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ADVANCED MATERIALS & PROCESSES

EMERGING ANALYSIS METHODS

MACHINE LEARNING FOR MICROSTRUCTURE CLASSIFICATION

P. 16

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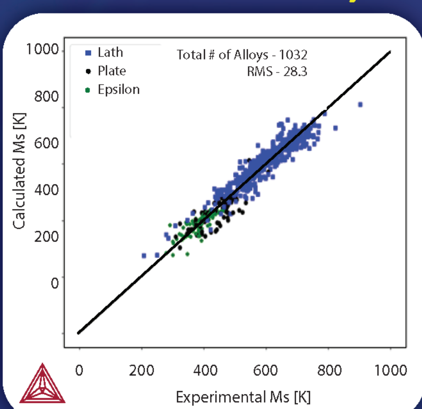
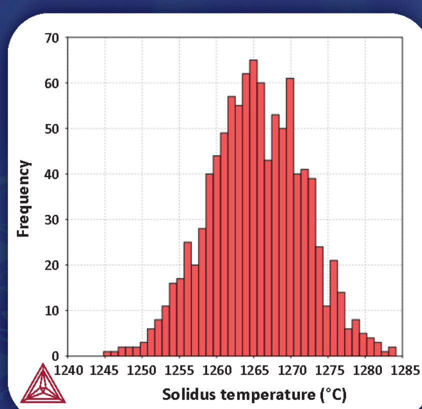


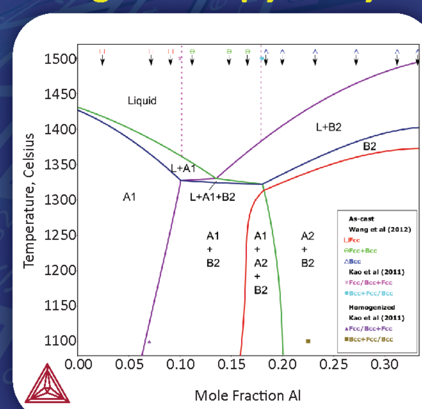
Comparison of calculated and experimental Ms temperatures for a wide range of steels

Nickel



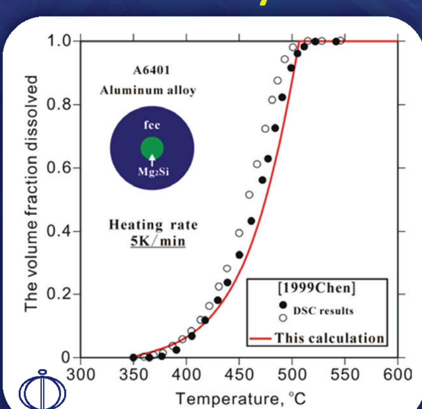
Variation in solidus temperature over 1000 compositions within alloy 718 specification

High Entropy Alloys



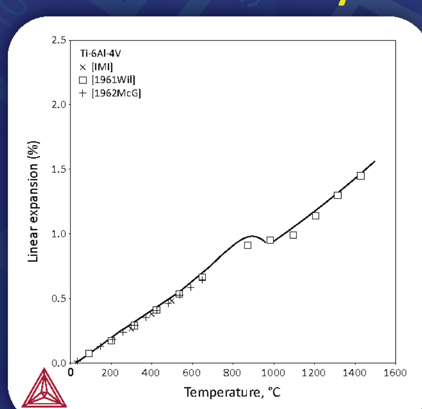
Calculated phase diagram along the composition line of CoCrFeNi-Al

Al Alloys



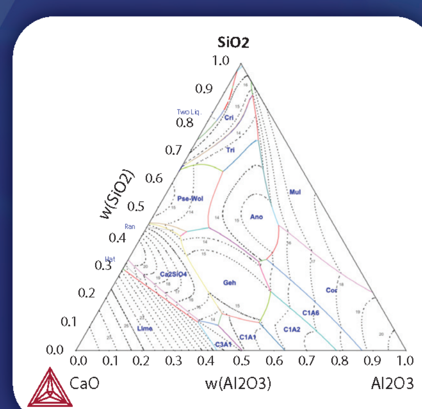
Dissolution of Mg2Si precipitate in Alloy A6401

Ti and TiAl Alloys



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

Oxides



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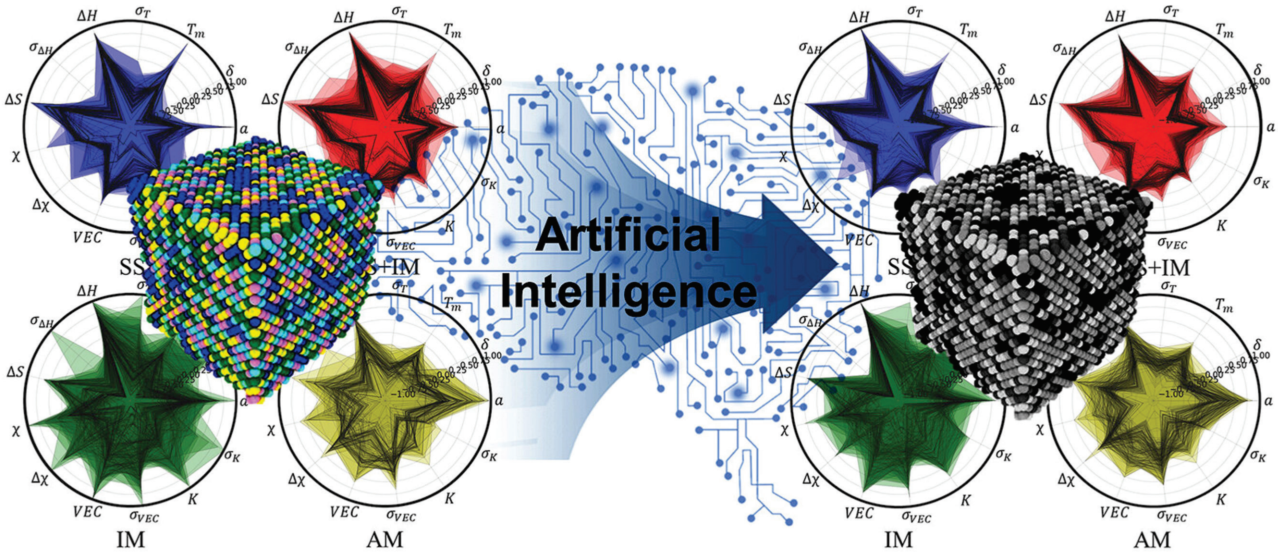

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MACHINE LEARNING FOR MICROSTRUCTURE CLASSIFICATION: HOW TO ASSIGN THE GROUND TRUTH IN THE MOST OBJECTIVE WAY

Martin Müller, Dominik Britz, and Frank Mücklich

The application of machine learning to the classification and segmentation of complex microstructures requires special attention when assigning the ground truth. Despite all progress in artificial intelligence, materials science knowledge is still indispensable in this process.

On the Cover:

Machine learning tools offer improvements in microstructure segmentation and classification. Courtesy of Saarland University.

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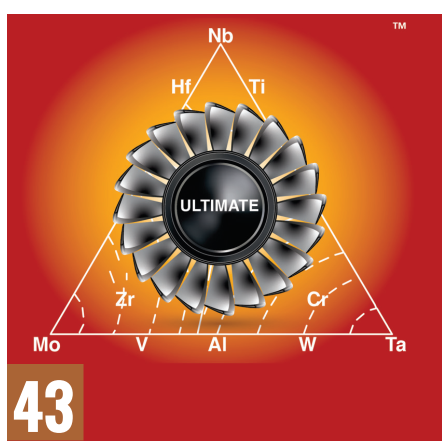
SUSTAINABILITY

This new department highlights developments in materials sustainability including biodegradable shoes and recyclable turbine blades.



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3D PRINTSHOP

Discover how researchers are 3D-printing shatter-free phone screens and room-temperature milk products.

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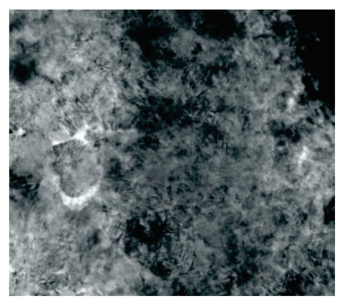

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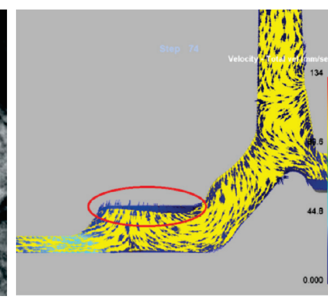

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HOPE EMERGING IN 2021

Thank goodness it's 2021! Never has the turning of a calendar been more anticipated around the globe. As the world awaits widespread distribution of newly developed vaccines for COVID-19, there is hope for better times ahead. We look forward to emerging from our bubbles. The biomedical industry is receiving praise for creating these vaccines in the shortest timeframe in history. Yet all the previous advances in technology, including machine learning and data science, enabled these quick turnaround-time discoveries.

Likewise, developments in materials science continue to roll out—faster everyday—by building on past successes. What's next for our industries?

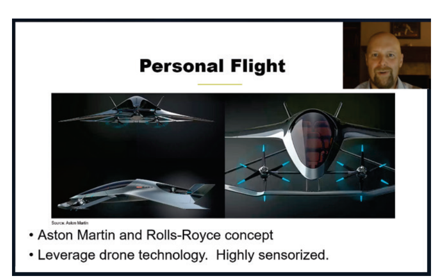
New years are full of Top 10 lists. So let's take a look at some of the most promising emerging technologies to watch this year. The Foresight 2021 report by Lux Research considers innovations across energy, materials, health, and digital sectors. Their Top 12 list (clearly 10 was not enough) includes: 1) autonomous vehicles, 2) national language processing, 3) plastic recycling, 4) AI-enabled sensors, 5) bioinformatics, 6) green hydrogen, 7) shared mobility (ride sharing), 8) alternative proteins, 9) 3D printing, 10) materials informatics, 11) precision agriculture, and 12) synthetic biology.

I am struck by how many of these areas ASM touches. As materials informatics features prominently, see this issue's lead article from Saarland University, which explores "Machine Learning for Microstructure Classification."

Several of the emerging areas relate to renewable energy and recycling. To increase coverage of this trend, our January issue introduces a new section of industry news on sustainability. We plan to highlight innovations and research related to environmentally friendly materials and processes as we make this page a regular part of our news department.

Both sustainable processes and emerging technologies were part of the EDFAS Virtual Workshop in early December. The event included an Emerging FA Techniques session. Keynote speaker, Tim Brosnihan of SEMI, spoke about how micro-electro-mechanical systems (MEMS) technology is enabling our digital world by playing an important role in industry, health, infrastructure, and alternatives. From the Apple Watch 6 to Vertiports (electric vertical take-off and landing sites) and personal flight vehicles, many of these new applications will require thousands of MEMS sensors.

In other news, last November, the DOE's Advanced Research Projects Agency-Energy (ARPA-E) awarded funding to 17 organizations for projects in its Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency (ULTIMATE) Program. See *ASM News* in this issue for details of the technological challenge they all take on. No less than 11 of the 17 projects have ASM members as the technical lead. ASM is everywhere! Are we surprised?

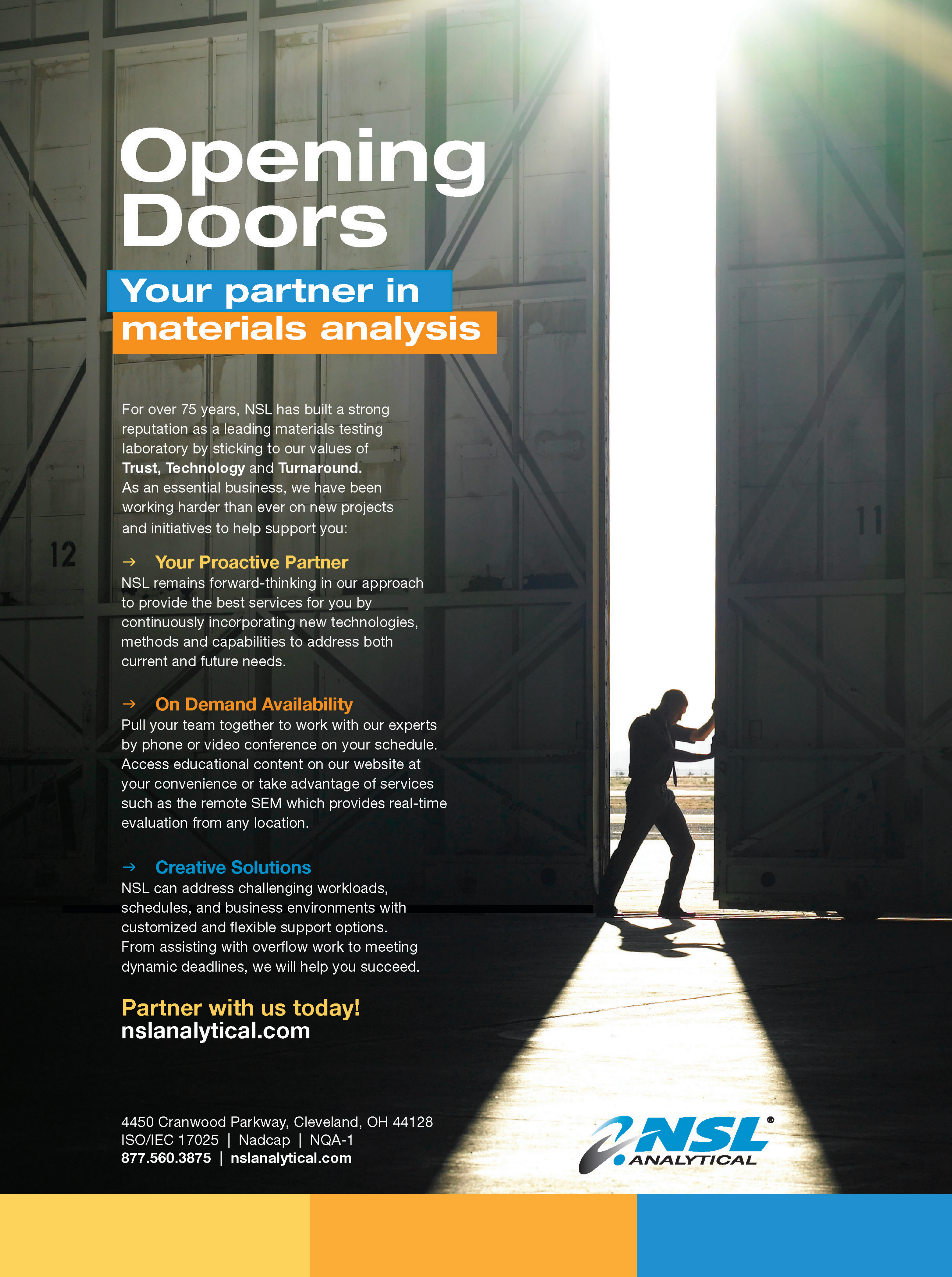


Tim Brosnihan highlights the rapid growth of MEMS technology.

ASM is bursting with pride at having our members in the ULTIMATE Program and leading many other areas of materials science. It will be exciting to see what innovations our members and the materials science community develop in 2021. The world awaits.

Joanne Miller

joanne.miller@asminternational.org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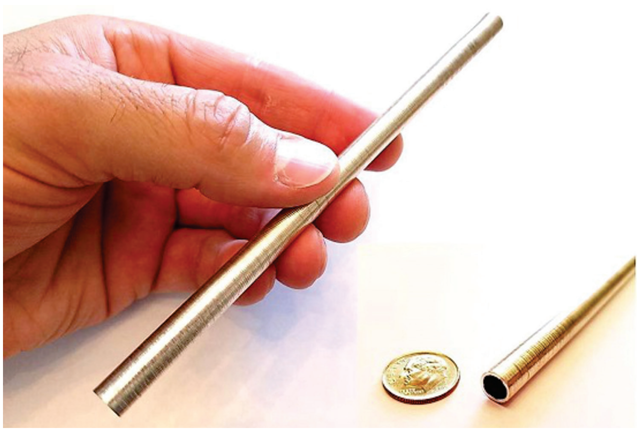
RESEARCH TRACKS

SHEAR GENIUS BOOSTS COPPER CONDUCTIVITY



PNNL's ShAPE process forms fully consolidated wire, rods, tubes, or other noncircular shapes using powder, flake, machining waste, or solid billet.

Researchers at the DOE's Pacific Northwest National Laboratory (PNNL), Richland, Wash., increased the conductivity of copper wire by roughly 5%—an advancement that could make a big difference in motor efficiency. The lab then partnered with General Motors to test the enhanced wire for use in vehicle motor components. As part of a cost-shared research project, the team validated the increased conductivity and found that the new copper composite also has higher ductility. In terms of other physical properties, it behaved just like regular copper, so it can be welded and subjected to other mechanical stresses with no performance degradation. Applications include any industry that uses copper to move electrical energy, such as power transmission, electronics, electric motors, generators, batteries, and others.

Using a novel manufacturing platform also developed at PNNL, researchers added graphene to copper and produced the composite wire. The increase in conductivity compared to pure copper is made possible by a new machine that combines and extrudes metal and composite materials, including copper. The lab's Shear Assisted Processing and Extrusion (ShAPE) process can improve the performance of materials extruded using this new method: Shear force is applied by rotating a metal or composite as it is pushed through a die to create a new form. The energy efficient approach creates internal heating by deforming the metal, which softens it and allows it to form into wires, tubes, and bars. ShAPE also eliminates pore spaces while uniformly distributing graphene additives within the metal, which may be the reason for improved electrical conductivity.

Research and development engineers at General Motors verified that the higher conductivity copper wire can be welded, brazed, and formed in exactly the same way as conventional copper wire. This indicates seamless integration with existing motor manufacturing processes. "Higher conductivity copper could be a disruptive approach to lightweighting and increasing efficiency for any electric motor or wireless vehicle charging system," says Darrell Herling of PNNL's Energy Processes and Materials Division. ShAPE is part of the lab's suite of solid phase processing solutions for industry. PNNL is interested in collaborating with partners to develop and demonstrate the ShAPE technology for additional applications of high conductivity metals. For more information on licensing and collaboration opportunities, contact technology commercialization manager Sara Hunt at sara.hunt@pnnl.gov.

For more on shear force developments at PNNL, see also the Metals, Polymers, and Ceramics news page in this issue.

FEEDBACK

I must tell you how impressed I am with the many great articles in *Advanced Materials & Processes.* I am retired, but with each issue I learn something new about the advances being made on the materials front.

Don Davis, Sr.

October *AM&P* was a fine issue! I also liked the Nitinol work. I have never seen an inclusion in Nitinol.

I enjoy studying other people's corrosion problems such as the Historic Monel series (*AM&P* September and November/December 2020 issues). So many kinds of corrosion on one piece! Of course as a metallurgist, I would never allow such damage to one of my projects. For example, when my wife died, I carved her grave "stone" of one-inch thick 6-4 titanium. Took me a year and three Dremels. But after 25 years in the ground, it shows no corrosion, nor will it show corrosion after one thousand years.

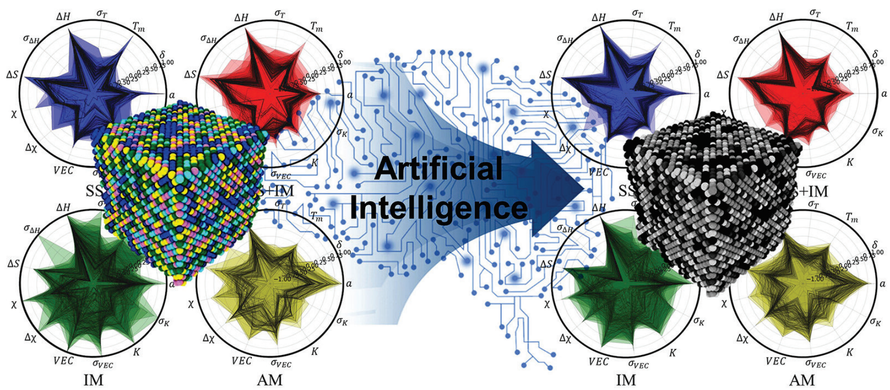
Chuck Dohogne

Living in a senior home, and in lockdown to our rooms since the first of March, makes each issue of this publication most welcome reading.

Ed Sauve

We welcome all comments and suggestions. Send letters to joanne.miller@asminternational.org.

MACHINE LEARNING | AI



AI is being used to develop high-entropy alloys.

CREATING HIGH-ENTROPY ALLOYS WITH AI

A research team at Pohang University of Science and Technology, South Korea, developed a technique for phase prediction of high-entropy alloys (HEAs) using artificial intelligence (AI). While traditional metal alloys are made by mixing one principal element for the desired property with two or three other elements, HEAs are made with equal or similar proportions of five or more elements. They are theoretically infinite and have exceptional mechanical, thermal, physical, and chemical properties, such as corrosion resistance and high strength.

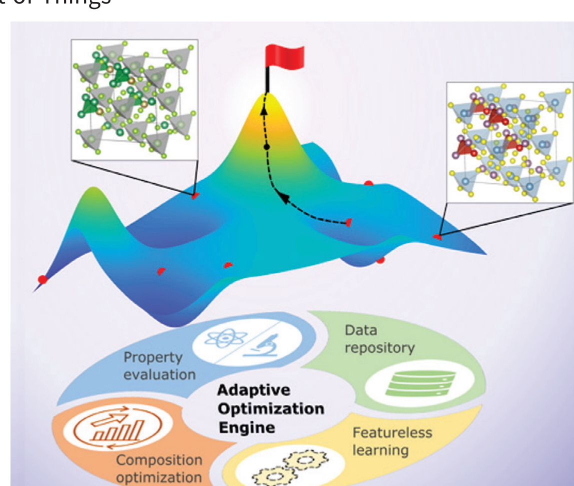
Researchers focused on developing models of HEAs with enhanced phase prediction and explainability by using deep learning, which was applied through three perspectives: model optimization, data generation, and parameter analysis. In particular, the emphasis was on building a data-enhancing model based on the conditional generative adversarial network. This allowed the AI models to reflect samples of HEAs that have not yet been discovered, thus improving phase prediction accuracy compared to conventional methods. In addition, the team developed a descriptive AI-based HEA phase prediction model to provide interpretability to deep learning models, thus acting as a black box while also providing guidance on key parameters for creating HEAs with certain phases. *www.postech.ac.kr/eng.*

MACHINE LEARNING FOR ELECTRONIC MATERIALS

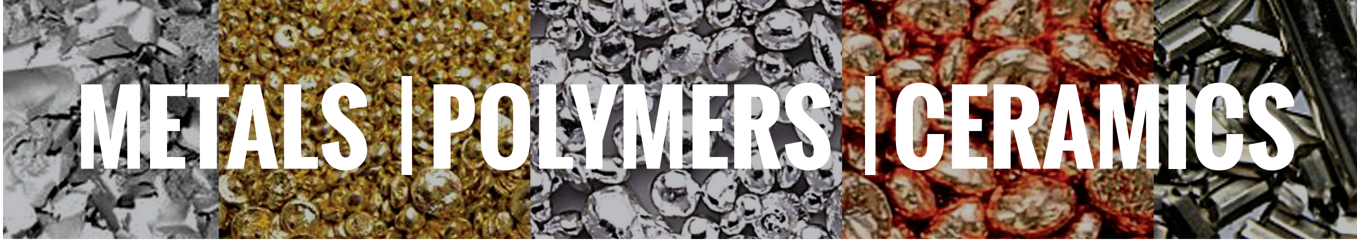
Researchers at Northwestern University's McCormick School of Engineering, Evanston, Ill., developed a new computational approach to accelerate the design of materials exhibiting metal-insulator transitions (MITs). These rare electronic materials have potential to deliver faster microelectronics and quantum information systems, key technologies behind Internet of Things (IoT) devices and large data centers. The new strategy integrates techniques from statistical inference, optimization theory, and computational materials physics.

The design of many different materials properties has been accelerated with data-driven methods aided by high-throughput data generation coupled with methods like machine learning. However, these approaches have not been available for MIT materials, which are classified by their ability to reversibly switch between electrically conducting and insulating states. Most MIT models describe a single material, making model generation challenging. At the same time, conventional machine learning methods have shown limited predictive capability for MIT materials due to the absence of available data.

The new method, called advanced optimization engine (AOE), bypasses traditional machine learning-based discovery models by using a latent variable Gaussian process modeling approach, which only requires the chemical compositions of materials to recognize their optimum nature. This allows the Bayesian AOE to efficiently search for materials with optimal band gap tunability and thermal stability. To validate their approach, the team analyzed hundreds of chemical combinations using density function theory-based simulations and found 12 previously unidentified compositions of complex lacunar spinels that showed optimal properties and synthesizability. These MIT materials are known to host unique spin textures, a necessary feature to power future IoT devices and other resource-intensive technologies. *mccormick.northwestern.edu.*



The advanced optimization engine could help accelerate design of materials with metal-insulator transitions.



METALS | POLYMERS | CERAMICS

Materials scientists use a pin-on-disk tribometer to impart shear deformation in materials. Courtesy of Arun Devaraj/PNNL.

UNDERSTANDING SHEAR DEFORMATION

Scientists at DOE's Pacific Northwest National Laboratory (PNNL) are using solid phase processing approaches to create materials with improved properties. Recent work has focused on a lightweight aluminum silicon alloy widely used in the defense, aerospace, and automotive industries. The team used shear force to restructure the alloy at the nanolevel. Distribution of the silicon was altered at the atomic level, making the microstructure much more robust than identical materials produced conventionally.

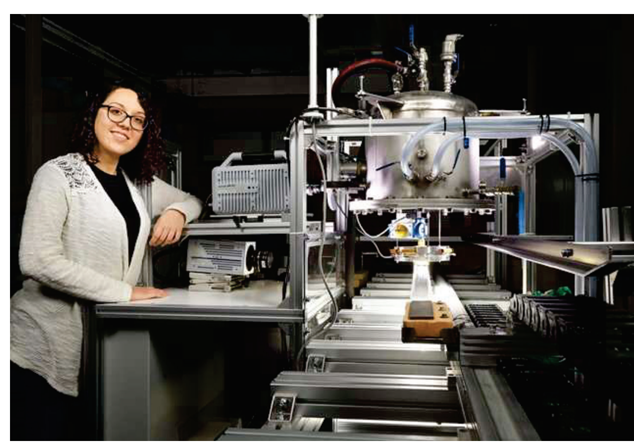
Using atom probe tomography and electron microscopy, the team observed how shear force changes the alloy's microstructure. The silicon particles fractured into smaller and smaller pieces until they were almost dissolved into the aluminum. The aluminum grains became much smaller. Both the aluminum and silicon phases displayed increased intermixing as a result of shear deformation. Understanding the influence of extreme shear deformation on a metal alloy's microstructure is crucial for optimizing novel solid phase materials processing methods.

PNNL's Solid Phase Processing Science Initiative funded this research as part of its efforts to advance the fundamental understanding of solid phase materials synthesis pathways and to enable the manufacture of next-generation materials and components that could make a difference in multiple industries, including aerospace, transportation, energy, and metals recycling. *pnnl.gov.*

WARM WATER TO COOL STEEL

After flat-rolling steel slabs of varying thicknesses, producers strive to cool the red-hot metal as quickly and evenly as possible. At Eindhoven University of Technology, the Netherlands, Ph.D. candidate Camila Gomez reproduced the cooling process of Tata Steel's blast furnaces in her lab and learned that using warmer water can be better. During the rolling process, the steel slabs grow in length from 20 to more than 200 meters. To cool the steel, the slabs pass underneath water flowing at high speed. Gomez explains, "At the end, the steel passes through the jets of water at a speed of almost 80 km per hour; since the cooling process thus takes place at an extremely high speed, it's difficult to study it at the factory."

To better adjust the industrial process to the production of new types of steel, it's important to know exactly what happens to the cooling water near the steel's surface. "Until now, there had been only experiments using stationary and slow-moving setups," Gomez says. "We've now built a setup in



Camila Gomez tests the cooling process on hot steel in this customized lab setup.

BRIEF

By embedding titanium-based sheets in water, a team led by scientists from the **RIKEN Center for Emergent Matter Science,** Japan, created an adaptive material that can be converted from a hard gel to soft matter using temperature changes. Inspiration for the new inorganic material came from a sea cucumber, an aquatic creature that can change its skin from a hard layer to a kind of jelly to escape predators. *www.riken.jp/en.*

the lab that allows us to move a piece of hot steel underneath a jet of water at a speed of almost 30 kilometers per hour as we make recordings close to the surface using high-speed cameras." Using a borescope, placed in the jets of water, she found that the cooling water can come into contact with steel with a temperature of no less than 900°C.

When Gomez raised the water temperature from 25° to 60°C, she was able to cool the steel in her test setup a further 50° without entering the unstable regime. This is knowledge that could be of high value to steel manufacturers, she says, since the water temperature can be easily adjusted without having to alter the entire production line. *www.tue.nl/en.*

BIOINSPIRED MATERIAL

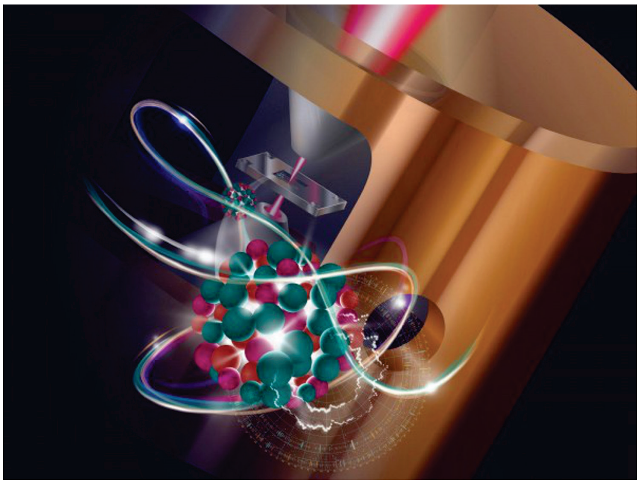
A research team from the University of Science and Technology of China (USTC) created a new method to manufacture materials with a similar structure as nacre from wood-derived fiber and mica, with adaption to mass production, good processability, and tunable coloration. The resulting material may be a new potential replacement for plastics.

Natural nacre has a hierarchically ordered structure at multiscale levels, enabling it to be both strong and tough. Inspired by nacre, the researchers mimic the ordered brick-and-mortar structure using the TiO_2-coated mica microplatelet (TiO_2-mica) and cellulose nanofiber (CNF) by the proposed directional deforming assembly method. This method directly presses the hydrogel of TiO_2-mica and CNF, while keeping the size on in-plane directions unchanged.

The obtained materials adapt to temperatures ranging from -130°C to 250°C, while standard plastics easily soften at high tempertures. The bio-inspired material also has excellent strength and toughness, more than two times higher than those of high-performance engineering plastics, making it a strong competitor to petroleum-based plastics. *en.ustc.edu.cn.*

A variety of all-natural bioinspired structural materials in different colors can be fabricated with TiO_2-mica. Courtesy of Guan Qingfang.

TESTING | CHARACTERIZATION



Infusing data science and AI into electron microscopy opens new possibilities in the science of imaging. Courtesy of Timothy Holland/PNNL.

REIMAGINING ELECTRON MICROSCOPY

Scientists are reimagining the tools used for work in atomic research. Published as a commentary in *Nature Materials,* an international team led by Pacific Northwest National Laboratory (PNNL), Richland, Wash., detailed a vision for electron microscopy infused with the latest advances in data science and artificial intelligence. They proposed a highly integrated, autonomous, and data-driven microscopy architecture to address challenges in energy storage, quantum information science, and materials design. This approach can provide new insight into materials properties, permitting experiments at a vast scale not possible today.

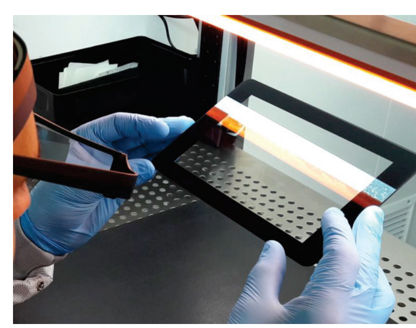
In their article, the research team proposes to integrate artificial intelligence and machine learning into each step of the microscopy workflow. They argue strongly for the development of a new microscopy infrastructure—advanced via multi-institute national technology initiatives—that would make data more accessible to research organizations worldwide. In this way, past measurements could be used to select techniques and interpret results in the moment, informing autonomous decision-making algorithms. Large libraries of past experiments could be used to highlight latent features and offer guidance for the user. A strength of this "crowdsourced" approach is that it is highly scalable, less prone to operator bias, and more repeatable, which will translate into improved results.

The team's vision is the result of the first Next-Generation Transmission Electron Microscopy workshop held at PNNL in 2018. Ultimately, the team hopes to show the immense, untapped potential of data science and its critical role in unlocking the full power of electron microscopy. *pnnl.gov.*

IMPROVING DEVICE TOUCHSCREENS

Scientists at The University of Tokyo have used electron energy loss fine structure spectroscopy with a scanning transmission electron microscope to reveal the local arrangement of atoms within a glass made of 50% aluminum oxide and 50% silicon dioxide. "We chose to study this system because it is known to phase separate into aluminum-rich and silicon-rich regions," says researcher Kun-Yen Liao. When imaging with an electron microscope, some electrons undergo inelastic scattering, causing them to lose some of their kinetic energy.

The amount of energy dissipated varies on the location and type of atom or cluster of atoms in the glass sample. Electron loss spectroscopy is sensitive enough to tell the difference between aluminum coordinated in tetrahedral as opposed to octahedral clusters. By fitting the profile of the electron energy



Aluminosilicate glass used in smartphone applications. Courtesy of SystemElecktronik.

BRIEF

A new research effort at **MIT,** Cambridge, Mass., aims to advance predictive simulation. The **Center for Exascale Simulation of Materials in Extreme Environments** (CESMIX) will bring together researchers in materials science, numerical algorithms, quantum chemistry, and computer science. The goal is to connect quantum and molecular simulations of materials with advanced programming languages, compiler technologies, and software performance engineering tools. CESMIX will initially focus on exascale simulation of materials in hypersonic flow environments. *news.mit.edu.*

loss fine structure spectra pixel by pixel, the abundance of various aluminum structures was determined with nanometer precision. The data was then interpreted with computer simulations.

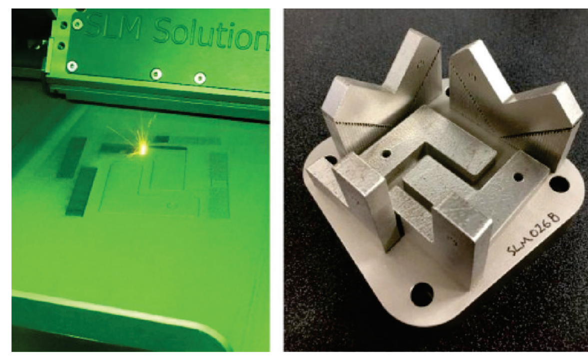
"Aluminosilicate glasses can be manufactured to resist high temperatures and compressive stresses. This makes them useful for a wide range of industrial and consumer applications, such as touch displays, safety glass, and photovoltaics," says Teruyasu Mizoguchi. *www.iis.u-tokyo.ac.jp/en.*

IDENTIFYING STRESS IN 3D PRINTING

As part of an international collaboration led by Linköping University, Sweden, along with ANTSO, Australia, researchers have discovered the origins of key adverse stress formation in the additive manufacturing (AM) process. They found that a careful selection of the printing orientation is important and has a significant impact on the magnitude of residual stresses and, therefore, the potential distortion of the AM part.

Researchers chose to focus on an L-shape to study the effects of a built-up orientation. Three experimental approaches were used to characterize the residual stresses in L-shaped parts. X-ray diffraction measurements were used to characterize surface stresses and laser scanning techniques measured overall distortions associated with separating the samples from the base plate. Neutron diffraction was necessary to measure residual stress in the interior of the samples due to the high penetration of neutrons.

The part printed in a horizontal orientation showed the least amounts of stress in all three directions, showing the way for the optimization of the build-up of generic L-shapes. However, in all orientations, there was a general tendency for compressive stress at the center of the part. Tensile residual stress was observed near the surface in all samples, which appears to be potentially problematic. The research included the development of a simplified simulation technique using finite element analysis for predicting residual stresses based on part geometry, which, when verified with neutron experimental results, was in a good practical agreement. *www.ansto.gov.au, www.strategiska.se/en.*



L-shaped samples before and after 3D printing.

PROCESS TECHNOLOGY

Rolled aluminum. Courtesy of Pixabay.

IMPROVING ALUMINUM ALLOY FATIGUE LIFE

Engineers from Monash University, Australia, determined that weak links, called precipitate free zones (PFZs), are the cause of poor fatigue performance of high-strength aluminum alloys. They demonstrated improvements in fatigue life of high-strength alloys by 25 times that of current state-of-the-art alloys. The work has significant implications for the transport manufacturing industry. The team created aluminum alloy microstructures that can heal PFZs while in operation using the mechanical energy imparted into the materials during the early cycles of fatigue. This delays the localization of plasticity and the initiation of fatigue cracks while enhancing fatigue life and strength.

"Our research has demonstrated a conceptual change in the microstructural design of aluminum alloys for dynamic loading applications," the team says. "The structure is trained and the training schedule is used to heal the PFZs that would otherwise represent the weak points. The approach is general and could be applied to other precipitate hardened alloys containing PFZs for which fatigue performance is an important consideration." *monash.edu.*

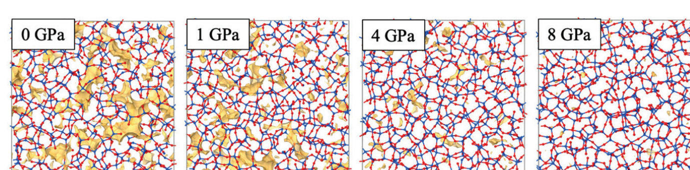
OPTICAL FIBERS UNDER PRESSURE

An international team of researchers from Hokkaido University, Japan, and Penn State University, State College, produced silica glass fibers under high pressure to significantly improve optical fiber data transmission. Using computer simulations, the researchers and their industry collaborators theoretically show that signal loss from silica glass fibers can be reduced by more than 50%, which could dramatically extend the distance data can be transmitted without the need for amplification.

Optical fibers have revolutionized high-bandwidth, long-distance communication, globally. The cables carrying the data are primarily made of fine threads of silica glass, slightly thicker than a human hair. The material is strong, flexible, and very good at transmitting information, in the form of light, at low cost. But the data signal peters out before reaching its final destination due to light being scattered. Amplifiers and other tools are used to contain and relay the information before it scatters, ensuring it is delivered successfully. Scientists are seeking to reduce light scatter, called Rayleigh scattering, to help accelerate data transmission and move closer toward quantum communication.

The team used multiple computational methods to predict what happens to the atomic structure of silica glass under high temperature and high pressure. They discovered large voids between silica atoms form when the glass is heated up and then cooled down under low pressure. But when this process occurs under 4 gigapascals, most of the large voids disappear and the glass takes on a much more uniform lattice structure. Specifically, the models show that the glass undergoes a physical transformation, and smaller rings of atoms are eliminated or "pruned," allowing larger rings to join more closely together. This helps to reduce the number of large voids and the average size of voids, which cause light scattering, and decrease signal loss by more than 50%.

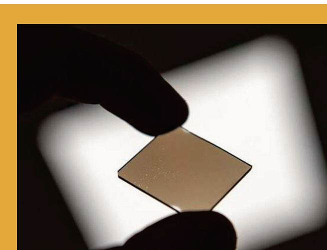
The researchers suspect even greater improvements can be achieved using a slower cooling rate at higher pressure. The process could also be explored for other types of inorganic glass with similar structures. *psu.edu, www.global.hokudai.ac.jp.*



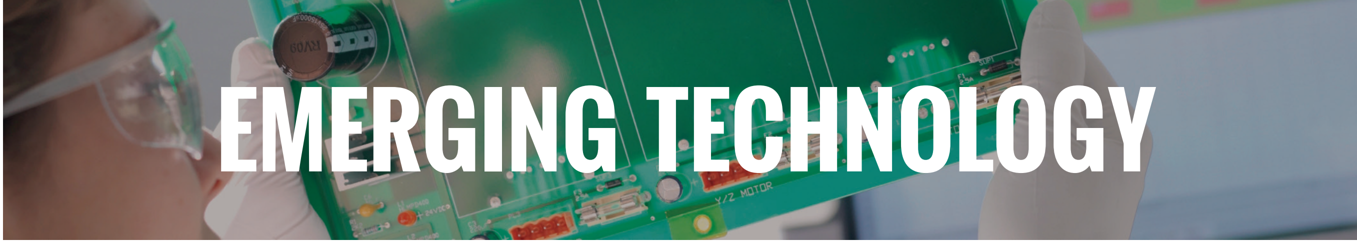
The voids in silica glass (yellow) become much smaller when the glass is quenched at higher pressures. Courtesy of Yongjian Yang, et al.

BRIEF

Scientists at the **National University of Science and Technology MISIS,** Moscow, developed a unique method to process bulk metallic glasses, significantly improving mechanical properties and eliminating brittleness. In future work, the team plans to use the new technology to produce titanium and other high-quality bulk metallic glasses. *www.en.misis.ru.*



Metallic glass sample. Courtesy of NUST MISIS.



EMERGING TECHNOLOGY

Example of a tough, strong, stretchable, and flexible object created through custom VAM at Lawrence Livermore. Courtesy of Maxim Shusteff/LLNL.

NEW RESINS FOR 3D PRINTING

Improving upon previous groundbreaking work, scientists at Lawrence Livermore National Laboratory (LLNL), Calif., have achieved a "significant advancement" for volumetric additive manufacturing (VAM), greatly expanding the range of material properties achievable with the technique. Researchers adapted a new class of materials, called thiol-ene resins, for their proprietary method that produces objects nearly instantly. The new materials have shown promise for applications including adhesives and electronics, and as biomaterials, the researchers say.

The resins can be used with LLNL's volumetric printing techniques, including Computed Axial Lithography (CAL), which produces objects by projecting beams of 3D-patterned light into a vial of resin.

The vial then spins as the light cures the liquid resin into a solid at the desired points in the volume, and the uncured resin is drained, leaving the 3D object behind in a matter of seconds. Previously, researchers worked with acrylate-based resins that produced brittle and easily breakable objects using the CAL process. With thiol-ene resins, researchers were able to build tough, strong, as well as stretchable and flexible objects using a custom VAM printer at LLNL.

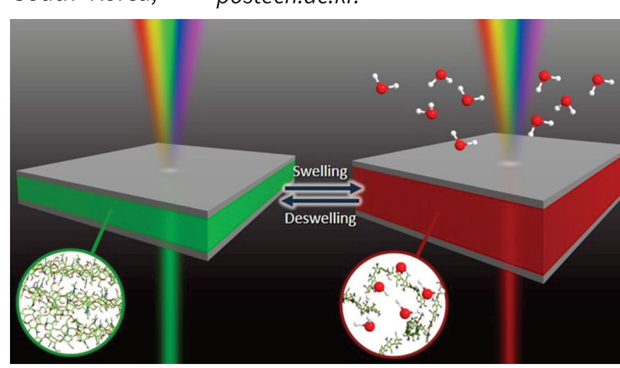
"These results are a key step toward our vision of using the VAM paradigm to significantly expand the types of materials that can be used in light-driven 3D printing," the researchers explain. *llnl.gov.*

SMART WINDOWS

A collaborative research team from Pohang University of Science & Technology (POSTECH), South Korea, developed new source technology for smart windows that change colors according to the amount of moisture, without needing electricity. They successfully created a variable color filter with a metal-hydrogel-metal resonator structure using a chitosan-based hydrogel and combined it with solar cells to make a self-powering humidity sensor.

The team found that when the chitosan hydrogel is made into a metal-hydrogel-metal metamaterial, the resonance wavelength of light transmitted changes in real time depending on the humidity of the environment. This is because the chitosan hydrogel repeats expansion and contraction as the humidity changes around it. Using this mechanism, the team developed a humidity sensor that can convert light's energy into electricity by combining a solar battery with a water variable wavelength filter made of the metamaterial.

"This sensing technology can be used in places like nuclear power reactors where people and electricity cannot reach," the researchers say. "It will create even greater synergy if combined with IoT technology such as humidity sensors that activate or smart windows that change colors according to the level of external humidity." *international.postech.ac.kr.*

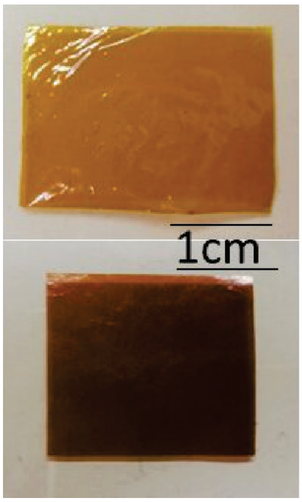


Depiction of a metal-hydrogel-metal filter structure that repeats expansion and contractions as moisture level changes around it. Courtesy of POSTECH.

BRIEF

The **National Science Foundation** awarded the **Cornell High Energy Synchrotron Source** $32.6 million to build a High Magnetic Field beamline, which will allow researchers to conduct precision x-ray studies of materials in persistent magnetic fields that exceed those available at any other synchrotron. *cornell.edu.*

SUSTAINABILITY



A cellulose-derived film has high thermostability and is flame resistant. Courtesy of JAIST.

HIGHEST HEAT-RESISTANT PLASTIC EVER

Widespread use of biomass-derived plastics is a key step toward establishing a sustainable society. However, the use of most biomass-derived plastics is limited due to their low heat resistance. Collaborative research between the Japan Advanced Institute of Science and Technology and University of Tokyo has successfully developed the white-biotechnological conversion from cellulosic biomass into aromatic polymers featuring the highest thermodegradation of any plastic.

Two specific aromatic molecules, 3-amino-4-hydroxybenzoic acid (AHBA) and 4-aminobenzoic acid (ABA), were produced from kraft pulp, an inedible cellulosic feedstock. After chemical conversion and polymerization, the resulting acid was processed into thermoresistant film. The result—organic lightweight plastic with high thermostability (over 740°C) developed from inedible biomass feedstocks, without the need for heavy inorganic fillers. *www.jaist.ac.jp.*

RECYCLABLE TURBINE BLADES

A new thermoplastic resin for wind turbine blades was recently validated at the National Renewable Energy Laboratory (NREL). Researchers demonstrated the feasibility of the material by manufacturing a 9-meter-long wind turbine blade using this novel resin, developed by Arkema Inc. in Pennsylvania. They also validated the structural integrity of a 13-meter-long thermoplastic composite blade manufactured at NREL.

Current wind turbine blades are primarily made of composite materials such as fiberglass infused with a thermoset resin, which requires additional heat to cure the resin, adding to blade cost and cycle time. Thermoplastic resin, however, cures at room temperature and is recyclable. The new process does not require as much labor, which accounts for roughly 40% of the cost of a blade. The innovative resin could also allow manufacturers to build blades on site, alleviating a problem the industry faces as it trends toward larger and longer blades. *www.nrel.gov.*

FLIP-FLOPS THAT WON'T LAST FOREVER

Possibly the world's most popular shoe, flip-flops account for a troubling percentage of plastic waste that ends up in landfills, seashores, and oceans. Now, scientists at the University of California, San Diego have formulated polyurethane foams made of algae oil to meet commercial specifications for biodegradable midsole shoes and the foot-bed of flip-flops.

The research was a collaboration between UC San Diego and startup Algenesis Materials. In addition to devising the right formulation for the commercial-quality foams, the UC team worked with Algenesis to not only make the shoes, but degrade them as well.

The team's efforts are also manifested in the establishment of the Center for Renewable Materials at UC San Diego. "The life of the material should be proportional to the life of the product," says the center's founder. "We don't need material that sits around for 500 years." *www.ucsd.edu.*

Biodegradable flip-flops. Courtesy of Stephen Mayfield/UC San Diego.

BRIEF

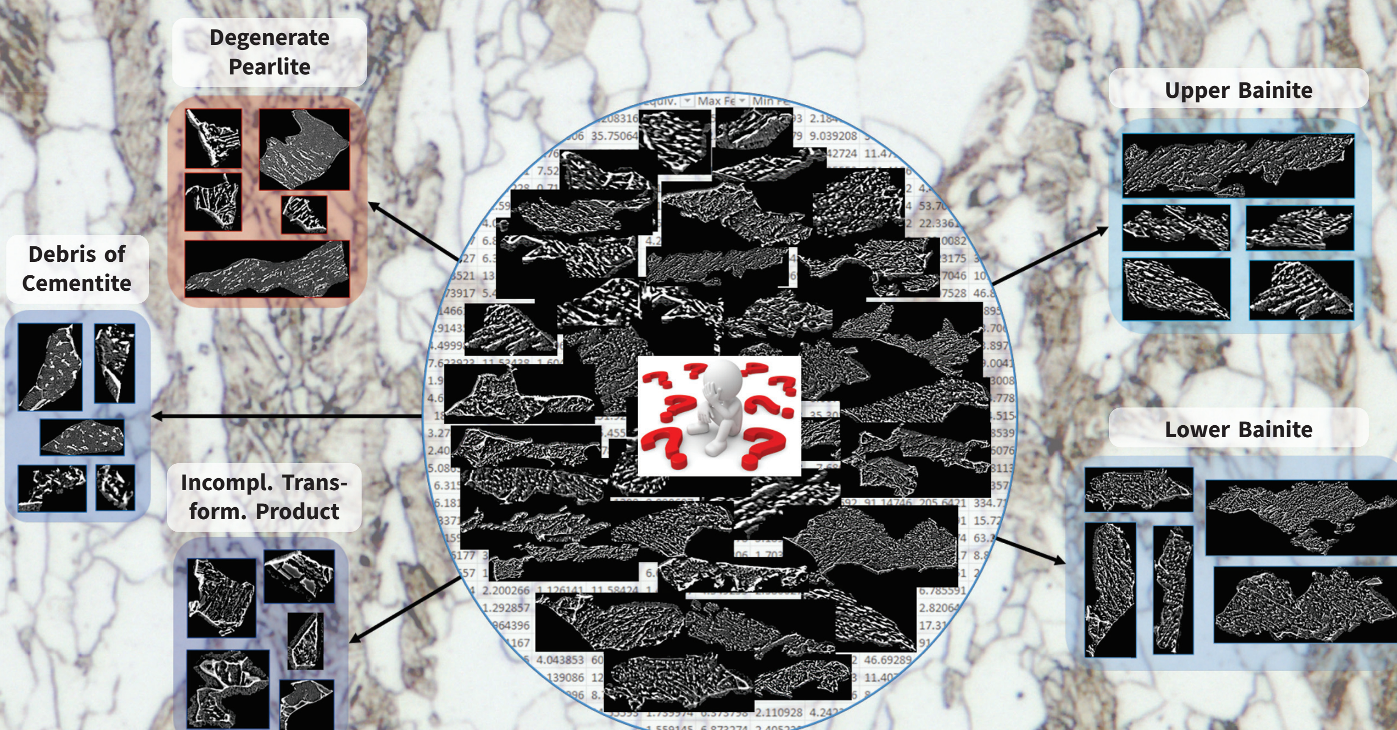
SUNY College of Environmental Science and Forestry and **Syracuse University** are collaborating to establish the New York State Center for Sustainable Materials Management, funded by a $5.75 million grant over five years from the New York State Department of Environmental Conservation. First of its kind in the U.S., the center will be devoted to practices in waste reduction, reuse, recycling, and composting. *www.esf.edu.*

The new Sustainability Research Center will augment New York State's recycling efforts.

MACHINE LEARNING FOR MICROSTRUCTURE CLASSIFICATION: HOW TO ASSIGN THE GROUND TRUTH IN THE MOST OBJECTIVE WAY

Martin Müller, Dominik Britz, and Frank Mücklich, FASM**
Saarland University, Germany

The application of machine learning to the classification and segmentation of complex microstructures requires special attention when assigning the ground truth. Despite all progress in artificial intelligence, materials science knowledge is still indispensable in this process.



*Member of ASM International

Artificial intelligence (AI) and machine learning (ML) have made their way into materials science and are omnipresent. AI is a branch of computer science that is dedicated to developing machines or algorithms to perform tasks that typically demand human intelligence. In ML, a subset of AI, computers are enabled to independently learn patterns and regularities from the available data without having been programmed especially for this task. Within ML, deep learning (DL) is currently a very popular and promising technology. Thus, there is a growing number of publications and conferences dedicating specific sessions to these topics, including in materials science. Currently, it seems that even without the appropriate material-specific background, many data scientists are jumping on this bandwagon to use ML and DL as a panacea, but occasionally without precisely grasping the complex material-specific questions. In general, only a small fraction of a ML-based segmentation or classification pipeline is composed of the ML code itself (Fig. 1). And when dealing with materials science tasks, additional questions and challenges arise that must be carefully considered (red framed boxes in Fig. 1).

However, materials scientists on the other hand, for whom traditional image processing methods such as thresholding are still the go-to solution, often do not have the necessary AI know-how for a successful implementation and application. Therefore, especially collaborations between materials and computer science and interdisciplinary research can create new synergies and great potential for applications in materials science. Prominent examples for AI and ML in materials science include the classification or segmentation of complex steel microstructures[2-4], processing-structure-property links, or ML-aided materials design and discovery[5,6]. Overviews of the spectrum of applications can be found in the references[7,8].

Areas in which ML offers decisive improvements are microstructure segmentation and classification. An essential and often mentioned advantage of ML is the increased objectivity compared to human expert results. However, during building the ML model in supervised learning, the so-called ground truth must be assigned by the human expert, i.e., the expert tells the ML algorithm which images or data points belong to which class. During this ground truth assignment, especially in the case of complex microstructures, a considerate subjective component can potentially be introduced that would negatively affect the performance of the entire segmentation or classification pipeline. While other "ML-inherent" issues like overfitting or generalizability have been extensively addressed, the problem of a subjective ground truth assignment for materials science applications is usually not sufficiently discussed. To better understand this issue, it may be helpful to consider typical benchmark image and data sets that are available in computer science for learning or developing new approaches. Most of these image sets consist of natural scene images, and the ground truth assignment is not problematic. Figure 2 compares and contrasts typical natural scene images, e.g., pet images (Fig. 2a), with microstructural images (Fig. 2b) of varying steel microstructures obtained using a scanning electron microscope (SEM).

This example is very striking as it illustrates quite clearly that the ground truth assignment for microstructure classification is much more complex and can easily include a subjective component added by the human expert. This leads us to the main question this article is concerned with: How can we assign the ground truth for microstructural classification or segmentation in the most objective way? This includes, for example, defining classes, assigning images to these classes, and annotating image regions for segmentation. These are all difficult tasks when the human expert must solely rely on the visual appearance of the microstructure, an aspect that is experienced in varying ways by different human experts.

At this point it should be emphasized that the ground truth assignment of the available images or data should not be looked at in isolation but in the context of a holistic way of building the ML model, which starts with choosing suitable samples and establishing reproducible sample contrasting (Fig. 1). Considering all these facts, it becomes clear that computer science expertise alone is not sufficient to solve AI tasks in materials science, but that domain knowledge of materials science and metallography is indispensable.

For this case study, bainitic microstructures have been chosen to illustrate the previously mentioned challenges and approaches on how to overcome them. Bainite is an essential constituent of modern high-strength steels. It combines high strength with high toughness, making it interesting for a variety of applications[9]. In addition to the existing challenge of characterization, the classification of bainite poses difficulties. Challenges when dealing with bainite include the variety and amount of involved phases,

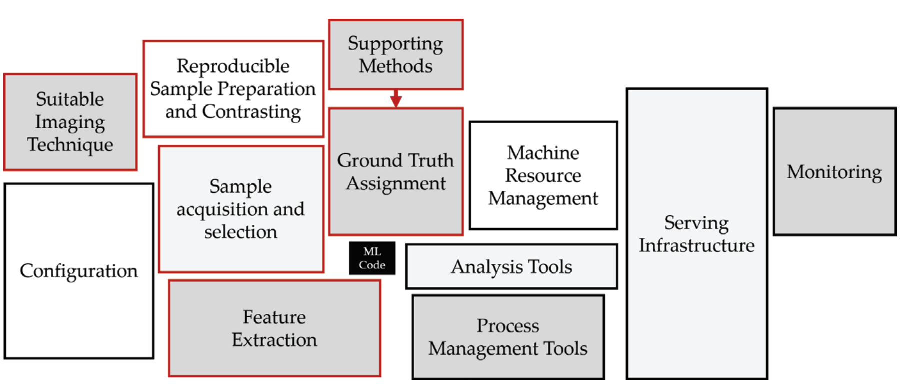


Fig. 1 — Only a small fraction of a ML-based segmentation or classification pipeline is composed of the ML code (small black box in the middle). Surrounding infrastructure and especially questions arising from applications in materials science (red frames) are vast and complex. Figure adapted from reference[1].

as well as the fineness and complexity of the structures. Also, there is no consensus among human experts about microstructure formation mechanisms[10] nor in labeling and classifying bainitic structures[4]. Thus, it is ideally suited for this case study.

A simple and effective means for a more objective ground truth assignment are so-called round robin tests in which images are given to a group of experts. Every expert judges the image individually. In the end, the image's class will be determined by a majority vote, i.e., the class assigned by most experts will be ultimately chosen. However, for bainitic structures this method can reach its limit when there is too much disagreement between experts and no preferred class. Then it is the task of materials scientists to find other methods that do not purely rely on how the microstructure visually appears to the expert eye. The following sections will look at three approaches: (1) correlative microscopy using electron backscatter diffraction (EBSD) as an additional information source; (2) use of specifically produced reference samples; and (3) unsupervised learning techniques.

CORRELATIVE MICROSCOPY

Usually, one single characterization method cannot capture all microstructural features relevant for quantification. By combining different characterization methods in a correlative approach, features from different length scales and varying complementing information sources can be combined, thus overcoming the disadvantages of a particular method. In this correlative approach, standard light optical microscopy (LOM), scanning electron microscopy (SEM), and additional EBSD measurements are combined. While LOM and SEM "only" enable the visual inspection of the microstructure, EBSD provides a completely different set of information, e.g., misorientation parameters or data about both grain and phase boundaries, which—in the case of bainite in particular—ideally complement the LOM and SEM images and help to better understand and assess the microstructure. This is exactly the added value that EBSD and correlative approaches in general provide. Furthermore, there is always the chance that the knowledge and references gained with the additional methods in the correlative approach (here EBSD), may permit to reduce further investigations to only one characterization method, ideally the simplest (here LOM).

To fully exploit the data from these different, complementing information sources, the different micrographs must be registered. For the methodology of image registration, the authors refer to the references[10,11]. Figure 3 shows two examples of how combining EBSD parameters with LOM and/or SEM images by overlaying can help in assigning the ground truth. Just relying on the LOM and/or SEM image may result in varying results from different experts.

In the case of the complex-phase steel micrograph in Fig. 3a, the lath-like bainite regions are to be annotated for ML segmentation. EBSD parameters

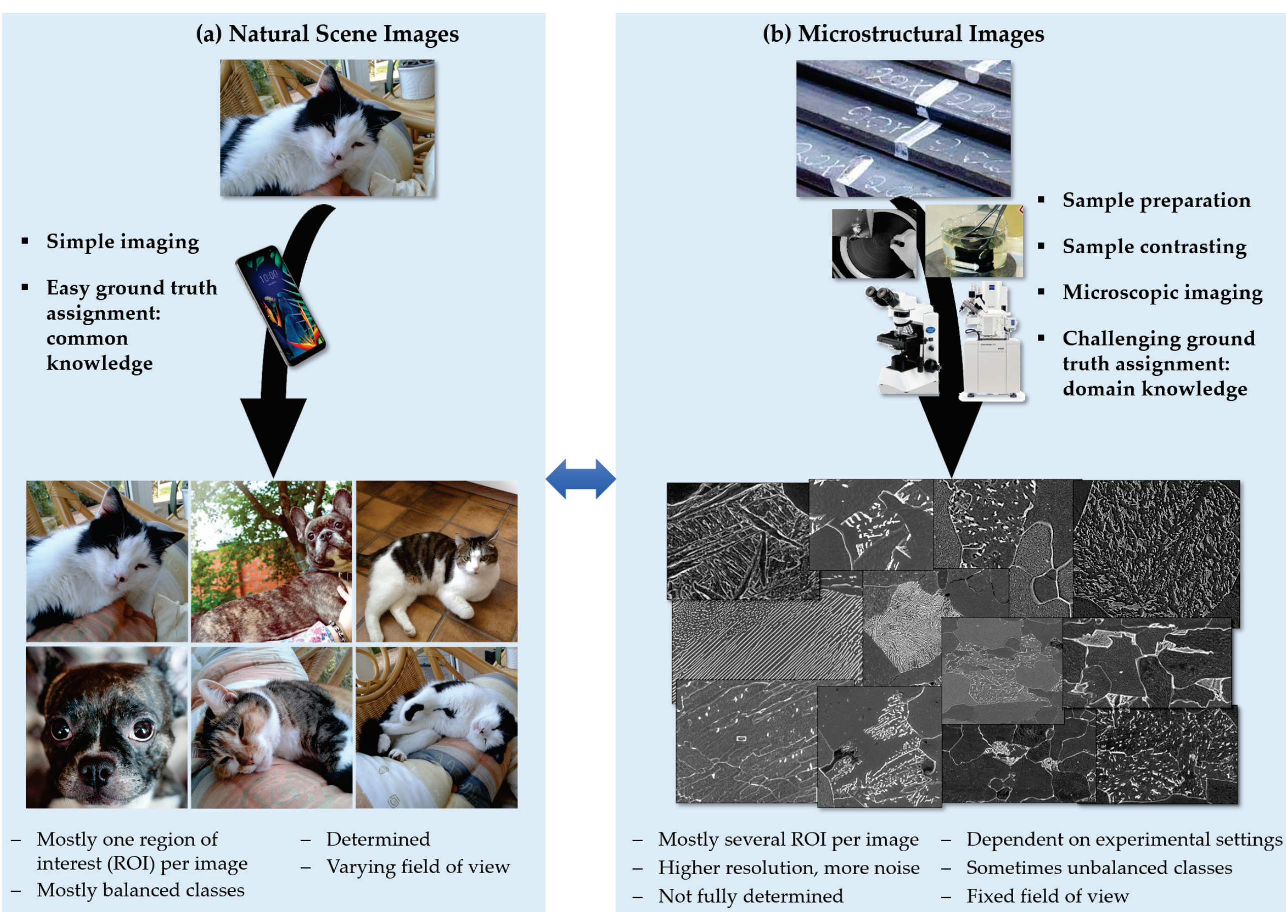


Fig. 2 — Comparison of typical characteristics of natural scene (a) and microstructural images (b).

such as misorientation data and grain or grain boundary visualizations help to better recognize bainitic regions, their boundaries and polygonal ferrite, leading to a more objective and reproducible ground truth. Figure 3b shows SEM images of two bainitic microstructures that are to be assigned to the correct class for ML classification. By overlaying the SEM image with EBSD grain boundary visualization and identifying the type of grain boundaries, i.e., sub-grain (red) vs. low-angle (green) vs. high-angle (blue) boundaries, a better understanding of the microstructure is achieved and an ideal complement to the visual appearance in SEM is found, which helps in performing a more objective ground truth assignment of the bainite class.

SPECIFIC PRODUCTION OF REFERENCE SAMPLES

In the following example, an existing data set of so-called two-phase steels that consist of a ferritic matrix and a carbon-rich second phase, which is either pearlite, bainite, or martensite, is considered. A classification of this carbon-rich second phase was already reported[2,13]. So far, the ground truth assignment has been very manageable as only pearlite, bainite, and martensite had to be distinguished. Now however, bainitic subclasses[14], e.g., upper and lower bainite are to be added. In theory, upper and lower bainite show quite distinct differences in the type of carbon precipitation and should be easily distinguishable. However, during the investigation of industrial samples from heavy steel plates, it became clear that there are more degrees of freedom and that in most cases, no typical textbook-like structures of upper and lower bainite were present. In order to obtain clearly defined bainitic structures, specific samples were produced using a quenching dilatometer. See Fig. 4.

Isothermal transformation at 525°C yielded fully upper bainite while isothermal transformation at 425°C led to the formation of fully lower bainitic microstructures. These benchmark structures can now be used to assign the existing images to upper and lower bainite. This can be done for example, by extracting suitable features from the images and performing a similarity search, i.e., finding the images in the existing image set that are most similar to the benchmark structures. This allows the extraction of two image sets for upper and lower bainite, respectively, which then can be used as input for further supervised classifications.

Although in this case study, the process parameters from the sample production directly correlate with the ground truth, the general approach of only using process parameters for assigning the ground truth must be taken with a grain of salt. It might be tempting to just assign one class for each variation in processing. However, this may cause several problems. First, by "skipping" the microstructure analysis, a researcher would revert to the approach of empirical processing-properties correlations instead of focusing on a microstructure-based materials development. Second, different processing routes can yield identical microstructures and identical basic properties.

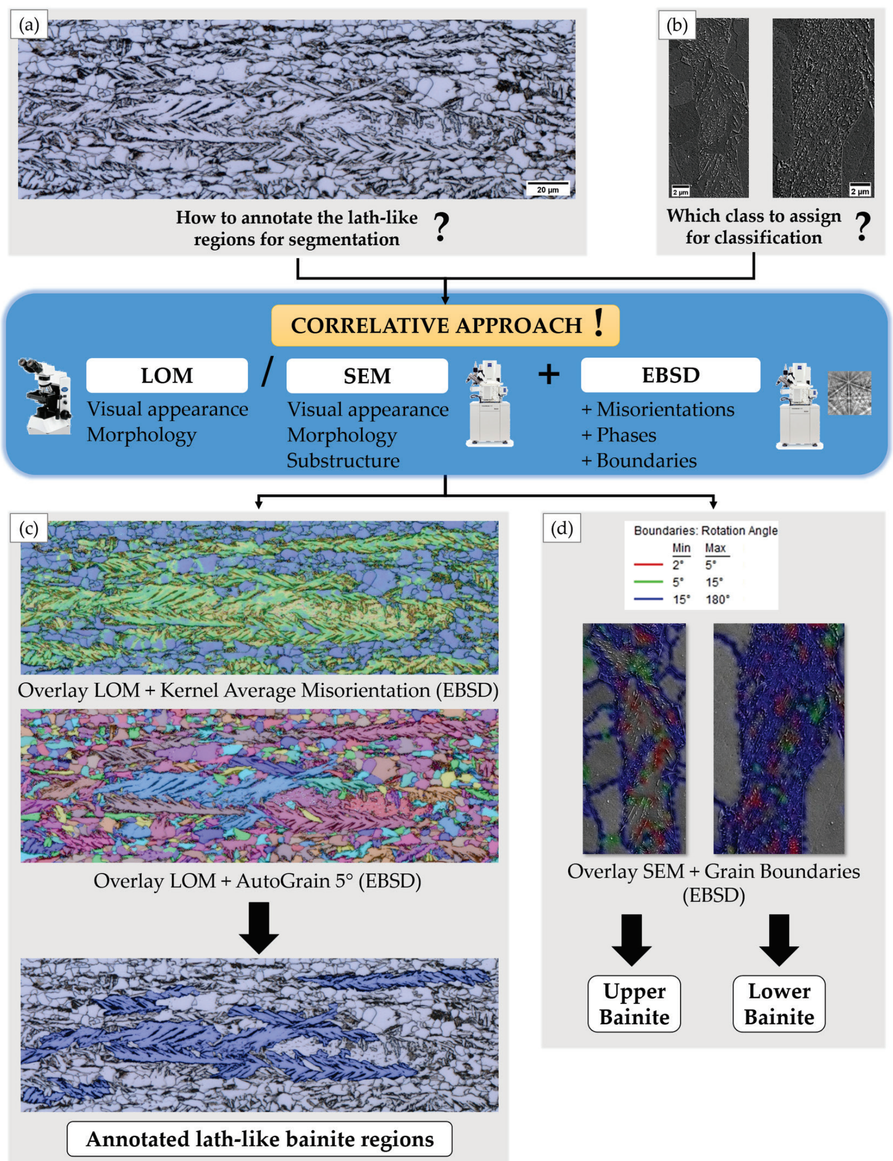


Fig. 3 — Questions regarding region annotation (a) or class assignment (b) can be answered objectively by correlative characterization, i.e., by incorporating EBSD data in addition to the merely visual appearance of the microstructure in LOM/SEM: (c) overlaying LOM with misorientation parameters and grain visualization from EBSD helps to objectively annotate lath-like bainite regions in complex-phase steel micrographs and (d) overlaying SEM with different types of grain boundaries from EBSD allows a correct identification of upper and lower bainite.

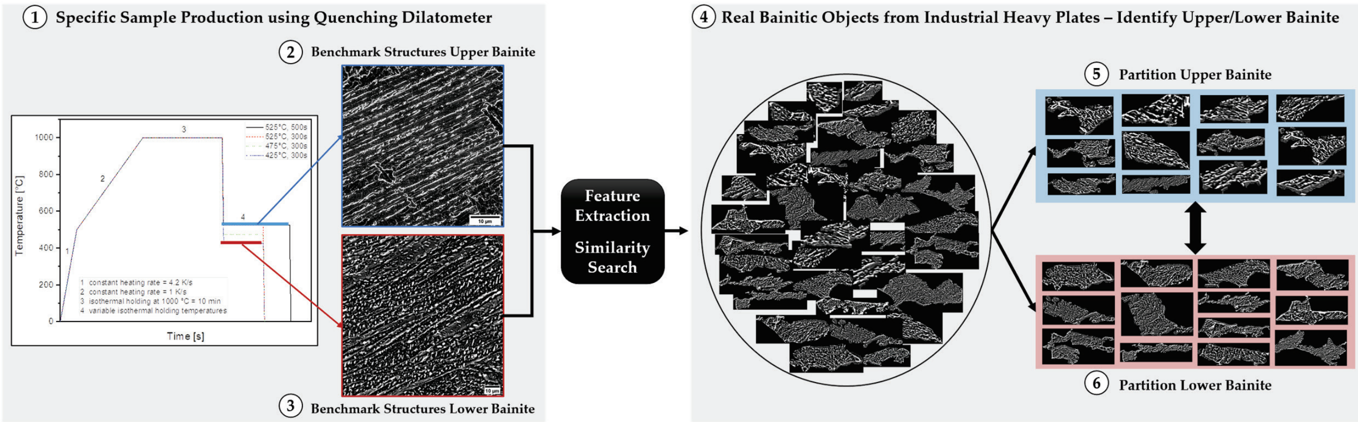


Fig. 4 — Specific sample production using quenching dilatometer (1) yielding benchmark structures for upper (2) and lower bainite (3). These can be used to divide real bainitic objects from industrial heavy plates (4) into upper (5) and lower bainite (6) partition.

Finally, it can lead to a definition of too many classes and thereby introduce the danger of overfitting the ML model.

UNSUPERVISED LEARNING TECHNIQUES

In contrast to supervised learning, there is no assignment of the ground truth by a human expert during unsupervised learning, which means that the ML algorithm is allowed to find structures in its input on its own. The most widespread unsupervised learning technique is clustering, which is used to explore data and find patterns or to discover groups of similar data points.

A general pipeline for clustering images by unsupervised learning was suggested by Kitahara et al.[15]. It consists of feature extraction by a pre-trained convolutional neural network, followed by dimensional reduction (principal component analysis plus t-distributed stochastic neighbor embedding (t-sne)) and finally a clustering algorithm (k-means). Of course, other types of features can also be used as input for this pipeline, e.g., manually engineered features from conventional microstructure quantification.

For this case study example, two-phase steels consisting of a ferritic matrix and a carbon-rich second phase that is either pearlite, bainite, or martensite are considered again and EBSD parameters (standard pattern quality and misorientation parameters), extracted separately for every second phase object, are used as input features. The first step investigates whether clustering can find the three main classes (pearlite, bainite, or martensite) in the data. Figure 5a shows the resulting clusters (after dimensional reduction (t-sne), determination of the optimal cluster number, and fuzzy c-means clustering). Black circles indicate data points with a low cluster membership grade. These are “low confidence data points” in the fuzzy overlap between clusters 1 and 2 or too far away from the cluster centers and can be filtered out before further evaluation. The corresponding human expert labels are shown in Fig. 5b. They are almost completely consistent with the clustering result (97.3% agreement).

In current research, this clustering approach is extended to bainite subclasses, enabling the comparison between human expert labels plus class definitions and the unbiased, AI determined clusters and introduce more objectivity to the controversy of bainite classification. Moreover, unsupervised learning provides another general benefit: the better insight into and understanding of the input data as it is possible to investigate why certain data points are close to the cluster centers,

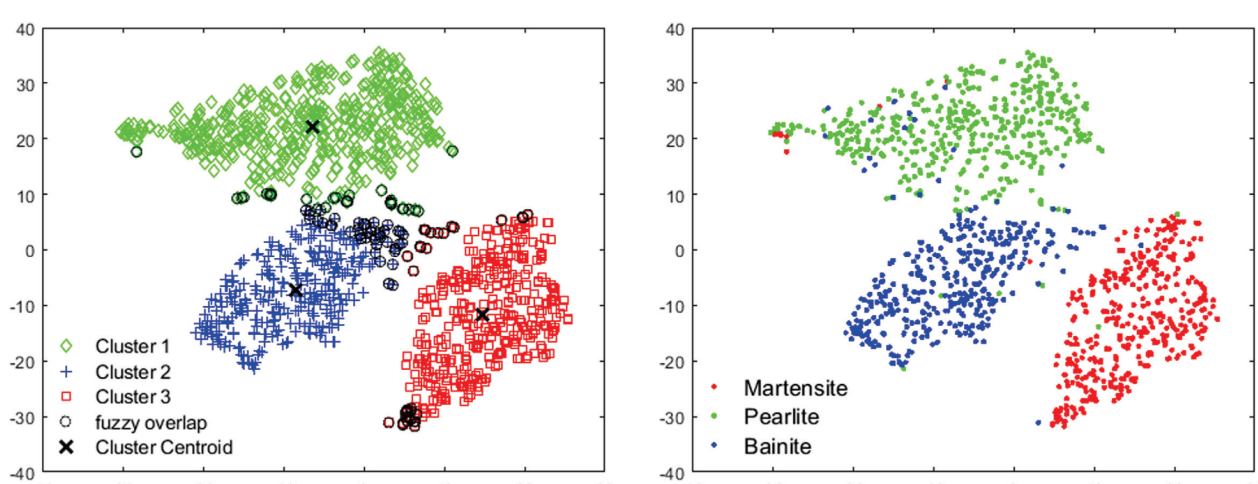


Fig. 5 — (a) 2D t-sne plot with 3 resulting clusters after fuzzy c-means clustering. (b) 2D t-sne plot with human expert labels.

i.e., high confidence data points and why others are low confidence data points in the fuzzy overlap between two clusters or assigned to the wrong cluster. Additionally, it can be used as "pre-labeling" for supervised ML.

CONCLUSIONS

Combining data science know-how with our materials science knowledge enables us to forge new paths in microstructure research and reach higher qualities in microstructure segmentation and classification. This marks a further step toward comprehensive and integral processing-structure-properties-performance correlations and understanding. Regarding ML-based segmentation and classification, a core aspect is the ground truth assignment, which must be well-founded and as objective as possible. For that we must look at the entire process of building a ML-based segmentation and classification pipeline in a holistic approach, which not only focuses on images and/or data and the corresponding ground truth, but starts by selecting suitable samples, establishing reproducible sample contrasting, and finding the optimum imaging technique. Metadata and a uniform ontology also play an increasingly important role in this context. Therefore, our domain knowledge in materials science and metallography is still indispensable.

When applying machine learning to complex microstructures such as bainite, the microstructure's visual appearance under a microscope might no longer be sufficient for an objective ground truth assignment and supporting methods must be found. The approaches presented in this bainite case study, i.e., correlative characterization using EBSD, specific production of reference samples, and use of unsupervised learning techniques, are also transferable to other microstructure characterization tasks. **~AM&P**

Acknowledgments

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2020-2021 PRESIDENT OF ASM INTERNATIONAL
DIANA M. ESSOCK

Sunniva Collins, FASM, 2014-2015 ASM President

It is a pleasure to introduce my good friend Diana M. Essock. I am so thrilled that she was selected as ASM's President for 2020-2021. I remember giving my presidential speech in Pittsburgh in 2014. I remarked at the time that it was an honor to be the second woman president of ASM International—after Dianne Chong—and I predicted others would follow. How exciting to see Diana take on this leadership role for ASM International!

Diana and I have known each other for nearly 30 years. I am pretty sure the first time we met was at an ASM Cleveland Chapter meeting back in 1990. I remember how friendly and welcoming she was to me. She had already made her mark on the chapter with strategic planning and documenting operational processes. Over the years, and through our ASM activities, we developed a wonderful friendship that continues to this day. In our careers, Diana and I have worked for different companies in Northeast Ohio, but always remained in good contact. Diana has been a technical contributor, an effective manager, and the owner principal of a successful technical consulting practice. She has a particular gift for technical marketing and has assisted several companies in honing their messages and connecting with potential customers. Over the years, Diana has demonstrated great technical business acumen and integrity, and has always supported ASM for both its technical and social functions.

ASM SERVICE

Diana is a dedicated contributor to ASM. Her service to the Cleveland Chapter has been outstanding. She has been Chapter chair, historian, and most recently co-chair with Dave Kovarik for the ASM Cleveland Chapter's 100th Anniversary celebration. Diana has also been a driving force on Chapter Council and was instrumental in the development of Leadership Days and its programming. During her term on the ASM Board of Trustees, she co-sponsored the establishment of the Women in Materials Engineering Committee (WiME) to meet the needs of women in ASM. She has been a champion for diversity and inclusion, and her ability to organize and create coalitions has already had a significant impact on the Society.

This past year as ASM vice president, Diana supported and gained approval from the Board for a proposal to expand the WiME Committee's initiative and establish the IDEA Committee—Inclusion, Diversity, Equity, and Awareness—which seeks to reach out to all underrepresented groups in ASM. She is a past recipient of ASM's Allan Ray Putnam Award, given annually to recognize the exemplary efforts of one volunteer to further the Society's objectives and goals. In recognition for her technical contributions to the materials field, she was named a Fellow of ASM International in 2007.

EDUCATION AND CAREER

Diana is a trailblazer! She was the first woman undergraduate from the materials science and engineering department at Case Western Reserve University. Originally planning to major in astronomy, Diana was introduced to materials science during the summer between her freshman and sophomore years. She spent those months analyzing lunar rocks and lunar glass with Prof. Arthur Heuer and Prof. Al Cooper. Heuer encouraged her to consider becoming a materials engineer. Subsequent summers were spent at Bell Laboratories and Battelle Memorial Institute performing microhardness studies on copper alloys, and high temperature flow studies of neodymium glasses for laser lens coatings, respectively. Her senior thesis involved the production, testing, and analysis of niobium single crystals.

Early days at Case Western Reserve University.

After receiving an M.S. in metallurgical engineering at The Ohio State University, where her thesis was on the sulfidation of molybdenum-iron alloys, Diana began her career at TRW Inc. Materials and Manufacturing Technology Center (MMTC). There she procured funding, and managed and conducted technology development programs for new materials and processes in the jet engine industry.

After the closure of TRW's MMTC, Diana worked at General Electric Company's Lighting Business from 1986 through 1990 on new product development and introduction. There she had the opportunity to create a new lamp product from inception through to final production. While at General Electric, she completed an executive MBA program at Baldwin Wallace College.

In 2000, Diana joined Foseco Metallurgical Inc., a worldwide developer and manufacturer of foundry consumables, as the director of new technology. Her primary role was to identify and develop new technologies from outside of the foundry industry for application to the foundry. Technological processes identified by Diana from the fields of powder metallurgy, technical ceramics, nanotechnology, and polymers were investigated at worldwide research organizations for Foseco.

With her experience in marketing and technology, Diana founded Metamark Inc. to provide consulting for a wide range of clients in the metals and materials industry. Diana works with clients to identify new markets for their current product lines, identify and establish contact with potential customers, and develop strategic plans for new market entry and growth.

PERSONAL INTERESTS AND ACTIVITIES

Diana is a world traveler and a constant learner. She has had the opportunity to travel worldwide for both business and pleasure. From her early days at Case where Diana had a minor/concentration in cultural anthropology, she has always been interested in people and cultures. She enjoys visiting ancient archeological sites and ruins. Another interest is hiking, and Diana has been known to work adventurous treks into her travel itineraries. A few years ago, Diana and her husband Tom Kolakowski hiked with friends from the North Rim of the Grand Canyon down to the bottom and out to the South Rim. She has also hiked the pilgrimage of the Camino de Santiago (the Way of Saint James), traveling with her close friend Nancy Fioraliso through the mountains of Northern Spain for about 100 miles along a path that has been used since Medieval times.

Diana with a Uros woman on a floating island in Lake Titicaca, Peru.

Diana supports the arts and has made good use of the cultural and recreational amenities in and around Cleveland. She is a patron of the Cleveland Orchestra and a member of the Cleveland Museum of Art and Holden Arboretum. In a typical year, she takes in a Broadway show or two at Cleveland's Playhouse Square, and enjoys exploring the food scene in Cleveland during Restaurant Week. An avid bicyclist, she travels the Canal Towpath here in Northeast Ohio, as well as other cycling paths. Two years ago, Tom and Diana rode the entire 150-mile length of the Great Allegheny Passage (GAP), a wonderful bike trail from Pittsburgh to Cumberland, Maryland.

Tom and Diana at the 100-mile marker along the Great Allegheny Passage.

I would be remiss if I didn't talk about Diana's artistic and creative side. She is a potter and enjoys designing and creating ceramics—a worthy pursuit for a materials scientist! She is also an avid gardener. In addition to working in her own flower and herb garden, she also volunteers at the Rusin Garden of the Cleveland Cultural Gardens (CCG). The CCG are owned by the City of Cleveland and run from University Circle along Martin Luther Boulevard to Lake Erie, following the path of Doan Brook. They were founded as peace gardens in the 1920s, reflecting the different immigrant groups that made up Cleveland's population and neighborhoods. Each of the gardens is maintained by a fraternal organization representing the culture of that particular garden. As Diana was exploring her family genealogy, she discovered that her father's family are Carpatho-Rusyn, the indigenous people of the Carpathian Mountains in Eastern Europe. In the 1930s there were over 30,000 Carpatho-Rusyns in the Cleveland area, and they established a garden in the CCG. This family connection brought Diana to an active role with the Cleveland Chapter of the Carpatho-Rusyn Society, the fraternal organization which maintains the CCG Rusin Garden. If your travels bring you to Cleveland, consider a visit to the Cleveland Cultural Gardens and you will see evidence of Diana's green thumb at the Rusin Garden.

Diana and friend, Nancy Fioraliso, at the Cathedral of Santiago de Compostela in Spain having finished their hiking pilgrimage.

I hope I've succeeded in giving you some sense of Diana. She's a thoughtful and curious person who enjoys making connections and building community. She's already been a great contributor to ASM, and as president I know she'll do great things. **~AM&P**

AUTOMOTIVE ALUMINUM–PART XI
They Made it Look Easy

Ford's aluminum F-150 venture was now entering the development phase, with teams in place that would spend the next 18 months designing both the truck and the facilities to produce it.

Laurent Chappuis, Light Metal Consultants LLC, Grosse Ile, Michigan*

Robert Sanders, Novelis Inc., Atlanta*

Following board approval in June 2010, Ford could now release funding to upgrade the stamping facilities and formalize the agreement supporting the new heat treat lines at Novelis Oswego and Alcoa Davenport. These hundreds of millions of dollars represented the ultimate vote of confidence for a project that still existed mostly in Excel spreadsheets. The venture was now entering the development phase, and Ford could begin assembling the teams that would spend the next 18 months designing the truck and the facilities to produce it. The board would then review the project one more time and authorize funding for the execution phase covering the production tooling and the fleet of verification prototypes. If everything went according to plan, the launch phase would follow.

MANUFACTURING CAPABILITY

Testing of Ford's initial F-150 prototype, dubbed X0, had been successfully completed and by July 2010, resistance spot welding had been ruled out as the main point joining method in favor of self-piercing rivets (Fig. 1). A week later, the program passed its next gateway and clay development started in earnest in the studio. Planning volumes were set, the general engineering concept was firming up, and a preliminary bill of material was assembled for the stamped parts.

For both the aluminum companies and Ford, the key to success was manufacturing capability. Due to two decades of aluminum-intensive vehicle development and the launch of the Jaguar products, Ford felt reasonably well prepared. In addition, the company was still making good use of the collaboration agreement with Jaguar Land Rover that ran through mid-2011. For the aluminum companies, the challenge stemmed from Ford's decision to use their internally developed high-speed heat treatment (post formed heat treatment, or PFHT, designated as T82 temper) to transform 6111 into a high-strength structural alloy. While both companies were familiar with the alloy as a thin gauge auto body sheet (ABS) product, Ford was calling for thicknesses up to 4 mm. The preliminary

Fig. 1 — From left, self-piercing rivets and typical cross section of a joint. Courtesy of Stanley Engineered Fastening.

**Member of ASM International*

specifications for T82 temper mandated a minimum yield strength of 260 MPa after forming and aging, while retaining excellent ductility. The transformation of 6111 would consume both companies and Ford for the next three years.

John Hill and his team at Ford's Research & Innovation Center were responsible for structural bonding development. One of the fundamental manufacturing issues was the survivability of the mill-applied surface pretreatment through the PFHT process: If it did not survive, individual parts would require surface treatment after heat treating, an expensive investment in both capital and factory floor space. The second question was whether parts could be heat treated without first washing off the stamping lubricant. They had positive answers to both issues by mid-December: PFHT could fit within the normal processing sequence, with the heat treat cycle as the only added step.

KEY SPECS

But in the beginning of the third quarter of 2010, the first order of business was to firm up material specifications for the new aluminum ABS. A cross-functional team from materials engineering, stamping engineering, research & innovation, and product engineering received a two-pronged mandate from management: Deliver specifications tight enough to allow dual sourcing without trauma, and ensure scrap compatibility to maximize the value of stamping offal. This meant a strict harmonization of both material properties and chemical composition limits. Harmonizing the composition and mechanical property limits for 6111, 5754, and 5182 progressed smoothly. The thin gauge outer skin alloys were the stumbling block, as Novelis and Alcoa were intent on supplying their own alloys. A glance at the registered chemical composition limits of the respective alloys explains their position (Table 1 and Fig. 2).

Their starting position was that, at a minimum, Ford would have to segregate by alloy, if not by supplier. From Ford's point of view, that position was clearly impossible. Harmonizing the composition of the skin ABS alloys became a focus of intense discussions between Ford and its suppliers that would stretch for the next 12 months. The breakthrough came when Ford realized that all of the "low Cu" alloys actually existed within a narrow overlapping compositional space that became the basis for the new "low Cu" specs.

Mechanical property specifications of 5xxx-O and 6xxx-T4 alloy sheet posed distinctly different challenges: For 5xxx, it was improving the measurement of uniform elongation and yield strength, while natural aging was the issue for 6xxx sheet. The specification concept was agreed on in third quarter 2011. However, the practical implications for lot release by the mills and stock management at Ford were not finalized until September 2014.

The product and manufacturing teams were concentrating on the fast approaching X1 prototype build. The "Go Fast" X0 prototypes had provided the product design team with some valuable information, such as improved correlation with computer-aided engineering (CAE), but the manufacturing team was starting from scratch. Neither the stamping engineering nor body construction teams had any experience with thick gauge 6111.

TABLE 1 – AA CHEMICAL COMPOSITION FOR VARIOUS 6XXX "LOW Cu" ALLOYS

Alloy	Date	Si	Fe	Cu	Mn	Mg	Cr	Zn	V	Other
6005	1962	0.6 – 0.9	0.35	0.1	0.1	0.40 – 0.6	0.1	0.1	…	
6005C	2005	0.40 – 0.9	0.35	0.35	0.5	0.40 – 0.8	0.3	0.25	…	0.50 Mn + Cr
Ac120/6016	1977/1984	1.0 – 1.5	0.5	0.2	0.2	0.25 – 0.6	0.1	0.2	…	
6014	1983	0.30 – 0.6	0.35	0.25	0.05 – 0.20	0.40 – 0.8	0.2	0.1	0.05 – 0.20	
6022	1995	0.8 – 1.5	0.05 – 0.20	0.01 – 0.11	0.02 – 0.10	0.45 – 0.7	0.1	0.25	…	
6451	2005	0.6 – 1.0	0.4	0.4	0.05 – 0.40	0.40 – 0.8	0.1	0.15	0.1	

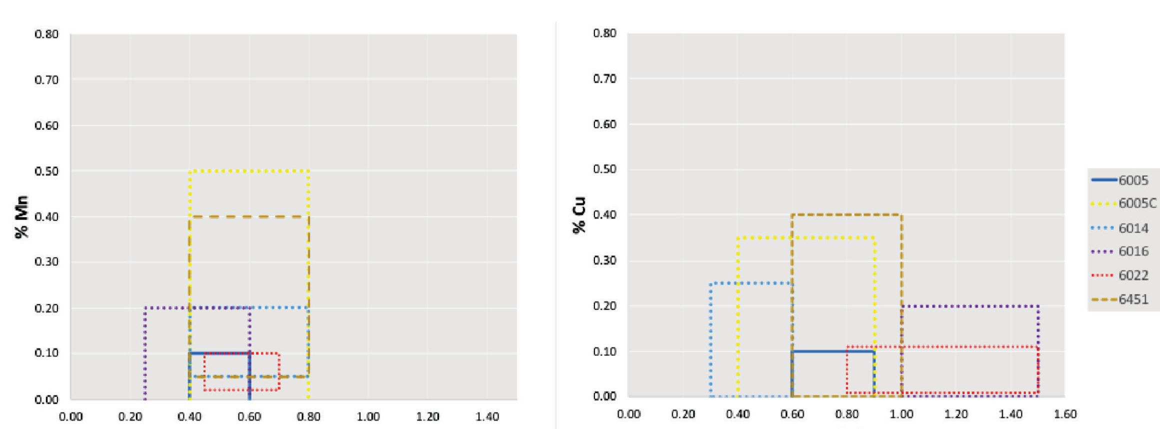

Fig. 2 — Graphic representation of Table 1.

JOINING ISSUES

The body construction team needed to establish a baseline for the more than 2200 self-piercing rivets (SPR) that would join the multiple stamped parts of the body and the box. The joint is a combination of up to four layers of sheet metal of different alloys and gauges (stack-up), each of which requires a specific tool setup. In the absence of any CAE program capable of modeling the insertion of an SPR, each joint schedule had to be developed experimentally and then verified and adjusted on the floor during the build. Adding to the complexity was a fixed floor space that restricted the number of stations, and short cycle times that precluded robots from tool switching on the fly.

The ideal joint schedules are those that can handle several stack-ups that might be found in a given station. Ford's P552 platform was comprised of a large number of stack-ups and numerous possible combinations. This resulted in a staggering number of schedules, each requiring statistically representative verification tests. The project was entrusted to the joining team at Ford's Research & Innovation Center. It would take them six months to plan the project, obtain funding, and secure new headcount, lab space, and equipment. By the time the lab began operating in third quarter 2011, the X1 prototypes had been built and tested, with ad-hoc joint schedules established on the fly with Henrob Corp., the SPR gun supplier. The lab's first mission was to support the M1 build scheduled for mid-April 2012.

For the stamping engineering team, CAE modeling work for X1 had started months earlier. It was an all-out effort by Bill Anglin's team at Troy Design and Manufacturing Co., under the supervision of Ford's stamping engineering CAE team and Laurent Chappuis, with technical support from Cedric Xia's team at the Research & Innovation Center. The tool build was completed by late third quarter 2010, and the correlation studies started after the delivery of X1 parts in the fourth quarter. The studies included full 3D scans of selected parts, which were then meticulously compared to CAE strain and springback predictions. The thick gauges planned for P552 required new forming limit curves that could not be developed using existing laboratory tooling. A new 200-mm limiting dome height tool had to be designed and funded, and was built by Ford's Dearborn Tool and Die team.

Meanwhile, Tesla surprised Detroit by showing a complete body-in-white with closures for its upcoming Model S at the North American Auto Show in January 2011 (Fig. 3). It was an aluminum-intensive design with extensive use of extrusions and castings. As such, it was more akin to an Audi A8 than the sheet-intensive Jaguar XJ.

The pace continued to accelerate in 2011, and by April, Ford's Expedition/Navigator models joined the Super Duty truck on the platform. X1 testing came and went, confirming the general design direction. P552's high volume precluded castings and its design would include 90% aluminum ABS by weight, a single laminated steel part, and strategically placed extrusions (Fig. 4).

PART SOURCING

In concert with Ford's purchasing team, the switch to an all-aluminum body enabled a re-think of the part sourcing strategy. In 2011, there were virtually no American stamped parts suppliers with significant aluminum expertise, and it would be Ford's responsibility to bring them the necessary technical support. A side effect of the switch to aluminum was a four-fold increase in the value of the work in process. To maximize the value of stamping offal, it made sense to concentrate the external sourcing to a select few suppliers, centered around Ford's historic Rouge Complex in Dearborn, Michigan. The complex included the Dearborn Stamping Plant, Dearborn Frame Plant, and the lead assembly plant for P552, the Dearborn Truck Plant.

The final sourcing strategy concentrated 75% of the parts by weight into Dearborn Stamping Plant, setting it up to become the largest all-aluminum stamping plant in the world. To handle this volume, the plant would be upgraded by adding four new press lines (P3 to P6), one high-speed cut-to-length line

Fig. 3 — Tesla Model S at the 2011 North American Auto Show, showing the use of extrusions and castings as well as sheet. Courtesy of L. Chappuis.

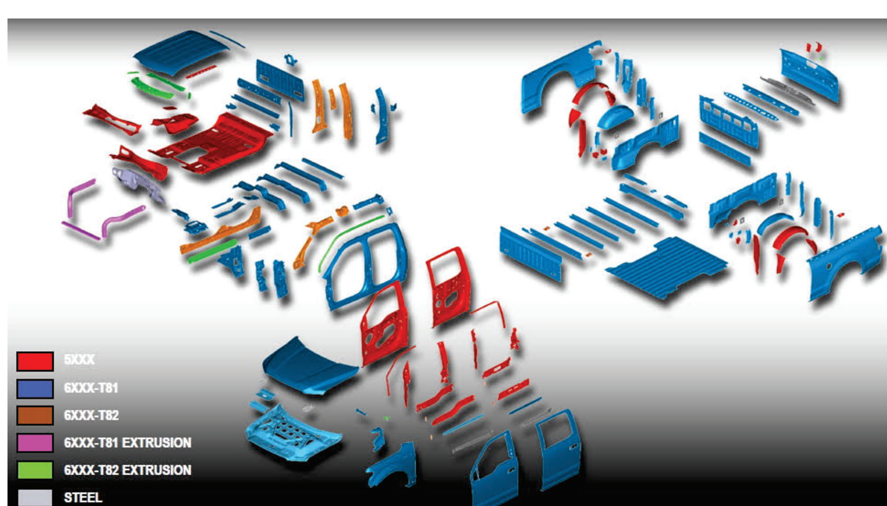

Fig. 4 — Material selection for the 2015 Ford F-150.

(AS1), two blanking lines (BL1 and BL2), and a roll-forming line (RF). The existing two large transfer presses (P1 and P2) and the two high-speed progressive lines (AP1 and AP2) would be refurbished and upgraded. Finally, the traditional scrap conveyor system would be replaced with a new cyclonic system, capable of sorting four scrap streams. This innovative design was made possible by isolating the door inners—the only large parts made of alloy 5182—in P2, which became the only press line capable of sorting four ways (Figs. 5 and 6).

The frame plant was scheduled to cease frame production in September 2011 with the demise of the Panther platform. The plant would be completely redone and transformed into a state-of-the-art aluminum parts manufacturing plant, to be renamed Dearborn Diversified Manufacturing Plant. The refurbished plant would include three complete tube forming lines and machining lines, two heat treat ovens, and a chemical surface treatment line. A later expansion to support the Ford Super Duty and Expedition/Navigator models would add two tube forming lines and an additional heat treat oven.

The consolidation of so many parts into Dearborn Stamping Plant required finding room to house multiple sub-assembly lines that were formerly spread out among several other plants. The solution was for the stamping plant to annex part of the Dearborn engine plant that housed the former fuel tank production lines.

Ford's Buffalo Stamping Plant was set to produce thick gauge 6111 structural parts. It already had one press line connected to a single stream cyclonic system. The new material specifications brought improved composition compatibility, allowing the existing low copper stream to be readily mixed with the much higher volume of 6111 scrap, thus avoiding an expensive upgrade. With Ford now scheduled to handle more than 85% of the stamping by weight, the remaining parts were divided between two local suppliers, Thai Summit in Howell, Michigan, and Veltri, just across the river in Windsor, Ontario. The part sourcing pattern was carefully managed to minimize both scrap sorting complexity and the investment required at both suppliers.

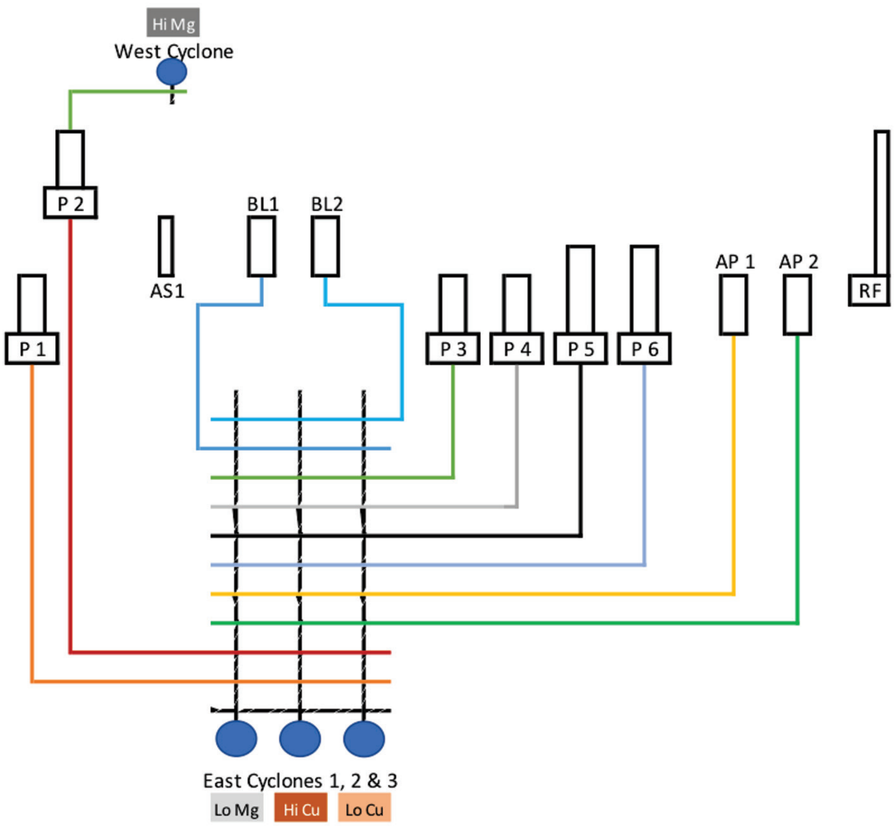

Fig. 5 — Four-way scrap system at the Dearborn Stamping Plant, as configured at the F-150 launch in September 2014.

Fig. 6 — East side cyclones and sorting tubes at Dearborn Stamping Plant, September 2014. Courtesy of L. Chappuis.

By mid-year, the design team had selected the winning theme and the studio was now finalizing all details of the clay models. Engineering of the underbody was well underway to support the upcoming fleet of development prototypes. Novelis publicly announced a $200 million automotive expansion to its Oswego, New York, plant on July 25, 2011, without mentioning Ford. Orders for Dearborn Stamping Plant's new press lines were out by

August, with the first new line expected to be commissioned by May 2013. On September 25, 2011, Alcoa announced a $300 million expansion to automotive sheet production at its Davenport mill in Iowa, again with no mention of Ford. That same month, Ford finally issued the first draft of the new material specifications to the suppliers.

By October, the new presses for the hydroforming lines were on order, along with the new scrap handling system. Yet before all of this new equipment could be installed, the buildings themselves needed to be refurbished. Dearborn Stamping Plant had opened its doors in 1939, and its windows still carried the blackout paint from WWII. This plant was scheduled to remain an active production site for the existing steel model until the final steel truck was produced at the Kansas City Truck Plant, and so it would be a mixed metal production site until then. During that transition, Dearborn Stamping Plant would only be able to sort the aluminum scrap three ways, with steel replacing the fourth stream.

Dearborn Stamping Plant had gone through a profound transformation in 2003 when F-150 had come to the Dearborn Truck Plant: All of the original press lines had been removed and replaced by two high-speed transfer lines at the south end of the plant. In 2011, the vast expanse between the two transfer lines and the two progressive lines in the north end stood empty, ready for what was in fact a rebirth. For the renovation, Ford hired Albert Kahn Associates, the architectural firm that had designed Dearborn Stamping Plant 80 years earlier. Two temporary walls were erected to separate the active site from the construction site. The next step was to establish a 3D CAD model of the plant with detailed 3D scans. The new press lines required new foundations, new operating floors, and new electrical, water, and compressed air distribution systems—along with raising the roof by 12 feet.

The bill for the upgrades to Dearborn Stamping Plant, Buffalo Stamping Plant, and Dearborn Diversified Manufacturing Plant would quickly exceed $400 million, funded in part by a loan from the Department of Energy's Advanced Technology Vehicles Manufacturing Loan Program. By June 2011, Ford was testing the first Novelis coil with A951 pretreatment from MSC Wallbridge. Other manufacturing development programs were now in full swing, including establishing dimensional tolerances for thick gauge 6111 parts, handling and racking methods for post formed heat treated parts, and statistical comparison of material property variability between different suppliers, to name a few.

RIVETING CONCERNS

The same month also saw the end of the cooperation agreement between Ford and Jaguar Land Rover following its sale to Tata. The AIV teams were now formally separated. The SPR testing workload grew quickly, to the point that some of the work had to be outsourced to Ford's European research centers in Aachen, Germany. But by November 2011, the two teams were reporting an unexpectedly high level of variability in their SPR results for 6111-T82 post formed heat treated (PFHT) materials. Based on Jaguar Land Rover's experience with PFHT, the team had expected some limit to the formability of the sheet during the highly-strained SPR process, but a wide range of variability in material was not acceptable.

A detailed investigation revealed that Novelis-supplied sheet had much lower ductility during self-piercing riveting than the corresponding Alcoa sheet. While Novelis launched an investigation to understand the cause of the problem, the Ford team happily booked the riveting performance offered by the Alcoa sheet and incorporated it into the material specifications. Novelis was now faced with two problems—finding the cause of the variability and improving the riveting performance to match Ford's new expectations. It was a difficult project because 6111 had been developed as a thin gauge alloy in Kingston, Ontario, but until the launch of the new lines in Oswego, New York, the only production site for its thick gauge version was in Nachterstedt, Germany.

> BY JUNE 2011, FORD WAS TESTING THE FIRST NOVELIS COIL WITH A951 PRETREATMENT FROM MSC WALLBRIDGE.

Development of a car or truck body is divided into two staggered tasks, the underbody and upperbody. One can think of the underbody as a pure engineering exercise that can proceed as soon as the basic architecture is specified. Because the underbody is responsible for many safety and comfort attributes, it is the subject of its own prototype event that Ford calls the M1 build: This build involves a production representative underbody mated to an ad-hoc prototype upperbody, in this case made of modified X1 parts. In contrast, upperbody development starts in the styling studio after selection of the styling theme; its progress is tied to the maturation of the design in the studio.

For P552, engineering of the underbody entered the CAE verification phase just before Christmas break and by January 2012, all energy was focused on preparing for the M1 build and related material orders. The convoluted supply routes meant long lead times for the aluminum blanks. With steel and earlier 5xxx-centric aluminum-intensive vehicle body structures, natural aging had never been a concern, but P552 was maturing into a largely 6xxx-T4 series project (Fig. 7).

The existing guidelines recognized a six-month shelf life for the T4 material. Thankfully, there were no shelf life issues for the PFHT parts, because they had already undergone artificial aging to T82 temper. The P552 program created a flood of small orders for laboratory testing that would cover a multitude of alloys and thicknesses. The larger orders for the various prototype builds came with short delivery schedules and sometimes late engineering changes. For the customer service organizations at Alcoa and Novelis, who were more accustomed to aerospace or can stock, it created an impression of utter chaos and disorganization. But managing it was a skill that the steel mills had long mastered and Ford clearly expected the aluminum mills to do the same. As tensions mounted, Duane Bendzinski of Alcoa and Jack Presutti of Novelis were powerful advocates for Ford. Newly established quarterly reviews between the mills and Ford eventually led to reorganizations and a substantial increase in resources that allowed the mills to start navigating their new reality.

By the time the M1 build started at the end of April 2012, Novelis had run a series of experiments in Nachterstedt that convinced them they had found a solution. Unfortunately, producing the required gauges and conducting all the necessary testing left no time for any additional development. By contract, the first "production" deliveries from the new production lines in Oswego were due to Dearborn Stamping Plant in less than 14 months. Ford could not afford the risk of any late disruptions, and by the time the M1 build ended in June, all parts scheduled for PFHT had been transferred to Alcoa.

EXECUTION PHASE

The upperbody development was progressing smoothly, and with positive customer clinics and engineering results, Ford's board gave formal program approval in mid-September. The development phase came to a close by Christmas with the completion of the upperbody design. It was "pencils down" for engineering and the start of the execution phase, when the largest expenditures take place to build the tooling and set up manufacturing for the new product. This period also includes the verification prototypes, a large fleet of all possible product combinations that starts about six months later.

In the meantime, Jaguar Land Rover introduced the 2013 Range Rover (L405) at the Paris Motor Show on September 29, 2012. It incorporated all of the lessons learned from a decade of XJ production, and its modern production body shop could handle more than double the volume of its steel predecessor.

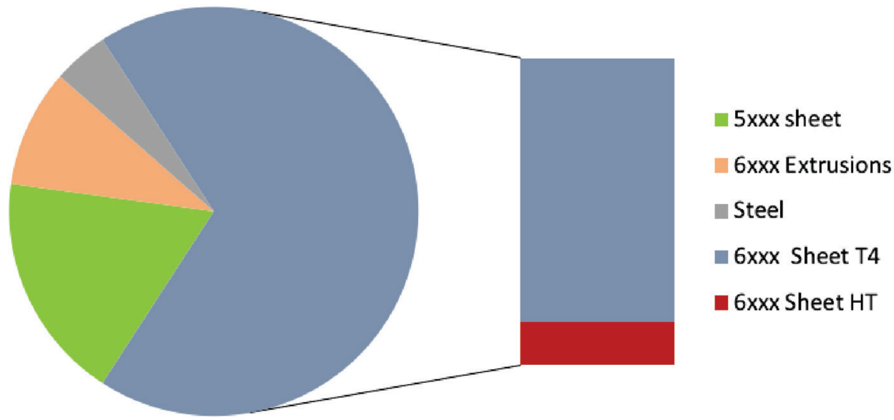

Fig. 7 — Material distribution by weight for the 2015 Ford F-150.

In Dearborn, P552's body construction team had found a solution to the model changeover problem: The new body shop would be assembled in separate segments in various locations around the Detroit Metro area, and in a break from protocol, all preliminary builds would take place at these satellite locations. The design was modular, so that each segment could be disassembled, moved, and reassembled quickly into the new body shop once available. Stamping had secured the required tool build capacity for not only P552, but also for the all-new Mustang that was due to launch almost simultaneously. Meanwhile, Tesla had struggled launching its Model S, and deliveries totaled 2650 by the end of 2012 with production rates slowly climbing.

The mills spent the first quarter of 2013 delivering orders for the stamping tool tryouts and the verification prototype build. Because the new lines would not be ready on time, the entire order book would be delivered through the surrogate production paths. With tool production sites dispersed around the world, the mills had started delivering the first coils in January. As the first prototypes were due by the end of May, managing the natural aging of the 6xxx alloys was a challenge that required constant vigilance.

DISASTER STRIKES

A small portion of the production was earmarked for the SPR development team at Ford's Research & Innovation Center. By definition, the verification prototype build was to use the proposed production riveting schedules. With no time allocated for further development, it was the team's last chance to fine-tune the riveting schedules. Disaster struck on Good Friday during testing at the research center: Amanda Freis was working with some Alcoa 6111 that had gone through the lab's PFHT cycle when she realized she could not rivet it successfully. After checking her setups, she alerted her technical leader, Aindrea Campbell, who after witnessing the failures called in George Luckey, the lab's aluminum ABS technical expert. After confirming it was indeed a metal problem, the alert went out: The immediate task was to figure out if it was an isolated coil issue or if it was shared by the rest of the Alcoa 6111. To find out, the trio continued testing well into the night. By midnight, it was clear that the issue affected every 6111 coil delivered by Alcoa. Material from Novelis Nachterstedt was performing as expected.

By Monday, the alarm had reached the highest level at both companies and it was clear that the verification prototype build timing was in jeopardy unless a solution and replacement metal could be determined right away. Led by Dan Bryant, an intense investigation immediately began at Alcoa Technical Center and Davenport Works. The focus quickly zeroed in on a process change put in place for the verification prototype orders, which had not been part of the previous orders. By the following week, Davenport was re-running the entire 6111 order book using the previous process, while the Detroit automotive team coordinated the surface coating, lubing, blanking, and deliveries. It was a herculean effort that demonstrated the quick maturation of the customer center and Alcoa's commitment to the project.

The successful resolution helped forge enduring bonds between the two technical teams. Another outcome was that Ford had now found a physical lab test that correlated nicely with riveting performance, and it was soon inserted into the material specification. By August, the verification prototype build had been completed and the last prototype testing was underway. In March 2013, Novelis announced the closure of its R&D lab in Kingston and the relocation of key engineers and scientists to its new global research and technology center in Kennesaw, Georgia.

TOOLING TRYOUTS AND NEW LINES

Dearborn Stamping Plant was now busy launching the first two of its four new press lines. The high-speed shear and blanker-1 were already running production. The first sets of tools would soon start their home line trials. Plant manager Frank Piazza somehow kept everything moving forward and was able to keep an epic menagerie of research Ph.D.s, facility planners, manufacturing engineering specialists, suppliers, pipe fitters, die makers, and production workers all in sync to deliver the project. Friday morning briefings were now famous for their intensity and focus.

Novelis Oswego ran its first coil on the new line on schedule in June 2013 and by August, they were qualifying thin gauge skin ABS with impressive elongation gains compared to the existing production from Kingston. Qualification for thick gauge structural 6111 sheet began in September, and Novelis soon found they could not meet Ford's new rivetability criterion. The crisis peaked in October, necessitating an emergency meeting with Ford at Oswego, when the cause of the issue was traced to the line design. Novelis had a solution, but it could not be implemented in time for the start of production.

Another issue was favoring a program delay: As the economy had recovered, light truck sales had steadily risen, and Ford's projected sales volumes for P552 had increased by almost 30%. By October 2013, Alcoa was forced to admit it could not support the new volumes from its Davenport and Danville facilities. Intense discussions were underway with Ford on how to solve this issue. Delaying the start of F-150 production by two months solved both suppliers' problems.

The solution to Alcoa's volume issues was two-fold: First, they would accelerate the launch of the expansion of their North Plant at Alcoa Tennessee, which had been scheduled to support Ford's Super Duty program; second, they would build a bank by running their plants at full production volumes as P552 production ramped up. The bank would start to deplete when demand from P552 outstripped Alcoa's capacity and would bridge the gap until Alcoa Tennessee caught up. Numerous simulations confirmed that by using a strict first-in-first-out strategy, the coils would not exceed their specified shelf lives.

The winter of 2013 was the coldest in memory. The extreme low temperatures froze the newly installed switch gear for Dearborn Stamping Plant's scrap handling system and a new enclosure had to be hastily ordered. The joining team's investigation into riveting performance of the 6xxx alloys determined that natural aging had a negative influence, and mandated all riveting to be complete within six months after heat treat. A new aging management system had to be invented and rolled out to the plants and suppliers. Within Dearborn Stamping Plant, a new computerized material management system was implemented, capable of tracking material from arrival in coil form to delivery as a finished part.

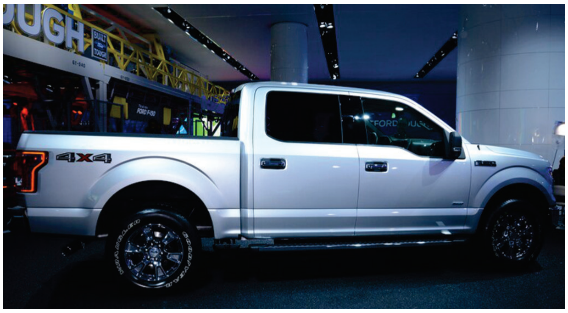

Fig. 8 — 2015 Ford F-150.

For the teams working on P552, time was flying. Some events stood out—notably, the introduction of the new Ford F-150 at the North American International Auto Show on January 13, 2014 (Fig. 8). Its all-aluminum body and box stunned the industry and the press was soon abuzz with speculation on how competitors and the public would respond. For the Ford team, the real shock was that it had remained secret up to that point.

Home line tryout came and went, followed by a series of pre-production builds, all taking place in the independent segments of the body shop scattered around Detroit. The last 2014 steel truck ran through Dearborn Truck Plant on August 23, 2014. Body shop demolition started immediately, and by September 13, the first aluminum body was passing through the new body shop, installed as a complete system for the first time. By then, the stamping plants were starting their production ramp-up, as Dearborn Truck Plant perfected its production system. The official Job 1 ceremony took place on November 11 and production began ramping up. Kansas City Truck Plant produced the steel truck until Christmas, and then finally, Dearborn Stamping Plant was an all-aluminum plant. By March, Kansas City Truck Plant had started production and P552 was fully launched at last. Less than 18 months later, it had exceeded the cumulative production numbers of all aluminum-intensive vehicles ever made.

Learn what happened next in Part XII of this article series—the final installment—to be published in a future issue of *AM&P*. **~AM&P**

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THE MATERIALS CHALLENGE

Using modeling and simulation tools to fill the gaps in advanced materials data.

One of the emerging paradigms of materials science and engineering is understanding the link between composition, process, structure, property, and performance. The combination of material chemistry and processing will influence the microstructure, which will determine the material properties. However, alloys are complex systems where the microstructure and properties are sensitive to variations in the processing conditions and chemical composition. Small differences in composition, particularly in terms of minor elements, can have large effects on processing windows and final properties.

How do I heat treat an alloy that has been processed in a new way? How do I design a heat treatment process for a novel alloy composition? What is the link between targeted material properties, composition, and thermal processing? Handbooks alone are not generally able to provide the answers to such questions as these data are typically only available for the most common alloys of a nominal chemistry or a specific heat treat process. Additionally, trial and error experiments can be time consuming and costly to perform. And what about designing new alloys and material classes where the data do not even exist? There are just too many variables to acquire these data experimentally.

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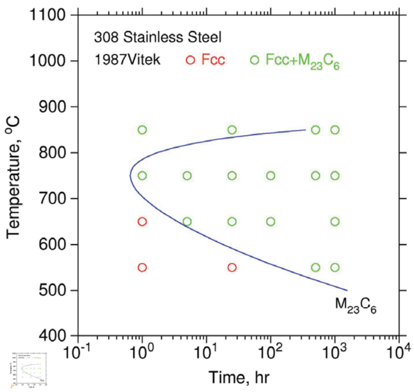
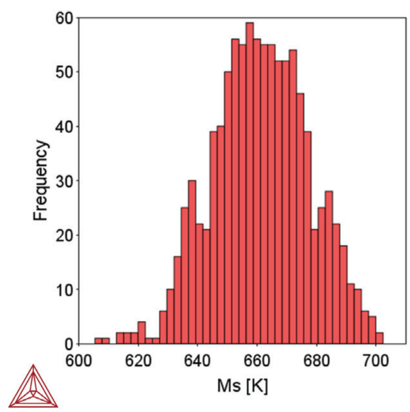


Time temperature precipitation of $M_{23}C_6$ in 308 stainless steel.



Calculated Ms temperatures for 410 stainless composition spec range.

and prediction of material properties for use in other modeling codes.

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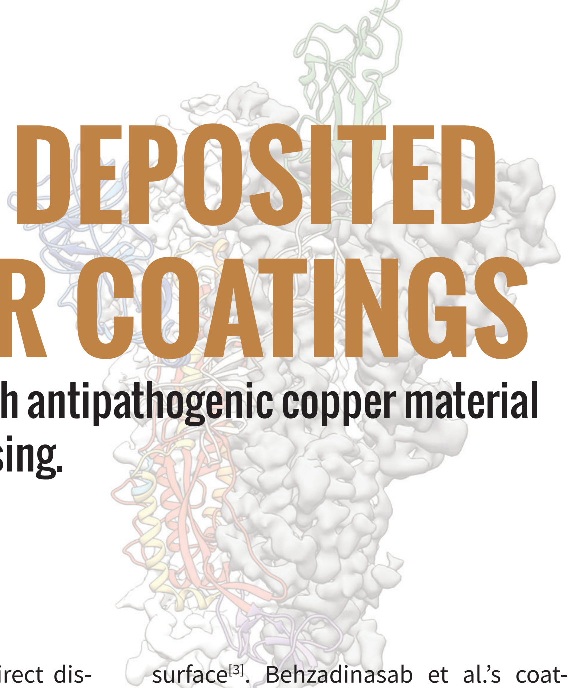
MATERIALS SCIENCE AND CORONAVIRUS SERIES

SUPERSONICALLY DEPOSITED ANTIVIRAL COPPER COATINGS



Enhanced antiviral performance is associated with antipathogenic copper material consolidations obtained using cold spray processing.

Bryer C. Sousa and Danielle L. Cote**

Worcester Polytechnic Institute, Massachusetts

As part of the "Materials Science and Coronavirus Series," *Advanced Materials & Processes* readers were introduced to the way copper can assist in the fight against COVID-19 (Can Copper Help Fight COVID-19?, May/June 2020), and a discussion was presented surrounding the renewed interest Cu has enjoyed as of late because of its antimicrobial behavior (Copper's Conductivity and Antimicrobial Properties Inspire Renewed Interest, July/August 2020). Most recently, Barber et al. pivoted toward the role stainless-steel can play when the commonly found alloyed material in hospitals and medical settings contains an adequate amount of Cu and Cu phases via compositional optimization and proper processing as well (Antimicrobial Copper-Containing Stainless Steels Show Promise, September 2020). The present article shall turn to the enhanced antimicrobial and antiviral performance associated with antipathogenic Cu material consolidations obtained using cold gas-dynamic spray (cold spray) processing.

FOMITE TRANSMISSION OF SARS-CoV-2

Before one spends time on the matter of antimicrobial copper coatings, contact-mediated (or fomite) transmission of SARS-CoV-2 must be established as a non-negligible transmission pathway. Fomite transmission from contaminated high-touch surfaces is considered a mode for COVID-19 transmission. Since fomite transmission of SARS-CoV-2 acts as an indirect disease vector and has been demonstrated numerable times as being non-negligible, surfaces that have been developed to inactivate SARS-CoV-2 will be discussed first; followed by copper as an antiviral surface; contemporary antimicrobial materials, generally; antipathogenic copper cold spray coatings; and then the matter of understanding copper cold spray's antimicrobial behavior, hereafter. To substantiate the fact that contact-mediated fomite transmission of SARS-CoV-2 plays a non-negligible role in the transference of COVID-19, readers are encouraged to consider the following reference[1].

Since the emergence of SARS-CoV-2 as a lethal infectious agent, which can remain active on common material surfaces for significant periods of time, researchers and global members of the materials science and engineering community began to develop coating technologies as viral transmission mitigators. Specifically, Mantlo et al. studied Luminore CopperTouch surfaces to evaluate the inactivation of SARS-CoV-2 and several filoviruses[2]. Mantlo et al. demonstrated the fact that their Luminore CopperTouch surfaces were found to be able to inactivate 99% of SARS-CoV-2 virions before two hours of exposure. Behzadinasab et al. reported another copper-based surface that was able to inactivate 99.9% of the SARS-CoV-2 virus after just one hour of exposure, relative to the uncoated surfaces, thus possibly outperforming the Luminore CopperTouch coating/surface[3]. Behzadinasab et al.'s coating was achieved by way of unifying cuprous oxide particles with polyurethane as a binding agent. Lastly, Hutasoit et al. demonstrated the fact that 96% of the SARS-CoV-2 virions were inactivated upon two hours of incubation time and exposure to an as-deposited Cu cold spray coating[4]. This is consistent with the observation reported in April 2020, by van Doremalen et al.[5], which noted that viable SARS-CoV-2 was no longer measurable upon four hours of exposure to a wrought Cu material.

COPPER AS AN ANTIPATHOGENIC MATERIAL

Numerable elemental metals, including Cu, Ag, and Sn, among others, have been classified as oligodynamic[6]; that is to say they've been shown to inhibit or kill microorganisms. However, copper has been isolated as the most actionable oligodynamic elemental metal studied by the biological community to date. Even though Cu maintains an appreciable oligodynamic capacity, many microbial agents shown to be susceptible to copper-based contact killing, in the case of bacteria, or contact inactivation, in the case of viruses, still require trace amounts of Cu to ensure that physiological coherency and homeostasis are both maintained[7]. More specifically, Cu acts as a critical trace metal for all aerobic organisms, for example, wherein Cu commonly serves as an enzymatic cofactor for the catalyzation of various redox reactions[7]. Indeed, this is because of Cu's ability to cycle between

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Cu^{1+} and Cu^{2+}. An extreme example of a class of aerobic microorganisms (under ideal conditions) follows from the aerobic methane-oxidizing bacterium known as methanotrophs. More specifically, methanotrophs are a gram-negative and methane oxidative form of bacteria with more than thirty Cu-containing proteins[8]. As such, researchers have attempted to invoke methanotrophs as being a potential surrogate for understanding how microbes generally uptake or remove Cu in a regulated fashion[9].

However, in doing so, researchers appeared to be unaware of the fact that the critical Cu-methanobactin responsible for the uptake and removal of Cu ions in methanotrophs have been shown to be unable to be internalized by non-methanotrophs, such as *E. coli*, in contrast with the internalization of Cu-methanobactin from one methanotroph to another[8]. As such, one cannot consider methanotrophs as suitable surrogate microbes for garnering wide-ranging Cu regulation mechanisms across various pathogens, as has previously been suggested elsewhere[9]. Accordingly, attention will be refocused back toward the vast span of Cu-sensitive pathogens, which are also non-methanotrophs, to potentially identify prospective commonalities underpinning Cu-regulation in microbial agents of interest. Therefore, one may consider the fact that gram-negative bacterial cells have been shown to commit metabolic self-destruction[10], wherein "the outer membrane is the initial target and Fenton reactions between respiration generated oxygen radicals and copper ions results in the generation of reactive oxygen species," thus leading to "metabolic suicide" as expressed by Warnes et al.[11]. In contrast with gram-negative bacteria, Warnes et al. found that viral copper contact inactivation efficacy (via viral RNA destruction) was proportional to the Cu-content associated with the dry Cu-surfaces that were inoculated with noroviruses. Warnes et al. also observed a reduction in the total copy number of viral-protein-genome-linked proteins, which are required for infectivity, with increasing copper content relative to a stainless-steel control[10].

The work by Warnes et al. that was just discussed is concerned with the viral inactivation mechanism associated with a non-enveloped viral pathogen that was directly exposed to and inoculated upon copper surfaces. However, SARS-CoV-1, MERS, and SARS-CoV-2 are examples of enveloped viruses, rather than non-enveloped viruses, and therefore react with Cu ions in a manner that is uniquely distinguishable from non-enveloped pathogens – precisely because of the presence of said envelope. Therefore, one currently hypothesized mechanism for copper contact inactivation of enveloped coronaviruses was achieved via the use of human coronavirus 229E[12]. In this case, Warnes et al. found that "Exposure to copper destroyed the viral genomes and irreversibly affected virus morphology, including disintegration of envelope and dispersal of surface spikes… the inactivation… was enhanced by reactive oxygen species generation" on the copper surface.

While it is appreciable to note that the microbiologists who penned the references cited above also observed the fact that the contact killing or inactivation rates vary as a function of Cu content, less intuitive material-level characteristics are also known to affect the antipathogenic performance of Cu surfaces too. Such characteristics include surface roughness[13], microstructure[14–16], and the like. For example, Champagne et al. hypothesized that the distinctive microstructures affiliated with pure copper arc sprayed, plasma sprayed, and cold sprayed, surfaces would yield dissimilar antipathogenic activity as a direct consequence of the microstructures associated with each material processing condition. Examination of microstructures associated with each of the three thermally sprayed coatings led to the following observation made by Champagne et al.[17]: "[differences] in microstructure are evident, suggesting that differences in biological activity may also occur." Such an observation is consistent with Champagne et al.'s hypothesis that antipathogenic performance depends upon not only copper content but also the microstructure associated with the deposited copper. Figure 1 presents the cross-sectional renderings of the resultant microstructures just discussed via optical microscopy.

ANTIPATHOGENIC COPPER COLD SPRAY COATINGS

Concerning the plasma spray-based, cold spray-based, and arc spray-based antipathogenic surfaces developed by Champagne et al. and detailed above, the resultant percent of MRSA that survived direct contact through two hours of inoculation on the surfaces

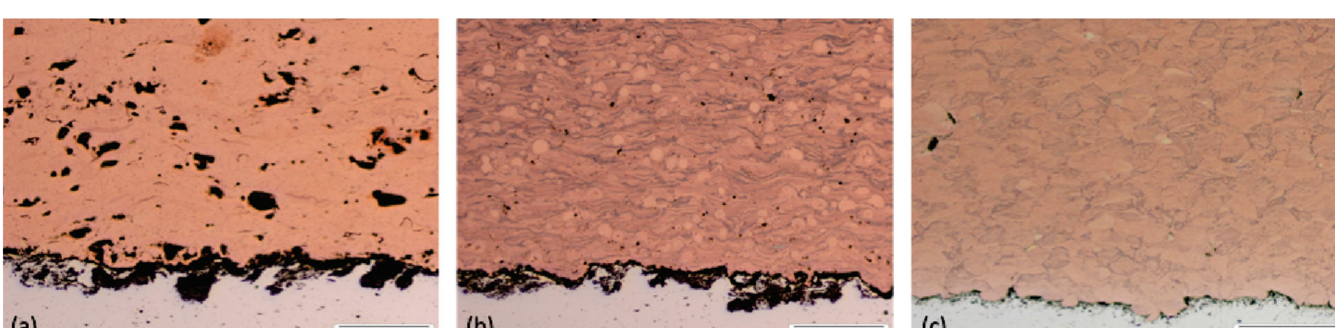

Fig. 1 — (a) Cross-sectional optical micrograph of the Cu wire arc sprayed coating; (b) cross-sectional optical micrograph of the Cu plasma sprayed coating; and (c) cross-sectional optical micrograph of the conventional Cu cold spray consolidation. Adapted from Champagne et al.[17].

substantiated the microstructurally dependent conjecture that had been put forth[17]. Remarkably, Champagne et al. found that the Cu cold spray surfaces killed greater than 99.999% of inoculated MRSA. Two years later, in 2015, a novel nanostructured Cu cold spray surface was found to inactivate 99.3% of inoculated Influenza A virions after two hours of exposure[18]. Such an inactivation rate was greater than that achieved when the conventional copper cold spray consolidation was utilized, which was originally reported upon in 2013, and had reached 97.7% inactivation. As will be discussed shortly hereafter, the nanostructured Cu cold spray surfaces were consolidated using a novel spray-dried feedstock material in comparison with the conventional use of gas-atomized feedstock powder. In addition to studying the virial inactivation rates achieved via Cu cold spray as a function of the microstructure of the resultant coatings, the conventional Cu cold spray coating process was redeployed two additional times using two additionally gas-atomized and pure copper powders from different powder suppliers. This was reportedly pursued by Champagne et al. in 2015 to ensure that the MRSA-based contact killing capacity of the consolidated surfaces could be reproduced for verification and validation of the observations first reported upon in 2013. Each additional version of the Cu cold spray coatings produced using conventional feedstock powder was found to be consistent with the original findings, wherein each of the surfaces reached a bacterial reduction rate greater than 99.9% of the inoculated MRSA following two hours of direct contact[18].

Nearly six years after Champagne et al.'s proof-of-concept study was published, da Silva et al. reported upon the antimicrobial properties of another conventionally deposited copper cold spray coating[19]. They found that their Cu cold spray coating was able to effectively achieve nearly complete inhibition of *Staphylococcus aureus*'s growth after ten minutes of continuous contact with the Cu surface. One month after da Silva et al.'s work was published, Sousa et al. reinvigorated the interest in the antipathogenic nanostructured Cu cold spray coatings by way of exploring the nanomechanical behavior of the consolidated surfaces through spherical nanoindentation stress-strain curve analysis[14]. Sousa et al. explored the mechanical properties of the novel nanostructured as well as conventional Cu cold spray coatings to assess their mechanical suitability and durability for common touch surfaces in hospital rooms that require resistance to plastic deformation and to also probe a hypothesis presented by Champagne et al., which concerned the use of hardness and/or strength to assess the amount of defect-mediated Cu ion diffusion pathways present in the coatings (Fig. 2).

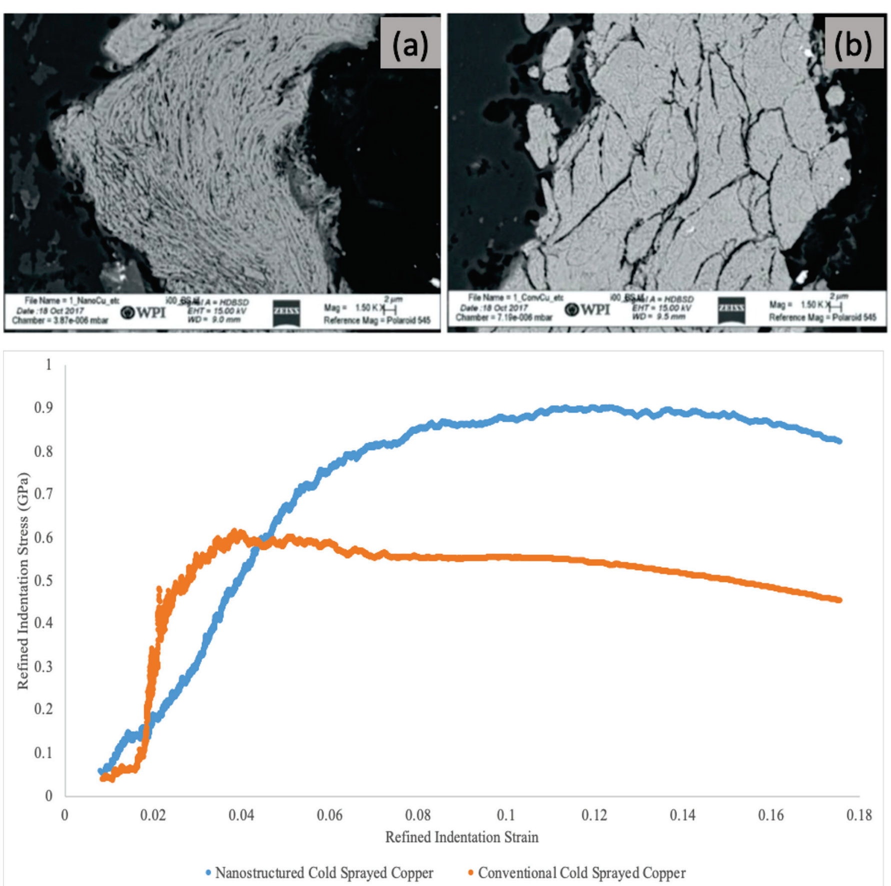

Fig. 2 — (a) Chemically etched, cross-sectional scanning electron micrograph of the nanostructured Cu cold spray coating; (b) chemically etched, cross-sectional scanning electron micrograph of the conventional Cu cold spray coating; and the refined indentation stress vs. strain curves for the nanostructured and conventional Cu cold spray coatings in the cross-sectional orientations shown in (a) and (b). Adapted from *Journal of Thermal Spray Technology*[15].

With the aforementioned in mind, Champagne et al. continued to critically examine their own research by way of synthesizing work reported between 2013 and 2019 through the lens of a hypothesis that identified the dislocation densities brought about by the cold spray deposition process as the microstructural feature most responsible for the antibacterial and antiviral functionality of the coatings[20]. As has been discussed elsewhere, the claim by Champagne et al. that dislocation density generation serves as cold spray's "application-dependent mechanism for antimicrobial effectiveness" has been refined and has refocused upon the degree of dynamic recrystallization grain refinement experienced by copper during cold spray processing[16]. In other words, Champagne et al., in 2019, reported dislocation density as the microstructural constituent responsible for enhanced antiviral contact inactivation or antibacterial contact killing, whereas Sousa et al. combined dislocation density with grain-boundary mediated atomic Cu diffusion. Regardless, Fig. 3 attests to the viral inactivation rate of cold sprayed Cu vs. structural Cu, irrespective of the scientifically reducible microstructural feature most able to enhance atomic Cu ion diffusivity from the consolidated coatings for the purpose of contact killing/inactivation applications.

Moreover, the virus-length-scale and bacterial-length-scale surface roughness of the conventional Cu and nanostructured Cu cold spray surfaces have also been reported[13]. Performed using atomic force microscopy (AFM) and 3D-confocal microscopy, the research by Sundberg et al. aimed to procure a more holistic understanding of the mechanisms underpinning the nanostructured Cu cold spray surface's enhanced antiviral performance when compared with the conventional Cu cold spray coatings' efficacy. Coupled AFM-confocal microscopy-based characterization of the nanostructured Cu and conventional Cu cold spray consolidations enabled prospective surface-phenomena and surface-mediated mechanisms underlying the antiviral efficacies to be investigated. Soon thereafter, Sundberg et al. continued their alternative analysis via the incorporation of corrosion studies and surface effects to thoroughly probe the ionic copper chemical reactivities associated with the conventional Cu and nanostructured Cu cold spray surfaces[21].

Turning to the research published to date and concerned with functionalized antimicrobial copper cold spray coatings since the global COVID-19 pandemic took effect, four additional research articles of immediate relevance are considered next. In large part, two studies[16,22] aimed to initialize the formulation of a properties-processing-structure-performance framework for antimicrobial copper cold spray. Also, additional microscopy-based, mechanically based, and chemically/physically based characterization of the nanostructured and conventional copper coatings, single-particle deposits, and feedstock materials was performed and reported upon[15]. In terms of microstructural inspection, Fig. 4 presents the cross-sectional renderings of the polycrystallinity associated with the conventional copper cold sprayed coatings.

As for Cu cold spray research that was published and specifically concerned with SARS-CoV-2 as the viral pathogen being explicitly studied, Hutasoit et al.'s testing resulted in 96% inactivation of the novel coronavirus within two hours of exposure to a conventional Cu cold spray surface via direct contact of the pathogen with their coatings. Hutasoit et al. also demonstrated that 99.2% inactivation was achieved at a five-hour exposure period. At the same time, Hutasoit et al. found that annealing the as-deposited conventional Cu cold spray coating resulted in a decrease in the antipathogenic efficacy, which is consistent with the framework presented by Sousa et al.[16]. In any case, the speed at which the coatings were applied, as well as the 45-degree angle relative to the stainless-steel push plate substrate, likely prevented the feedstock powder from being maximally deformed and therefore incapable of reaching optimal atomic Cu ion diffusivity. Thus, inactivation rates with more idealized processing parameters would likely achieve greater than 96% reduction of SARS-CoV-2 at the two-hour mark[4]. Lastly, Hutasoit et al.'s recorded reduction percentage at two hours is also consistent with the as-deposited conventional copper cold spray coating procured for Influenza A inactivation, wherein a 97.3% reduction was achieved for another viral agent[18].

Around the same time, Lucas et al. reported a greater than seven log decrease in microbes exposed to a conventional copper cold spray coating; wherein noteworthy decreases in

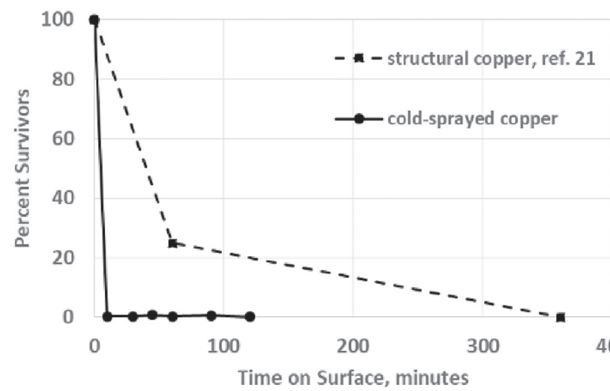

Fig. 3 — Percent of Influenza A that remained active as a function of exposure time to Cu cold spray surfaces in comparison with a traditionally structural copper component. Adapted from Champagne et al.[20].

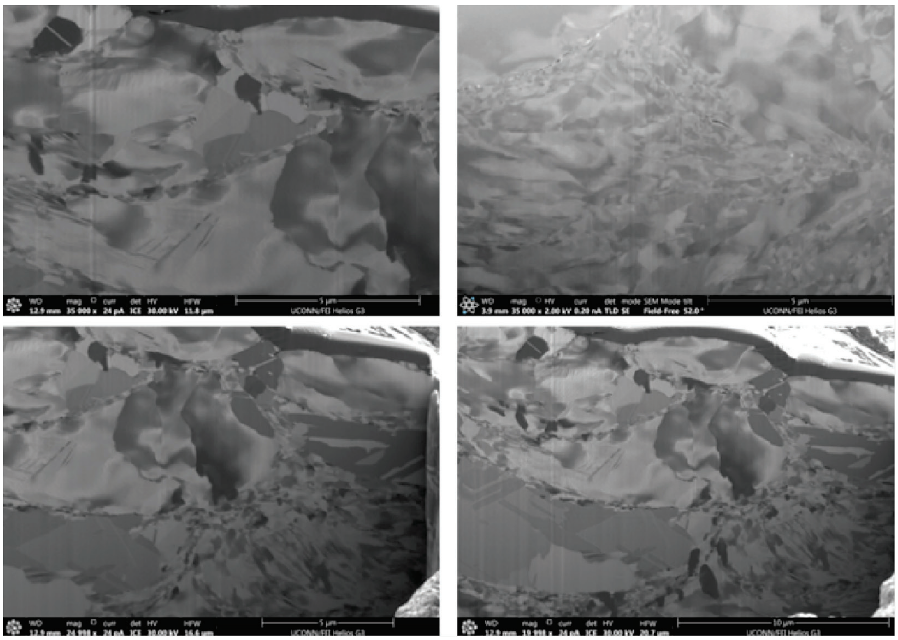

Fig. 4 — Cross-sectional high-resolution scanning electron micrographs of conventional copper cold spray material consolidations. The samples were prepared using a focused ion beam milling system. Two of the micrographs were adapted from Sundberg et al.[13].

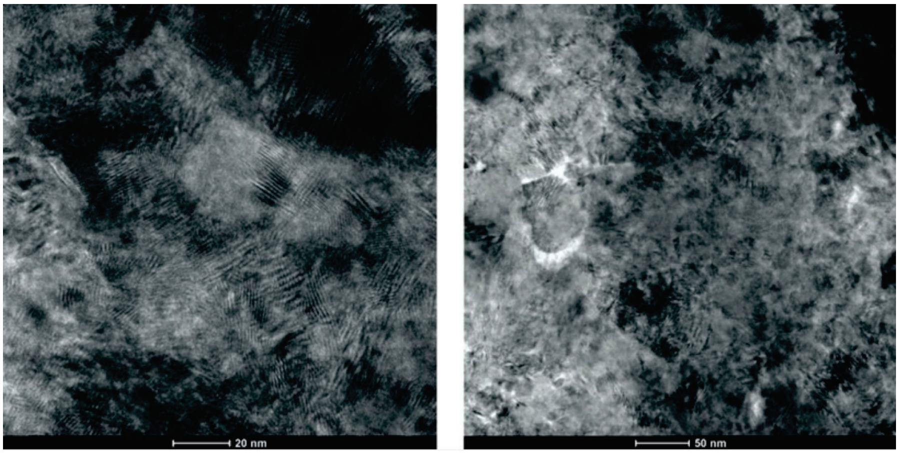

Fig. 5 — Scanning transmission electron microscopy-based cross-sectional micrographs of the deformed microstructure of the nanostructured Cu cold sprayed coatings. A large amount of atomic lattice fringes is observed in the leftmost micrograph. Adapted from Sousa et al.[16].

microbial concentration were recorded within minutes when numerable pathogens were inoculated. This is in comparison with their finding that only a one log decrease of infectious microbial agents on wrought copper sheets, after three hours of direct contact. Moreover, Lucas et al. found that copper-coated 3D printed ABS realized complete contact killing of the inoculated microbes within 15 minutes of exposure; copper-on-copper reached microbial inhibition after 10 minutes, and a five-minute elimination period was identified for the copper cold spray coatings that included a 5 wt. % addition of silver, i.e., the second most oligodynamic elemental agent next to copper, into the feedstock. This included gram-positive *Staphylococcus aureus*, gram-negative *Pseudomonas aeruginosa*, *Candida albicans*, gentamicin-methicillin–resistant *S. aureus*, azlocillin-carbenicillin–resistant *P. aeruginosa,* and fluconazole-resistant *C. albicans*[23].

CONCLUSION

This article invoked the non-negligible nature of contact-mediated fomite transmission of SARS-CoV-2 from contaminated high-touch surfaces; discussed Cu's oligodynamic activity; and analyzed the performance and application of copper cold spray processing for the purpose of procuring antimicrobial and antiviral coatings with enhanced functionality. By introducing the preventive role supersonically deposited antiviral copper coatings can play as a pandemic countermeasure, materials scientists and engineers can more readily engage in prospective optimization and deployment of antipathogenic Cu cold spray surfaces. For example, the discussion surrounding the link between microstructure, atomic Cu ion diffusivity, and antiviral/antibacterial performance, provides materials researchers with a target microstructure that may be tunable via advanced processing parameter development. Installing antimicrobial Cu cold spray coatings as a technology well-suited for rapid inactivation of SARS-CoV-2 can enhance the resiliency of populations in the short-term. In the long-term, prolonged public health benefits will also be achieved since the supersonically deposited Cu coatings remain antiviral and antibacterial for prolonged periods of time, thus remaining functional when future pandemics (which could center upon a pathogen with a greater tendency of disease transmission via fomite pathways) follow COVID-19. **~AM&P**

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

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DEFECT ANALYSIS AND PROCESS OPTIMIZATION FOR FORGED ALUMINUM WHEELS

Modeling and simulation are used to solve the problem of folded grooves, a common occurrence during aluminum wheel forging.

Jing Li, Qinhuangdao Discastal-Xinglong Wheel Manufacturing Co. Ltd., China
Jian-fang Liu, Research Center of Light Alloy Wheel Engineering of Hebei Province, China

As lightweighting has become an important trend in automotive manufacturing over the past several years, the wheel industry has followed suit. Because aluminum alloys feature low density, light weight, high corrosion resistance, and good heat transfer performance, they are widely used to make wheels. Casting and forging are the primary methods used to manufacture aluminum alloy wheels. Casting imparts moderate mechanical properties—good enough to meet the needs of most wheels—while the rate of finished products with few defects is high, and the cost is low.

Wheels produced by forging feature high mechanical properties, including tensile strength 1.3 to 1.5 times that of cast wheels, elongation 1.2 to 1.5 times greater, and weight reduction of 5-10% versus a cast wheel with the same specifications. Although forged wheels provide a lightweighting advantage over cast wheels, they are more expensive due to higher equipment costs and more involved production steps. However, due to the performance advantages of forged wheels, certain automotive categories such as bus fleets often use them. And with recent growth in the forged wheel market, prices are becoming more competitive with cast versions. As the market is expanding, factors such as metal utilization rates are becoming increasingly important—with rates for forged wheels now climbing above 60% in some cases.

With bus wheels, a grooved structure exists at the junction of the wheel's rims and spokes. Some wheels have a deeper shape than others, and weight can reach as high as 2 kg. To achieve efficient metal utilization, the groove shape must be forged when the blank is forged. During production, the groove is a location where folding defects are easily generated. How to solve the folding problem at this spot is a perplexing issue for the entire wheel industry. To address this defect, the authors used modeling as the primary tool to analyze and optimize the process.

PROCESS DETAILS

The process of forging wheels begins with using a large press to apply pressure to aluminum alloy bars to generate plastic deformation to make wheel blanks. During production, a spray disc is used to deliver lubricant before bar is placed into the mold. The press is then run until the mold is closed. Finally, the press opens the mold and removes the wheel blank. According to factors such as specific wheel requirements and the type of forging equipment, specific steps including pre-forging and final-forging are often involved.

In this study, a forged aluminum bus wheel design is explored. In order to improve the metal utilization rate, the groove is designed at the indented

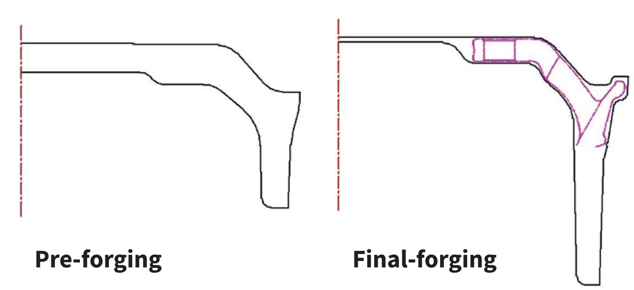

Fig. 1 — Forging process design steps include pre-forging and final-forging.

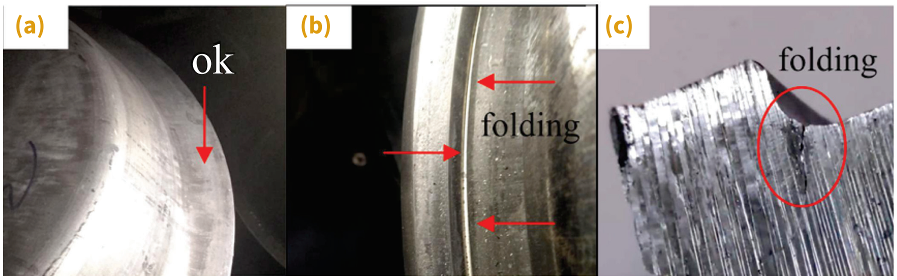

Fig. 2 — (a) pre-forging flange; (b) final forging flange; and (c) section after cutting final forging blank.

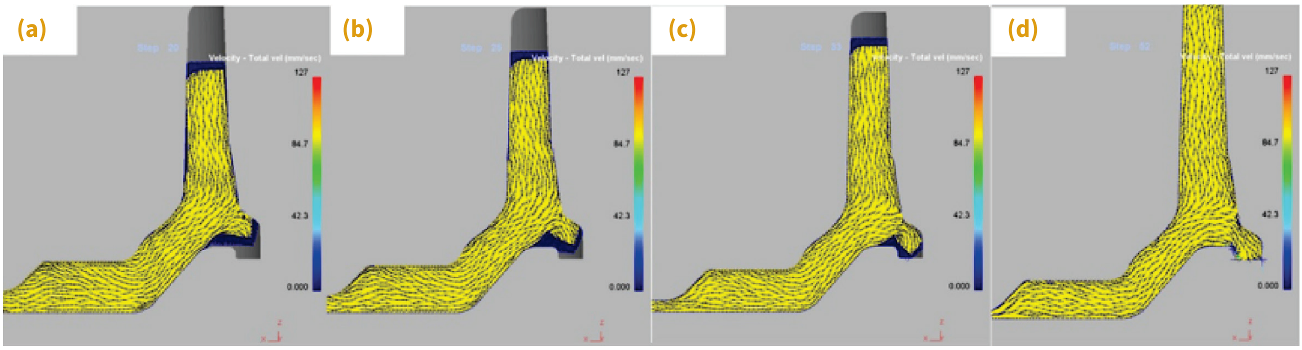

Fig. 3 — Analysis of metal flow direction in rim groove: (a) flow direction is normal; (b) and (c) problems with flow direction appear; and (d) final shape.

portion of the wheel flange to save blank weight and forging is divided into two steps, pre-forging and final-forging (Fig. 1).

During forging, a constant pressure production mode was used with pressure set to 5500-7000 tons, the working speed of the slider was 8-15 s/mm, and the pressure holding time was 0-6 s. Lubrication settings were 0-1500 ms for the upper die center area, 0-2000 ms for the other upper die area, and 0-1000 ms for the bottom die area. Results of the actual production included zero defects in the groove of the pre-forging flange, and good blank quality. However, the final-forging became folded in the groove of the wheel flange and was distributed for one week, which was apparent to the naked eye. A deep fold crack was discovered in the cutting sample of the wheel (Fig. 2).

DEFECT ANALYSIS

Based on this defect, the authors concluded that the design of the initial and final forging steps is incorrect. More specifically, they suspected that the pre-forging design was causing metal to backflow and create folds. To verify this, a simulation analysis was conducted using DEFORM software from Scientific Forming Technologies Corp., Columbus, Ohio. Analysis results are displayed in Fig. 3. Metal flow conditions exhibit the following features: (a) flow is normal; (b) a metal flow problem has occurred, with the flow direction of the flange moving upward, the flange position pressed down by the mold, and the metal flow at the flange position flowing back, forming a fold; (c) the folding position moves to the outside of the flange; and (d) the fold finally moved to the outer corner of the flange, consistent with actual production results.

According to both the physical production defects viewed on site and the simulation results of the DEFORM software, it appears that the folding of the rim groove is caused by the flow of metal in different directions during forming. In order to achieve better metal utilization, the design of the final-forging blank must be as consistent as possible with the shape of the final product. The flow direction of the metal can only be controlled by adjusting the shape of the forging blank to avoid metal backflow at the flange.

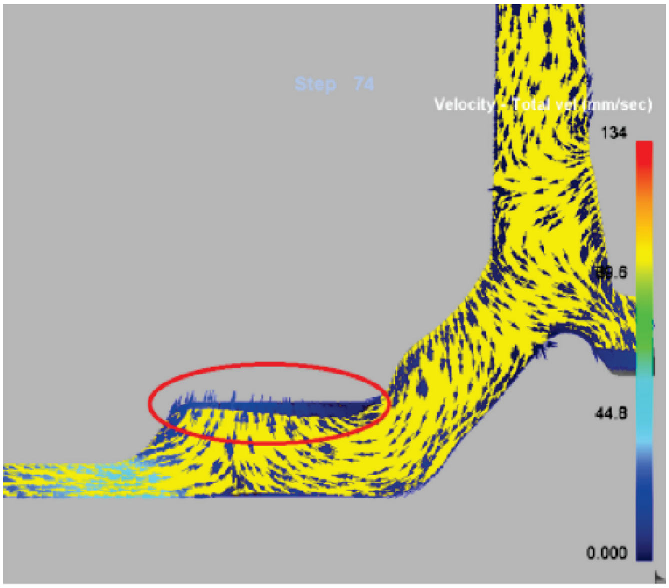

Fig. 5 — Problems during adjustment.

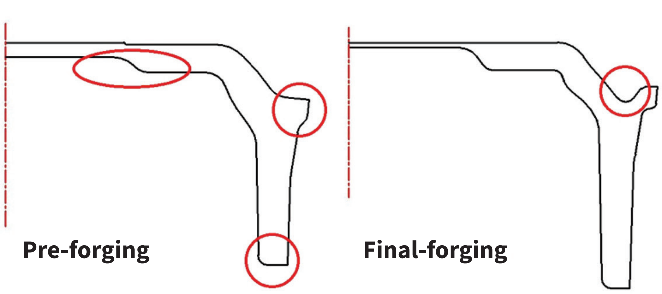

Fig. 4 — Three positions on the flange required adjustments.

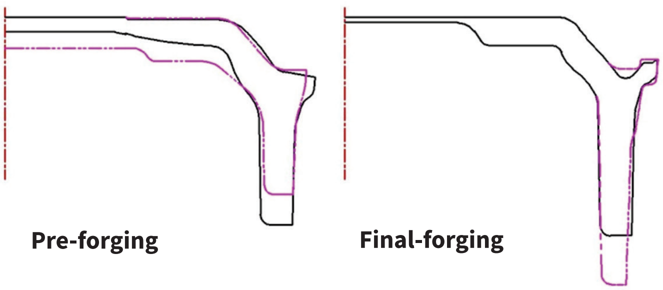

Fig. 6 — The solid line indicates the final blank, while the dotted line shows the initial blank.

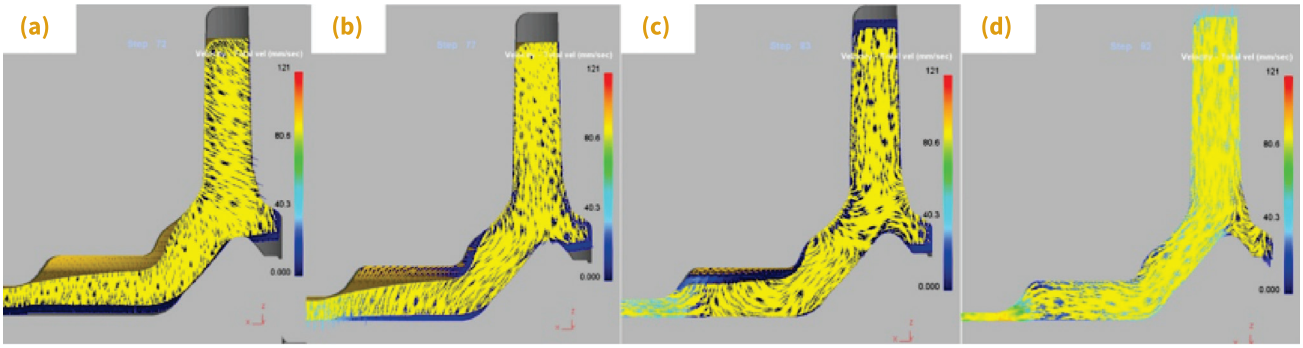

Fig. 7 — Analysis results of the final design using DEFORM software: (a) Flow direction is normal; (b) &(c) obvious problems with flow direction; and (d) final shape.

DESIGN OPTIMIZATION

Based on conclusions drawn from the defect analysis, the work plan was adjusted. To achieve better metal utilization, the shape of the flange groove was deepened, reducing the amount of blank metal required. In addition, the three positions of the pre-forging were adjusted (Fig. 4). With regard to the rim, the new approach minimizes the height difference between the pre-forging and final-forging of the rim, thereby reducing the amount of metal flow during final forging of the spoke. For the flange, the new design ensures the correct amount of metal at the rim and reduces excess metal flow into the rim area during final forging. Finally, for the attachment face, the new design moves some of the metal from the rim area to the flange.

The process steps were adjusted in accordance with the design modifications and DEFORM simulation analysis was used to verify the effect of each change. Multiple designs were considered to finalize the optimal solution.

There were also problems in other locations of the blank. As shown in Fig. 5, the design features a closed area in the plane of the attachment face, forming an approximate triangle. According to long-term production experience, it can be assumed that this design will produce folding defects. This example shows that any process adjustment is not confined to a certain position, but affects the entire blank.

After many adjustments, the final design is shown in Fig. 6.

Once the final design is imported into DEFORM for analysis, one can see that the optimized plan eliminates defects at the flange position as well as the tendency to form new defects at other locations (Fig. 7).

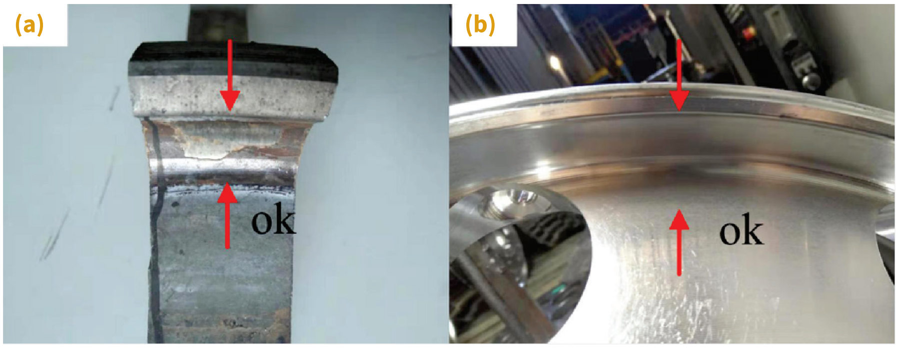

Fig. 8 — Actual processing effect: (a) blank; and (b) finished product after processing.

During final production verification, 50 sample wheel hubs were produced. Only three hubs contained significant folds and were scrapped, achieving a yield rate of 94%. Although a few of the other blanks were slightly folded, they could all be processed without any problems (Fig. 8).

CONCLUSION

Folding of the flange groove is caused by the flow of metal in different directions during forming. The flow direction of the rim is upward, while the metal flow at the flange position is downward. These two flow directions are at an angle, creating a fold. To reduce or avoid the occurrence of groove folding, it is necessary to closely align the pre-forging and final-forging steps. The focus of the pre-forging step design is to minimize metal flow at the rim and flange position during final-forging. Because forging is a complicated forming process, any local adjustment may cause defects in other locations. Simulation software can help eliminate design errors before production begins. **~AM&P**

For more information: Jing Li, Qinhuangdao Discastal Xinglong Wheel Co. Ltd., Qinhuangdao 066000, Hebei, China, +8615603383770, lijing1325285395@163.com.

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ASMNEWS

PRESIDENT ESSOCK APPOINTS COMMITTEE AND COUNCIL CHAIRS

ASM International President Diana Essock, FASM, appointed a chair to each of the Society's general committees and councils. All appointments were unanimously approved by the Board of Trustees. Terms began September 1, 2020. Congratulations to all of our ASM International leaders!

Prof. Krishan Chawla, FASM, professor, University of Alabama at Birmingham, continues as chair of the International Materials Review Committee.

Dr. Adam Farrow, manufacturing manager, Los Alamos National Laboratory, continues as chair of the Content Committee, and continues as chair of the AM&P Editorial Committee.

Dr. Kyle Gibson, principal metallurgist, Argen Labs, was appointed chair of the Technical Books Committee.

Mr. Jeff Grabowski, manager of business development, QuesTek Innovations LLC, was appointed chair of the AeroMat Organizing Committee.

Dr. Khalid Hattar, principal member of technical staff, Sandia National Laboratories, was appointed chair of the Membership Engagement Council.

Mr. Jonathan Healy, venture fellow, Naval Surface Warfare Center, continues as co-chair of the Emerging Professionals Committee.

Dr. William Joost, technology development manager, U.S. Department of Energy, continues as chair of the Materials Property Database Committee.

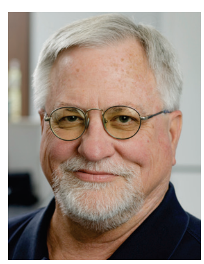
Mr. John Kuli, technology and innovation leader, Materion Corp., was appointed treasurer and chair of the Finance Committee.

Prof. Jeffrey C. LaCombe, associate professor, University of Nevada, Reno, was appointed chair of the Alloy Phase Diagram Committee.

Dr. Dana Medlin, FASM, senior managing consultant, EAG Laboratories, continues as chair of the Education Committee.


Chawla


Farrow


Gibson


Grabowski


Hattar


Healy


Joost


Kuli


LaCombe


Medlin

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 or 800.336.5152 (toll free in U.S. and Canada) | F 440.338.4634 | E MemberServiceCenter@asminternational.org | W asminternational.org

HIGHLIGHTS COMMITTEE AND COUNCIL CHAIRS

Dr. Manish Mehta, FASM, founder/president, M-Tech International LLC, continues as chair of the Emerging Technologies Awareness Committee.

Ms. Carolyn Merritt, office manager, Test Spectrum Inc., continues as chair of the Action in Education Committee.

Dr. Brittnee A. Mound-Watson, manufacturing engineer, Lockheed Martin, was appointed co-chair of the Emerging Professionals Committee.

Mr. Ben Rasmussen, engineer manager, Caterpillar Inc., continues as chair of the Volunteerism Committee.

Dr. Marissa Reigel, R&D execution manager, Savannah River National Laboratory, was appointed chair of the ASM IDEA Committee.

Prof. Timothy J. Rupert, associate professor, University of California, Irvine, was appointed chair of the Awards Policy Committee.

Mr. Craig Schroeder, senior engineer, metallurgy, Element, continues as chair of the Handbook Committee.

Dr. Dileep Singh, FASM, materials scientist, Argonne National Laboratories, was appointed chair of the Journal of Materials Engineering and Performance Committee.

Dr. Mark F. Smith, FASM, deputy director, Materials Science and Engineering Center (retired), Sandia National Laboratories, continues as chair of the Investment & ASM Materials Education Foundation Investment Committees.

Mrs. Beth Snipes, FASM, senior materials engineer, TEC Materials Testing, was appointed chair of Chapter Council.

Dr. Ashok Kumar Tiwari, CHEMI-CHEM, was appointed chair of India Council.

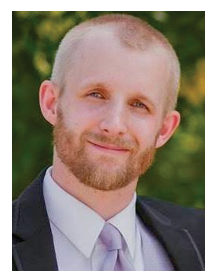
Dr. Andrzej Wojcieszynski, FASM, senior principal engineer, Allegheny Technologies Inc., continues as chair of the ASM Programming Committee.

Mr. Jordan Wilhelm, quality assurance technician, Unilock, continues as chair of Canada Council.


Mehta


Merritt


Mound-Watson


Rasmussen


Reigel


Rupert


Schroeder


Singh


Smith


Snipes


Tiwari


Wojcieszynski


Wilhelm

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.

Annual ASM Award Nominations

The deadline for the majority of ASM's awards is February 1. We are actively seeking nominations for all of these awards, a sampling of which is listed below:

- Edward DeMille Campbell Memorial Lectureship
- Distinguished Life Membership
- William Hunt Eisenman Award
- Gold Medal
- Silver Medal
- Bronze Medal
- Historical Landmarks
- Honorary Membership
- Medal for the Advancement of Research
- Allan Ray Putnam Service Award
- Albert Sauveur Achievement Award
- Albert Easton White Distinguished Teacher Award
- J. Willard Gibbs Phase Equilibria Award

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

2021 Bradley Stoughton Award for Young Teachers

Winner receives $3000. Deadline March 1. This award recognizes excellence in young teachers in the field of materials science, materials engineering, design, and processing.

Do you know a colleague who:

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

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

NOMINATIONS SOUGHT FOR AFFILIATE SOCIETY BOARDS

The Awards and Nominations Committees for six of ASM's Affiliate Societies are seeking nominations for their Board of Directors, as noted below. **All nominations are due no later than February 1 and all terms begin October 1.**

Electronic Device Failure Analysis Society (EDFAS) is seeking nominations to fill two board member positions. EDFAS members in good standing are encouraged to nominate themselves or another member. For more information on eligibility and how to submit a nomination, visit the EDFAS website at asminternational.org/web/edfas.

Failure Analysis Society (FAS) is seeking nominations to fill one vice president and one secretary for two-year terms, two board member positions, and one emerging professional board member role. Any member of FAS in good standing is encouraged to nominate themselves or another member. For more information on eligibility and how to submit a nomination, visit the FAS website at asminternational.org/web/fas.

Heat Treating Society (HTS) is seeking nominations to fill one vice president and one secretary for two-year terms, three board member positions, and one emerging professional board member role. Candidates must be an HTS member in good standing. Nominations should be made on the formal nomination form and can be submitted by a chapter, council, committee, HTS member, or an affiliate society. The HTS Awards and Nominations Committee may consider any HTS member, including those who have served on the HTS Board previously. For more information on eligibility and for a copy of the nomination form, visit the HTS website at asminternational.org/web/hts.

International Metallographic Society (IMS) is seeking nominations to fill one vice president and one secretary for two-year terms. Any IMS members in good standing are encouraged to nominate themselves or another member for any of these positions. Current board members whose terms are expiring may be eligible for nomination and possible reelection on an equal basis with any other candidate. For more information on eligibility and how to submit a nomination, visit the IMS website at asminternational.org/web/ims.

International Organization on Shape Memory and Superelastic Technologies (SMST) is seeking nominations to fill three board member positions. Any member of SMST in good standing is encouraged to nominate themselves or another member for one of these positions. For more information on eligibility and how to submit a nomination, visit the SMST website at asminternational.org/web/smst.

Thermal Spray Society (TSS) is seeking nominations to fill three board member positions, specifically from the government and international thermal spray community. Nominees must be a member of the ASM Thermal Spray Society and must be endorsed by five TSS members. Board members whose terms are expiring may be eligible for nomination and possible reelection on an equal basis with any other nominee. For more information on eligibility and for a copy of the nomination form, visit the TSS website at asminternational.org/web/tss.

MD CORNER

Initiatives at the Dome

Aderhold

By the time you read this we will have made it through 2020. By any account, it was an interesting year! I, for one, am glad to have it behind us. Our Operations team at the ASM Dome did an amazing job staying focused on our mission of generating, curating, and disseminating high quality materials information and services to our members and member companies.

The first two months of 2020 started off well, then COVID-19 hit. Luckily, the investments we made in communication and collaboration tools allowed us to quickly pivot and have everyone working from home without missing a beat. Even though the pandemic made things harder, we still made a lot of progress.

As part of our digital-first strategic initiative, we added Alloy Digest, conference proceedings, technical books, and lots of additional content into the Digital Library. We worked with our chapters to help them go virtual with ASM Connect, our collaboration platform, and Zoom licenses. So while we couldn't meet in person, we could still meet virtually. We released the *ASM Handbook,* Volume 24: *Additive Manufacturing Processes,* both digitally and in print, and we launched the Materials Properties for Data Science platform that will allow our members to search a massive database of inorganic materials data through a graphical user interface or through an API. Lastly, with tremendous support and advice from our members, we built a prototype of our Data Ecosystem, which will add education, data, and services to help our members take advantage of Materials 4.0 and data analytics. You will hear a lot more about that in 2021.

We also focused on how we can help our materials community grow both globally and across other engineering disciplines. We are in discussions with several societies in Europe and Asia on how we could work together to help the community. At the Dome, we are building both corporate and affiliate membership types to help us connect to other societies and work together on committees or projects. Since we know that many non-materials engineers and scientists work with or need materials as part of their job, we are developing technical and data management classes that can help mechanical engineering or other engineering disciplines enhance their knowledge of materials. And lastly, we continue to support the Materials Education Foundation, which did an outstanding job switching to Virtual Teacher and Student Camps that help develop our next generation of materials professionals.

Last but not least, is our initiative to cultivate a culture and practice of diversity, equity, and inclusion. Building off the success we had with Women in Materials Engineering, we formed the IDEA Committee, a membership-driven group geared toward fostering an authentic culture of inclusion, diversity, equity, and awareness. A primary goal of the committee is to identify and remove barriers to successful involvement of all genders, races, ethnicities, and backgrounds represented by the ASM membership.

Overall, 2020 was a tough year, but through hard work and dedication our team at ASM Headquarters made a lot of progress, and I thank them for it!

As always, I welcome your thoughts and ideas, feel free to let me know what you're thinking.

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

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.

SEEKING 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 first 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 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 reach out to Mary Anne Jerson at 440.671.3877, maryanne.jerson@asminternational.org. **Nomination deadline for both awards is March 1.**

HTS AWARD DEADLINES

Nominations Sought for 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 to recognize 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, ASM President 1983, ASM Distinguished Life Member, FASM, and founding president of the ASM Heat Treating Society. Bodeen is chairman of the board and retired president and CEO of Lindberg Corp.

Recommendations must be submitted to ASM no later than **February 1 of the year the award is to be presented.**

ASM HTS/Bodycote 'Best Paper in Heat Treating' Contest

The ASM Heat Treating Society established the Best Paper in Heat Treating Award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advantage in managing the business of heat treating. The award, endowed by **Bodycote Thermal Process-North America,** is open to all full-time or part-time students enrolled at universities (or their equivalent) or colleges. The winner will receive a plaque and a check for $2500. Paper submission deadline is **February 1.**

HTS/Surface Combustion Emerging Leader Award

The ASM HTS/Surface Combustion Emerging Leader Award was established in 2013 to recognize an outstanding early-to-midcareer 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.

Recommendations must be submitted to ASM no later than **February 1 of the year the award is to be presented.**

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

FROM THE FOUNDATION

2021 Planning


Wilson

Happy 2021! We have all been anxiously awaiting this year and I hope that it brings you the hope and happiness you desire.

After a tumultuous 2020 for the ASM Materials Education Foundation, we look forward to what 2021 will bring and the programming we will be able to offer. To best serve students and teachers, the ASM Foundation will again be holding ASM Virtual Materials Camps.

This early decision allows the Foundation to plan curriculum and commit resources for the best possible programs this year. We will be able to use this year as an opportunity to reach students and teachers in new areas, potentially those from remote locations that have difficulty attending in-person programming.

We will not move forward with the Eisenman Materials Camp for Students again this year but will continue with the Virtual Materials Camps for Students that we developed last summer. Students gave the remote program positive reviews, and our outstanding volunteers provided a memorable experience.

While, of course, we prefer offering in-person learning, 2020 showed us that community building and hands-on learning can be successful online. In 2021, we will build on the early success and make additional improvements to benefit our students and teachers.

The ASM Foundation team will plan on our 2022 offerings including in-person programming as well as some remote options. We continue adding to the ASM Foundation's toolbox to reach students and teachers wherever they are and continue to increase the number of students learning about STEM and materials science.

Thank you for your continued understanding, support, and participation.

Carrie Wilson
Executive Director
ASM Materials Education Foundation

Student Speaker Symposium (S^3) Winners

After the COVID-19 pandemic caused the cancellation of the in-person IMAT Student Poster Competition, the ASM Student Board Members organized a Student Speaker Symposium Competition. Speakers created five-minute videos showcasing their research.

Awards included First ($1000), second ($750), and third ($500) for both graduate and undergraduate categories. A Most Popular Presentation Award ($500) was given to the video (title slide shown here) garnering the most "likes" on the ASM YouTube Channel. Congratulations to the fall 2020 winners of the S^3!

Graduate Category

- First Place: Diptak Bhattacharya, Colorado School of Mines, *Liquid Metal Embrittlement Susceptibility of Zn-Coated Advanced High Strength Steels*
- Second Place: Rafael Rodriguez, University of Pittsburgh, *Microstructure Characterization and Post-Heat Treatment Design for High-Strength Low-Alloy Steels Strengthened with Fe_2SiTi Precipitates*
- Third Place: Geeta Kumari, Michigan State University, *A Strategy to Make Turbine Blades Stronger: Bi-Modal Distribution of the γ' Phase in Ni-Based Superalloy*

Undergraduate Category

- First Place: Jacob Wall, The University of Alabama, *Low-Temperature Processed Highly Efficient Hole Transport Layer Free Carbon-Based Planar Perovskite Solar Cells with SnO_2 Quantum Dot Electron Transport Layer*
- Second Place: Gabriella Tuell, Colorado School of Mines, *Metamorphic Manufacturing*

Most Popular Presentation

- Juan Bosch Giner, The University of Akron, *Diffusion and Critical Chloride Threshold in Reinforced Fly Ash Concrete*

Juan Bosch Giner won the Most Popular Presentation award in the Student Speaker Symposium Competition.

EMERGING PROFESSIONALS

EPC Strategic Group Alignment for 2021

Jonathan Healy

Starting in 2020, ASM embarked on the "ASM Realization" to further expand the return on investment from the "ASM Renewal." In doing so, ASM plans to strategically target the growth of digital-first capabilities and become more interdisciplinary, diverse, and global as quickly as possible.

Healy

To aid these efforts, the Emerging Professionals Committee (EPC) has maintained the strategic alignment formed out of the 2019 EPC Annual Business Meeting. These strategic groups include: *Digital Metrics, Membership & Chapter Engagement, and Mentorship.*

Digital Metrics. The EPC has realized that as the "Materials Information Society," it is increasingly important that we as a Society understand and leverage the data available to us. In fact, it is pivotal in developing our digital-first capabilities. Fittingly, this group will help establish the baseline for EPC activity engagement in addition to developing trackable metrics.

Membership & Chapter Engagement. Engagement at all levels of the Society is crucial to ASM's goals of further developing as a diverse, interdisciplinary Society. To this end, this group has a dedicated purpose of increasing engagement and membership of the emerging professional demographic across our Society's many chapters.

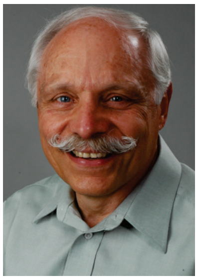
Mentorship. While not explicitly stated in the strategic plan, it is a fundamental aspect of our Society. The emphasis placed on mentorship will only increase with the growing surge of early-career professionals joining ASM at historic rates. This group will foster authentic mentorship not as a box to check, but rather a foundation to build upon. This will be executed by developing an actionable plan to support the needs of the emerging professional community over the course of the Renewal.

While it is our hope to make great strides in furthering these strategic initiatives, we realize that they cannot be accomplished overnight and require dedicated efforts on the part of our committee members. If you are an emerging professional interested in helping with these efforts, or know of one who might be interested, please apply for a position with the EPC at https://bit.ly/33Wuyup. **The deadline to apply is March 8, however it is never too early to submit an application.**

Contributor Spotlight

Howard A. Kuhn, Ph.D., FASM

University of Pittsburgh



Kuhn

Dr. Howard Kuhn is an adjunct professor at the University of Pittsburgh, Swanson School of Engineering, where he teaches courses in manufacturing and additive manufacturing and performs research on additive manufacturing for tissue engineering. He also presents tailored professional development courses on powder metallurgy and additive manufacturing to industrial and government facilities.

Kuhn is a Fellow of ASM International and a member of the ASM Failure Analysis Society and the Pittsburgh Chapter. His voluntary contributions to ASM publications include serving as a volume editor (with David L. Bourell, William Frazier, and Mohsen Seifi) of the recently released *ASM Handbook,* Volume 24: *Additive Manufacturing Processes,* and also Volume 8: *Mechanical Testing and Evaluation* (with Dana Medlin). He has contributed articles to ASM Handbooks Volume 7: *Powder Metallurgy* and Volume 14A: *Metalworking: Bulk Forming,* among others.

He is an editor of the ASM book *Handbook of Workability and Process Design* (with George E. Dieter and S. Lee Semiatin) and serves as an instructor of the ASM education courses Powder Metallurgy for Additive Manufacturing and Metallurgy for Additive Manufacturing (with Daniel P. Dennies). He also taught 3D printing to high school students at Materials Mini-Camp presented by the ASM Materials Education Foundation.

From 2003 to 2018, Kuhn was director of research at ExOne and a founding deputy director of America Makes (National Additive Manufacturing Innovation Institute) where he served as technical advisor, 2012-2018. He was vice president and chief technical officer at Scienda LLC, 2000-2002, and co-founder of Concurrent Technologies Corp. (CTC), a subsidiary of the University of Pittsburgh. He also co-founded Deformation Control Technology, a consulting firm serving the metalworking industry.

While at CTC and as a member of the adjunct faculty at the University of Pittsburgh, Kuhn established and taught the first distance-learning courses between multiple sites for the university's M.S. program in manufacturing systems engineering.

At Drexel University (1966-1974) and the University of Pittsburgh (1975-1987), he developed courses in deformation processing, powder metallurgy, and engineering design. In 1984, Kuhn became the first recipient of the University of Pittsburgh Chancellor's Distinguished Teaching Award.

View the table of contents and abstracts for all the ASM Handbook volumes in the ASM Digital Library at dl.asminternational.org. If you are interested in becoming a volunteer author or editor for the ASM Handbooks series, contact handbooks@asminternational.org.

WOMEN IN ENGINEERING

*This profile series introduces materials scientists from around the world who happen to be females. Here we speak with **Tabitha H. Crocker,** research engineer, American Cast Iron Pipe Company, Birmingham, Alabama.*

Crocker

What does your typical workday look like?

My title of research engineer is a bit of a misnomer because I don't do what people traditionally refer to as research. I mostly help contractors with technical questions, review drawings and plans, and calculate restraint lengths. I also do ductile iron pipe joint demonstrations and visit jobsites around the country to help contractors with the application of our products. Most recently, I've started doing some of our investigations on returned materials.

What is your greatest professional achievement?

I spearheaded the creation of a women's resource group at my current company, which serves the water/wastewater/oil and gas industries. I was drawn to creating a women's group after I found a documentary online called "Hard Hatted Woman." I don't think women are well represented in skilled trades and I really want to be an agent of change for that. I want women in manufacturing to feel like they have a voice and for them to be given opportunities to gain leadership skills and fill management positions. Though I face my own challenges as a female engineer, I feel that I'm given more opportunities because of my status as an engineer. I want to be known as an advocate for women in skilled trades such as welding, and I want to do it by taking advantage of my position as an engineer.

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

Ironically, I never knew that I wanted to be an engineer until I became one! When I decided to go to college, it was because I wanted to be an astronaut. I had read somewhere that most astronauts were aerospace engineers so, on the college application, I checked the box for aerospace engineer and moved on. I had no clue what it meant until my second semester.

What are you working on now?

At the moment, I'm balancing my full-time position as a research engineer with going to back school. This month

I'll be graduating with a master's in aerospace engineering and mechanics and will start work toward a Ph.D. in materials science. My research experience varies from gravitational lensing and dark matter to plant bioinformatics, cancer, tissue engineering, and 3D printing. At this point, I'm just trying to become an expert at something!

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

CHAPTERS IN THE NEWS

Cleveland Hosts Smithsonian Curator

The Cleveland Chapter was treated to a presentation on November 24, 2020, on "Electrifying Materials" by Harold Wallace, Jr., a curator of the electricity collections at the Smithsonian's National Museum of American History. During his virtual presentation, Wallace shared examples of objects in the museum's collection and discussed the materials found in them, how his team handles these objects, and how they preserve them for future display or travel to other exhibitions. From hazardous and exotic components discovered in unexpected places to the challenges presented by aging objects, Wallace described how he works with these materials from a museum perspective.

This cup, featuring a top section of glass with lead lining and a bottom made of uranium glass, is an example of the sometimes hazardous materials in the Smithsonian's collection.

Congratulations to this ASM Chapter celebrating a milestone of serving local members!

Saginaw Valley — 75 Years

Thank you for your commitment!
We look forward to celebrating your future success!

Hartford Features Modeling Expert

Dr. Vasisht Venkatesh, FASM, was the featured speaker for the November 10, 2020 meeting of the ASM Hartford Chapter. Venkatesh, associate director of materials processes modeling at Pratt & Whitney, spoke via Zoom on "Residual Stress – Origins, Measurement, Modeling and Design." He leads and manages efforts in the development, implementation, and maturation of computational tools and methods. His duties include assessing the current state of materials and processes computational tools and methods, and developing a plan to broaden utilization of such methods across the discipline. Venkatesh also led the Air Force-funded Foundational Engineering Problem on Residual Stress in Ni base Superalloy Turbine Disks that developed a framework for model-based definitions enabling communication between supplier and OEM, model integration, model maturity assessments, and a rigorous approach to uncertainty quantification in component processing and residual stress measurements.

Venkatesh

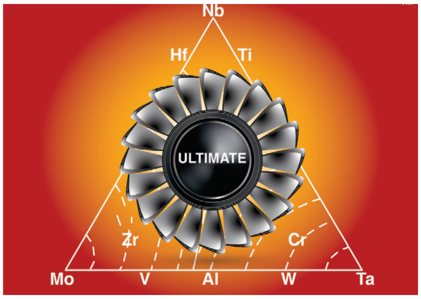
Carolinas Central Takes a Tour

On October 22, 2020, the Carolinas Central Chapter toured Accident Reconstruction Analysis (ARA) in Raleigh, N.C.

ARA's client base consists of insurance companies, the legal community, private industry, and government agencies. ARA engineers perform analysis, research, design, simulation, and testing in the fields of mechanical, materials, automotive, aerospace, and civil engineering. Their cases vary from large scale investigations to small claims involving property damage and personal injury.

Pictured from left are Kanishq Nema, Danny Brinkley, Ben Carter, and Ian Turowski. The camera shy photographer was Jackie Earle, FASM.

MEMBERS IN THE NEWS



DOE Awards Funding for Phase I of ULTIMATE Program: ASM Members Lead Selected Projects

The U.S. Department of Energy announced $16 million in funding for 17 projects as part of Phase 1 of the Advanced Research Projects Agency-Energy's (ARPA-E) Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency (ULTIMATE) program. ULTIMATE teams will develop ultrahigh temperature materials for gas turbine use in the aviation and power generation industries. Several ASM members served as the technical lead/principal investigator for winning projects. They are listed below along with the awarded organizations, project descriptions, and funding amounts.

Dr. Akane Suzuki: General Electric Company, GE Research; ULTIMATE Refractory Alloy Innovations for Superior Efficiency (RAISE) – $1,600,000

Prof. Ji-Cheng Zhao, FASM: University of Maryland, College Park; New Environmental-Thermal Barrier Coatings for Ultrahigh Temperature Alloys – $600,000

Dr. Ravi Chandran, FASM: University of Utah; Designing Novel Multicomponent Niobium Alloys for High Temperature: Integrated Design, Rapid Processing & Validation Approach – $800,000

Dr. Raymundo Arroyave, FASM: Texas A&M Engineering Experiment Station; Batch-wise Improvement in Reduced Design Space using a Holistic Optimization Technique (BIRDSHOT) – $1,200,000

Dr. Xingbo Liu, FASM: West Virginia University Research Corp.; High-Throughput Computational Guided Development of Refractory Complex Concentrated Alloys-based Composite – $700,000

Dr. Ali Yousefiani: The Boeing Company; Ultra-High Performance Metallic Turbine Blades for Extreme Environments – $800,000

Dr David Alman, FASM: National Energy Technology Laboratory; Rapid Design and Manufacturing of High-Performance Materials for Turbine Blades Applications above 1300 Celsius – $1,500,000

Prof. John Perepezko: University of Wisconsin-Madison; Additive Manufacturing of Ultrahigh Temperature Refractory Metal Alloys – $650,000

Dr. Govindarajan Muralidharan: Oak Ridge National Laboratory; Development of Niobium-Based Alloys for Turbine Applications – $700,000

Prof. Zi-Kui Liu, FASM: Pennsylvania State University; Design and Manufacturing of Ultrahigh Temperature Refractory Alloys – $1,200,000

Dr. Greg Olson, FASM: QuesTek Innovations LLC; Concurrent Design of a Multimaterial Niobium Alloy System for Next-generation Turbine Applications – $1,200,000

ULTIMATE projects address two target temperature levels and seek to develop ultrahigh temperature materials for continuous operation at 1300°C (2372°F) in a stand-alone material test environment or at 1800°C (3272°F) with coatings and cooling. Teams will also develop new manufacturing processes that ensure turbine blades can not only operate at these ultra-high temperatures, but also withstand the extreme operating environments commonly found in natural gas turbines in both the aviation and power generation industries.

Phase 1 ULTIMATE teams will demonstrate proof of concept for alloy compositions, coatings, and manufacturing processes through modeling and laboratory scale tensile coupon testing of basic properties. At the conclusion of Phase 1, teams will be down-selected to participate in Phase 2, with up to $14 million in additional funds available to teams. The full list of Phase 1 projects can be viewed at https://bit.ly/33Moswu.

CAREERHUB
POWERED BY ASM INTERNATIONAL

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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.

STRESS RELIEF

'PARTNERS' STATUE RESTORED AT DISNEYLAND

Disneyland Resort revealed the refurbishment of its iconic Partners statue which has been restored to its original grandeur and stands in front of Sleeping Beauty Castle in Disneyland park. The beloved Partners statue, created by famed Disney sculptor Blaine Gibson, features Walt Disney and Mickey Mouse.

Over time, the bronze had oxidized, and because of the applied patina, acrylic polymer and wax, it required a more intensive process than just a simple cleaning or polishing. Over four days, an artisan utilized a process using crushed walnut shells to gently strip the figure down to the bare bronze. After cleaning, various chemicals were applied and heated with a blowtorch to create a reaction and fuse with the bronze. The figure was coated in a polymer to protect the patina, then coated with a very thin layer of wax. *disneyparks.disney.go.com*.

The left photo was taken in 1993 at the statue's original unveiling, the right photo shows the restored statue in 2020.

DESIGN SECRETS OF A NEARLY INDESTRUCTIBLE INSECT

Researchers at the University of California, Irvine and other institutions have revealed the material components that make the diabolical ironclad beetle so indestructible. "The ironclad is a terrestrial beetle, so it's not lightweight and fast but built more like a little tank," says principal investigator David Kisailus.

The researchers learned that the bug's secret lies in the material makeup and architecture of its exoskeleton, specifically, its elytra. Analysis showed that the elytra consists of layers of chitin, a fibrous material, and a protein matrix. In collaboration with a group from the Tokyo University of Agriculture and Technology, they examined the chemical composition of the exoskeleton of a lighter flying beetle and compared it to that of their earthbound subject. The diabolical ironclad beetle's outer layer has a significantly higher concentration of protein, about 10% more by weight, which the researchers suggest contributes to the enhanced toughness of the elytra.

The diabolical ironclad beetle's exoskeleton is one of the toughest, most crush-resistant structures in the animal kingdom. Courtesy of David Kisailus/UCI.

The team also investigated the geometry of the medial suture joining the two parts of the elytra together and found that it looks very much like interlocking pieces of a jigsaw puzzle. They built a device inside an electron microscope to observe how these connections perform under compression, similar to how they might respond in nature. The experiment revealed that, rather than snapping at the "neck" region of these interlocks, the microstructure within the elytra blades gives way via delamination, or layered fracturing. Further microscopic examination disclosed that the outside surfaces of these blades feature arrays of rodlike elements called microtrichia that the scientists believe act as frictional pads, providing resistance to slippage. *www.uci.edu*.

SUPER OVEN BAKES PIZZA IN 37 SECONDS

Neapolitan pizza is usually baked in about 90 seconds at around 840° F. Swedish industrial heating company Kanthal built an oven that can make the pizza in only 37 seconds. The oven is built on the infrared heating principle, meaning that it uses electromagnetic radiation to heat up the object it hits. In addition to the electromagnetic radiation, there are reflectors that help to spread the heat. The oven has eight porcupine elements made from the iron-chromium-aluminum alloy Kanthal AF, four in the upper part and four in the lower part of the oven. The porcupine design of the spiral element provides good temperature uniformity as the radiant heat together with the larger surface of the coil contributes to a better performance of the elements The alloy was chosen for its exceptional shape stability at high temperatures together with very good oxidizing qualities. The element temperature is 1650° F. *kanthal.com.*

Precise heating creates the perfect pizza crust – not too soggy or burnt. Courtesy of Kanthal.

ADVANCED MATERIALS & PROCESSES

EDITORIAL PREVIEW

FEBRUARY/MARCH 2021

Metallography and Materials Characterization

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- Case Studies using Micro-XRF
- Characterization of Rare Earth Elements

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- First Quarter Advertising Specials

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APRIL 2021

Aerospace Materials and Testing

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- Microstructure of 3D-Printed Filters
- Study of South American Copper Artifacts

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- ITSC - May 24-27, Quebec City
- SMST 2021 - May 17-21, San Diego, CA

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3D PRINTSHOP

Polycarbonate webs synthesized using additive manufacturing absorb up to 96% of impact energy. Courtesy of Shibo Zou.

PRINTED PLASTIC WEBS PROTECT PHONE SCREENS

A Polytechnique Montréal team recently demonstrated that a fabric designed using additive manufacturing absorbs up to 96% of impact energy – all without breaking. The design was inspired by the properties of spider webs. “A spider web can resist the impact of an insect colliding with it, due to its capacity to deform via sacrificial links at the molecular level, within silk proteins themselves,” professor Frédérick Gosselin explains. “We were inspired by this property in our approach.”

The researchers used polycarbonate to achieve their results; when heated, polycarbonate becomes viscous like honey. Gosselin’s team harnessed this property to “weave” a series of fibers less than 2-mm thick, then repeated the process by printing a new series of fibers perpendicularly, moving fast, before the entire web solidified.

As it’s extruded by the 3D printer to form a fiber, the molten plastic creates circles that ultimately form a series of loops. “Once hardened, these loops turn into sacrificial links that give the fiber additional strength. When impact occurs, those sacrificial links absorb energy and break to maintain the fiber’s overall integrity,” Gosselin adds.

This nature-inspired innovation could lead to the manufacture of a new type of bullet-proof glass or to the production of more durable plastic protective smartphone screens. “It could also be used in aeronautics as a protective coating for aircraft engines,” Gosselin notes. *polymtl.ca.*

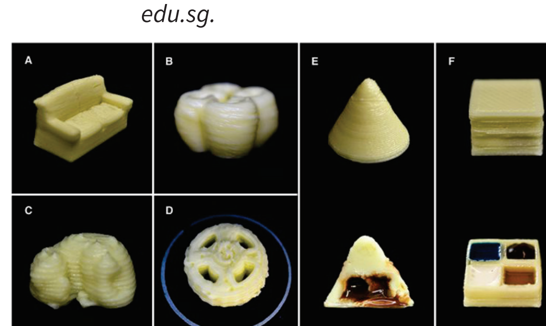
3D PRINTING MILK-BASED PRODUCTS AT ROOM TEMP

Researchers from the Singapore University of Technology and Design (SUTD) developed a method to perform direct ink writing (DIW) 3D printing of milk-based products at room temperature, while maintaining its temperature-sensitive nutrients.

3D printing of food has been achieved by different printing methods, including selective laser sintering and hot-melt extrusion. However, these methods are not always compatible with nutrients found in certain types of food. For instance, milk is rich in both calcium and protein, but as these nutrients are temperature sensitive, milk is unsuitable for 3D printing using the aforementioned printing methods which require high temperature. While cold extrusion is a viable alternative, it often requires rheology modifiers or additives to stabilize printed structures.

To tackle these limitations, researchers from SUTD’s Soft Fluidics Lab changed the rheological properties of the printing ink and demonstrated DIW 3D printing of milk by cold-extrusion with a single milk product – powdered milk. The team found that the concentration of milk powder allowed for the simple formulation of 3D-printable milk inks using water to control the rheology. Extensive characterizations of the formulated milk ink were also conducted to analyze their rheological properties and ensure optimal printability.

“Cold-extrusion does not compromise heat-sensitive nutrients and yet offers vast potential in 3D printing of aesthetically pleasing, nutritionally controlled foods customized for individual requirements,” says assistant professor Michinao Hashimoto, principal investigator of the study. *www.sutd.edu.sg.*



3D-printed milk and multi-food models: (a)-(d) Couch, cloverleaf, fortress, and wheel, respectively; (e) Cone containing liquid chocolate syrup as an internal filling; (f) Cube with four compartments containing various syrups as internal fillings. Courtesy of SUTD.