axial ICP-OES technology to create a combined system that delivers both. With the addition of next generation interelement correction software, interference can be removed automatically, enabling the resolution of overlapping wavelengths.

Interelement correction is only the first step in automating workflows. ICP-OES software is designed to support ease of operation, with instrumentation control managed entirely through the software. Start-up, calibration, performance checks, and maintenance alerts are automated through a series of electronic workflows, thereby freeing technicians to complete specialist tasks, protecting the method from human error, and increasing reproducibility.

Although the analysis time is now similar for both ICP technologies, at around two minutes per sample, ICP-OES removes a dilution step compared to the preparation required for ICP-MS technology, saving on average two hours per sample. Once prepared, samples are easily analyzed with ICP-OES, which removes laborious sample preparation protocols and the potential interference that follows. With a much-reduced contamination risk, ICP-OES systems can be located in standard laboratory space, without the need for cleanroom requirements. This broadens the usability and accessibility of this technology, allowing a greater number of laboratories to install the technology and strengthen their analytical capabilities.

In a recent study, a team of technicians demonstrated the application of advanced ICP-OES technology in axial viewing mode for a range of electronic waste products. The study showed an excellent large linear dynamic range for REE (1 to 10,000 µg/L) and basic metals (1 to 100,000 µg/L) on disassembled mobile phone components (see Fig. 2).

Sensitivity in the low parts per billion range was achieved for all targeted analytes in the axial viewing mode and excellent system robustness was demonstrated. No significant results bias was seen in over two consecutive

Elements and wavelengths (nm)	R^2	IDL (µg·L⁻¹)	MDL for TFT screens (µg·L⁻¹)	MDL for PCBs (µg·L⁻¹)	MDL for speaker magnets (µg·L⁻¹)
Ce 404.076	1.0000	1.3	16.6	13.3	34.0
Ce 535.353	1.0000	1.4	-	-	-
Dy 353.170	1.0000	0.3	-	-	-
Dy 400.045	0.9998	1.2	-	-	-
Er 337.271	1.0000	0.4	-	-	-
Eu 412.970	1.0000	0.1	1.2	1.0	2.5
Eu 420.505	1.0000	0.1	1.7	1.4	3.6
Gd 335.047	1.0000	0.8	10.9	8.7	22.3
La 412.323	1.0000	0.3	-	-	-
Lu 261.542	0.9999	0.1	0.8	0.7	1.7
Nd 406.109	1.0000	1.3	-	-	-
Nd 430.358	1.0000	1.6	21.4	17.1	43.7
Pr 422.535	1.0000	0.6	7.1	5.7	14.5
Pr 390.844	1.0000	1.6	-	-	-
Pr 417.939	0.9999	2.1	27.3	21.8	55.9
Sc 357.253	1.0000	0.2	-	-	-
Tb 367.635	1.0000	1.4	-	-	-
Th 318.019	1.0000	4.1	-	-	-
Tm 313.126	1.0000	0.3	-	-	-
Y 371.030	0.9999	0.1	4.9	3.9	10.0
Yb 289.138	1.0000	0.4	-	-	-

Fig. 1 — Analyte wavelengths, coefficient of determination R^2 (over a calibration range of 1–10,000 µg/L), instrumental detection limits (IDL, calculated by Qtegra ISDS Software), and method detection limits (MDL) for the rare earth elements and Th for the axial mode of the iCAP PRO XP Duo instrument.

days of continuous data acquisition (see Figs. 3 and 4).

DRIVING HIGH-THROUGHPUT PERFORMANCE IN COMMERCIAL LABORATORIES

By switching to ICP-OES technology and advanced software, laboratories can reduce laborious and manual sample preparation steps from REE analysis workflows and streamline their analytical procedures. Matrix robustness and reduced interference through interelement correction software ensure a high spectral resolution while maintaining a high linearity range. These automated e-workflows lower training requirements, allowing technicians to perform analyses and reducing the need for onsite specialists. In turn, automation leads to more accurate results and higher throughput, driving greater laboratory productivity. Cost benefits are further realized through the lower capital outlay needed for investment in ICP-OES technology and the significant savings in operational expenditure through the removal of clean-room requirements and expensive high-purity dilution acids.

The applications for ICP-OES do not stop with REEs—this flexible technique is being embraced by other industries looking to reduce the cost of effective detection of trace elements, including the study of platinum group elements, analysis of the production of metals and alloys, and the investigation of environmental waste streams. Just as in REE analysis, ICP-OES is being used throughout lifecycles, from ore exploration to final products and their reuse.

The detection and analysis of REEs and other recoverable materials in e-waste and environmental samples are crucial to embracing a sustainable model for electronics manufacturing in times when recycling and reusing is more important than ever—it is a

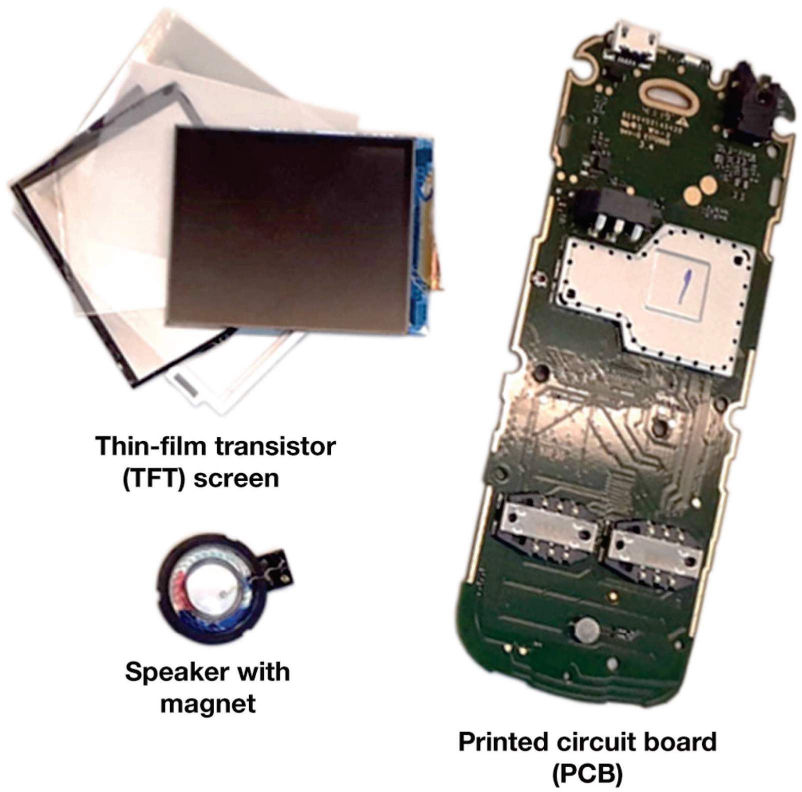


Fig. 2 — Disassembled mobile phone components selected for analysis: TFT screens, speaker magnets, and PCBs.

Element and wavelength (nm)	TFT screen 1 (μg.g^{-1})	TFT screen 2 (μg.g^{-1})	PCB 1 (μg.g^{-1})	PCB 2 (μg.g^{-1})	Speaker magnet 1 (μg.g^{-1})	Speaker magnet 2 (μg.g^{-1})
Rare earth elements (REE)						
Ce 404.076	<DL	<DL	1.025	1.016	28,678.856	27,907.174
Eu 412.970	<DL	0.768	<DL	<DL	<DL	<DL
Eu 420.505	<DL	0.765	<DL	<DL	<DL	<DL
Gd 335.047	0.079	0.141	3.598	3.959	4047.393	5930.288
Lu 261.542	0.022	0.017	1.947	1.633	17.255	16.207
Pr 417.939	<DL	<DL	<DL	<DL	12,802.391	14,267.827
Nd 430.358	<DL	<DL	<DL	<DL	37,392.193	40,643.866
Y 371.030	0.015	0.020	0.833	1.132	<DL	<DL
Metals						
Ag 328.068	13.599	41.205	289.296	496.581	<DL	<DL
Al 167.079	1085.738	1322.702	475.877	486.056	22,820.756	28,300.425
Au 242.795	5.404	1.686	2.604	0.989	29.942	31.624
Cr 205.560	252.225	183.967	1057.523	945.728	3036.511	3549.902
Cu 324.754	1364.658	5841.867	189,027.425	164,140.575	-	-
Fe 259.940	877.812	677.548	2406.179	2130.731	803,015.933	840,304.409
Ni 231.604	189.522	218.559	1663.002	1647.645	1107.861	1091.483
Pb 220.353	0.074	0.171	5.111	4.025	235.458	254.557
Zn 213.856	47.018	56.269	699.394	704.884	31,947.532	35,770.742

Fig. 3 — Final calculated concentrations (μg/g) of REEs and metals in undiluted samples of mobile phone components: TFT screens, PCBs, and magnets from the speakers.

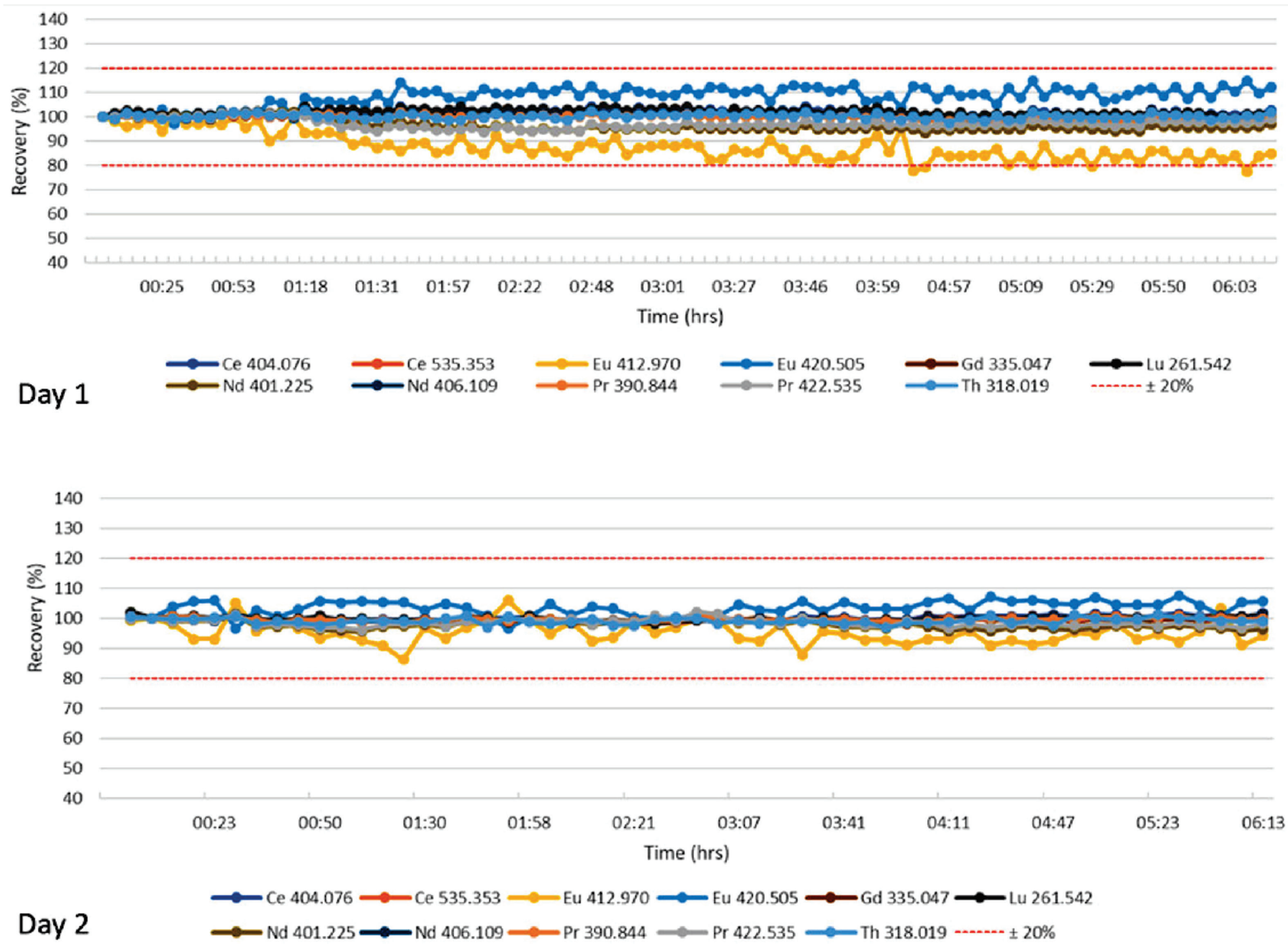


Fig. 4 — Recoveries of analytes, displaying instrument stability during long-term experiments run over two days. Each experiment constitutes at least six hours of continuous analysis in axial mode of the iCAP PRO XP Duo instrument.

significant step on the journey toward circular manufacturing. Although the demand and the justification for change are both evident, current analytical techniques are creating a bottleneck and impeding organizations as they take the first tentative steps. If recovery is too difficult or expensive then companies will be forced to take the seemingly easier route toward REE ore extraction, and the mountain of e-waste will continue to grow. Laboratories adopting advanced ICP-OES techniques for the detection and analysis of REEs can now deliver a more robust, high throughput and cost-effective service. By providing high-sensitivity results, with a large linear dynamic range, in a faster time frame, at a lower cost, laboratories are in a position to support the electronics industry's move toward a more sustainable future. The rising demand for REEs needs to be met in a more sustainable way; adopting quicker and more cost-effective analytical techniques for e-waste and environmental monitoring is one big step on that journey. **~AM&P**

For more information: Sukanya Sengupta, product specialist ICP-OES & GIRMS, Thermo Fisher Scientific, Hanna-Kunath Str. 11, 28199 Bremen, Germany, +49.0.421.5493.528, sukanya.sengupta@thermofisher.com, www.thermofisher.com/tea.

Reference

1. Rare Earth Magnet Market Outlook to 2030, Adamas Intelligence, www.adamasintel.com/unfathomable-rare-earth-demand-growth.

ASM PROGRESS REPORT: DEDICATED TO OUR MISSION AND ACCELERATING OUR TRANSFORMATIVE JOURNEY

With a strong strategic plan, ASM faced the changing landscape caused by the pandemic with new task forces and acceleration toward virtual offerings.

Diana Essock, FASM, ASM President

Traditionally, at this time of the year, a report is issued here in *AM&P* regarding the results of strategic planning events and highlighting activities for the coming year. This past year has been different from any other in recent memory. The COVID-19 pandemic has concentrated our efforts on addressing the needs of all Society member communities to provide products, services, opportunities, and events in an effective and safe manner.

RESPONDING TO A PANDEMIC

With this serious situation at hand, ASM has acted to meet these pandemic challenges for both our staff and members head-on. We've developed the tools to transition our operations to optimize the provision of virtual offerings, and with these expanded capabilities, sought out new opportunities for our Society. The speed of change has been amplified during the pandemic. Building upon our prior year's renewal and realization activities, ASM was well positioned to quickly switch to virtual operation at both the headquarters and with membership interactions. Though ASM has been impacted particularly in areas such as education and events, our leadership and staff are energized, creative, and responsive, and are preparing us for the future, as shown in Fig. 1.

Unlike ever before, the July 2020 strategic planning activities were totally virtual. They were focused on the impact of the current environment on ASM, and the implications for near- and long-term worldwide transformations. The entire ASM staff, our trustees, and senior leaders, were brought together for virtual brainstorming experiences. These sessions were held using a platform for video and audio communications with breakout room capabilities. This all-inclusive virtual strategic planning process stimulated the advancement of new thoughts and concepts. With the inspirations from these sessions and guided by our key strategic initiatives, we are positioning our Society for this unique time in history.

"ALONE WE CAN DO SO LITTLE, TOGETHER WE CAN DO SO MUCH." – HELEN KELLER

STRATEGIC GOALS

Our strategic goals continue to focus on: 1) membership growth and increased engagement, 2) technical excellence, and 3) strategic partnerships and collaborations. We now view our goals through this new environmentally imposed lens, and we are positioning

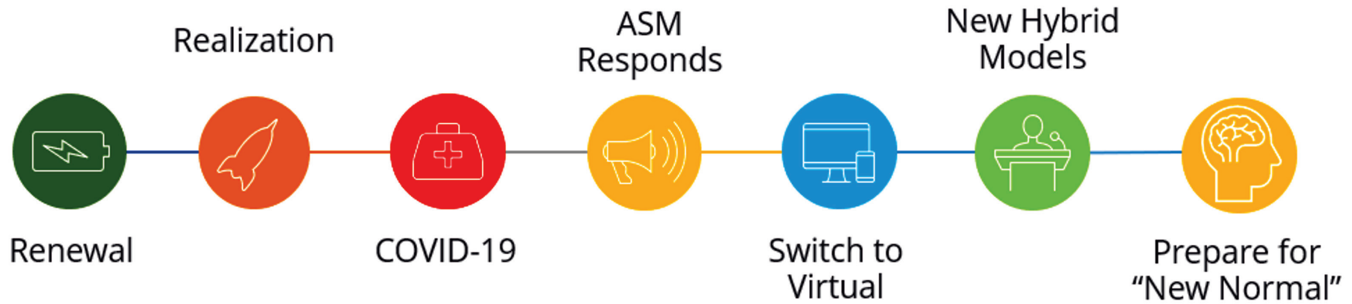


Fig. 1 — Schematic depicting ASM's 2020 priorities before and after the onset of COVID-19.

our Society to be an adaptive and resilient organization that maximizes value by facing our challenges and focusing on new opportunities.

Though our members are individually separated, we are working to bring our communities together. ASM has launched an array of new virtual programs to stay connected and to provide our audiences globally with needed information. A portion of our inaugural IMAT 2020 conference and exhibition was rapidly transformed to become our first all virtual event creatively incorporating presentations, Q&A sessions, exhibitions, and networking opportunities. Additionally, digitally accessible publications were expanded. New live virtual education programs were developed, and self-study and digital short courses expanded. Our members can learn at their own pace from anywhere in the world. Data ecosystem initiatives were fast-tracked to meet the needs of our membership.

During this past year, we unexpectedly found ourselves facing a world turned upside down, yet the ASM staff quickly reinvented how we do many things, enabling us not only to function in a virtual world but also to seek new ways to help our members, as shown in Fig. 2.

To help our Chapters, Affiliates, Councils, and Committees, and to promote technical interchange throughout our Society, virtual connection tools like RingCentral/Zoom have been provided to them. Chapters can now offer virtual programs not only to their local members but to all ASM members globally. Members are able to login to ASM Connect through our website, find out about events at other chapters, and register for them. Having this ability to plan and attend events not only provides for added technical exchanges but encourages communication between far-flung members.

"THE FUTURE AIN'T WHAT IT USED TO BE." – YOGI BERRA

ASM Connect offers our members the ability to reach out virtually to like-minded members with questions, suggestions, and ideas. The membership networking platform is helping to foster communications. ASM Connect is a place for knowledge exchange, idea incubation, professional networking, and promoting dynamic discussion groups. Members can establish communities of interest and build connections with their colleagues. Indeed, such self-assembled communities have led to the establishment of new ASM technical committees. As participation on Connect increases and our communities grow, we are able to offer added value to our membership.

BOARD-LED TASK FORCES

In addition to the challenges of the pandemic, our society has undergone a transition to help ensure alignment of ASM's activities with our strategic goals. Ad hoc Board-led Task Forces (BTF) have been developed, which bring together key expert members, staff, and trustees around topics of Societal interest to promote communication and understanding around strategic initiatives. There are BTF in topic areas such as: Digital Strategy, Global Networks, Diversity/Equity/Inclusion, Chapters, Interdisciplinary Focus, and Technical Networking/Academia. These BTF bring together a wide scope of expertise for the benefit of the Society. Our virtual communication tools have enhanced our ability to develop and optimize these BTF.

With the above-mentioned strategic goals in mind, our prior strategic key initiatives continue to be of importance. Members of the BTF play key roles

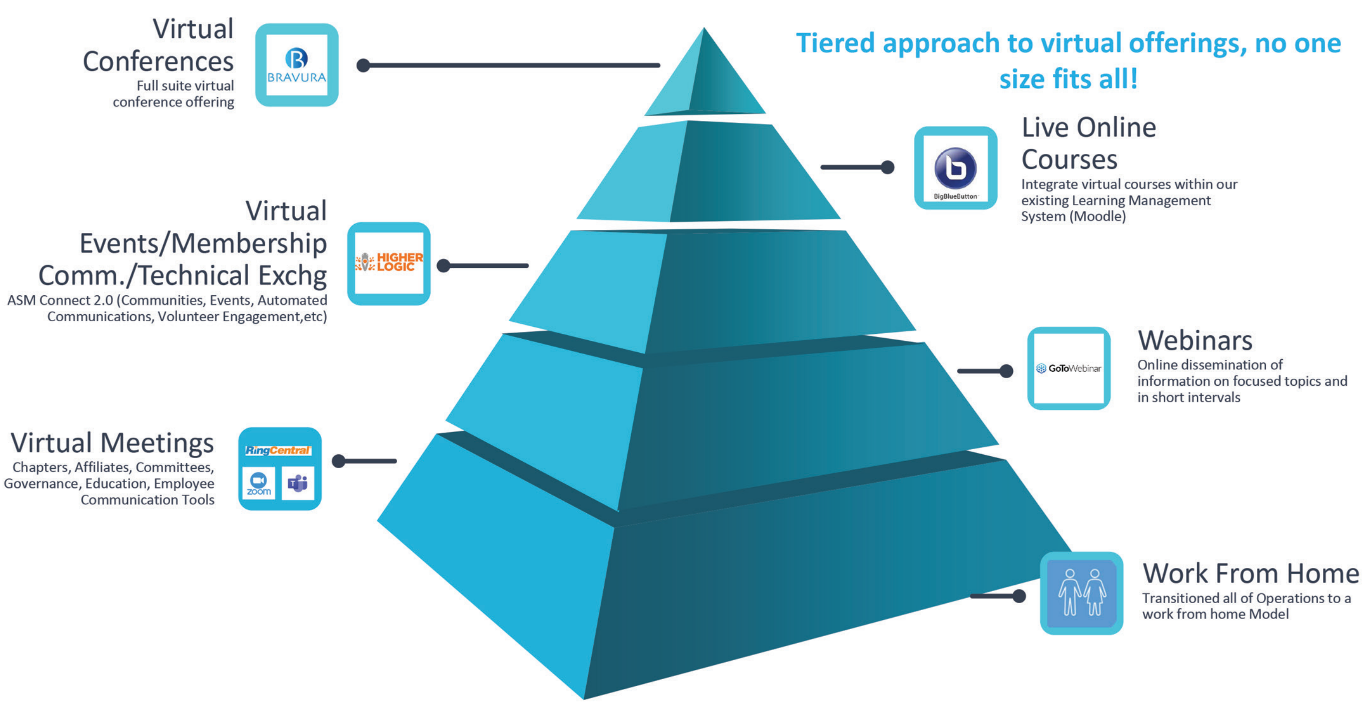


Fig. 2 — ASM ramped up its virtual capabilities in multiple ways last year.

through their respective focus topics to assist and promote these initiatives. The strategic key initiatives include:

- *Develop a digital-first platform* that encompasses all aspects of ASM activities around the curation, delivery, and maintenance of technical content, and expansion of our digital library, and modeling and simulation offerings along with the development of educational programs in this area. Proactively seek out data and content partnerships.
- *Establish an interdisciplinary collaboration framework* to engage organizations related to the materials community and form mutually beneficial relationships with other engineering and design communities to which we can offer materials expertise, services, and knowledge.
- *Create a global professional network* with materials-oriented technical and professional societies through strategic global collaborations and joint activities including webinars, workshops, conferences, and publications.
- *Cultivate a foundational culture and practice of diversity, equity, and inclusion* for all ASM stakeholders. Thriving in the modern climate requires full engagement of the entire breadth and depth of the materials community.

For more than a century, ASM International has been known for developing new products and services that meet the needs of our members and the materials community. Our current operating plan positions us for growth of our developing data ecosystem with products around the provision of high-quality data, tools, and data analytical services. Educational programs in the areas of data management, modeling, and simulation are under development and are key to meeting the cutting-edge needs of the materials community.

MISSION AND VISION

ASM International is a member-based, volunteer driven Society focused on meeting the needs of members and the worldwide materials community. Our vision is to be the leading global resource for materials information. Our mission is to gather, process, and disseminate materials information globally through education, networking, and professional development for members, organizations served by our members, and the materials community. Serving all members of our community during this time and growing to meet their needs is at the forefront. Diversity, equity, and inclusion are our overarching goals. The newly formed IDEA Committee is helping us meet this challenge. We never lose sight that our members are the key to the successful operation of our Society.

As the future unfolds and the world evolves, we focus not on what we have lost but on our new expanded capabilities. Together, we can look to the coming year with hope and the promise that better days are ahead. **~AM&P**

For more information: Diana Essock, FASM, president, ASM International, diana.essock@asminternational.org. View the ASM Strategic Plan at asm international.org/about/strategicplan.

ASMNEWS

AFFILIATE SOCIETIES NAME COMMITTEE CHAIRS FOR 2020-2021 TERM

The boards of the Electronic Device Failure Analysis Society (EDFAS), Failure Analysis Society (FAS), Heat Treating Society (HTS), International Metallographic Society (IMS), and Thermal Spray Society (TSS) have appointed chairs to each of their committees for the 2020-2021 term. Chairs for ASM Society and General Committees and Councils appeared in the January 2021 issue of ASM News. The purpose of each committee is stated on its affiliate society website under the Membership and Networking tab.

Electronic Device Failure Analysis Society (EDFAS)

James Demarest, senior engineer, IBM, serves as president of EDFAS.

Lee Knauss, FASM, director, engineering and science, Booz Allen Hamilton, serves as immediate past president of EDFAS and chair of the EDFAS Awards & Nominations Committee.

Felix Beaudoin, FASM, PMTS product development engineer, GlobalFoundries, serves as vice president/finance officer of EDFAS.

Bhanu Sood, Code 371 – Reliability and Risk Assessment Branch, NASA Goddard Space Flight Center, continues to serve as chair of the Education Subcommittee.

Tom Moore, FASM, president, Waviks Inc., continues as chair of the EDFAS Membership Subcommittee.

Nicholas Antoniou, vice president of product management, PrimeNano Inc., continues to serve as chair of the *Electronic Device Failure Analysis* Editorial Board.

Susan Li, senior manager, Cypress Semiconductor Corp., was named vice chair of the Events Committee.

Failure Analysis Society (FAS)

James Lane, director, materials science practice, Rimkus Consulting Group Inc., serves as president of FAS.

Pierre Dupont, key account manager – industry, Schaeffler Belgium Sprl/byba, serves as immediate past president of FAS and chair of the FAS Awards & Nominations Committee.

Michael Connelly, FASM, consultant, Connelly Consulting, continues to serve as chair of the Education Subcommittee.

Michael E. Stevenson, president, ESI, continues as chair of the *Journal of Failure Analysis and Prevention* Editorial Committee.

Erik Mueller, materials research engineer, National Transportation Safety Board, was named chair of the International Relations Committee.


Demarest


Knauss


Beaudoin


Sood


Moore


Antoniou

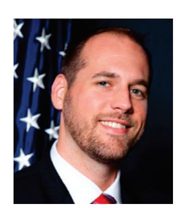

Li


Lane


Dupont


Connelly


Stevenson


Mueller

In This Issue

ASM INTERNATIONAL
Submit news of ASM and its members, chapters, and affiliate societies to Joanne Miller, editor, ASM News | ASM International 9639 Kinsman Road | Materials Park, OH 44073 | 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 ext. 0 or 800.336.5152 (toll free in U.S. and Canada) | F 440.338.4634 | E MemberServiceCenter@asminternational.org | W asminternational.org

Steven Bradley, FASM, principal, Bradley Consulting Services, continues to serve as chair of the FAS Membership Outreach Subcommittee.

Andrew Havics, director, pH2 LLC, continues to serve as chair of the FAS Programming Committee.

Heat Treating Society (HTS)

Eric Hutton, vice president operations - aerospace/defense east, Bodycote, serves as president of HTS.

Jim Oakes, vice president of business development, Super Systems Inc., serves as HTS immediate past president and treasurer, as well as chair of the HTS Awards & Nominations and the HTS Finance Committees.

Mohammed Maniruzzaman, engineering specialist, Caterpillar Inc., continues as chair of the HTS Education Subcommittee.

Michael A. Pershing, senior technical steward, Caterpillar Inc., continues as chair of the HTS Research & Development Committee.

Dennis Beauchesne, general manager, ECM USA Inc., continues as chair of the HTS Technology & Programming Committee.

Collin Russell, research & development engineer, Los Alamos National Laboratory, was named chair of the HTS Membership Subcommittee.

Timothy De Hennis, senior metallurgist, Boeing, and **Chuck Faulkner,** commercial delevopment manager-heat treatment, Quaker Houghton, continue to serve as co-chairs of the HTS Exposition Subcommittee.

International Metallographic Society (IMS)

Daniel Dennies, FASM, principal and CEO, DMS Inc., serves as president of IMS.

James E. Martinez, project manager, NASA, serves as immediate past president and chair of the IMS Awards & Nominations Committee.

Michael Keeble, U.S. labs and technology manager, Buehler, a Division of ITW, serves as vice president and continues to serve as chair of the IMS Buehler Technical Paper Award Committee.

Ellen Rabenberg, materials engineer, NASA Marshall Space Flight Center, was named chair of the International Metallographic Contest Committee.

Brett Leister, engineer, Naval Surface Warfare Center, was named chair of the IMS Education Committee.

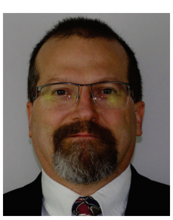
Dana Drake, lab engineer metals, EOS of North America, was named chair of the Micrograph Database Committee.

Chris Bagnall, FASM, consultant, MCS Associates Inc., continues to serve as chair of the Sorby Award Committee.

Donald Susan, principal member of technical staff, Sandia National Laboratories, continues to serve as chair of the Annual Meeting/Events Committee.

David Rollings, vice president sales and marketing, Ted Pella Inc., was named chair of the Corporate Sponsorship Committee.


Bradley


Havics

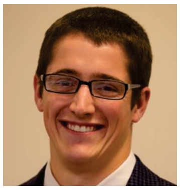

Hutton


Oakes

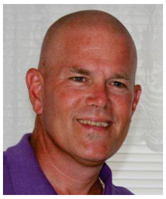

Maniruzzaman

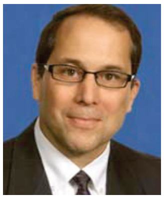

Pershing


Beauchesne


Russell


De Hennis


Faulkner


Dennies


Martinez


Keeble


Rabenberg


Leister


Drake


Bagnall


Susan


Rollings

Thermal Spray Society (TSS)

William Lenling, FASM, TSS-HoF, founder/CTO, Thermal Spray Technologies Inc., serves as president of TSS.

Rogerio Lima, senior research officer, National Research Council of Canada, serves as vice president of TSS and chair of the Program Committee.

André McDonald, FASM, professor and associate chair (research), University of Alberta, Canada, serves as immediate past president and chair of the TSS Awards & Nominations Committee.

Robert Miller, materials engineering consultant, R.A. Miller Materials Engineering, continues to serve as chair of the Accepted Practices Committee.

Shari Fowler-Hutchinson, product/sales development manager, Saint-Gobain, continues to serve as chair of the Exposition Subcommittee.

Robert Vassen, FASM, professor, Forschungszentrum Jülich Gmbh, Germany, continues to serve as chair of the *Journal of Thermal Spray Technology* Committee.

Fardad Azarmi, professor of mechanical engineering, North Dakota State University, continues as chair of the TSS Training Subcommittee.

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


Lenling


Lima


McDonald


Miller


Fowler-Hutchinson


Vassen


Azarmi

BOARD NOMINATIONS

ASM Seeks Vice President and Board of Trustees Nominations

ASM is seeking nominations for the position of vice president as well as three trustees. The Society's 2021 vice president and trustee elects will serve as a voice for the membership and will shape ASM's future through implementation of the ASM Strategic Plan.

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

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

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

Deadline for nominations is March 15. For more information, visit asminternational.org/vp-board-nominations or contact Leslie Taylor, leslie.taylor@asminternational.org or 440.338.5472.

ASM and its Affiliate Societies Seek Student Board Members

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

- An opportunity like no other!
- Expenses to attend meetings paid for by the respective Society
- Take an active role in shaping the future of your professional Society
- Actively participate in your professional Society's board meetings
- Gain leadership skills to enhance your career
- Add a unique experience to your resume
- Represent Material Advantage and speak on behalf of students
- Work with leading professionals in the field

Opportunities specific to each Society:

ASM International

- Attend four board meetings (July 26-27, September 12-15 during IMAT, spring and summer 2022)
- Term begins June 1

ASM Electronic Device Failure Analysis Society

- Attend one board meeting (fall 2021)
- Participate in three teleconferences
- Term begins October 1

ASM Failure Analysis Society

- Attend one board meeting (fall 2021)
- Participate in three teleconferences
- Term begins October 1

ASM Heat Treating Society

- Attend one board meeting (fall 2021)
- Participate in two teleconferences
- Term begins October 1

ASM International Metallographic Society

- Attend one board meeting (fall 2021)
- Participate in monthly teleconferences
- Term begins October 1

ASM International Organization on Shape Memory and Superelastic Technologies

- Attend one board meeting (spring 2022)
- Participate in three teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins October 1

ASM Thermal Spray Society

- Attend one board meeting in the U.S. (fall 2022)
- Participate in three teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins October 1

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

IDEA COMMITTEE Update on Activities

Erin Barrick, Sandia National Laboratories

The IDEA (Inclusion, Diversity, Equity, and Awareness) Committee has been busy at work since its formation in June 2020. In September, as part of the virtual Leadership Days series, the committee hosted a “Diversity, Equity, and Inclusion” workshop where chapter leaders brainstormed ideas to broaden membership, increase attendance at events, and lower barriers to participation.

The committee is also actively engaged in organizing webinars focusing on themes central to its mission. In November, a webinar presented by committee member Danielle Cote, professor at Worcester Polytechnic Institute, “How to Create a Welcoming Technical Workspace: Stories and Personal Experiences,” was an eye-opening narrative and included creative role-reversals, permitting all audience members to grasp the magnitude and impact of inequities encountered in the modern workplace. Webinar participants expressed interest in furthering the conversation and developing strategies to improve workplace environments. Building upon this first webinar, Vanessa Raquel Raponi, founder of EngiQueers Canada, led a webinar in February, “Building a Support Network from the Ground Up,” which included tangible techniques and resources to improve your organization’s culture. Webinars are available to view anytime at asminternational.org/on-demand.

One of the most successful activities of the committee is identifying candidates and assisting with nomination packages for awards, ASM Fellows, and leadership positions. Let us know if you would like help with a nomination package. Also, join us for a diversity workshop this spring featuring Erin Cech, professor of sociology at the University of Michigan, as the keynote speaker, who has devoted her research to examining inequality in STEM fields.

We look forward to bringing more programs on inclusion, diversity, equity, and awareness to the ASM community in the future.

Title slide from a recent IDEA Committee webinar.

Get Engaged, Get Involved, Get Connected

The IDEA Committee is always looking for new members. Specific openings are posted online under “Volunteer Opportunities” on ASM Connect, connect.asminternational.org. We’re seeking participants, leaders, and project ideas for the LGBTQ+ subcommittee as well as the underrepresented minorities subcommittee. We also invite volunteers to help plan the annual Women in Materials Engineering breakfast, to be held at IMAT 2021. Sign up through ASM Connect or contact Vicki Burt at vicki.burt@asminternational.org for more details.

SOLICITING NOMINATIONS FOR EDFAS AWARDS

The Electronic Device Failure Analysis Society (EDFAS) is seeking nominations for two awards to recognize the accomplishments of its members. The awards are given annually, with the debut presentations made at ISTFA 2017. Nominate a worthy colleague today!

EDFAS Lifetime Achievement Award

The EDFAS Lifetime Achievement Award was established by the EDFAS board of directors to recognize leaders in the EDFAS community who have devoted their time, knowledge, and abilities toward the advancement of the electronic device failure analysis industry.

EDFAS President's Award

The EDFAS President's Award recognizes exceptional service to EDFAS and the electronic device failure analysis community. Examples of such service include committee service, service on the board of directors, organization of conferences or symposia, development of education courses, and student and general public outreach. While any member of EDFAS is expected to further the Society's goals through service, this award recognizes those who provide an exceptional amount of effort in their service to the Society.

For complete rules and nomination forms, visit the EDFAS website at asminternational.org/web/edfas/societyawards or contact Mary Anne Jerson at 440.338.5446, maryanne.jerson@asminternational.org.

Nomination deadline for both awards is March 15.

HTS AWARD DEADLINES

HTS
Heat Treating Society
ASM INTERNATIONAL

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 advancement in managing the business of heat treating. The award, endowed by Bodycote Thermal Process-North America, is open to all students, in full time or part-time education, at universities (or their equivalent) or colleges. The winner will receive a plaque and a check for $2500. **Paper submission deadline is March 15.**

George H. Bodeen Heat Treating Achievement Award

The George H. Bodeen Heat Treating Achievement Award was established by the ASM Heat Treating Society in 1996, recognizes distinguished and significant contributions to the field of heat treating through leadership, management, or engineering development of substantial commercial impact. The award is named in honor of George H. Bodeen, FASM, ASM President 1983, ASM Distinguished Life Member, and founding president of the ASM Heat Treating Society. **Nomination deadline is March 15.**

HTS/Surface Combustion Emerging Leader Award

The ASM HTS/Surface Combustion Emerging Leader Award was established in 2013 to recognize an outstanding early to mid-career heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. The award, endowed by Surface Combustion, includes a check for $4000. The winning young professional will best exemplify the ethics, education, ingenuity, and future leadership of our industry. **Nomination deadline is March 15.**

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

ATTENTION STUDENTS: 2021 ASM International Student Paper Contest

Deadline April 1

The ASM International Student Paper Contest is designed to increase interest and awareness in materials science and engineering, and provide recognition for outstanding student efforts in the field. The contest is open to all Material Advantage student members who are enrolled at a college or university offering courses in materials science and engineering. The winner will receive a cash prize of $500, plus up to $500 toward travel expenses to attend IMAT 2021. In addition, a full set of ASM Handbooks (or an ASM Handbooks Online subscription) will be presented to the school or student chapter

Bernoulli Andilab, a Ph.D. student at Ryerson University, was the 2020 Best International Paper Award winner.

of the winning entry. For contest rules, past recipients, and a sample form, visit asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination form link.

2021 Bradley Stoughton Award for Young Teachers

Winner receives $3000

Deadline March 30

This award recognizes excellence in young teachers in the fields of materials science, materials engineering, design, and processing. Do you know a colleague who:

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

Nominate a colleague for the 2021 award by contacting christine.hoover@asminternational.org.

Engineering Materials Achievement Award

Deadline March 30

This award recognizes an outstanding achievement in materials or materials systems related to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product. Do you know of an innovative, cutting-edge scientific achievement that has distinctly impacted industry, technology, and society within the past 10 years? If so, consider submitting a nomination for the 2021 award. View sample forms, contest rules, and past recipients at asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination form link.

Canada Council Award Nominations due April 30

ASM's Canada Council is seeking nominations for its 2021 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 2021 awards! Award rules, past recipients, and sample nomination forms can be found at asminternational.org/membership/awards/nominate.

ASM-IIM Visiting Lecturer Program Seeks Applicants

Deadline March 30

The cooperative Visiting Lecturer Program of ASM International and the Indian Institute of Metals (IIM) is seeking applicants for 2021. View rules, past recipients, and criteria at asminternational.org/membership/awards.

Mark Your Calendar: Upcoming Award Deadlines

March 30 – ASM-IIM Visiting Lecturer
March 30 – Bradley Stoughton Award for Young Teachers
March 30 – Engineering Materials Achievement Award
April 1 – ASM International Student Paper Contest
April 30 – Canada Council Awards

To nominate someone for any of these awards, email christine.hoover@asminternational.org for a unique nomination link.

A TRIBUTE TO GEORGE DIETER

Dr. George E. Dieter, Jr., FASM, 1928-2020.

ASM members share heartfelt tributes and fond memories of a man whose legacy continues to impact not only the Society but the greater materials and design communities.

"At the Illinois Institute of Technology, we used George's *Mechanical Metallurgy* book as our foundational text for all our mechanical behavior of materials courses. George's legacy will live on for many generations to come. This is a great loss to our profession." – *Judith Todd, FASM, ASM vice president*

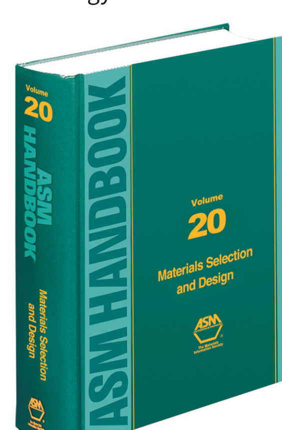
"Professor George Dieter was a technical giant upon whose shoulders many of us launched successful careers. I will always be grateful, not only for his technical contributions, but also for his caring and thoughtful work on behalf of his students, his colleagues, and society. I had the pleasure of presenting him with the ASM Presidential coins of Drs. Frederick Schmidt and William Frazier during his 90th birthday celebration at the University of Maryland. The presentation honored his outstanding contributions to ASM International." – *William E. Frazier, FASM, ASM past president*

William Frazier (left) represents ASM at George Dieter's 90th birthday celebration at the University of Maryland in 2018.

"I will be forever grateful to Professor Dieter for providing the opportunity (coercing me), as a mechanical engineer, to join the faculty at Drexel University, grow as a young professor under his mentorship, and collaborate at the interface between materials engineering and mechanics. He introduced the materials world to two revolutionary educational concepts through his textbooks: *Mechanical Metallurgy* and *Engineering Design - A Materials and Processing Approach.* George left huge footprints around the world and a legacy of positive influences on many lives that will be felt long into the future. In addition to our common alma mater, Carnegie Tech (now CMU), George and I had the same birthday—12 years apart—and we exchanged birthday cards every year over the past five decades." – *Howard A. Kuhn, FASM, ASM Handbook editor and instructor*

"I, like many others, used Professor Dieter's textbook during my undergraduate training. Furthermore, I had the pleasure of getting to know him better because he was a consultant to the company I first worked for directly out of graduate school. I was always a bit in awe when he visited the lab where I worked. George was truly a great member of our materials community and so well deserving of the ASM awards he received. His impact will be felt for generations." – *Diana Essock, FASM, ASM president*

"Professor A.W. Grosvenor, the founder of our materials science and engineering (MSE) department at Drexel, in his last year as head (1962) hired Dieter, as his successor. A great era started for Drexel Metallurgy. Dieter hired Dick Heckel, Alan Lawley, and others and built a department that was ahead of the whole university by a decade or two. We will remember him as a restless and continuously innovative engineer/educator who benefited the profession and the many students who interacted with him directly or indirectly." – *Antonios Zavaliangos, A.W. Grosvenor Professor of Materials Science and Engineering, Drexel University*



Dieter served as volume chair of *ASM Handbook*, Vol. 20.

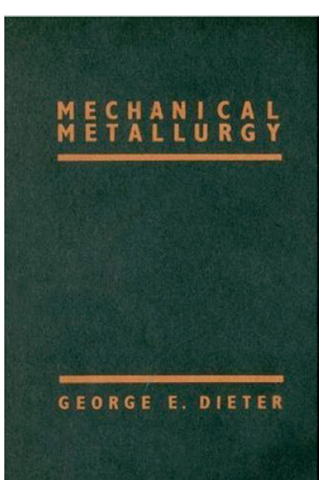
"I am deeply saddened by the passing of Dr. George Dieter. I only met George in person a few times at gatherings of the A. James Clark College of Engineering of the University of Maryland (UMD). I joined UMD in July 2019 as chair of the MSE department and had chatted with George about meeting for lunches, which did not occur due to COVID-19. It is regrettable that I did not get more chances to learn about academic leadership from him. At my suggestion, which was strongly supported by the chair of the UMD mechanical engineering (ME) department, Professor Balakumar Balachandran, the UMD Clark School of Engineering has established a George Dieter Endowed Distinguished Lecture Series in Mechanics and Materials." – *Ji-Cheng (JC) Zhao, FASM, University of Maryland, ASM trustee*

DIETER LECTURE SERIES

The **George Dieter Endowed Distinguished Lecture Series in Mechanics and Materials** at the University of Maryland will feature the very best scholars in both ME and MSE and will be attended by faculty and students of both departments. To contribute to this endowment fund, visit https://bit.ly/2NaMSdE.

Capturing the sentiments of the entire campus, UMD President Dr. Darryll J. Pines stated, "Dr. Dieter is an institution. He is a foundation. He is a legend."

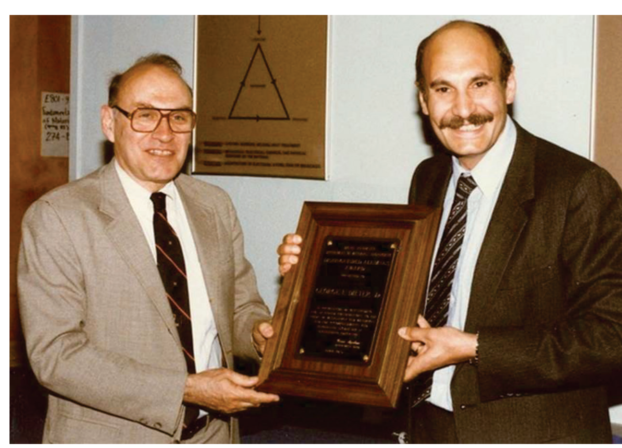
"When my freshman year began in 1962, George Dieter joined Drexel Institute of Technology (now Drexel University) as head of the metallurgical engineering department. I had started my B.S. in electrical engineering but did not enjoy the classes. In my sophomore year, George brought his co-worker, Richard Heckel from the DuPont Research Center to Drexel and I took his first course in Fundamentals of Ferrous Metallurgy, which was great. I switched my major and have never regretted the change! Dieter added several new faculty while I was there, and made great improvements to the program. I was lucky to take his excellent Mechanical Metallurgy course and I have two editions of his book." – *George Vander Voort, FASM, ASM Handbook editor, past trustee*



George Dieter's seminal textbook has been taught worldwide for decades.

"My HERO from my 10 years at Drexel. There are so many worldwide who used Dean Dieter's classic text. His entire devotion to his students, young and old, changed lives and re-engineered society. He certainly was instrumental in guiding me when I was 18! He used to tell all freshman MSE students to read *Metal Progress* cover-to-cover each month, even if they didn't initially understand it. In my case, I've been reading what is now *Advanced Materials & Processes* since October of 1963! We lost a giant!" – *Frederick E. Schmidt, FASM, ASM past president*

"George Dieter was my teacher, mentor, and guardian angel of sorts. I was an immigrant to America having had two years of high school before entering Drexel in the metallurgical engineering department that Dieter headed. The support, inspiration, and encouragement George Dieter gave me was pivotal for my success as an undergraduate. He was an amazing individual; highly disciplined, a visionary, and a superb strategic mind. His legacy to the field is huge. He was a leader who ensured that others were given opportunities to lead. He cared deeply about his fellow colleagues, students, and staff. His disciplined stern facade was just that. He had a heart of gold and touched many of us. We spoke two weeks before his passing. We said our goodbyes, and both knew in silence that it was our last encounter. He will always be remembered." – *Diran Apelian, FASM, ASM Materials Education Foundation immediate past chair*



George Dieter (left) receiving an award in 1984 for his leadership and service from Diran Apelian, then head of Drexel University's materials engineering department.

"George was a terrific metallurgist and made substantial contributions to the discipline. He was also a great guy with some amazing stories. I very much enjoyed the times he was able to attend chapter meetings. Truly a legend." – *Toni Marechaux, FASM, ASM trustee*

DEADLINE EXTENSION: Accepting Nominations through March 30 for the following ASM Awards:

Distinguished Life Membership*

- Typically awarded to the president or CEO of an organization
- Devoted time to the advancement of materials
- Knowledge of the materials industry

Medal for the Advancement of Research*

- Typically awarded to an executive responsible for corporate decisions in support of R&D

Honorary Membership*

- Awarded for distinguished service to the MSE profession, in areas of ASM's strategic plan/initiatives, and progress for mankind

**ASM membership not required*

William Hunt Eisenman

- Achievements in industry in practical application of materials science and engineering through production or engineering use
- Five years current, continuous ASM membership
- Three statements from close associates

Bronze Medal

- Two years of current, continuous ASM membership
- Candidate should have demonstrated outstanding technical contributions and volunteerism on a national level
- Candidate shall be no more than 35 years of age on January 1 of the year in which the award is given
- Recognizes ASM members who are in early-career positions typically 0-10 years

Historical Landmark

- Sites and events must in some way be of significant historical importance in the field of materials science and engineering
- Emphasis on technological development rather than on individuals
- Recommend site/structure should be at least 50 years old

For more information, visit asminternational.org/membership/awards/.

EMERGING PROFESSIONALS

How are Engineering Undergraduate Students Surviving if They Can't Learn in Labs?

Abbie Ganas and Ho Lun Chan

The COVID-19 pandemic has shifted the paradigm of teaching. As students and teachers are now well aware, online learning comes with daunting obstacles such as "Zoom fatigue." Moreover, as engineering students head toward graduation, those looking to secure jobs in industry face an unprecedented obstacle: Hiring committees may not hire them because they are lacking necessary laboratory skills. In the past few weeks, we have been speaking with students and instructors at different universities and listening to their stories about teaching virtual laboratory courses. We were surprised to discover that a handful of instructors have experimented with some creative approaches to teaching laboratory classes asynchronously. We are happy to share two success stories here.

Naz and Armando Shehi are senior chemical and materials engineering students at California State Polytechnic University Pomona. In their virtual "Corrosion and Materials Degradation" laboratory course, instructors developed video instruction and assisted them in making their own homemade demo to perform brass immersion experiments. During the experiments, Naz and Armando simply needed to take daily macrographs using their cell phones and verbally describe their observations.

"I was able to see the corrosion processes happening daily while still being safe and economical. I would have never thought that this sort of demonstration could be done at home," said Armando.

Maryann Veyon, a chemical engineering senior student at Case Western Reserve University, went through a very similar experience to that of Naz and Armando in her "Process Control" course. Instructed to use no more than $50 for her project, she and her group mates engineered an abandoned fish tank to study how sound barriers are affected by airflow.

"It won't be great, but I got some value out of it once I got over the headaches it was giving me," said Maryann.

To some students, it was a shock when they realized what they could accomplish scientifically at home. Although a virtual laboratory course is hardly comparable to its in-person counterpart, it reminds us that with ingenuity and adaptability—qualities the best professional scientists and engineers possess—excellent technical skills can be developed in even the most unusual of circumstances.

Ho Lun Chan is an ASM student board member. Abbie Ganas and Ho Lun Chan are part of a non-profit group *called Acta Millennia Inc., aiming to broaden accessibility of high-quality science to the general public.*

FROM THE FOUNDATION

Dear Friends: We Need You

For years, the ASM Materials Education Foundation has had dedicated chapter members who have helped locally organize an ASM Materials Camp for teachers (or students) in their area. This year, we will again be offering ASM Virtual Materials Camps for both students and teachers.

Daehn

While we won't need support securing lunches and parking for participants, we still need your help with outreach to encourage students and teachers to participate. Because the ASM Materials Camps will be online, teachers can participate from anywhere. Please help us take advantage of this year to reach teachers in areas who would not normally have access to an in-person program.

No matter where you live, you can help the ASM Foundation to reach teachers in your area. We hope that you will. We can provide a flyer to be distributed electronically or in print and teachers can be referred to the ASM Foundation website for the full schedule of ASM Materials Camps, including different program options.

And, of course, we still need your financial support for these programs. While we are not incurring some of the travel costs of in-person programs, we are still paying master teachers, shipping supplies, and preparing from inside the Dome. Funds that we receive this year will only help us to remain strong and be in an even better position to increase the in-person programming we plan to offer in 2022.

Don't forget that we are now serving teachers and students throughout the school year through our Teacher Tuesdays webinar series and the ASM Foundation's new Materials Club for high school students that offers enrichment and engagement with professionals. Please continue to share these opportunities with teachers and students in your area. Additional information can be found at asmfoundation.org.

The year 2020 ended much better than we might have thought at the beginning of the pandemic: We closed the year with finances in the black and were able to serve 660 teachers and 150 students in virtual programs to outstanding reviews. *Thank you for your ongoing support of our mission and work that allow these successful programs to continue through it all!*

Glenn S. Daehn
Chair, ASM Materials Education Foundation

OPPORTUNITIES FOR STUDENTS AND TEACHERS

Undergraduate Scholarships

Scholarships from $1500 to $10,000 available to Material Advantage students. **Deadline May 1.**

Technical and Community College Scholarships

Scholarships of $500 each. **Deadline May 1.**

Undergraduate Design Competition

This competition encourages the strengthening of design curricula in materials science and engineering departments. The awards include: First Prize: $2000 + $500 travel assistance + $500 to the department for support of future design teams; Second Prize: $1500 + $500 travel assistance; Third Prize: $1000 + $500 travel assistance. **Deadline June 30.**

Student Chapter Grants

These grants support Material Advantage student chapters in their outreach activities. Five grants of $500 each. **Deadline May 31.**

Student Materials Camp

This popular program utilizes hands-on learning principles of applied math, physics, and chemistry led by a distinguished world-class faculty. The program is aimed at stirring students' interest in science and getting them excited about materials engineering careers, as they learn to be team players and become "science detectives" at the camp. (All 2021 Materials Camps will be held virtually.) **asmfoundation.org.**

Teacher Materials Camp

This weeklong program for middle school and high school teachers demonstrates how to use low/no cost simple labs and experiments with everyday materials that can be integrated into existing math/science lesson plans. These simple activities and experiments are proven to actively engage students in learning more about applied science. (All 2021 Materials Camps will be held virtually.) **asmfoundation.org.**

Kishor M. Kulkarni Distinguished High School Teacher Award

This award honors the accomplishments of one high school science teacher who has demonstrated a significant and sustained impact on pre-college age students. Award: $2000 cash grant plus the recipient's travel cost of up to $500 to receive the award at the ASM Awards Luncheon. **Application deadline June 30.**

"Living in a Material World"— $500 Teacher Grants

Provides support for K-12 teachers to develop and implement science teaching activities. Award: 20 grants of $500 each. **Deadline: May 25.**

To learn more about any of these programs, visit asmfoundation.org.

WOMEN IN ENGINEERING

This profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with ***Micca Belke,*** *metallurgical engineer II at Mercury Marine, Fond Du Lac, Wisconsin.*

Belke

What attracted you to engineering?

I have always enjoyed figuring out how to put things together and learning how things work. Engineering for me was a way to gain greater knowledge into how parts are fabricated.

What part of your job do you like most?

The diversity; every day is something new. Working on something new every day allows me to continuously learn new skills and discover new ways parts can fail.

What is your greatest professional achievement?

Having the opportunity to speak with students at my alma mater where I enjoy talking with them about their aspirations and give them advice where I can.

What is your engineering background?

I have a bachelor's degree in metallurgical engineering and am currently working to obtain an MBA. I had four internships in steel mills as an undergrad that taught me a lot about how steel is made and formed. I currently work in a materials lab performing failure analysis work where I get to look at a wide variety of parts that make up marine engines.

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

When I was young, I thought I wanted to be a veterinarian; high school biology taught me otherwise! I love math and sciences and knew that engineering was the right choice for me.

Best career advice, given or received?

Never stop learning, have self-confidence, and build relationships.

Finish this sentence: Women in materials engineering are…

Inspiring! So many talented women out there doing amazing things keeps me motivated to improve myself.

Favorite motto or quote?

"In every walk with nature one receives far more than he seeks." - John Muir

What's the last book you read?

"Playing to Win: How Strategy Really Works" by A.G. Lafley and Roger L. Martin

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

ASM PROGRESS REPORT

For an update from ASM President Diana Essock, FASM, on the Society's strategic plan and latest initiatives, see the article on pages 31-33 in this issue. To view the ASM strategic plan, visit asminternational.org/about/strategicplan. To get involved in any of ASM's new initiatives, log on to ASM Connect at connect.asminternational.org.

Essock

CHAPTERS IN THE NEWS

Santa Clara Learns about African Iron Age


Todd

The ASM Santa Clara Valley Chapter was treated to an evening of spirited archaeometallurgy when ASM Vice President Judith Todd, FASM, spoke on The African Iron Age on December 16, 2020. In 1972, Todd lived for a year in the remote highlands of South-West Ethiopia among the Deemay people, who were producing iron by methods used 2000 years ago. In her presentation, Todd took the group on a virtual trip back to the African Iron Age to learn about the importance of iron not just for tools but in warding off the "evil eye," the daily life of the Deemay, and the position of the smith caste in society. The role of inclusion analysis in determining patterns of trade in iron artifacts was also discussed. Todd is P.B. Breneman Chair and professor of ESM at Penn State University.

Brandywine Delves into Materials Data


Frame

Lesley Frame was the featured speaker for the Brandywine Chapter's third technical meeting of the season. Her December 8, 2020, talk on "Materials Data for Process Modeling" addressed some of the current challenges associated with selecting and collecting materials data as inputs to multiscale behavior models of materials for thermal and mechanical manufacturing processes. Deterministic and stochastic approaches were discussed along with the need for uncertainty quantification of simulation results. Ongoing research by the Center for Materials Processing Data (CMPD) was presented as an example of some of these materials data challenges. ASM International serves as the business administrator for CMPD. Frame is director of the CMPD and assistant professor of MSE, University of Connecticut.

NY/NJ Hosts Biomedical Expert


Zakharchenko

On December 10, 2020, the NY/NJ Chapter hosted a virtual technical talk on "Implantable Materials for Cardiovascular Applications Research" presented by Andrey Zakharchenko, a postdoctoral fellow in the laboratory of Dr. Robert Levy at the Children's Hospital of Philadelphia. He shared that although bioprosthetic heart valves made from animal-derived materials often work for many years in adults, they tend to fail in children as early as within one year due to valve calcification and structural degeneration. Zakharchenko discussed a new valve coating procedure using a biocompatible and non-immunogenic polymer, polyoxazoline (POZ) developed by his team. The use of POZ helps block the accumulation of serum proteins, stabilizes inner collagen structure, and improves fluid performance of the valve. Zakharchenko specializes in bioprosthetic heart valve research and investigates the failure mechanisms of biomaterials used in these devices. His research interests include development of new biomaterials in medicine, novel therapies for heart valve disease, and nanomedicine.

Hartford Holds Titanium Talk


Grohowski

The ASM Hartford Chapter's January 12 meeting saw a 36% increase over their average attendance. Participants in the virtual meeting hailed from a wide geographic area including Albany, Los Angeles, Seattle, and Vancouver. The chapter, which celebrated 100 years in October 2020, saw a lot of positive energy from this meeting. The technical talk on "Advances in Titanium MIM & Additive Manufacturing" was presented by Joseph Grohowski, founder and president of Praxis Technology. He developed Praxis' titanium metal injection molding (MIM) process for manufacturing implant-grade titanium and multiple technologies for porous titanium. Parts manufactured via titanium MIM use nearly 100% of the metal powder, offering better material utilization, which translates to more cost savings. His talk included new heat treatment processes that greatly improve the performance of additively manufactured titanium.

VISIT THE CAREER HUB

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

IN MEMORIAM

Dieter

George E. Dieter, Jr., FASM, died at age 92 on December 12, 2020. Dieter was professor emeritus of mechanical engineering, Glenn L. Martin Institute Professor of Engineering, and dean of the A. James Clark School of Engineering at the University of Maryland from 1977-1994. Born on December 5, 1928, in Philadelphia, he earned a B.S. in metallurgical engineering from Drexel Institute of Technology in 1950 and a Sc.D. from the Carnegie Institute of Technology in 1953. After working as a research engineer at the E.I. DuPont Engineering Research Laboratory in Wilmington, Delaware, he turned his career to academia. Dieter was department head and dean of metallurgical engineering at Drexel University, 1963-1968. In 1973, he returned to Carnegie Mellon University to serve as director of their Processing Research Institute. After joining the faculty of the University of Maryland (UMD) in 1977, Dean Dieter became a campus treasure, serving in various academic leadership roles, most recently as professor emeritus. A materials teaching lab in the Jeong H. Kim Engineering Building at the A. James Clark School of Engineering at UMD was recently named the George E. Dieter, Jr. Materials Instructional Laboratory.

Dieter wrote two seminal books: *Mechanical Metallurgy,* now in its third edition and one of the standard texts still widely used to teach engineering; and *Engineering Design* (coauthored with Linda C. Schmidt), now in its sixth edition. He also was the volume chair of the *ASM Handbook,* Vol. 20, *Materials Selection and Design,* (1994-1997). Dieter served as an ASM Trustee from 1978 to 1981 and received numerous awards including ASM's Albert Easton White Distinguished Teacher Award (1986) and Albert Sauveur Achievement Award (1992). In 1993, Dieter was elected to the National Academy of Engineering for "contributions to engineering education in the areas of materials design and processing." He was a member of the ASM Washington DC Chapter.

See also "A Tribute to George Dieter" on pages 40-41 in this issue of AM&P.

Morral

John E. Morral, FASM, age 81, passed away on December 21, 2020. Morral was born in Kokomo, Indiana, on August 3, 1939. He received his undergraduate and M.S. degrees in metallurgical engineering from The Ohio State University (OSU), graduating in 1965. He completed his doctoral work at the Massachusetts Institute of Technology, receiving his Ph.D. in 1969. Morral was employed by the University of Connecticut in 1971 as a professor and department head, retiring in 2003. He then moved to Columbus, Ohio, to chair the OSU Department of Materials Science and Engineering, retiring in 2012 and becoming an emeritus professor there. Following his second retirement, he accepted the position of editor-in-chief of ASM International's *Journal of Phase Equilibria and Diffusion.* After nine years, he was still serving the society in that role at the time of his death. He was the recipient of numerous awards for his many years of work. In 2018, he was honored by ASM with the J. Willard Gibbs Phase Equilibria Award "for fundamental and applied research on topology of phase diagrams and theory of phase equilibria resulting in major advances in calculation and interpretation of phase equilibria and diffusion." Morral was a long-time member of the Alloy Phase Diagram Committee. He was also a member of the ASM Columbus Chapter as well as ASM's Failure Analysis Society, Heat Treating Society, International Metallographic Society, and the International Organization on Shape Memory and Superelastic Technologies.

ADVANCED MATERIALS & PROCESSES EDITORIAL PREVIEW

APRIL 2021

Aerospace Materials and Testing

Highlighting:

- Developments in Titanium for Aerospace
- Preservation of Under-utilized Machinery during COVID
- Study of South American Copper Artifacts

Special Supplements:

- *International Thermal Spray and Surface Engineering* newsletter covering coatings in the aerospace and defense industries, along with TSS news and initiatives.
- *SMST NewsWire* newsletter covering shape memory and superelastic technologies for biomedical and actuator applications, along with SMST news and initiatives.

Advertising Bonus:

- Show issue for AeroMat and ITSC Virtual Events

Advertising closes March 6

MAY/JUNE 2021

Materials for Energy/Automotive/Power Generation

Highlighting:

- Concentrated Solar Power Materials
- Battery Materials for Automotive
- Wind Energy Growth

Advertising Bonus:

- Heat Treat Preshow Issue

Special Supplements:

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

Advertising closes April 21

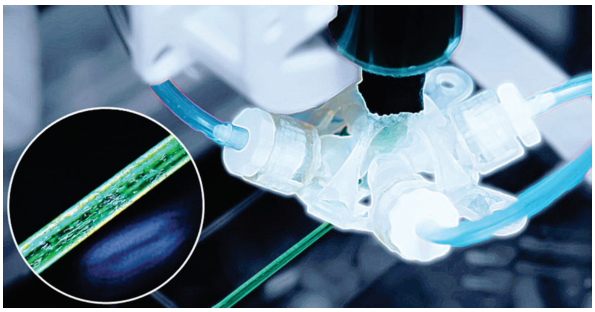
Subscriptions/Customer Service:
800.336.5152
MemberServiceCenter@asminternational.org

Information on Advertising and Sponsorships:
Kelly Johanns
440.318.4702
kelly.johanns@asminternational.org

Download the Media Kit at:
asminternational.org/advertise-webform

AD INDEX

3D PRINTSHOP



The morphing nozzle 3D prints fiber-filled composite materials with on-demand control of fiber alignment. Courtesy of University of Maryland.

MORPHING NOZZLE LEADS TO '4D' APPLICATIONS

Engineers at the University of Maryland (UMD) have created a 3D-printing nozzle that changes shape, or "morphs," enabling control of fiber orientation in composite materials. The nozzle offers researchers new means for 3D printing fiber-filled composites, materials made up of short fibers that boost special properties over traditional 3D-printed parts, such as enhancing part strength or electrical conductivity. The challenge is that these properties are based on the directions or orientations of the short fibers, which has been difficult to control during the 3D printing process, until now.

"When 3D printing with the morphing nozzle, the power lies on their side actuators, which can be inflated like a balloon to change the shape of the nozzle, and in turn, the orientations of the fibers," says Ryan Sochol, an assistant professor in mechanical engineering and director of the Bioinspired Advanced Manufacturing Laboratory at UMD.

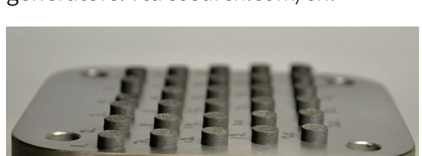
To demonstrate the new approach, researchers looked at emerging "4D printing" applications. "4D printing refers to the concept of 3D printing objects that can reshape or transform depending on their environment," says UMD mechanical engineering professor David Bigio. "We looked at how printed parts swelled when submerged in water, and specifically, if we could alter that swelling behavior using our morphing nozzle."

The team is exploring the use of their strategy to realize biomedical applications in which bulk printed objects could reshape in the presence of particular stimuli from the body. They are also in discussions with several Department of Defense laboratories to use the new morphing nozzle to support production of weapons for defense and other military systems. *umd.edu.*

MAGNETS FOR MORE EFFICIENT ELECTRIC MOTORS

A new material under development is suitable for 3D printing permanent magnets for electric and hybrid vehicle motors. A European consortium, 3DREMAG, led by VTT Technical Research Centre of Finland, plans to develop a fully 3D printable electric motor, one that would be approximately 30% lighter than today's motors.

The Nd-Fe-B powder is the first permanent magnet material customized for 3D printing. The material can be used to produce fully dense metallic and resource-efficient permanent magnets for electric and hybrid vehicle motors, electric bicycles, and consumer electronics, as well as for wind turbine generators. *vttresearch.com/en.*



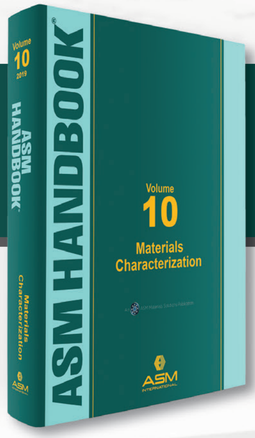
Magnets 3D printed from Nd-Fe-B powder. Courtesy of VTT.

LOW-COST WEATHER MONITORING STATIONS PROVE ACCURATE

An inexpensive monitoring system with 3D-printed parts and low-cost sensors can be just as accurate as commercial ones, researchers found. Adam K. Theisen, at Argonne National Laboratory, led the project, which compared the printed station with a commercial-grade station for eight months.

A team at the University of Oklahoma used open-source plans to print over 100 weather station parts. Instead of using polylactic acid, more common in 3D printing, they used acrylonitrile styrene acrylate, which is considered more durable outdoors. The low-cost sensors accurately measured temperature, pressure, rain, UV, and relative humidity. With the exception of a couple of instruments, the plastic material held up in the Oklahoma weather from mid-August 2018 to mid-April the following year. The ability to print specialized components could make weather stations more feasible in remote areas because replacement parts could be fabricated right away when needed. *anl.gov.*

3D-printed weather station installation in the field. Courtesy of Argonne National Laboratory.



ASM HANDBOOK, VOLUME 10:
MATERIALS CHARACTERIZATION

This handbook provides detailed technical information that will enable readers to select and use analytical techniques that are appropriate for their problem. Helpful tables and charts list the most common characterization methods for different classes of materials. The articles also describe materials characterization in general terms according to material type and serve as a jumping off point to the more specific technique articles.

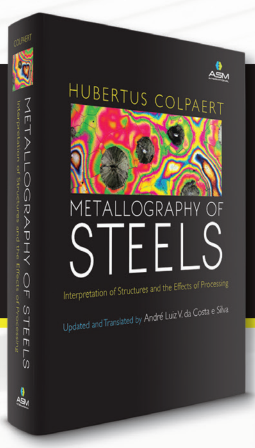
FORMATS:

Print:
ISBN: 9781627082112
Product Code: 05918G

Pages: 807

ASM Digital Library:
EISBN: 9781627082136
ASM Digital Library subscription is one-year single user access

Order today! asminternational.org/hbvol10 | 800.336.5152



METALLOGRAPHY OF STEELS:
INTERPRETATION OF STRUCTURE AND THE EFFECTS OF PROCESSING

BY HUBERTUS COLPAERT
UPDATED AND TRANSLATED BY ANDRÉ LUIZ V. DA COSTA E SILVA

This best-selling book is a combination of a metallographic atlas for steels and cast irons and an introductory textbook covering the fundamentals of phase transformations and heat treatment of these materials. Every important stage of processing, from casting to cold working is clearly discussed and copiously illustrated with metallographs that show the obtained structures, both desired and those achieved when deviations occur.

FORMATS:

Print:
ISBN: 9781627081481
Product Code: 05922G

Pages: 699

ASM Digital Library:
EISBN: 9781627082594
ASM Digital Library subscription is one-year single user access

Order today! asminternational.org/metallographyofsteels | 800.336.5152

ASM INTERNATIONAL

Thermo-Calc Software

Empowering Metallurgists, Process Engineers and Researchers

What do you do when the materials data you need doesn't exist?

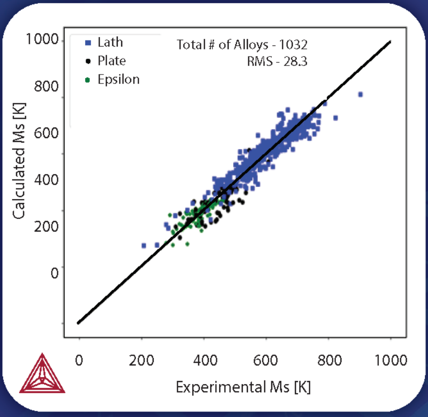
With Thermo-Calc you can:

- ✓ **Calculate** phase-based properties as a function of composition, temperature and time
- ✓ **Fill in** data gaps without resorting to costly, time-consuming experiments
- ✓ **Predict** how actual vs nominal chemistries will affect property data
- ✓ **Base Decisions** on scientifically supported models
- ✓ **Accelerate** materials development while reducing risk
- ✓ **Troubleshoot** issues during materials processing

Over 40 Thermodynamic and Kinetic Databases

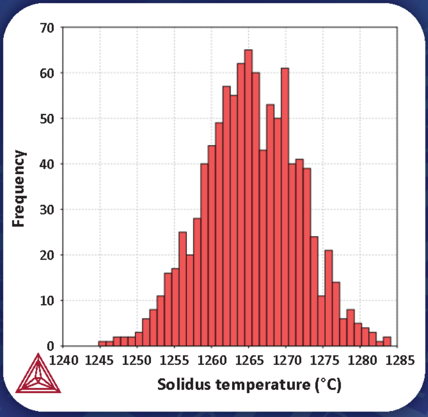
Choose from an extensive selection of thermodynamic and mobility databases in a range of materials, including:

Steel and Fe-Alloys



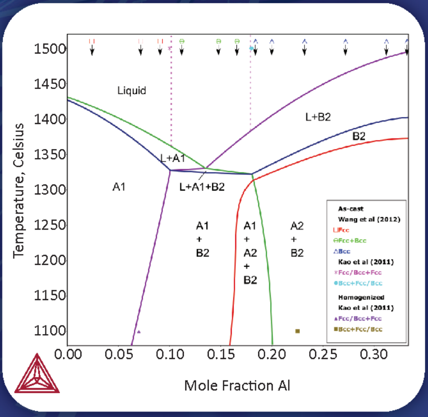
Comparison of calculated and experimental Ms temperatures for a wide range of steels

Nickel



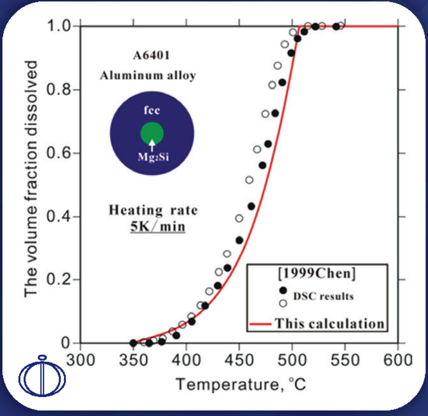
Variation in solidus temperature over 1000 compositions within alloy 718 specification

High Entropy Alloys



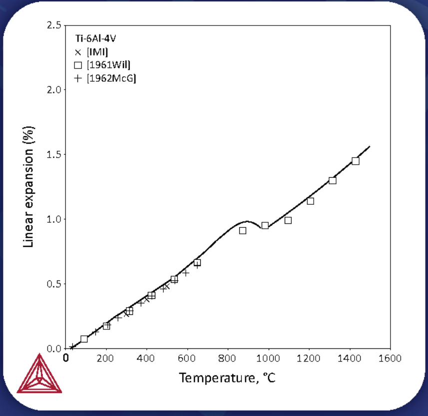
Calculated phase diagram along the composition line of CoCrFeNi-Al

Al Alloys



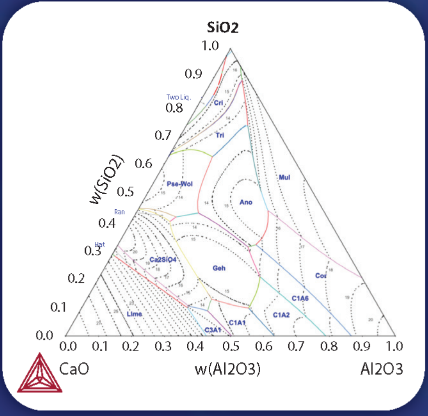
Dissolution of Mg2Si precipitate in Alloy A6401

Ti and TiAl Alloys



Linear expansion vs Temperature for Ti-6Al-4V

Oxides



Ternary liquidus projection in oxide systems

www.thermocalc.com info@thermocalc.com