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ADVANCED MATERIALS & PROCESSES

ADDITIVE MANUFACTURING

FAIR PRINCIPLES FOR AM DATA MANAGEMENT

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45 *iTSSe* Newsletter Included in This Issue

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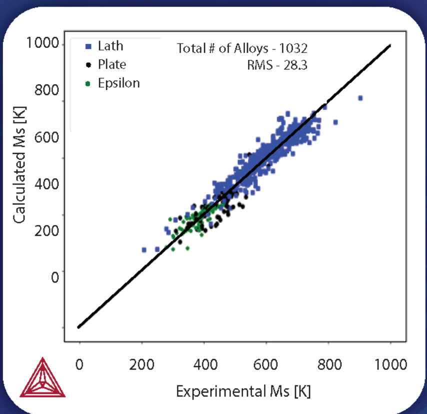
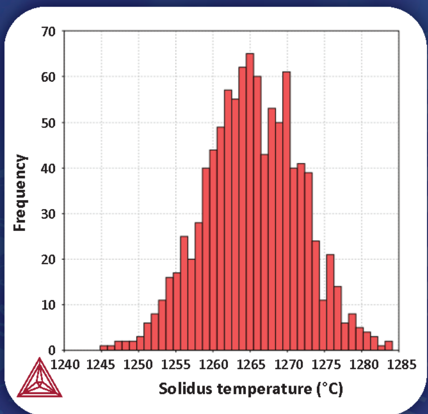


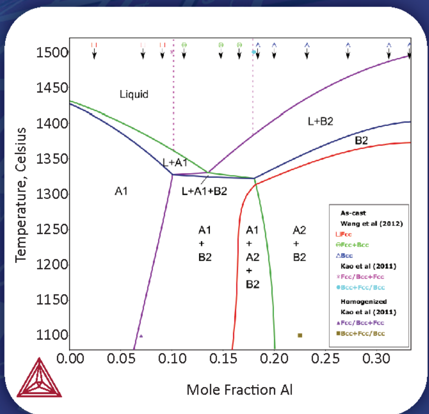
Comparison of calculated and experimental Ms temperatures for a wide range of steels

Nickel



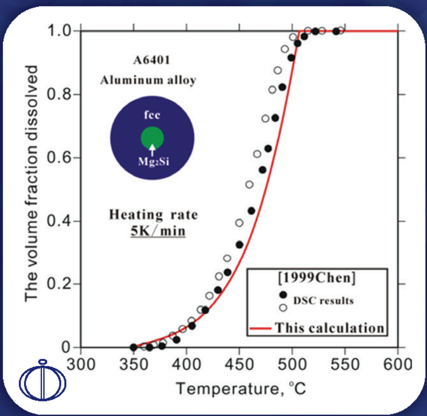
Variation in solidus temperature over 1000 compositions within alloy 718 specification

High Entropy Alloys



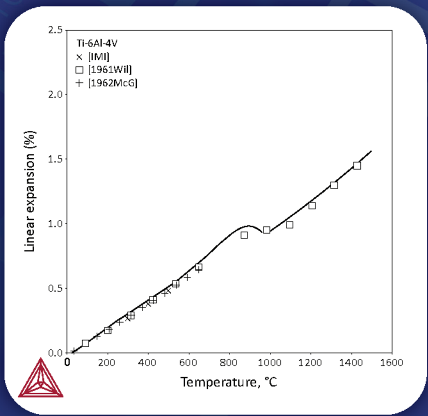
Calculated phase diagram along the composition line of CoCrFeNi-Al

Al Alloys



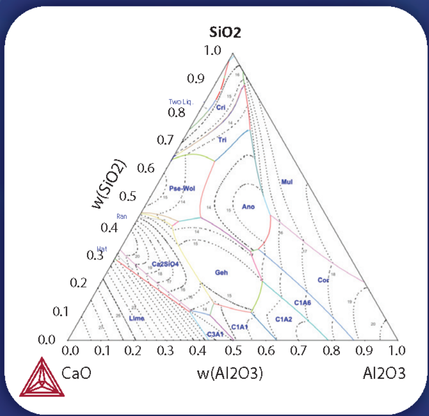
Dissolution of Mg2Si precipitate in Alloy A6401

Ti and TiAl Alloys



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

Oxides



Ternary liquidus projection in oxide systems

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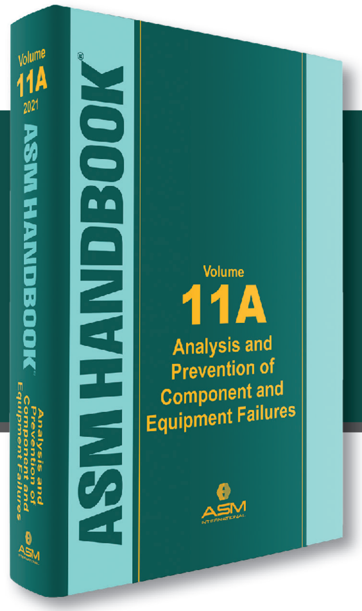

ASM HANDBOOK, VOLUME 11A:

ANALYSIS AND PREVENTION OF COMPONENT AND EQUIPMENT FAILURES

VOLUME EDITORS: BRETT A. MILLER, ROCH J. SHIPLEY, RONALD J. PARRINGTON, AND DANIEL P. DENNIES

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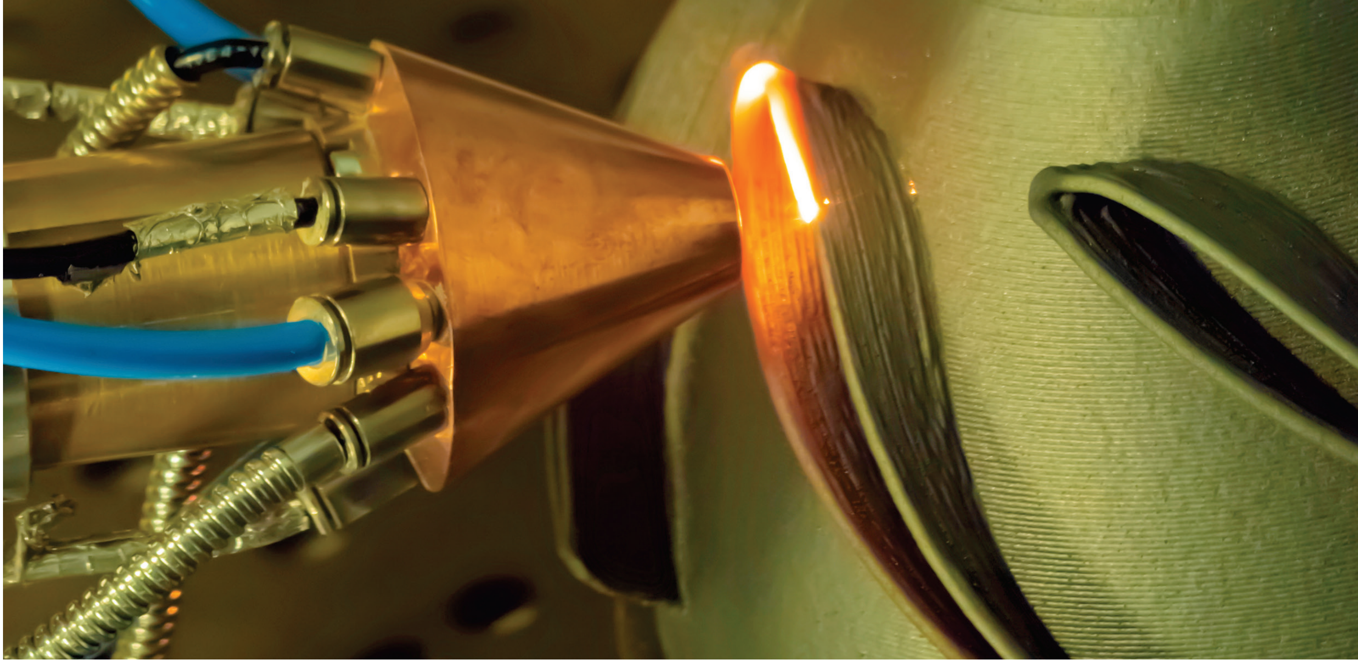

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UNLEASHING THE POTENTIAL OF ADDITIVE MANUFACTURING: FAIR AM DATA MANAGEMENT PRINCIPLES

William E. Frazier, Yan Lu, Paul Witherell, Ray Fryan, and Alex Kitt

Additive manufacturing workshop advocates the use of guidelines for data management to realize Materials 4.0 and achieve process qualification.

On the Cover:

A 3D printer produces a steel part. Courtesy of Aleksey Popov/Dreamstime.

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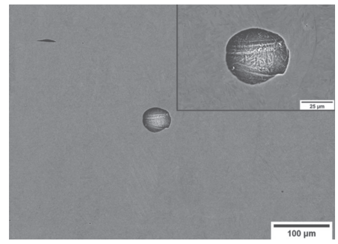

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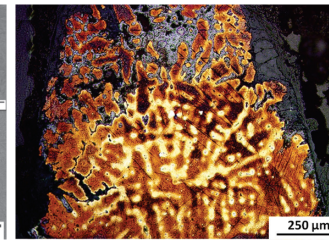

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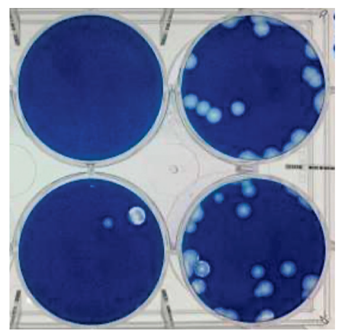

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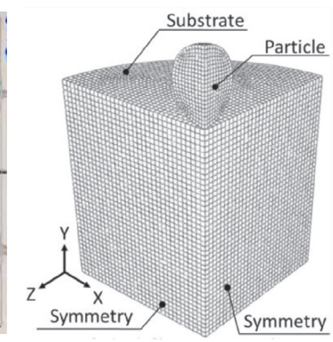

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45 *iTSSe*

The official newsletter of the ASM Thermal Spray Society (TSS). This timely supplement focuses on thermal spray and related surface engineering technologies along with TSS news and initiatives.

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THE NEW AM BUILD: COLLABORATIONS

This past spring, I was fortunate to view several talks from the AeroMat and ITSC 2021 Virtual Events, including a panel discussion on "Emerging Additive Manufacturing of Materials" moderated by James Cotton, FASM. Speakers from McGill University, QuesTek Innovations LLC, Airbus, and more shared insights on the biggest challenges and latest trends in the thriving additive manufacturing (AM) sector. Some of the key challenges and opportunities include qualification of vendors and parts, proper welding and joining of AM parts, and creation of high entropy alloys. Much research will be required to solve these issues. But several groups are already making headway and "building a better model"—like AM itself—one layer at a time.

In the AeroMat "Emerging Materials and Processes" session, I learned from Nicolas Nutal of CRM Group that Belgium has its own consortium for AM. Nutal's work, aided by the consortium, focuses on the use of advanced aluminum in additively manufactured, high-end spacecraft parts. Consulting with others in the group, they determined that the 2000/7000 aluminum series cannot be used in fusion welding due to poor weldability. So they are now developing new aluminum alloys more compatible with AM.

As another example, Ron Aman, principal engineer at EWI, mentioned in his AeroMat keynote that EWI leads an AM consortium. The group serves as a platform for collaboration between industry, government, and academia; works together on precompetitive research opportunities; and partners on government-funded projects.

For this issue of *AM&P,* EWI provided a co-author to help describe another AM collaboration: a workshop developed by NIST, ASM International, and Pilgrim Consulting LLC to address the need for AM data management standards and the acceleration of part certification. With ASM past president William E. Frazier, FASM, as the lead author, the article describes the path forward to a collaborative AM data management system. The plan includes building community acceptance through influential early adopters. Indeed, our views can be influenced by people and organizations we look up to. We can benefit from their experience and wisdom.

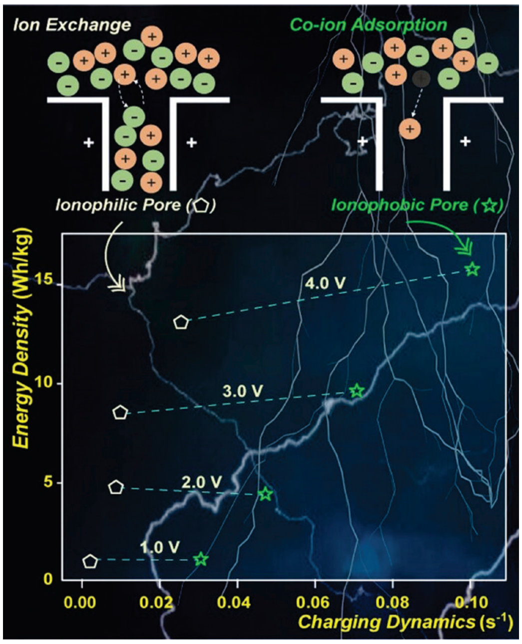
As Mitchell Dorfman, FASM, TSS-HoF, prepares for retirement from Oerlikon Metco, an attendee at his joint AeroMat/ITSC keynote Q&A session asked what he found most rewarding in his career. Part of his answer was "working together and solving problems to get a new material into an application." More praise for the benefits of collaboration. For additional industry insights, see a summary of his keynote talk in this issue's *iTSSe* supplement.

Also in *iTSSe*, we are proud to share the names of members of our TSS community who are on a Stanford University list of the world's top 2% most-cited researchers. In addition to the TSS-related names on pages 51-52, we were pleased to find other ASM members on the Stanford list including these Fellows: Rodney Boyer, Zi-Kui Liu, Tresa Pollock, Christopher Schuh, and David B. Williams.

This is clear evidence that ASM members are recognized as trusted sources of reliable materials information. Our expert members are building up the materials community by authoring highly cited papers, presenting at global events, leading international collaborations, and solving new materials challenges in AM and many other sectors.

joanne.miller@asminternational.org

RESEARCH TRACKS



A team from Cardiff University and Los Alamos National Lab created the first 3D replica of spin-ice.

3D MAGNETIC NANOSTRUCTURES COULD TRANSFORM COMPUTING

A team led by scientists at Cardiff University, U.K., and including researchers at Los Alamos National Laboratory, N.M., created the first 3D replica of a spin-ice material using a sophisticated type of 3D printing and processing. They say the 3D printing technology allowed them to tailor the geometry of the artificial spin-ice, meaning they can control the way the magnetic monopoles are formed and moved around in the systems. Being able to manipulate the mini monopole magnets in 3D could open up numerous applications, from enhanced computer storage to 3D computing networks that mimic the neural structure of the human brain.

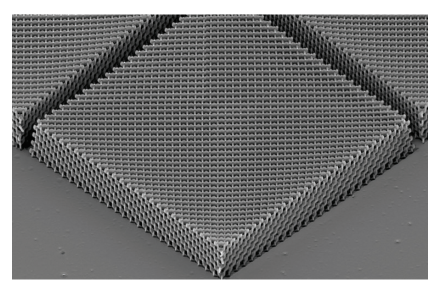
The artificial spin-ice was created using 3D nanofabrication techniques in which tiny nanowires are stacked into four layers in a lattice structure. Magnetic force microscopy was then used to visualize the magnetic charges present on the device, allowing the team to track the movement of the single-pole magnets across the 3D structure.

"Ultimately, this work could provide a means to produce novel magnetic metamaterials, where material properties are tuned by controlling the 3D geometry of an artificial lattice," says researcher Sam Ladak of Cardiff University. "Magnetic storage devices are another area that could be massively impacted by this breakthrough. As current devices use only two of the three dimensions available, this limits the amount of information that can be stored. Since the monopoles can be moved around the 3D lattice using a magnetic field, it may be possible to create a true 3D storage device based upon magnetic charge." *www.cardiff.ac.uk.*

IONOPHOBIC ELECTRODE IMPROVES ENERGY STORAGE

A group of scientists led by Zhang Suojiang, a professor at the Institute of Process Engineering (IPE) of the Chinese Academy of Sciences, discovered that ionophobic electrodes can boost energy storage performance. Electric double-layer capacitors (EDLCs) with ionic liquids (ILs), a new type of energy storage device, can fill the gap between the power density of batteries and the energy density of conventional capacitors, say researchers. However, ILs in nanopores often exhibit sluggish diffusion dynamics, which hinder high power density.

In this study, the team proposed a new strategy to improve the energy density and power density of EDLCs with ILs based on massive molecular dynamics simulations. When comparing EDLCs with an ionophilic electrode to those with an extremely ionophobic electrode, the researchers found that the charging time for the latter decreased by roughly 80% while the capacitance increased by nearly 100%. The idea of introducing ionophobicity holds promise for improving the design of IL-based high-performance supercapacitors and other new energy storage devices and applications. *www.cas.ac.cn.*

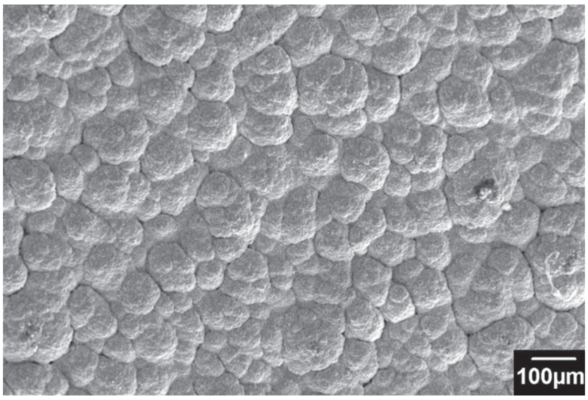


Ionophilic and ionophobic pore mechanisms and their influence on charging dynamics. Courtesy of IPE.

BRIEF

Researchers at the **University of Marburg,** Germany, and **Aalto University,** Finland, discovered a new carbon network that is atomically thin like graphene, but is made up of squares, hexagons, and octagons forming an ordered lattice. In contrast to graphene and other forms of carbon, the new biphenylene network has metallic properties. *www.aalto.fi.*

MACHINE LEARNING | AI



Flower-like ceramic coating structure inspired by nature, for use in aero engines.

AI DRIVES CERAMIC COATINGS INNOVATION

Tanvir Hussain, a materials scientist at the University of Nottingham, U.K., received nearly $3 million to develop new coatings for use in aerospace that could reduce CO_2 emissions and help spacecraft travel further into the solar system. The five-year fellowship, funded by the Engineering and Physical Sciences Research Council, aims to find new modeling and processing techniques to overhaul the design and manufacture of advanced ceramic materials for next-generation air and space travel.

Using artificial intelligence and advanced chemistry, Hussain will manipulate the molecular architecture of ceramic materials to make them more durable and sustainable. The project aims to produce ceramic coatings designed and manufactured with thermal, electrical, and environmental barrier properties that can be fine-tuned to specific aerospace applications. Examples include thermal barrier coatings to protect superalloys from high temperatures, environmental barrier coatings to protect ceramic composites from steam, insulating coatings for electric motors for the electrification of aircrafts, and corrosion and wear-resistant coatings for critical engine components.

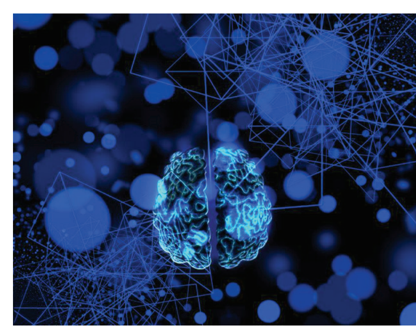
"The research will lead to the creation of products for the aerospace industry with improved properties, performance, and reduced materials processing times that can be manufactured in large volumes at a fraction of the cost of today's methods," says Hussain. *www.nottingham.ac.uk.*

FINDING SINGLE-ATOM-ALLOY CATALYSTS WITH AI

Researchers from Skolkovo Institute of Science and Technology (Skoltech), Russia, and their colleagues from China and Germany developed a new search algorithm for single-atom-alloy catalysts (SAACs) that found more than 200 new candidates. SAACs, where single atoms of rare and expensive metals such as platinum are dispersed on an inert metal host, are highly efficient in numerous catalytic reactions, including selective hydrogenations, dehydrogenations, C-C and C-O coupling reactions, NO reduction, and CO oxidation.

Assistant professor Sergey Levchenko and his colleagues were able to identify accurate and reliable machine learning models based on first-principles calculations for the description of the hydrogen binding energy, dissociation energy, and guest-atom segregation energy for SAACs. This led them to make a much faster (by a factor of 1000) yet reliable prediction of the catalytic performance of thousands of SAACs. They used artificial intelligence to extract important parameters (descriptors) from computational data that correlate with the catalytic performance of SAACs and at the same time are very fast to calculate.

"The developed methodology can be easily adapted to designing new functional materials for various applications, including electrocatalysis, fuel cells, reforming of methane, and water-gas shift reactions," says Levchenko. *www.skoltech.ru.*



New research is using machine learning to find promising single-atom-alloy catalysts (SAACs), providing a recipe to determine the best SAACs for a range of applications. Courtesy of pixabay.com.

BRIEF

Materials scientist Ming Tang of **Rice University,** Houston, in collaboration with physicist Fei Zhou at **Lawrence Livermore National Laboratory,** Calif., developed a technique to predict the evolution of microstructures in materials. The research explores how neural networks can train themselves to predict how a structure will grow in a certain environment. Tang believes the computation efficiency of neural networks could speed development of new materials, such as for his lab's design of more efficient batteries. *rice.edu.*

METALS | POLYMERS | CERAMICS

Jonas Björk, assistant professor at Linköping university, led the polymer innovation. Courtesy of Thor Balkhed.

BRIEFS

In a joint venture, **SSAB, LKAB,** and **Vattenfall** report production of the world's first hydrogen-reduced sponge iron at pilot scale. The new hybrid technology captures roughly 90% of emissions produced by steelmaking. The pilot plant in Sweden has completed test production of sponge iron and proves it is possible to use fossil-free hydrogen gas to reduce iron ore instead of using coal and coke to remove the oxygen. The goal is to eliminate CO_2 emissions from the steelmaking process by using only fossil-free feedstock and energy. *www.hybritdevelopment.se.*

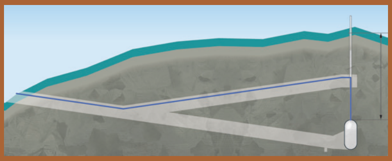


Illustration of hydrogen storage. Courtesy of SSAB.

MAKING ULTRATHIN POLYMERS

Researchers from Sweden's Linköping University, Sweden, and Germany's Technical University of Munich and the Deutsches Museum, along with other international collaborators, created a new method to manufacture 2D polymers. The discovery makes it possible to develop new ultrathin functional materials with highly defined and regular crystalline structures.

The polymerization of the material takes place in two steps. The researchers use a contraction of fluorinated anthracene triptycene, known as fantrip, to cause the molecules to spontaneously arrange themselves into a pattern suitable for photopolymerization when they are placed onto a graphite surface covered with an alkane. The next step is the photopolymerization itself, when the pattern is solidified with light. The molecules are illuminated by a violet laser that excites the electrons in the outermost electron shell, causing strong and durable covalent bonds to form between the molecules. The result is a porous 2D polymer, half a nanometer thick, consisting of several hundred thousand molecules identically linked, culminating in a material with nearly perfect order—right down to the atomic level. *www.liu.se/en.*

TOUGHENING CERAMICS

With existing techniques, it has been a challenge to observe transformation toughening in zirconia ceramics during dynamic fracture at the atomic level. Now, researchers from the University of Tsukuba, Japan, are using time-resolved x-ray diffraction to get real-time in situ pictures of materials' responses to dynamic loading. Transformation toughening of ceramic materials is related to changes in their arrangement on the atomic level, which is why the new imaging technique is critical to gaining a complete picture of the process. The researchers use the time-resolved diffraction method to follow the behavior of yttria-stabilized tetragonal zirconia polycrystals subjected to shock loading. Studying these polycrystals, they demonstrated the toughening is related to a process known as spall fracture, providing insight into the origin of the high spall strength of zirconia ceramics. The researchers believe that

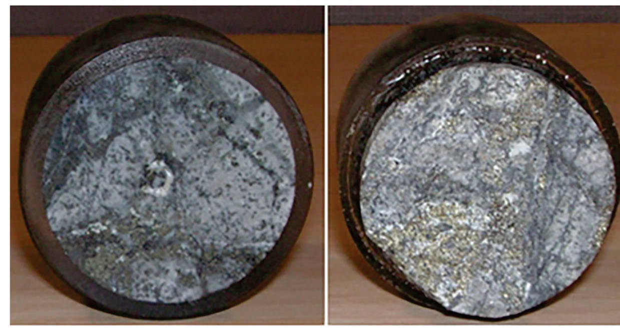
Honeywell, Houston, and **Cobalt Blue Holdings Ltd.,** Australia, announced Honeywell will provide control, automation, and energy optimization solutions to help Cobalt Blue streamline its Broken Hill Cobalt Project (BHCP). Located in western New South Wales, BHCP will develop a new global supply of ethically sourced cobalt for green energy applications such as lithium-ion batteries and wind turbine blades. *honeywellprocess.com.*

their findings will contribute to the continued development of tough ceramics for a wide range of applications from electric insulator parts to kitchen utensils. *www.tsukuba.ac.jp/en.*

SUSTAINABLE MINERAL EXTRACTION

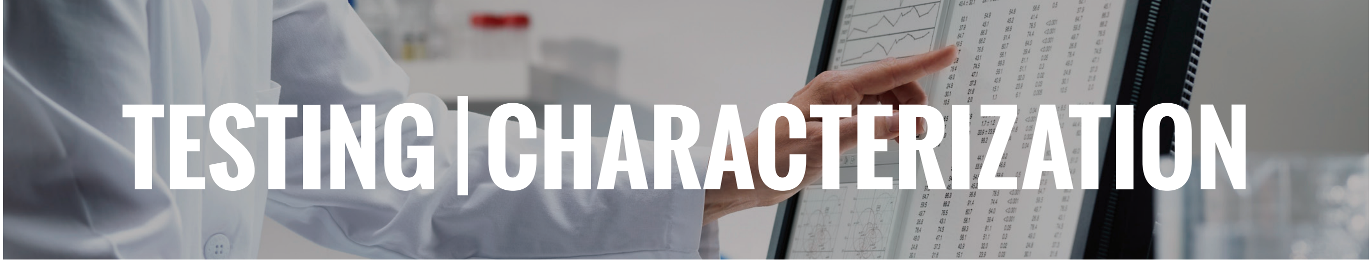
A team of international researchers, including collaborators from the University of Exeter, U.K., developed a new method to extract metals, such as copper, from their parent ore body. The researchers provided a proof of concept for the application of an electric field to control the movement of an acid within a low permeability copper-bearing ore deposit to selectively dissolve and recover the metal in situ. Their new method contrasts the conventional approach for the mining of such deposits where the material must be physically excavated, which requires removal of both overburden and any impurities within the ore, known as gangue material. The researchers believe the new technique has the potential to transform the mining industry, because it has the capability to dissolve metals from a wide range of ore deposits that were previously considered inaccessible. Also, due to the noninvasive nature of the extraction, the work will help usher in a more sustainable future for the industry.

Making mineral extraction more sustainable is especially imperative now in order to provide the breadth of metals required to deliver green technology, such as renewable energy infrastructure and electrified vehicles, while limiting any potential environmental damage associated with the mining process. The team demonstrated that a targeted electric field can be used to dissolve and then recover copper in situ from the ore—avoiding any requirement to physically excavate the material. *www.exeter.ac.uk.*



Copper ore sample before the start of the experiment. Source-facing side (left) and target-facing side (right). Courtesy of University of Exeter.

TESTING | CHARACTERIZATION



Atomic-resolution details about magnesium chloride are now obtainable via a new technique. Courtesy of Irina Vodneva.

MORE SUSTAINABLE PLASTICS

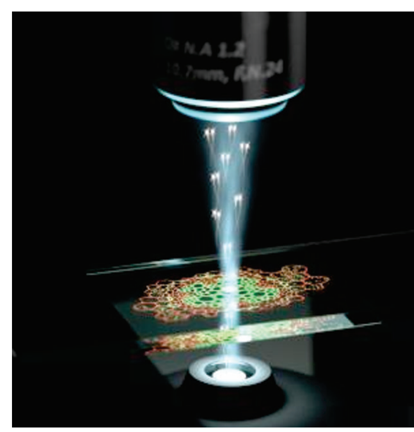
A new path toward sustainable plastics is being forged by researchers at the DOE's Lawrence Berkeley National Lab, Calif., in collaboration with Dow and Eindhoven University of Technology in the Netherlands. Their new technique provides atomic-resolution details about magnesium chloride, a material involved in the production of the most common plastic, polyethylene. The researchers used pulsed electron beams in an electron microscope to produce first-of-their-kind images of magnesium chloride. A continuous electron beam rapidly damages this delicate, beam-sensitive material, but the new technique allowed the researchers to study it without harm.

According to the scientists, the new method is useful for imaging a wide range of materials that are normally damaged inside an electron microscope. Pulsed electron beams also could be used to study soft membranes and plastics in general, advancing the quest for sustainable plastics. *lbl.gov.*

SEEING THE INVISIBLE

Researchers at the University of Queensland, Australia, created a quantum microscope that can reveal biological structures that would otherwise be impossible to see. This opens opportunities for applications in biotechnology and could extend far beyond into areas ranging from navigation to medical imaging. The microscope is powered by the science of quantum entanglement, an effect Einstein described as "spooky interactions at a distance."

Warwick Bowen from UQ's Quantum Optics Lab says it is the first entanglement-based sensor with performance beyond the best possible existing technology. "This breakthrough will spark all sorts of new technologies—from better navigation systems to better MRI machines," continues Bowen. Entanglement is thought to lie at the heart of a quantum revolution, and the researchers say their work demonstrates that sensors that use it can supersede existing, nonquantum technology—and, furthermore, that it's the first proof of the paradigm-changing potential of entanglement for sensing. Australia's Quantum Technologies Roadmap sees quantum sensors spurring a new wave of technological innovation in healthcare, engineering, transport, and resources.



Graphical depiction of the new quantum microscope in action. Courtesy of University of Queensland.

A major success of the team's quantum microscope was its ability to catapult over a hard barrier in traditional light-based microscopy. "The quantum entanglement in our microscope provides 35% improved clarity

BRIEF

Rolls-Royce recently opened Testbed 80 in Derby, U.K., reportedly the world's "largest and smartest indoor aerospace testbed," according to company sources. The $125 million project required three years of construction. The new facility will support the next stage of the company's high-efficiency UltraFan engine program, with the first demonstrator to be tested in 2022. It will also test a range of current engines such as the Trent XWB and Trent 1000 as well as future hybrid or all-electric flight systems. *rolls-royce.com.*

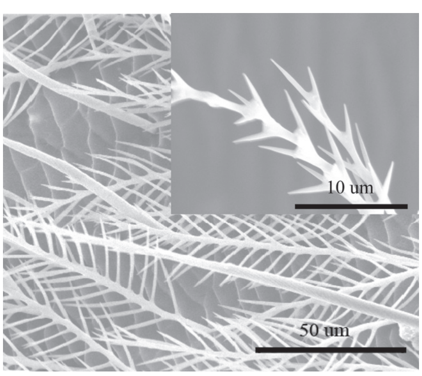
Testbed 80. Courtesy of Rolls-Royce.

without destroying the cell, allowing us to see minute biological structures that would otherwise be invisible," they say. "The benefits are obvious; from a better understanding of living systems, to improved diagnostic technologies." According to the researchers, there exist potentially boundless opportunities for quantum entanglement in technology. *www.uq.edu.au.*

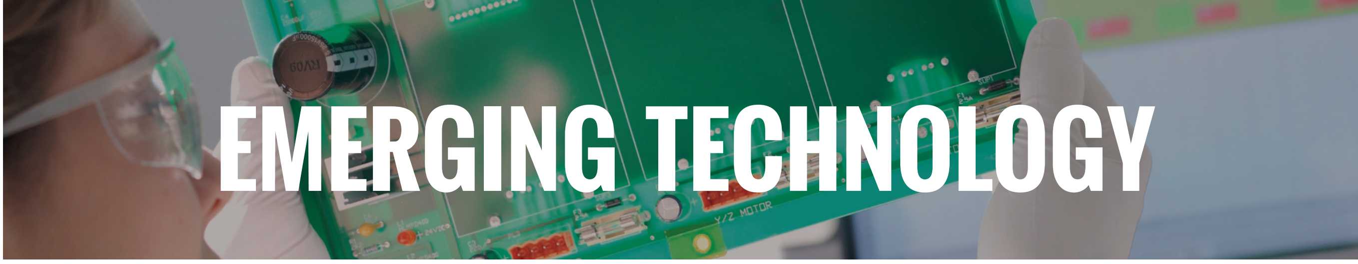
ENERGY CONSERVATION BASED ON BEES

By studying bees, researchers from two universities in China found that tiny hairs reduce friction from their movements, saving energy for the insects' daily activities while reducing wear and tear. This knowledge could help researchers design longer-lasting moving parts. A bee's abdomen is divided into several tough outer plates that make up its exoskeleton. When the abdomen flexes and extends, these segments slide over each other, creating friction. However, the overlapping portions of the segments show very little wear and tear, a finding that has puzzled scientists. The researchers wanted to investigate the anti-friction mechanism of the honeybee abdomen, which could someday be used to extend the lifetime of engineered soft devices, such as actuators and hinges.

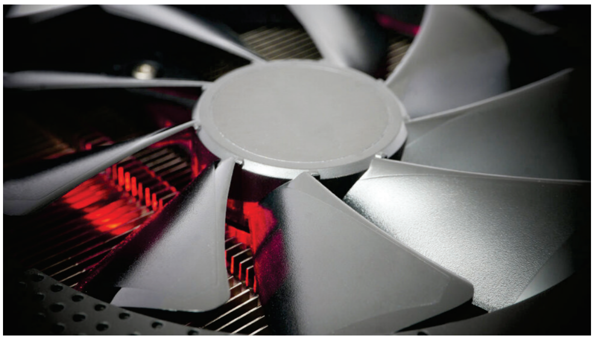
To do this, they observed honeybee abdomens under a scanning electron microscope, finding numerous branched hairs on the outer surface. Then, using atomic force microscopy, they measured the friction caused by moving an exoskeletal segment across either a hairy or hairless surface. Under the same load, the friction for the hairy surface was lower than that for a smooth surface. As the load increased, friction for the hairless surface rose, whereas no obvious rise in friction was observed for the hairy surface. The researchers calculated that the hairy surface reduced abrasion during abdominal contraction by about 60% and also saved energy with each contraction, adding up to a large amount of conserved energy essential for conducting bees' daily activities. *https://english.bit.edu.cn.*



Tiny hairs on a honeybee's abdomen reduce friction during bending, saving large amounts of energy during the bee's daily activities. Courtesy of *ACS Applied Materials & Interfaces.*



EMERGING TECHNOLOGY



New alloys help reduce the weight of heat removal systems in electric vehicles, consumer electronics, and household appliances. Courtesy of NUST MISIS.

MAKING LIGHTWEIGHT DEVICES

Scientists from the National University of Science and Technology MISIS, Russia, in collaboration with LG Electronics, South Korea, created new high heat conductivity magnesium alloys that differ from their counterparts in increased reliability and low cost—plus, the ability to reduce the weight of heat-removing elements by a third without losing efficiency. Reducing the temperature directly affects the prolongation of the devices' life cycle. Based on the results of the work, LG Electronics registered patents for a high-heat-conducting magnesium alloy developed at NUST MISIS and a radiator incorporating it in the U.S., the European Union, Korea, and China. The researchers are working on new compositions of magnesium-based alloys, which can provide high strength and corrosion resistance along with low cost and high thermal conductivity. *www.en.misis.ru; lg.com.*

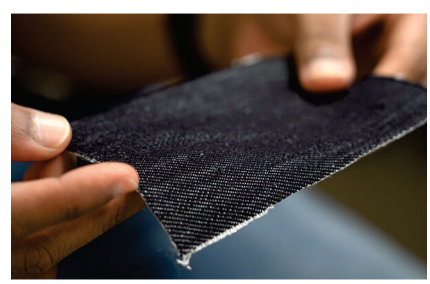
COOLING FABRIC

A type of fabric typically used for hiking gear was found to have remarkable heat-conducting properties on par with stainless steel. The discovery, made by a team of Purdue University, West Lafayette, Ind., engineers, could potentially lead to wearable electronics that successfully cool both the device and the wearer's skin. The material is made of ultrahigh molecular weight polyethylene fibers, which are sold commercially under the brand name Dyneema. These polymer-based fabrics are marketed for their high strength, durability, and abrasion resistance, and are often used to create body armor, specialty sports gear, ropes, and nets. Purdue heat transfer researchers recently investigated other uses for the fabric, specifically as a cooling interface between human skin and wearable electronics.

"This fabric has great flexibility and thermal properties. If you stitch it differently, weave it differently, or start blending the polymers with different materials, you could tailor the fabric's properties to different applications," the researchers say. "These polymer fabrics have amazing thermal properties that can keep these devices cooler and avoid low-degree skin burns."

The team discovered these properties by benchmarking Dyneema against conventional cotton fabrics as well as polyethylene sheets in rigid nonwoven form. They obtained several different commercially manufactured fabric samples and even wove their own samples from raw Dyneema fibers. The samples went into a small vacuum chamber, with a metal wire laid across the surface as a heat source. Using an infrared microscope, they generated detailed data about how much heat was being conducted through the fabric's surface, and in which direction. They found that the Dyneema fabric has 20-30 times higher thermal conductivity than other fabrics—comparable with steel.

The fabric naturally has these properties with no additional circuity or other equipment, but the researchers also have plans to test how weaving in different materials affects the fabric. According to the researchers, it's also possible to integrate other types of fibers to achieve different combinations of properties. *purdue.edu.*



A commercial fabric typically used for hiking gear has the heat-conducting properties of stainless steel, allowing the material to dissipate heat more effectively than other fabrics. Courtesy of Purdue University/Jared Pike.

BRIEF

Interlink Electronics Inc., Irvine, Calif., opened a new materials science and research & development lab in Camarillo, Calif. The facility includes state-of-the-art materials characterization, printing, prototyping, and testing equipment for advanced research into novel sensing materials, devices, and applications. *interlinkelectronics.com.*

UNLEASHING THE POTENTIAL OF ADDITIVE MANUFACTURING: FAIR AM DATA MANAGEMENT PRINCIPLES

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Additive manufacturing workshop advocates the use of guidelines for data management to realize Materials 4.0 and achieve process qualification.

*Member of ASM International

We are at the dawn of Materials 4.0, a critical component of the digitally driven, data enabled epoch of research and manufacturing, Industry 4.0[1-4]. In this new era, every aspect of a product's life cycle (research, development, engineering, design, manufacturing, deployment, sustainment, and sunsetting) is interconnected and interdependent. Concomitantly, digitally intense manufacturing technologies of significant importance have emerged. Additive manufacturing (AM) is one such manufacturing technology area that has demonstrated its potential to enhance innovation, accelerate product deployment, and reduce cost.

AM is not a single technology, but instead refers to several layer-by-layer processes that fall within its scope. These layer-by-layer processes are commonly defined as a "a process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies"[5]. The flexibility offered by AM gives it a certain advantage over many traditional processes, such as the potential to produce components where and when they are needed. Part-defining technical data packages can be sent electronically to any global manufacturing site. Long lead time, complex components, such as aircraft forgings and castings, can be produced in days or weeks compared to months or years. However, the Achilles' heel of this vision remains the inability to rapidly and cost effectively qualify AM processes and certify components.

The traditional means of process qualification involves optimizing the materials technology process, "freezing" it, and then developing statistically substantiated design allowables[6]. Unfortunately, AM does not lend itself to this methodology as key process parameters may be part-specific and a function of material, geometry, orientation, and proprietary processing. Because of the multitude of factors affecting part quality, the qualification process is time consuming and very costly. A great deal of effort has been devoted to overcoming this challenge. AM standards are being developed. Integrated computational materials engineering (ICME) tools are being developed. Modeling and simulations tools, as well as artificial intelligence (e.g., machine learning, neural networks, etc.) are being employed, and new testing methodologies are being adopted.

Application of these physics-based and data analytical tools requires the capture, transformation, curation, and analysis of data from across the product's life cycle. Further, given the complexity of the processes, vast amounts of data are required to achieve any correlations of significance. Few have the necessary resources to attain the required amount of data. To reduce cost, time, and duplicative work, government, academic, and corporate organizations must be able to share data easily across organizational lines. Unfortunately, there are many obstacles to the facilitation of data sharing. Today most data are stored in a range of diverse formats, e.g., paper files, PDFs, spreadsheets, relational databases, etc. They are stored in an equally diverse set of containers including in engineers' desk drawers, desktop computers, product life cycle management systems, and in the cloud.

FAIR AM DATA MANAGEMENT PRINCIPLES

Emerging from a series of additive manufacturing workshops held by the U.S. Navy, National Institute of Standards and Technology (NIST), America Makes, and U.S. Department of Defense (DoD) has come a community consensus for a transformational shift in AM process and part qualification and the imperative to adopt FAIR AM data management practices[7]. The workshops were held at these locations and dates:

- Navy Additive Manufacturing Technology Interchange (NAMTI) 2018, (Navy, Quantico, Va., November 27, 2018).
- AM Materials Database and Data Analytics Workshop, (NIST, Gaithersburg, Md., May 7, 2019).
- Additive Manufacturing for Maintenance Operations (AMMO), (America Makes/DoD, Crystal City, Va., June 18, 2019).
- Additive Manufacturing for Maintenance Operations (AMMO), (America Makes/DoD, Crystal City, Va., June 23, 2020).

A fundamental tenet emerged that the challenge could be addressed by building upon the FAIR principles of data management[8]. Simply stated, AM data must be captured, curated, and managed in a form that allows the characteristics of Findability, Accessibility, Interoperability, and Reusability, i.e., FAIR. Details of these principles may be found at https://www.go-fair.org/fair-principles/ and are summarized in Table 1[9].

THE COST OF NOT BEING FAIR

The European Union has published compelling evidence of the impact on the research community of not having FAIR data[10]. They estimated the annual cost of not having FAIR data to be a minimum of €10.2bn per year. An additional cost to innovation was estimated at €16.9bn per year. Further, they stated, "The actual cost is likely to be much higher due to unquantifiable elements such as the value of improved research quality and other indirect positive spillover effects of FAIR research data." They went on to conclude that about 80% of the duplicative funded work could be avoided with FAIR. Furthermore, the need for FAIR data extends beyond the research community in AM, to practitioners and developers as well.

As Fig. 1 indicates, those who work primarily with data spend 80% of their time finding, filtering, reformatting, and integrating data[11,12].

FAIR AM DATA MANAGEMENT WORKSHOP

Under the backdrop of this community alignment, the FAIR Additive Manufacturing (AM) Data Management Workshop was held virtually on October 27-28, 2020[13]. The workshop was organized and executed by NIST, ASM International, and Pilgrim Consulting LLC. A workshop assessment[14], speaker briefs, agenda, etc., may be found

TABLE 1 – FAIR GUIDING PRINCIPLES

Findable	Accessible
Metadata and data should be easy to find for both humans and computers. Machine-readable metadata are essential for automatic discovery of datasets. F1. (Meta)data are assigned a globally unique and persistent identifier F2. Data are described with rich metadata (defined by R1 below) F3. Metadata clearly and explicitly include the identifier of the data they describe F4. (Meta)data are registered or indexed in a searchable resource	*After the user finds the required data, she/he needs to know how it can be accessed & authenticated.* A1. (Meta)data are retrievable by their identifier using a standardized communications protocol A1.1. The protocol is open, free, and universally implementable A1.2. The protocol allows for an authentication and authorization procedure, where necessary A2. Metadata are accessible, even when the data are no longer available
Interoperable	**Reusable**
The data must be integrated with other data. The data needs to interoperate with applications, etc. I1. (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation I2. (Meta)data use vocabularies that follow FAIR principles I3. (Meta)data include qualified references to other (meta) data	*In order to optimize the reuse of data, metadata and data must be well-described so that it can be replicated and/or combined in different settings.* R1. (Meta)data are richly described with a plurality of accurate and relevant attributes R1.1. (Meta)data are released with a clear and accessible data usage license R1.2. (Meta)data are associated with detailed provenance R1.3. (Meta)data meet domain-relevant community standards

at https://www.asminternational.org/web/nist-asmdatamanagementworkshop. The purpose of the workshop was to:

1. Facilitate the establishment of a strategic path forward regarding needed AM data management standards and R&D, and
2. Accelerate AM part deployment and reduce the time and cost associated with AM process qualification and part certification.

To do so, the thought leadership of an eclectic and diverse group of world-renowned experts were invited to participate. A total of 128 people participated in the event: 30% from government, 25% from academia, 33% from industry, and 12% from standards developing organizations (SDOs) and non-profit organizations.

Since the FAIR Data Management Principles have not yet been substantively embraced by the materials engineering or the additive manufacturing communities, the workshop organizers elected to have FAIR experts (working in the biological community) deliver the Day 1 plenary addresses. The invited FAIR keynote speakers were Dr. Mark Wilkinson, University Politecnica de Madrid; Dr. Erik Schultes, Go-FAIR; and Matthew Trunnel, Pandemic Response Commons.

The Day 2 plenary session highlighted extant and ongoing work being done by standards development organizations and non-profit organizations. Dr. Mohsen Seifi, ASTM, and Kathryn Hyam, ASME, provided updates on their organizations' data management stand-

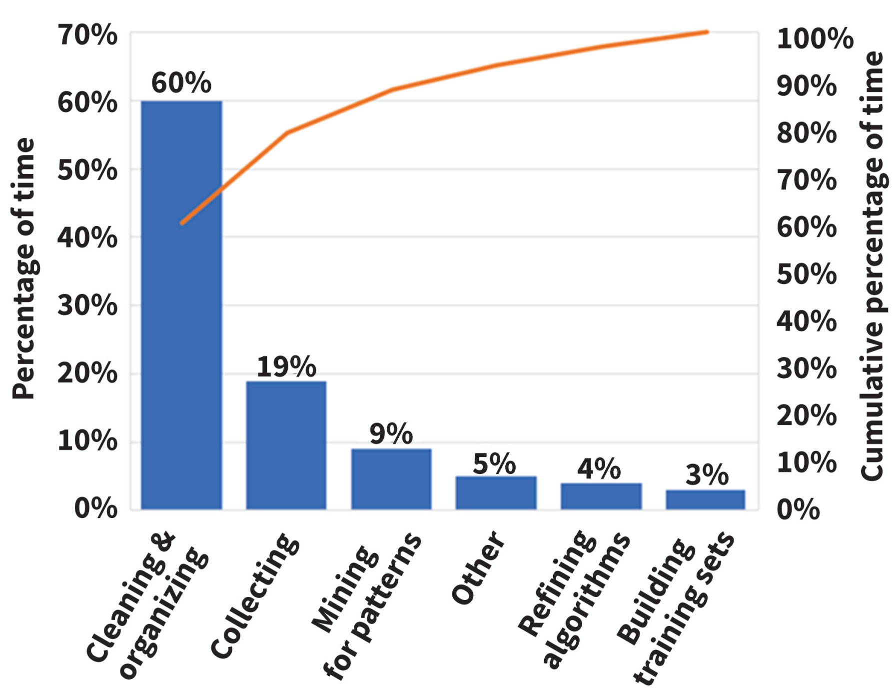

Fig. 1 — How data scientists spend their time.

ards development work. Dr. Brandon Ribic, America Makes, and Doug Hall, Battelle Memorial Institute, discussed the AM data management strategy of their non-profit organizations.

Participants were divided into four working groups aligned to the FAIR Data Management Principles, i.e., 1. Findable, 2. Accessible, 3. Interoperable, and 4. Reusable. Each working group was co-led by NIST and industry personnel. Working groups identified and prioritized the challenges associated with achieving the workshop goals and recommended approaches to overcome those challenges.

An abbreviated summary of the salient observations of the workshop are as follows:

- There are political, economic, social, and technological (PEST) impediments to effective data management. The technological challenges were viewed as tractable; the political, economic, and social challenges will require cross-agency and government/private sector collaborative efforts.
- Data scientists spend 80% of their time finding, filtering, reformatting, and integrating data, leaving only 20% of their time for data analysis. This 80/20 ratio (time to prepare data/time using data) needs to be changed to 20/80.
- The current work to establish an AM common data dictionary (CDD) was highlighted.
- The need for a common data exchange format (CDEF) for AM was validated.
- Continued work is required to build and expand community consensus around the FAIR principles.
- Utilization of WWW consortium standards was an implicit theme. Similarly, the use of JavaScript object notation (JSON), representational state transfer API (REST API), and web ontology language (OWL2) was implicit to the participants' thinking.
- Establishing a "Data Commons" for the facile, cost effective exchange of AM data, models, and tools deserves to be explored.

The workshop identified challenges associated with implementing FAIR principles, which were:

- Enhanced interoperability requires the establishment of a common data model and formal knowledge representation.
- The ability to find and access data requires that the manual labor, difficulty, and cost associated with obtaining machine-readable information from tribal/artisan knowledge sources be significantly reduced.
- Ensuring that data is reusable and accessible requires that the generator of data be incentivized to collect, organize, and curate it in a manner suitable for reuse. Note, the data generator has all the burden and little to gain while the data user has none of the burden with everything to gain.
- The principal impediment to data accessibility is the political, economic, and social resistance to data sharing. This is especially true for proprietary, confidential, and classified data.
- Proprietary data formats impede the findability and accessibility of data.
- The interoperability, reusability, and findability of data is hindered because of the lack of common data/metadata formats, metadata definitions, and missing data.

PATH FORWARD

Based upon the results of the workshop, the critical elements of a strategic path forward, and toward a realization of Materials 4.0, were identified. See Fig. 2. Overcoming the PEST challenges

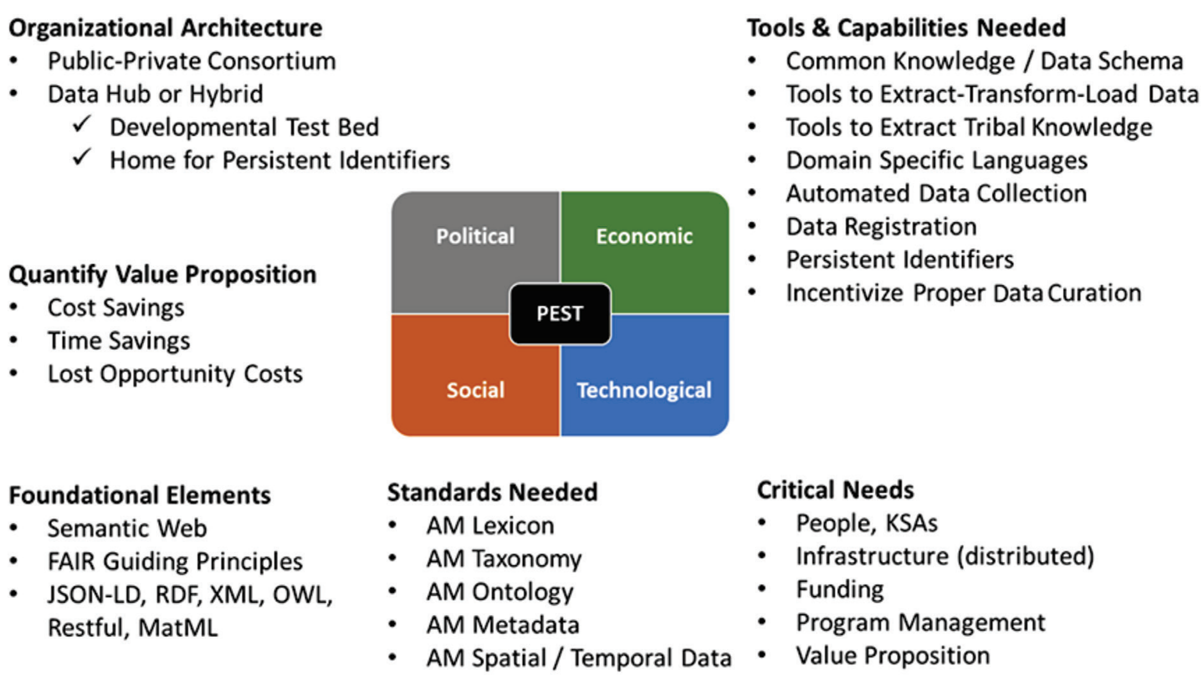

Fig. 2 — Critical elements of an additive manufacturing data management plan: A PEST problem.

is viewed as central to success. Quantifying the value proposition is required to overcome the activation energy associated with concerns (e.g., IP rights, ROI, security, etc.), and provides a business rationale for investment in FAIR data management. Standards are needed to facilitate interoperability. These must include a common data dictionary, a domain specific AM ontology, and metadata formats. The foundational elements include many data standards and architectures developed by the World Wide Web Consortium (W3C). In addition, the aspirational goal of the Semantic Web must be embraced, i.e., to format data in such a way as to make it both machine and human readable.

There are critical imperatives associated with implementing effective FAIR data management principles and being productive in Industry 4.0. The work before us will require cross disciplinary efforts. The knowledge, skills, and abilities of the materials scientist and engineer must expand to include that of data science. Further, there is a need for an organization, perhaps a public-private consortium, to serve as a focal point for prototyping data management technologies and serving as the steward for persistent data identifiers.

EXAMPLE DATA MANAGEMENT CONCEPTS

Technology Stack: When considering the development of a viable data management system, it is perhaps useful to view it in terms of a technology stack, Fig. 3. This permits a systems-level perspective. In this table, the FAIR principles, Semantic Web, the World Wide Web (WWW), etc., are viewed as the foundation upon which an effective data management structure must be built. The applications and platforms listed at the top of the table illustrate how the data might be used by the consumer. The wide breadth of applications underscores the need for the use of FAIR data management principles and a well-defined knowledge management architecture.

AM generates large amounts of data, and effective knowledge management is crucial to the advancement of AM. A well-structured and community accepted domain ontology supports knowledge sharing, i.e., interoperability. A pragmatist may characterize an ontology as a model constructed to describe reality that consists of a taxonomy, lexicon, concepts, and defines interrelationships. Here, the goal of an ontology is to support knowledge sharing and the electronic management of scientific information. R. Arp et al. state, "Ontology is a top-down approach to the problem of electronically managing scientific information," and go on to say "Definitions are perhaps the most important component of ontologies, since it is through definitions that an ontology draws its ability to support consistent use across multiple communities and disciplines, and to support computational reasoning"[15]. Hence, the hard work of establishing components (i.e., dictionary, thesaurus, taxonomy, and ontology) of effective AM data management is critical to achieving innovation and accelerated product deployment[16,17].

The means of data curation and management is also very important. Data must be extracted, transformed, and loaded into the curation site in such a way as to make it usable to data consumers. Several common architectures are considered data repositories. Whether the data is physically curated at a "brick and mortar" location or in the cloud, its purpose and functionality is largely determined by political, social, and economic consideration. For example, a data commons typically supports precompetitive R&D and provides the community with access to both data and computational tools. A data warehouse, however, is typically employed by corporations to deliver specific, actionable business information. Data hubs have characteristics that may make them well suited for agile team formation, secure data curation, and collaboration. However, the sustainability of any of these repositories requires a viable long term business model. One study[18] of 48 repositories in 18 countries assessing their business case concluded, "Yet good data stewardship is costly and research budgets are limited. So, the development of sustainable business models for research data repositories needs to be a high priority in all countries."

EWI AM Qualification: EWI and partners have shown proof of concept that data-enabled approaches can change the approach to qualification

Applications & Platforms Computational and Modeling & Simulation ICME, CAD, CAM, FEM, PLM, Accounting, Logistics, Forecasting
Data Analytics Artificial Intelligence & Statistical (Machine Learning, Neural Networks, Genetic Algorithms, ANOVA)
Data Repositories Data Hub, Data Lake, Data Commons, Data Warehouse, Federated Database
Knowledge Management Lexicon, Thesaurus, Taxonomy, Ontology, Persistent Identifiers
Foundational Elements WWW, FAIR, Semantic Web JASON-LD, NoSQL, RDF, XML, RESTful, OWL, MatML

Fig. 3 — FAIR AM data management technology stack.

of additive components. Currently, the qualification and certification of a production part is based on expensive and part-specific point-qualification datasets. As an alternative approach, EWI, GE Research, Raytheon, and Youngstown State University showed proof of concept for feature-based qualification in an America Makes program entitled "Feature-Based Qualification Method for Directed Energy Deposition AM." In this approach, feature specific datasets are used to train machine learning methods to predict microstructure and mechanical performance. This abstraction from part-specific to feature-specific qualification drastically extends the predictive power of a given dataset. The combination of techniques like these and the reusable nature of FAIR data will provide a paradigm change in qualification/certification.

NIST & Data Hub: Figure 4 illustrates a fast AM qualification framework based on federated FAIR AM data. Five key components are identified to enable the fast AM qualification process including: a collaborative and federated AM data hub, advanced data analytics to leverage on heterogeneous datasets, integrated computational material engineering (ICME), a hybrid method to combine data-driven models with first principle-based models for better predictive accuracy, and an adaptive sampling mechanism for material test planning.

A collaborative AM data management system combines community efforts and leverages on legacy FAIR data to turn the small data sets from individual material tests into vast amounts of data necessary for statistically sound process qualification. With advanced data analytics, such as transfer learning, heterogeneous data sets with a multitude of geometries, material types, and processes can be mined to develop empirical correlations between material properties, microstructure, part geometry and process parameters. Methods like transfer learning make machine learning systems more efficient and able to work with less data. In addition, combining physics-based modeling and toolsets like ICME can provide additional data sets based on simulations. AM qualification can also benefit from better design of experiments using physics-based models. Such advancements lead to less effort and time for material and process testing and promise to speed up AM process/material/part qualification. It is critical to develop and validate efficient and effective advanced data analytics, complemented by physics-based models, capable of undertaking rapid explorations of AM process-structure-property relationships with limited and diverse data sets.

ASM International Ecosystem: ASM International has recognized the need to enable the digital capabilities of its membership and has embarked on an ambitious initiative to bring these capabilities to fruition. This initiative is tentatively labeled the ASM Data Ecosystem and is currently a "proof of concept" digital materials analytical environment. Ultimately, this proof of concept will be scaled into a fully featured digital "store" where members can access materials data, simulation tools, and use computational infrastructure with much lower barriers to entry. If targeted and executed properly, many of the FAIR data principle imperatives will be advanced, and some of the PEST challenges will be mitigated. The Data Ecosystem that ASM International is currently building will have many similarities with the data commons previously described. In addition to the digital environment, ASM will join high-quality and pragmatic data management education to the core "table stake" of high-quality, useful materials data. The schematic of this initiative is provided in Fig. 5.

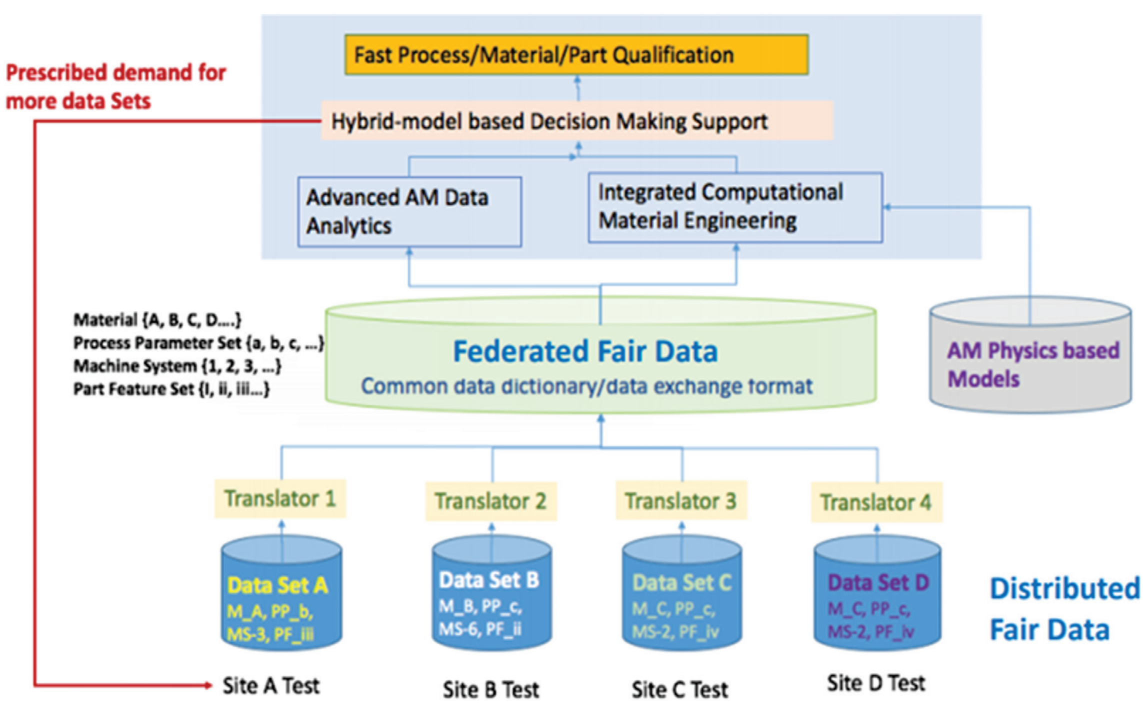

Fig. 4 — A FAIR additive manufacturing framework for rapid qualification.

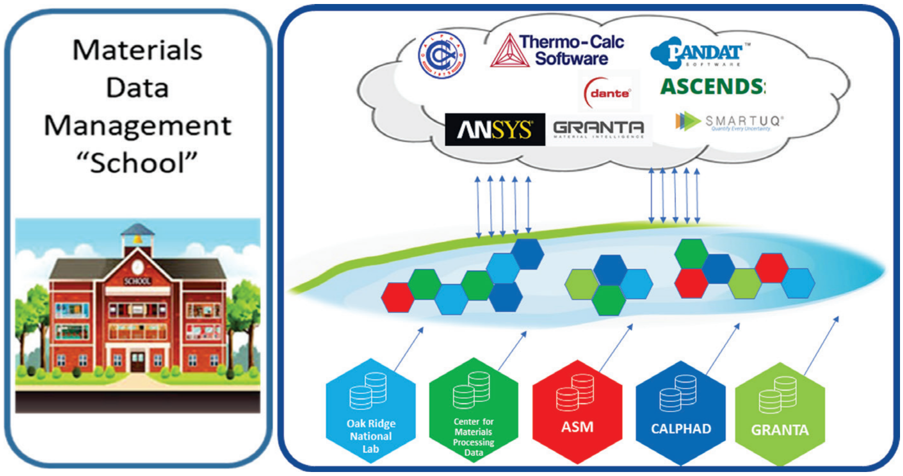

Fig. 5 — ASM International envisions Materials Data Management Ecosystem. Companies listed are examples only.

TABLE 2 – LIST OF ACRONYMS

Acronym	Description
AM	Additive manufacturing
ANOVA	Analysis of variance
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CDD	Common data dictionary
CDEF	Common data exchange format
FAIR	Findable, accessible, interoperable, and reusable
FEM	Finite element methodology
ICME	Integrated computational materials engineering
JASON	JavaScript object notation
KSA	Knowledge, skills, and abilities
MatML	Materials extensible markup language
NoSQL	Nonstructured query language
OWL	Web ontology language
PEST	Political, economic, social, and technological
PLM	Product lifecycle management
RDF	Resource description framework
SDO	Standards development organizations
WWW	World wide web
XML	Extensible markup language

The network of experts, adjacent organizations, working groups, and project teams that will be part of advancing FAIR principles and mitigating PEST challenges highlights the most important driver of real advancement in Materials 4.0 and democratizing digital capabilities—people! Many forms of structured and nonstructured collaboration will enable the movement toward FAIR, including focused project teams, consortia, and communities of practice. The challenges are real, and big, but not insurmountable. Creating such an environment for productive collaboration will require close partnerships between industry, government, academia, SDOs, and technical professional societies.

SUMMARY

The potential significance of FAIR data is hard to overstate, but equally hard to prove in totality. FAIR data can change the paradigm for research and development, qualfication/certification, and acquisition, sustainment. We can predict the benefits by extrapolating the needs of today, but we expect the real benefit to be unimaginable. The internet has taught us that the availability of knowledge leads to impactful but unpredictable advancements. However, these advancements rely on network effects and require a critical number of users.

A concentrated effort is needed to prime the AM FAIR data pump. It needs to begin addressing the PEST challenges by proving a tangible value of FAIR data while demonstrating a model for rapid technical development of the AM FAIR data infrastructure. This must be accomplished in a way that builds community acceptance among industrial users, government users, and database management providers. Most importantly, this progress needs to attract influential early adopters of FAIR AM data. **~AM&P**

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DIFFERENCES IN DEFECT DISTRIBUTION ACROSS SCAN STRATEGIES IN ELECTRON BEAM AM Ti-6Al-4V

The fraction and size of pores present in EBM Ti-6Al-4V specimens varies depending on the melting strategy used, whether linear raster melting or point melting.

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In recent years, additive manufacturing (AM) has begun to displace traditional manufacturing techniques for specific applications. Notable benefits of AM include reduced times from design to product, an improved buy-to-fly ratio, lower waste, and the ability to produce complex geometries[1,2]. An additional benefit of additive manufacturing is the variety of manufacturing processes that span across heat source (e.g., laser, electron beam, plasma), input material type (e.g., powder, wire), atmosphere, and the number of axes of control among others[2-4]. This variability in processing route means that a process can be identified and optimized for a class of products or parts. Despite these various advantages, one of the primary drawbacks of AM processes is porosity within builds, which ultimately reduces the ability of a part to withstand tensile stresses and can lead to premature failure[4-6].

Electron beam melting (EBM) is a powder bed fusion technique that uses an electron beam as a heat source to melt powder particles that have been spread over a build plate[7]. Unlike laser-based processes, EBM requires the build chamber to be at vacuum, reducing the probability of porosity stemming from gases present within the build chamber[1]. Gas pores in EBM are thus typically caused by either gases present in the feedstock material (i.e., retained gas porosity) or vaporization of select elements (i.e., keyholing)[4,8]. Gas pores formed through either mechanism result in nearly spherical morphologies whose locations within the layer of a build and presence within a solidified part are influenced by the fluid dynamics of the melt pool[4,9,10].

The most common scan strategies of EBM are point-melting and variations on linear raster scan strategies, i.e., moving the electron beam in a linear fashion across the powder bed following a pattern[11]. Point-melting scan strategies, less commonly studied and used, involve point-by-point melting of small volumes of material of the powder bed. Research has shown that point-by-point melting strategies can be used for site-specific control of the resulting microstructure and texture by varying process parameters and the location and order of points melted, thereby leading to local and specific variations in mechanical properties[12,13].

OBSERVATIONS IN AS-BUILT SAMPLES

Ti-6Al-4V specimens were produced at Oak Ridge National Laboratory Manufacturing Demonstration Facility using an ARCAM EBM Q10plus system and TEKNA Ti-6Al-4V plasma atomized powder. Each specimen had a geometry of 15 x 15 x 25 mm.

Three different scan strategies were used to produce the samples: a linear raster scan (L), random point-melting (R), and what is known as the Dehoff point-melting strategy (D). The raster scan L consisted of a serpentine pattern that rotated 67.5° after the end of every layer. Each 15 x 15 mm area of R and D was segmented into coordinates. A computer-generated random function was used for R, to assure every coordinate (or point) was melted only once and all coordinates were melted every layer. The Dehoff (D) strategy requires melting in an ordered manner by organizing the coordinates into arrays and subarrays and following a specific order. More information about all three of these scan strategies can be found in M. Quintana[14], M. Kirka[15], and P. Nandwanda[16]. The layer thickness was 50 µm for all strategies, and all samples were printed at the same time on a stainless steel build plate. Samples were imaged using an FEI Teneo LoVac field-emission scanning electron microscope (SEM). Images were then analyzed using MIPAR image analysis software.

Analysis of internal planes of the samples resulted in the spherical (gas) pore data presented in Table 1 and Figs. 1 and 2. The raster scan strategy (L) had three times as many pores as either of the two point-melting strategies. All spherical pores over 25 µm were only observed in the L sample, meaning the selected strategy has a large influence in both the number of pores formed and their sizes. The distribution of pores relative to build height in each sample was also assessed (Fig. 2) by classifying pores as belonging to one of three equal sized bins (each ~8.3 mm in height, labeled top, middle, and bottom). Samples R and L have a uniform distribution throughout the sample, while D has slightly fewer pores in the middle and more in the bottom.

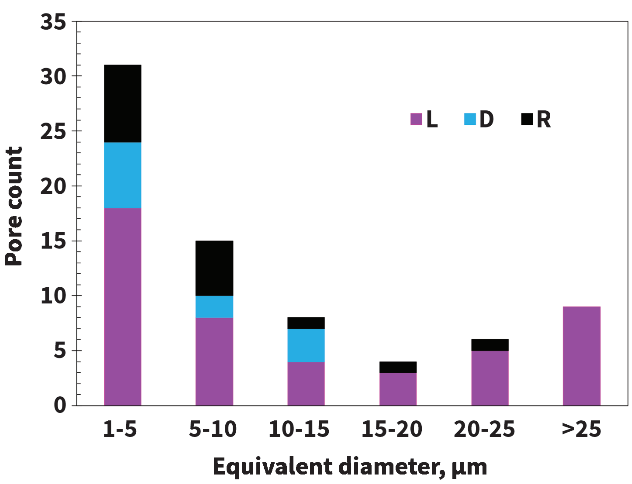

Fig. 1 — Equivalent diameter distribution of the spherical pores across the three strategies (L, D, and R) observed in one internal plane (15 x 25 mm).

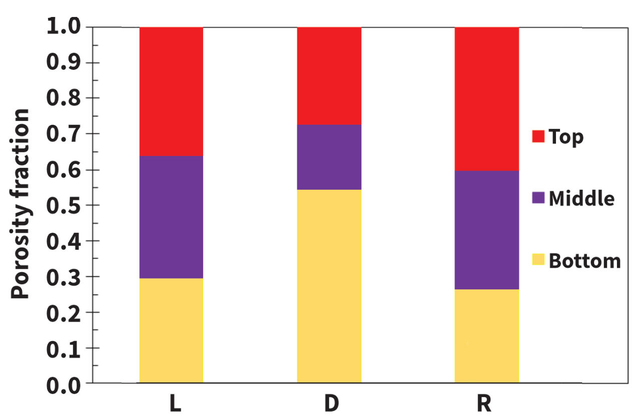

Fig. 2 — Distribution of spherical porosity across raster, Dehoff, and random strategies sub-separated into top, middle, and bottom regions within each sample.

Porosity is, by nature, very common in AM builds, and because pores are typically considered defects, research has been done to optimize AM parameters to minimize both the volume fraction and the size of pores in final parts[17,18]. As expected, the measurements of small amounts of porosity in the samples show both large standard deviations (Table 1) and a broad range of pore diameters. A comparison between the samples (strategies) can provide insights into the influence of melt pool morphologies and process parameters on the sizes of gas pores.

FLUID DYNAMICS IN AM MELT POOLS

Melt pool fluid dynamics can be divided into two general stages: first, the powder initially interacts with the heat source and melts, creating a region ruled by thermocapillary forces; and second, the heat source moves away and the melt pool begins to cool, switching the dominating force from thermocapillary to drag. Thermocapillary forces move pores in the direction of the thermal gradient, which, in the case of both raster and point-melting strategies, will bring pores to the surface of the melt pools[4]. As the melt pool cools, the thermal gradient is reduced, which in turn reduces the magnitude and influence of the thermocapillary force and makes drag the driving and dominant force (particularly in the tail end of the elongated raster melt pool). Fluid flow no longer drives pores to the surface and instead they are trapped inside the liquid material[4]. In other words, pores are more easily eliminated from the leading edge of a raster melt pool, as opposed to the tail end, as a result of thermocapillary forces dominating over drag forces.

Notably, because the heat source does not move during the residence time in point-melting strategies, the melt pool does not develop a trailing region (i.e., a "tail"), and instead is by

TABLE 1 – STATISTICS OF SPHERICAL PORES: ANALYSIS OF ONE INTERNAL PLANE FOR EACH STRATEGY

Scanning strategy	Pore count	Area fraction*	Equivalent diameter (µm)		
			Average	Standard deviation	Range
L	47	0.0000433	14.20	13.55	1.6-51.7
R	15	0.0000028	7.17	5.20	2.8-20.1
D	11	0.0000018	6.97	4.74	2.2-14.8

**Area fraction is based on a sectioned surface of 15 x 25 mm.*

and large consistently the leading edge of a raster melt pool. Though research into the fluid dynamics in point melting is scarce, parallels can be drawn from publications on laser spot welding[19], where Marangoni convection (i.e., thermocapillary forces) dominates melt pool thermodynamics. Thermal gradients within individual melt pools are therefore higher in point-melting strategies compared to linear raster with elongated melt pools. Higher thermal gradients allow thermocapillary forces to dominate the fluid flow through a greater relative volume of each melt pool and eliminate some of the gas porosity present in the melt pools by dragging them to the surface where they are eliminated.

Melt pool fluid dynamics and the ability of gas bubbles to escape the melt pool are not influenced by location (in a plane) or by height, as observed in the L, D, and R samples, only by varying the scanning strategy. Thermal gradients within AM parts are known to vary along the height of a part, based on thermal conductivity through the build plate as opposed to the surrounding powder bed, pre-heat temperatures, time at temperature, and the number of layers above a selected region, among other factors[2,14]. These thermal gradient variations affect thermal (and thermomechanical) gyrations and corresponding phase transformations, which results in notable differences in the resulting microstructure[2,14]. The fact that no significant variation in spherical porosity was observed along the build height suggests that the best time for gas pores to escape is during initial melting, either while the electron beam is centered on the melt pool or immediately after, particularly for point-melting strategies.

INDUSTRIAL RELEVANCE

While some of the typically undesirable attributes of AM builds (e.g., residual stress and surface roughness) can be mitigated with post-processing or concurrent hybrid-processing steps (e.g., annealing, in-situ or ex-situ machining)[2], porosity, on the other hand, is difficult to eliminate with these methods[4,16]. Porosity is detrimental in all structural metals, as all pores act as stress concentrators and can lead to premature failure[1,2,6,20]. Investigations into optimizing processing parameters to reduce porosity in powder bed fusion (PDF) AM techniques are common[1,4,5], but tend to focus on power and scan speed and rarely venture into differing scan strategies.

In AM builds, the size of the gas pores ranges considerably, from tens of microns (Fig. 3a) to less than 5 microns (Fig. 3b). The smaller pore sizes are more commonly observed in the point-melting scans. With low volume fractions of porosity, it can be difficult to determine accurately the amount and size of porosity. Knowledge of the size of gas pores is critical, as large pores (Fig. 3a) will lead to a larger local loss of tensile properties than smaller pores.

As mentioned, post-processing steps, typically in the form of heat treatments, are usually not successful at removing all pores in as-built parts[2,4,16]; thus, methods of reducing and eliminating porosity during the build process itself is preferable and the most effective route to ensure the final mechanical performance of a part is as expected during the design process. This work provides analysis on strategies which mitigate porosity (i.e., point-melting strategies are better than raster scans at eliminating porosity and reducing the size of the pores present) as a result of the forces dominating different stages of the melt pool fluid dynamics.

CONCLUSIONS

Observations of the spherical porosity in EBM Ti-6Al-4V builds have shown a clear difference in the resulting fraction and the size of pores present between a linear raster-melting strategy and point-melting strategies (Dehoff and random). Whether as a result of retained gas porosity from the powder, or vaporized elements in the build, samples from all three melting strategies present gas porosity. Fewer spherical gas pores were observed in both of the point-melting EBM scan strategies as opposed to the prototypical, and widely used, linear raster melting scan strategy. Point-melting strategies also resulted in spherical gas pores with an average diameter of half the size of the average diameter of pores in the raster-melting strategy. Pores with a diameter greater than 25 µm were only observed in the L sample.

Gas pores are neither preferentially formed nor retained at any particular height of the sample, leading to the

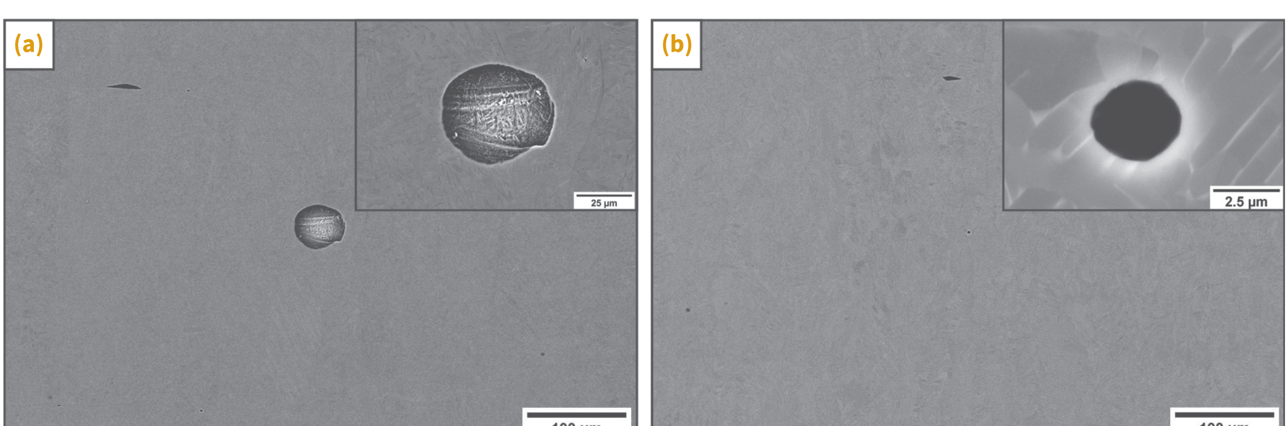

Fig. 3 — Spherical pores observed in EBM samples obtained with different scanning strategies: (a) linear raster scan-L and (b) point-melting scan-R.

conclusion that it is the fluid dynamics of the melt pools and not the thermal gyrations generated by the parameters that most strongly influences the ability of gas bubbles to escape the melted material during the AM process.

This difference can be attributed to the nature and morphology of the melt pools and the fluid dynamics from point-melting strategies, compared to the relatively larger and elongated melt pools that form in raster-melting strategies that contain two very distinct fluid dynamics domains, with opposing driving forces. Melt pools in point-melting strategies are almost exclusively dominated by Marangoni convection, whereas raster-melting strategies also contain a tail end to the melt pool that is dominated by drag forces. **~AM&P**

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ARCHAEOMETALLURGY OF COPPER AND SILVER ALLOYS IN THE OLD WORLD

The production and processing of advanced materials, namely metals and alloys, began in the Old World about 8000 years ago and developed over many millennia, providing a lasting legacy for modern civilizations.

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Metals and alloys constitute an essential part of the development of societies from Neolithic times, and the earliest process metallurgy, melting and consolidation of native metals, may be traced back to about 6000 B.C. The importance of metals technology in ancient societies is shown by referring to the main periods of post-Neolithic prehistory as the Copper, Bronze, and Iron Ages[1]. Approximate dates for the beginnings of these technologies in the Near East areas are: copper (6000 B.C.), bronzes (3500 B.C.), and iron (1500 B.C.). However, recent data suggest that complex tin bronzes were smelted much earlier in the Balkans, around 4500 B.C.[2], but this technology was effectively lost after 4000 B.C.

Understanding process metallurgy in the ancient world is a major remit of archaeometallurgy. Over the last 50 to 60 years there have been international efforts to establish and promote scientific studies of (i) metallurgical processes and artifacts, from raw materials to final production, and (ii) by-products, tools, and equipment, e.g., slags, crucibles, and furnaces (Fig. 1).

These studies use a wide range of modern scientific methods and laboratory instruments to better understand the complex processes involved, and also the artifacts themselves and their eventual deterioration (especially corrosion) over the millennia. This latter aspect is directly linked to conservation and restoration techniques.

The difficulties that had to be overcome are well demonstrated by experimental archaeometallurgy, i.e., pyrometallurgical experiments to smelt metals from ores in ancient-style crucibles and furnaces. Even with modern scientific knowledge these experiments may be only partially successful and sometimes fail completely. Such experiments enable a veritable appreciation of the empirically derived skills of ancient metalworkers.

This article gives a brief overview of the production and processing of ancient bronzes and silver in the Old World, and also mentions post-processing problems including corrosion and embrittlement, owing to long-term burial before archaeological recovery.

ANCIENT COPPER ALLOYS

The first evidence of using native copper to make small and decorative objects comes from the Near East and Caucasus and is dated to about 8000 B.C.[1]. Processing native copper by melting and casting began around 6000 B.C., and reduction of copper ores (smelting) to derive copper began around 4000 B.C. It is important to note that the ores were mined from copper sulfide deposits, where the weathered upper layers consisted mostly of copper carbonates and oxide. These could be simply added to smelting crucibles and furnaces. However, continued mining reached the sulfide deposits, and these had to be oxidized (roasted) before smelting.

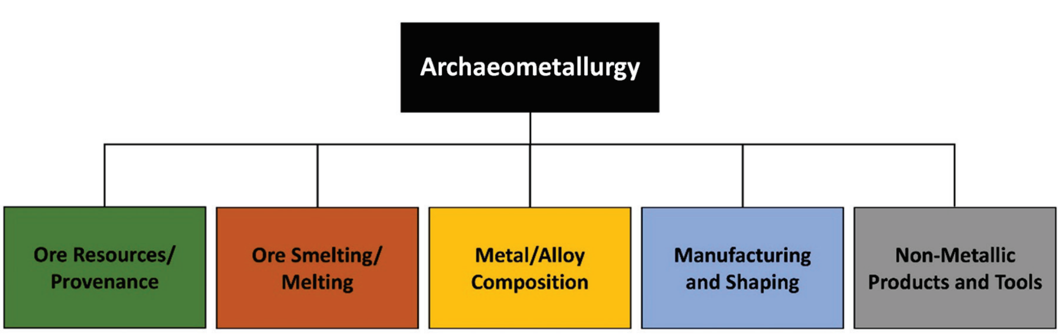

Fig. 1 — Schematic of the main aspects of archaeometallurgical studies. Adapted from Bayley et al.[3].

Early processing was done using crucibles containing crushed ores and charcoal, with forced airflow provided by bellows-powered blowpipes. Later on, crucible and hearth furnaces using forced air via tuyères provided more controlled conditions. Figure 2 is a schematic of a smelting furnace from the Near East Late Bronze Age (LBA: 1550–1200 B.C). Besides initial metal production, such a furnace could be used to remelt additions of other copper metal before tapping into clay or stone molds to cast ingots or artifacts, for example, vessels, tools, and ornaments.

Large "oxhide-shaped" copper ingots were widely used in Eurasia as trade items in the LBA[4], and these could be remelted with additions of tin or tin oxide (cassiterite), and possibly other alloying metals, to produce bronze ingots or cast artifacts including vessels, tools, weapons, and ornaments.

Near East Early Bronze Age (EBA: 3300–2100 B.C.) ingots were probably forged by cold-working rather than hot-working[5], and with intermittent annealing, depending on the metalsmith's experience with the materials and the required artifacts. This practice continued well into the Iron Age, beyond 1500 B.C. Hot-working would have gradually developed as an alternative, except for high-tin bronzes, because "hot shortness" (brittle cracking at high temperatures) would become increasingly likely with tin contents above 8 wt%[6].

ANCIENT BRONZES

The history of ancient bronzes is complex, spanning a "classic" period of more than 2000 years in Eurasia (3300–1200 B.C.). Many issues are still unresolved, despite extensive studies since the early 20th century. Perhaps the most important question is whether the presence of alloying elements in copper was always accidental or became intentional. Considering the three main types of bronzes, antimony bronze, arsenical bronze, and tin bronze, the evidence of intentional alloying for tin bronzes is incontrovertible. However, deliberate alloying with antimony and arsenic can be questioned[5,7], since these elements were often present in copper-bearing ores. On the other hand, analysis of Early Bronze Age slags from Iran shows that speiss, an iron-arsenic alloy, was probably added to copper ore or during remelting to obtain arsenical bronzes[8,9]. Also, although digressing here from the Old World, there is convincing evidence that the Andes region arsenical bronzes containing 0.5–2 wt% arsenic were intentionally produced from about 850 A.D. for cold-hammering into culturally desirable small implements and thin sheet materials[10].

Returning to Eurasia, two more important questions arise. Why did tin bronzes become the main type, largely replacing arsenical bronzes after 2500 B.C., and why did antimony bronzes almost disappear after 2000 B.C.[7]? Possible answers have been given, but there is no consensus. Firstly, antimony bronzes may have been supplanted because their lesser hardness, and hence lesser strength, made them unsuitable for tools or weapons. This could have resulted in a lack of demand and trade in favor of tin bronzes, though this is not (yet) known[7].

The more intriguing question is the predominance of tin bronzes over arsenical bronzes, beginning in the later EBA. There are three basic hypotheses: (i) tin bronzes were intentional alloys but arsenical bronzes were not; (ii) tin bronzes had superior mechanical properties; (iii) smelting arsenic-containing ores resulted in poisonous fumes that became recognized as a health hazard. The first hypothesis has been discussed already: intentional alloying to obtain Eurasian arsenical bronzes is a distinct possibility[8], and the Andean region study reinforces this[10]. The second hypothesis is disfavored by an extensive study and comparison of the mechanical properties of arsenical and tin bronzes[10]. There remains the possibility that smelting arsenical ores was abandoned in Eurasia owing to health concerns. However, arsenical bronzes were still being produced in the LBA (Fig. 3), *1000 years* after tin bronzes became predominant.

The majority of Near East tin bronzes have tin contents less than about 12 wt%, typically ranging from 5–10 wt% from about 3000 B.C.[4]. The earliest EBA alloys have lower tin contents, 1–3 wt%; and there are occasional exceptions, the high-tin alloys already mentioned. Hence most of the materials and artifacts would have had homogeneous single-phase microstructures after working and annealing, very different from the inhomogeneous as-cast structures (Fig. 4).

ANCIENT SILVER ALLOYS

Owing to native silver's scarcity, there is limited evidence of its direct use for artifacts, a few of which have been dated to 4300–4000 B.C.[11]. Silver was more abundant as a minor component in the ores of other metals, especially lead[12]. Beginning before 3000 B.C., lead obtained from smelting argentiferous lead ores was further processed by cupellation to extract the silver. This process became the primary source of ancient silver and silver artifacts, although some artifacts were obtained from direct smelting of silver ores[12].

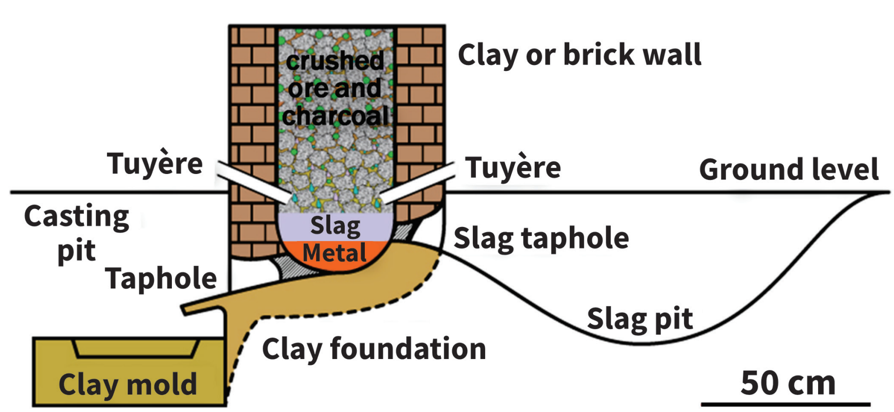

Fig. 2 — Schematic copper smelting furnace, Crete, Late Bronze Age. Adapted from Tylecote[4].

Cupellation was a multistage process employing three separate hearths. Figure 5 is a schematic of a first stage hearth for enriching smelted lead bullion. This was remelted to a high temperature using wood fuel. Bellows-powered tuyères oxidized the lead to litharge (PbO), which melts at 880°C, hence the need for a high temperature. The litharge drained via a surface groove and was discarded. More bullion was added until sufficient silver-enriched lead was obtained for the second stage. Then the enriched lead was transferred to a second hearth and again oxidized, but here the litharge was removed by dipping iron rods into it (before 1000 B.C., wooden poles) to form layered litharge cones on the rods. These rods were repeatedly removed, the litharge cones discarded, and the rods re-dipped. Eventually this second stage left a silver globule on the hearth. In the third stage, a number of globules were melted and further refined in another hearth to obtain ingots, the remaining PbO being absorbed by pores in the cupel wall.

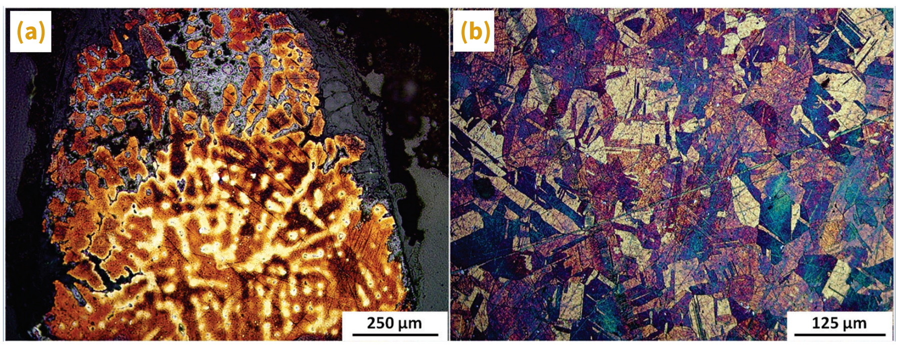

Fig. 3 — Metallographs of two binary Cu-As alloy artifacts from Iran. (a) An EBA as-cast axe head, 2.17 wt% As. (b) An LBA worked and annealed bowl, 2.10 wt% As.

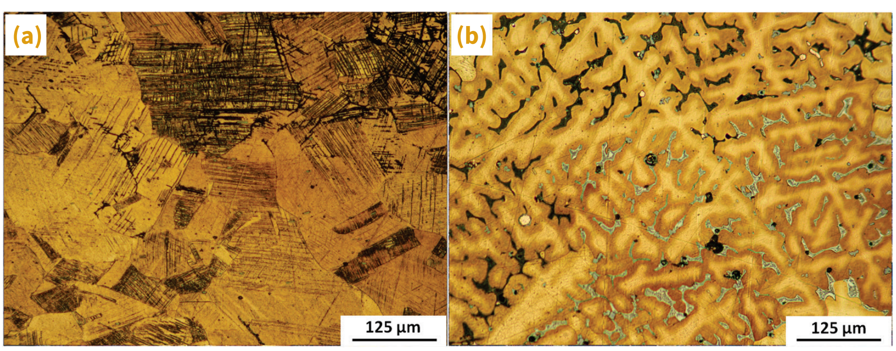

Fig. 4 — Metallographs of two binary Cu-Sn alloy artifacts from Iran. (a) An EBA worked and annealed vessel, 8.67 wt% Sn. (b) An Iron Age I as-cast tool, 10.83 wt% Sn. Note that (a) shows some retained cold-work, and (b) shows interdendritic (α + δ) eutectoid, shrinkage porosity and coring.

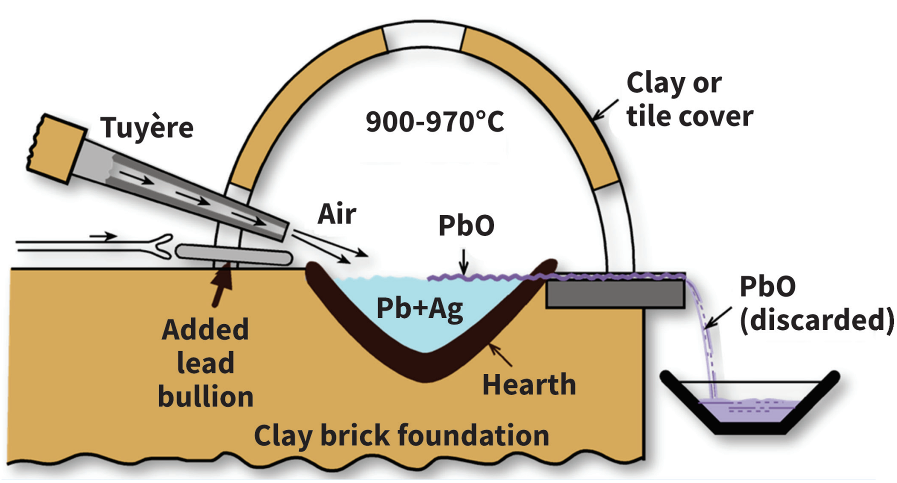

Fig. 5 — Schematic of Stage I cupellation about 500 B.C., Laurion, Greece. Adapted from Conophagos[13].

Cupellation is very effective in producing silver above 95% purity. It usually contains minor-to-trace amounts of copper, gold, bismuth, and lead (generally below 1 wt% for each), and traces of antimony, arsenic, tellurium, zinc, and nickel. Several studies have shown that copper contents above 0.5–1 wt% indicate deliberate additions, most probably to increase the strength and wear resistance in high-silver alloys, and also in larger amounts to make lower-quality artifacts and coins. Copper additions appear to have been done since about 3000 B.C.[14]. The artifacts themselves were commonly made from ingots by cold working with intermittent annealing, although cast silver objects were also produced. Many artifacts were high-quality thin-walled vessels with exquisite craftsmanship.

POST-PROCESSING PROBLEMS: CORROSION AND EMBRITTLEMENT

Unfortunately, many ancient bronze and silver artifacts have suffered corrosion and embrittlement damage owing to millennia of burial before recovery. An example from the famous high-silver Gundestrup Cauldron, dated to the 1st or 2nd century B.C., is given in Fig. 6. There are numerous publications on the burial damage, and they usually concentrate on conservation and restoration techniques but not on details of the damage. Basically, both ancient bronzes and silver may undergo both general corrosion and stress corrosion cracking (SCC), which is promoted by retained cold work and also external forces on thin-walled hollow artifacts (e.g., vessels and cups) during burial. The SCC damage is both intergranular and transgranular (along slip planes). Also, some silver artifacts show evidence of intergranular microstructural embrittlement, most probably due

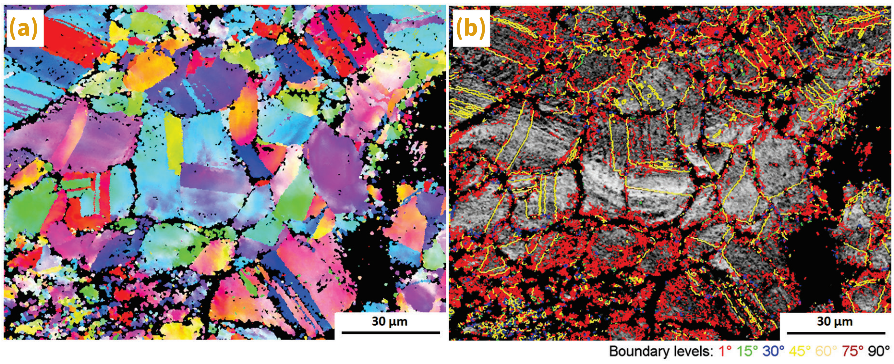

Fig. 6 — Electron back-scatter diffraction metallographs of corrosion damage in a sample from the Gundestrup Cauldron[15]. (a) Inverse pole figure color-coded map, showing equiaxed grains and annealing twins. (b) Boundary rotation angle map showing retained cold-work as dislocations (red) and deformation twins (narrowly spaced irregular yellow boundaries). The corrosion is preferentially associated with retained cold work and has been identified as stress corrosion cracking (SCC)[16].

to long-term segregation of lead, originally retained in solid solution after cupellation and working and annealing. **~AM&P**

Note: The authors recently prepared an article for a new (2022) edition of *ASM Handbook,* Volume 12, *Fractography,* which discusses the types of damage in ancient metals, including tin bronze and high-silver artifacts[17]. The implications of all these types of damage for conservation and restoration are discussed in the article.

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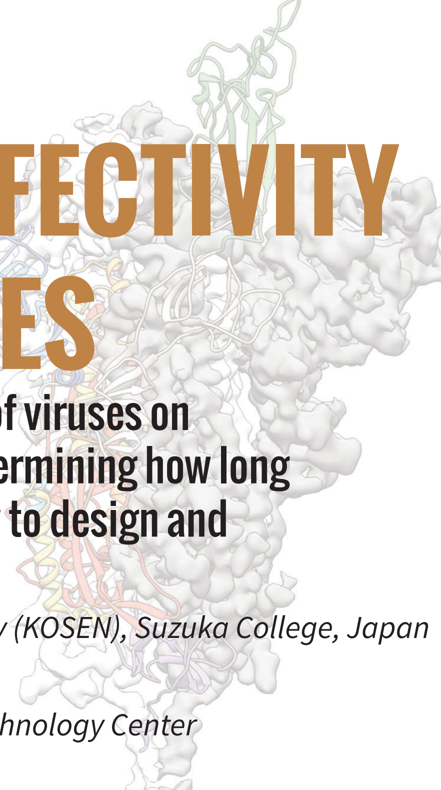
GET ENGAGED, GET INVOLVED, GET CONNECTED

Join the conversation about historic metals. The archaeometallurgy community on ASM Connect welcomes new participants. Visit connect.asminternational.org, search for the Archaeometallurgy Committee, and get into the conversation!



MATERIALS SCIENCE AND CORONAVIRUS SERIES

MEASURING VIRUS INFECTIVITY ON MATERIAL SURFACES

Various methods are available to evaluate the behavior of viruses on material surfaces, an important area of research for determining how long a virus can live on an inanimate object, and learning how to design and develop advanced antiviral materials.

Hideyuki Kanematsu and Risa Kawai, National Institute of Technology (KOSEN), Suzuka College, Japan*

Dana M. Barry, Clarkson University and SUNY Canton, New York

Eri Nakajima and Yasuo Imoto, Japan Textile Products Quality and Technology Center

According to statistics investigated by the National Institute of Technology (KOSEN) in Japan, the country's antibacterial materials market value was around $8 billion in 2019. This category includes both antiviral and antifungal materials. By the end of 2020, the market had doubled[1]. As the battle against COVID-19 continues, we have learned that viruses not only spread from human to human directly through breathing shared air, but also via the surfaces of products[2]. Viruses remain infective on material surfaces, yet the duration of infectivity varies depending on the specific material.

BACTERIAL VERSUS VIRAL INFECTION

Bacteria and viruses do not share the same mechanism for infection[3]. Most bacteria produce toxic substances (toxins and enzymes) that destroy cells in human bodies (Fig. 1). In contrast, viral infections use a different mechanism. Viruses are mainly composed of nucleic acids (DNA or RNA) and proteins. The nucleic acid is in the center and is usually surrounded by a sheath of proteins called a capsid. Many viruses belong to the simple structural group of noroviruses, which are most common during winter and often cause gastroenteritis. Other viruses have an envelope outside of the capsid, which is composed of double lipid layers. Sometimes the bar-type glycoproteins look like spikes on the surface of the envelope. COVID-19 and influenza A belong to this group (Fig. 2).

In the case of viruses, they first attach to host cells. In fact, the driving force of the virus is the interaction between the protein components on its surface and a specific receptor on the host cells. After adsorption of the virus on host cells, parts or entire viruses enter the cells. Next, the nucleic acid of the virus is incorporated into the host cells. Reproduction of the nucleic acids begins, as well as the synthesis of proteins in the host cell. Finally, new viruses are born and released from the host cell. In this manner, viruses spread from human to human.

In the case of inanimate materials, virus growth cannot occur because there are no receptors on the material to act as a host. In addition, the collapse of viral structures, deformation, and reactions with environmental components could decrease or end the infectivity of the virus as it sits on the material. Further, because the infectivity of the virus decreases at different rates depending on the substrate, the collapse or change

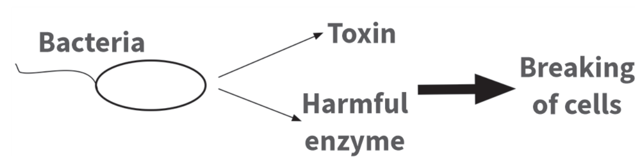


Fig. 1 — Infection and microbes.

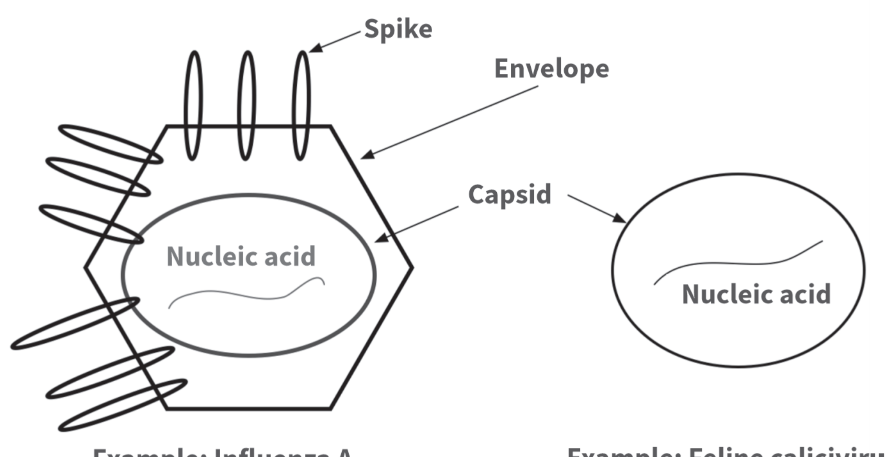


Fig. 2 — Schematic of viral structures.

*Member of ASM International

of viral structures must involve the specific components of the substrate itself. From the standpoint of antiviral materials development, this effect should be investigated further.

VIRUSES ON MATERIALS

Viruses can live on inanimate materials even though there are no virus-receptor interactions as there are in biological systems. The virus generally maintains its activity for a couple of days—during which time it can still infect human beings. The duration of infectious capabilities depends on the properties of the specific material involved. As described above, there must be some reaction or interaction between the virus and the material. To find the mechanism of the interaction or potential reaction, an evaluation system must be developed so that new and advanced antiviral materials can be created.

MEASURING VIRUS ACTIVITY

Various methods are available to evaluate the behavior of viruses on material surfaces. For example, transmission electron microscopes (TEMs) are often used to visualize viruses. There are also detection methods such as the antigen-antibody reaction (AAR) (called immunochromatography) and enzyme-linked immunosorbent assay (ELISA). However, these techniques are not suitable for evaluating the antiviral characteristics of materials. This is because those evaluation methods usually depend on expensive and high-performance apparatus requiring experienced operators, and quantitative evaluation is difficult. Fortunately, a few other evaluation methods have been developed to determine the antiviral characteristics of materials.

Because viruses are particles on the nanoscale, it is difficult to count their numbers. Such a process requires a high-resolution microscope such as a TEM. Evaluation of viral infectivity is usually achieved by measuring the cellular degeneration of the virus. When viruses are active, they retain the ability to attack cells, and this is the phenomenon used for evaluation.

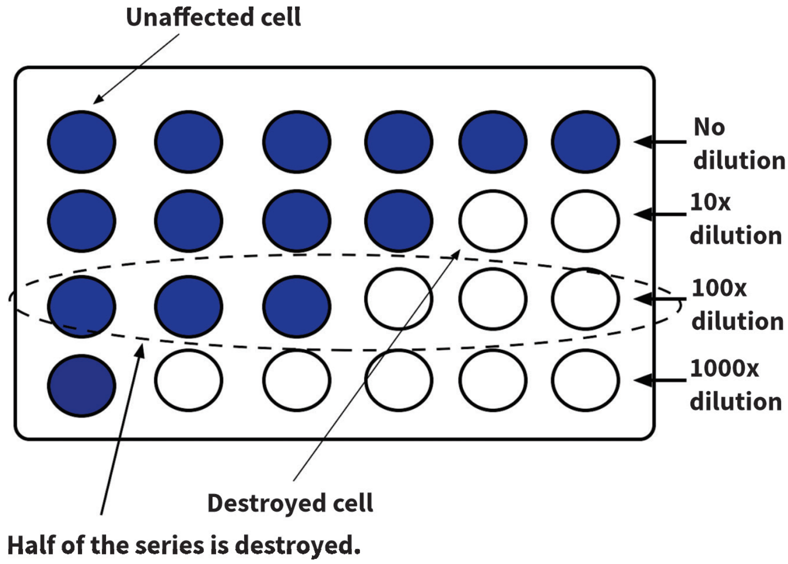


Fig. 3 — TCID50 assay.

This type of evaluation is called the tissue culture infectious dose 50 assay, or TCID50 assay[4,5]. In this method, a series of diluted viral solutions are prepared and inoculated into the cellular mediums (Fig. 3). When half of the prepared cellular mediums for each series of diluted viral solutions is destroyed, the concentration of the viral solution is defined as infectivity. For example, in Fig. 3, suppose the amount of inoculation is x ml and for the 1% diluted series, half of the inoculated cells would be destroyed. In this case, we could calculate the infectivity of the virus as follows:

Viral infectivity = 100 (dilution factor) / x (1)

Or,

Viral infectivity = log (100/x) (2)

An alternative technique is a plaque assay[6,7]. This method exploits the phenomenon of viruses forming visible destroyed areas, which appear as white circular shapes on the surface of cellular cultures. The area is called plaque. The number of plaque shapes is countable and the logarithmic number (plaque-forming unit or PFU) is defined as infectivity. Figure 4 shows an example of plaque formations.

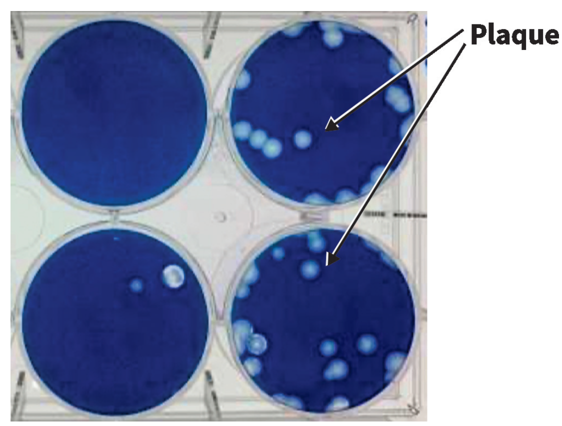


Fig. 4 — Plaque formation.

Consider an example where the plaque number of a target specimen would be P_T, while that for a non-worked specimen, or the initial plaque number as a control, would be P_0.

Then the viral infectivity could be defined by the following equation:

Viral infectivity of materials = $-(\log P_T - \log P_0)$ (3)

It is important to understand the infectivity of materials, and another type of evaluation involves the film covering method (Fig. 5). In a previous article in this magazine, one of the authors highlighted the use of this technique to evaluate the antibacterial effect of different materials[8].

In this method, a designated amount of viral solution (containing a

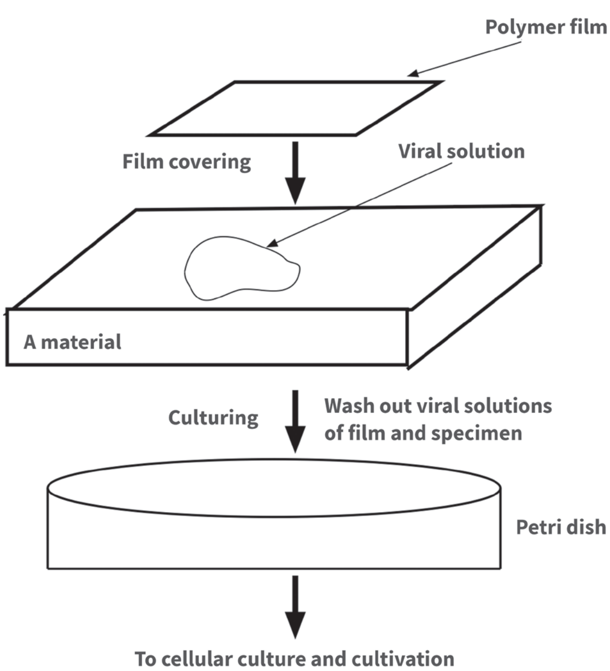


Fig. 5 — Film covering method for antiviral evaluation.

SIAA
ISO 21702

Fig. 6 — SIAA certification mark for antibacterial materials.

specific kind of virus) is placed on a material. Then a polymer film (serving as a cover) is positioned over the solution. After a certain amount of time, culturing is stopped in an incubator at a specified temperature. Next, the film and specimen are washed out into a petri dish and the washed-out solution is inoculated into a cellular culture. After cultivation takes place for a certain amount of time at a set temperature, the plaque forms are counted. From this, the infectivity of the material is determined.

This assay and the corresponding evaluation method for the antiviral characteristics of materials (particularly polymeric materials) are standardized as ISO 21702. The Society of International Sustaining Growth for Antimicrobial Articles (SIAA)[9] organized various committees and investigated the effectiveness of this method. After the ISO standard was established, SIAA created a certification mark and began to certify the quality of antiviral characteristics of different products in July 2019 (Fig. 6)[10].

The assay does not always indicate that the viral infectivity of a material (as obtained by these methods) is the index for human infection. The direct relationship between these variables requires further research. However, this assay could be used to determine how long viruses on material surfaces retain their potential to infect people. Therefore, the development and use of this method continues to be of significant interest. **~AM&P**

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

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AUTHOR SPOTLIGHT: HIDEYUKI KANEMATSU

Hideyuki Kanematsu is a professor of materials science and engineering at the National Institute of Technology (NIT) (KOSEN), Suzuka College in Japan. His research focuses on how to measure and control the infectious capability of material surfaces. Kanematsu and his team concentrate on the interaction between materials and microbes in different settings, from healthcare and food sanitation to corrosion and power generation. Kanematsu received his country's Minister of Education, Culture, Sports, Science, and Technology Award in early May, considered the number one prize from the Minister of Education in the Japanese government. He is a longtime member of ASM and currently serves on the AM&P Editorial Committee and the International Materials Reviews Committee.

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IMAT

ASM'S ANNUAL MEETING

INTERNATIONAL MATERIALS, APPLICATIONS & TECHNOLOGIES

2021

SEPTEMBER 13–16, 2021 | ST. LOUIS, MISSOURI

SHOW PREVIEW

ASM International invites you to participate in its new fall event, IMAT 2021—the International Materials, Applications, & Technologies Conference and Exhibition. Meet us in St. Louis from September 13-16 for a comprehensive lineup of technical sessions, high-level keynotes, networking events, and an exhibit floor. With a theme of Solving Global Materials Challenges, the conference combines with a two-day exposition to bring together major OEMs, materials partners, and suppliers to highlight advanced materials, processes, and applications throughout the materials community.

No other conference integrates applied materials technologies and applications with economics, environmental issues, and enabling digital technologies. With its broad reach, ASM unites different market segments that cross the entire materials world and connects industry, academia, and government to solve global materials challenges. The result is a program rich with top-notch experts brought to you by ASM and its organizing partner, Association for Materials Protection and Performance. Also, for your comfort, many new safety protocols will be in place to protect the health of our attendees. Join us for this exciting one-of-a-kind materials event!

TECHNICAL PROGRAM

This new IMAT event features robust programming with nearly 450 technical presentations in 17 topic areas, with additive manufacturing, failure analysis, and joining as some of the largest symposia. Special sessions on corrosion control will be delivered by event partner, Association for Materials Protection and Performance.

Multiple panel sessions are planned.

SCHEDULE AT-A-GLANCE

The preliminary schedule included here is subject to change. Below is an abbreviated schedule of events, highlighting technical programming and exhibit hours. Visit imatevent.org for full schedule.

MONDAY, SEPTEMBER 13	
7:00–9:00 a.m.	ASM Women in Engineering Breakfast
9:00–10:00 a.m.	Keynote Session: Dr. Radenka Maric
10:20 a.m.–5:00 p.m.	IMAT Technical Programming
10:20 a.m.–5:00 p.m.	Emerging Professionals Symposium
TUESDAY, SEPTEMBER 14	
8:00 a.m.–5:00 p.m.	IMAT Technical Programming
9:00 a.m.–6:00 p.m.	Exhibit Hall Open
2:30–4:00 p.m.	Keynote Session: HEAT TREAT/IMAT JOINT SESSION Dr. James M. Boileau, FASM Dr. Paul Edwards
4:00–5:30 p.m.	Poster Session: Fluxtrol Student Research Competition: PHASE 1 - POSTER PRESENTATION and general conference posters
4:00–5:30 p.m.	Welcome Reception with Exhibitors
6:00–7:30 p.m.	Young Professionals Reception
WEDNESDAY, SEPTEMBER 15	
8:00 a.m.–5:00 p.m.	IMAT Technical Programming
9:00 a.m.–5:00 p.m.	Exhibit Hall Open
11:00 a.m.–12:00 p.m.	Keynote Session: James Ruud
1:00–2:00 p.m.	Fluxtrol Student Research Competition—Phase 2 Oral Presentations
6:00–9:00 p.m.	"The Heat is On" Networking Event at the Anheuser-Busch Brewery/Biergarten
THURSDAY, SEPTEMBER 16	
8:00 a.m.–12:00 p.m.	IMAT Technical Programming
9:00 a.m.–12:00 p.m.	Exhibit Hall Open

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KEYNOTE SPEAKERS

TUESDAY, SEPTEMBER 14

HYDROGEN AS AN ENERGY CARRIER
11:00 A.M.–12:00 P.M.

DR. IAN M. ROBERTSON, FASM
ASM-TMS Distinguished Lecture in Materials & Society
Dean of the College of Engineering
University of Wisconsin

TUESDAY, SEPTEMBER 14

JOINT HEAT TREAT/IMAT KEYNOTE SESSION

OPPORTUNITIES IN THE ELECTRICAL VEHICLE WORLD
2:30–4:00 P.M.

DR. PAUL EDWARDS
IMAT Speaker
Director/Materials Engineering, Tesla

DR. JAMES M. BOILEAU, FASM
Heat Treat Speaker
Metallurgist, Element Materials Technology and Retired Materials Technical Expert, Ford Motor Company

WEDNESDAY, SEPTEMBER 15

EMERGING MATERIALS TECHNOLOGIES FOR POWER GENERATION
11:00 A.M.–12:00 P.M.

DR. JAMES RUUD
Senior Principal Scientist
GE Global Research Center

Subject to change. Speakers current as of June 24.

SPECIAL AWARD LECTURES

ALPHA SIGMA MU LECTURE

INNOVATION THROUGH DESIGN STRATEGY: A MATERIAL'S JOURNEY FROM COATINGS TO BIOMEDICAL INTERVENTION

PROF. SUDIPTA SEAL, FASM
Materials Science & Engineering, AMPAC, University of Central Florida

ASM EDWARD DEMILLE CAMPBELL MEMORIAL LECTURES

2021 COMPUTATIONAL MATERIALS SCIENCE: PAST, PRESENT, AND FUTURE

PROF. ELIZABETH HOLM, FASM
Carnegie Mellon University

2020 ADDITIVE MANUFACTURING: DISRUPTING GLOBAL SUPPLY CHAINS AND ENABLING SUSTAINABLE DEVELOPMENT

DR. MRITYUNJAY SINGH, FASM
Chief Scientist
Ohio Aerospace Institute

HENRY CLIFTON SORBY LECTURES

2021: MICROSCOPY, DISLOCATIONS, AND INTERFACES

PROF. C. BARRY CARTER
Distinguished Affiliate Scientist, CINT at Sandia National Laboratories and Emeritus Professor, University of Connecticut, Storrs

2020: THE ROLE OF ADVANCED MICROSTRUCTURAL ANALYSIS IN OPTIMIZATION OF MATERIAL PERFORMANCE IN DEMANDING ENVIRONMENTS

PROF. M. GRACE BURKE, FASM
Professor and Director of the Materials Performance Centre at the University of Manchester, U.K.

Subject to change. Speakers current as of June 24.

SPECIAL EVENTS

ASM WOMEN IN MATERIALS ENGINEERING BREAKFAST
MONDAY, SEPTEMBER 13 | 7:00 – 9:00 A.M.
Sandra Magnus, former NASA astronaut, will present and lead a discussion on “Avoiding A Single Engineering Narrative.” This breakfast is a popular annual event and usually sells out.

WELCOME RECEPTION WITH EXHIBITORS
TUESDAY, SEPTEMBER 14 | 4:00 – 5:30 P.M.
Take the opportunity to network with colleagues, attendees, and exhibitors in a casual setting on the show floor.

FAS, HTS, AND IMS GENERAL MEMBERSHIP MEETINGS
Three ASM affiliate societies, Failure Analysis Society, Heat Treating Society, and International Metallographic Society, will conduct their annual business meetings at IMAT. At those gatherings, officers will be elected for the 2021-2022 term and other society business will be transacted. FAS, HTS, and IMS members and guests are welcome. Check imatevent.org for dates and times.

EXHIBITOR LIST

EAG Laboratories
Electron Microscopy Sciences
Fritsch Milling and Sizing
GeniCore
Hitachi High-Tech America, Inc.
HORIBA Scientific
International Thermal Systems LLC
JEOL USA
KnightHawk Engineering
Laboratory Testing Inc.
LECO Corporation
MTS Systems Corporation
Nabertherm Inc.
NSL Analytical Services
Park Systems Inc.
Quartz Imaging
QuesTek Innovations LLC
Rhenium Alloys
SINTX Technologies
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Exhibitor list current as of June 24.

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EXHIBITION HOURS

Tuesday, September 14 | 9:00 a.m. – 6:00 p.m.
Welcome Reception with Exhibitors: 4:00 – 5:30 p.m.
Wednesday, September 15 | 9:00 a.m. – 5:00 p.m.
Thursday, September 16 | 9:00 a.m. – 12:00 p.m.

HEAT TREAT 21

31ST HEAT TREATING SOCIETY CONFERENCE & EXPOSITION

SEPTEMBER 14–16, 2021 | ST. LOUIS, MISSOURI

SHOW PREVIEW

The ASM Heat Treating Society will hold its 31st conference and exhibition in St. Louis this September. More than 3500 people are expected to gather to exchange ideas, information, and insights on heat treating technology and how it can be employed to improve the quality of metals and alloys and add value to products made from them. In addition to a strong technical program, the two and a half day event also includes networking opportunities, social activities, and educational courses. Meet us in St. Louis to take part in this can't-miss, biannual heat treating event.

SPECIAL EVENTS

ASM-HTS GENERAL MEMBERSHIP MEETING

TUESDAY, SEPTEMBER 14 7:00 – 8:00 A.M.

Open to all attendees. The purpose of the meeting is to provide a brief report on the Society's activities, introduce HTS leadership, and present HTS awards.

EXHIBITION HOURS

Tuesday, September 14 | 9:00 A.M. – 6:00 P.M.
Welcome Reception with Exhibitors: 4:00 – 5:30 P.M.
Wednesday, September 15 | 9:00 A.M. – 5:00 P.M.
Thursday, September 16 | 9:00 A.M. – 12:00 P.M.

SOLUTIONS CENTER AT HEAT TREAT 2021

The crowd-pleasing Solutions Center focuses on solving actual customer problems with FREE presentations given by Heat Treat and (NEW!) IMAT exhibiting companies! The talks will include products and/or services that can help attendees solve a particular manufacturing problem or improve productivity. Presentations will be offered Tuesday – Thursday in the Industry Forum area at the back of the 600 aisle.

For event details and to register, visit **heattreatevent.org**

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HTS Heat Treating Society ASM INTERNATIONAL
ASM INTERNATIONAL

PROGRAM HIGHLIGHTS

JOINT HEAT TREAT/IMAT KEYNOTE SESSION

OPPORTUNITIES IN THE ELECTRIC VEHICLE WORLD

TUESDAY, SEPTEMBER 14 | 2:30 – 4:00 P.M.

Within the last 5 years, electric vehicles (EVs) have begun to transition into the mainstream of vehicle production and sales. Given the increased public support for controlling climate-affecting emissions, it can be reasonably projected that this change to EVs will continue to increase. As an example, while currently occupying only 2% of global new vehicle sales, it is estimated that EV sales will grow to over 50% by 2050. Correspondingly, the number of internal combustion (IC) engine-powered vehicles will decrease. This shift will cause a fundamental change in the amount of business as well as the way heat-treaters conduct their business.

DR. JAMES M. BOILEAU, FASM
Heat Treat Speaker
Metallurgist, Element Materials Technology and Retired Materials Technical Expert, Ford Motor Co.
The Electric Vehicle: Driving Change in the Heat Treat Industry

DR. PAUL EDWARDS
IMAT Speaker
Director/Materials Engineering, Tesla
Materials Revolutions Require Admitting You're Wrong

HEAT TREAT KEYNOTE SESSION:

WEDNESDAY, SEPTEMBER 15 | 8:00 – 8:45 A.M.

DR. KATHY L. HAYRYNEN
Vice President of R&D, Applied Process
Ferrous Metallurgy and Heat Treatment are NOT Dead!

ASM WOMEN IN ENGINEERING BREAKFAST

MONDAY, SEPTEMBER 13 | 7:00 – 9:00 A.M.

This breakfast is a popular event and usually sells out. Sandra Magnus, former NASA astronaut, will present and lead a discussion on "Avoiding A Single Engineering Narrative."

YOUNG PROFESSIONALS NETWORKING EVENT

TUESDAY, SEPTEMBER 14 | 6:00 – 7:30 P.M.

This special networking event, for young professionals age 35 and under, will feature drinks, hors d'oeuvres and the opportunity to connect with peers in the industry. In addition to Heat Treat registrants, young professionals from IMAT and the Motion + Power Technology Expo are invited to attend.

EDUCATION COURSE

MATERIALS SELECTION AND HEAT TREATMENT OF GEARS

THURSDAY, SEPTEMBER 16 | 8:00 A.M. – 5:00 P.M.

Because of their unique contribution to the operation of so many machines and mechanical devices, gears have received special attention from the technical community for more than two millennia. New developments in gear technology, particularly from the materials and heat treatment perspectives, have improved gear performance. This course, developed jointly by the ASM Heat Treating Society and AGMA, will provide an overview of materials selection and heat treatment of gears.

TECHNICAL PROGRAM

More than 100 technical presentations, including a special Residual Stress track on Tuesday, will be delivered from Tuesday through Thursday as part of the technical sessions. For details on session topics and schedule, visit asminternational.org/heattreat.

THE HEAT IS ON!

WEDNESDAY, SEPTEMBER 15 | 6:00 – 9:00 P.M.
Anheuser-Busch Brewery/Biergarten

Join conference attendees from IMAT and MPT Expo for a celebration of beer and food at this iconic and historic brewery. Attendees will also have the opportunity to tour the famous Clydesdale stables, historic brewhouse, and Beechwood aging cellars. Transportation provided from the convention center. Tickets are sold separately and cost $85.

Subject to change. Speakers current as of June 28.

For event details and to register, visit **heattreatevent.org**

EXHIBITOR LIST

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Zircar Zirconia, Inc.

Note: Exhibitors list current as of June 28.

For event details and to register, visit **heattreatevent.org**

MAKING A MATERIAL DIFFERENCE

2020 ANNUAL REPORT

ASM MATERIALS
EDUCATION FOUNDATION

DID YOU KNOW:

Master Teachers are the heart of our ASM Materials Camp® for Teachers and support our teachers with courses that are engaging and inspiring. Master Teachers attend and train at a number of ASM Materials Camps before leading one themselves, in addition to their own extensive classroom experiences.

Our Master Teachers worked extremely hard in 2020 revamping the curriculum and adjusting due to the restraints of COVID-19. They worked tirelessly to ensure what was offered was not subpar and went above and beyond to carry out the curriculum for our teachers and students. Their flexibility to make the programs virtual and to continually make improvements throughout the pandemic shows their best-in-class endeavors and their long-standing commitment.

The primary goals of our Master Teachers are:

- To help teachers prepare for, execute, and implement materials science successfully in their classrooms
- To allow teachers to perform/practice labs and demos in a supportive environment
- To share classroom experiences by incorporating ASM Materials Camp® curriculum into their classrooms

2020 SNAPSHOT:
MATERIALS SCIENCE IN A VIRTUAL WORLD

Throughout 2020, the Foundation operated 23 virtual ASM Materials Camps® for Teachers and three virtual ASM Materials Camps® for Students, with Missouri University of Science and Technology also hosting an online camp. We gratefully accepted financial support for them from corporations, foundations, ASM Chapters, universities, and many individuals.

ASM MATERIALS CAMP® FOR TEACHERS PARTICIPANT QUOTES:

"Wow! This has been amazing so far! The pacing is great and just the right amount of time with the hands-on activities. Thank you as well for the wealth of resources and knowledge from a variety of experts."

"The week was full of great resources from Master Teachers, guests, and other teachers. The online format allowed for additional ways to share with other teachers."

2020-2021 BOARD OF TRUSTEES

PILLAR SOCIETY

The Pillar Society represents the four pillars of the ASM Materials Education Foundation's purpose:

Education • Knowledge • Leadership • Service

The Society recognizes and appreciates donors who have made end-of-life commitments to the Foundation during their lifetime. These ultimate gifts are greatly appreciated as they express the donor's strong commitment to excite young people in materials, science, and engineering careers.

Do you want to leave a legacy for tomorrow's youth and your own field? To become a member of this elite Society, simply contact the ASM Materials Education Foundation and provide a declaration of your intentions to remember the Foundation in your will or trust.

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** As of June 6, 2021*

"Our instructors were absolutely awesome and their passion really came through making learning exciting and inspiring. This is how we keep students in the classroom and coming to school every day!"

- ASM Materials Camp® for Teachers attendee

FINANCIALS

STATEMENT OF FINANCIAL POSITION (PRE-AUDIT)
DECEMBER 2020 & 2019

ASSETS

CURRENT ASSETS	2020	F/N	2019
CASH AND SHORT-TERM INVESTMENTS	$25,000		$10,674
ACCOUNTS RECEIVABLE			
Receivables	$8,050	1/	$40,505
Prepaids	0		0
Inventory	0		0
TOTAL CURRENT ASSETS	**$33,050**		**$51,180**
INVESTMENTS AT MARKET VALUE			
CAMP 1 Funds (fixed interest)	$21,235		$20,734
Balance of Funds	$14,881,237		$14,645,725
TOTAL PORTFOLIO AT MARKET VALUE	**$14,902,472**	**2/**	**$14,666,459**
Debt Owed by ASMI	$101,464	3/	0
Life Insurance Cash Surrender Value	$9,271		$8,042
Fixed Assets - Fundraising Software	0		0
Accumulated Depreciation - Fundraising Software	0		0
TOTAL ASSETS	**$15,046,257**		**$14,725,681**

LIABILITIES & ASSETS

CURRENT LIABILITIES	2020	F/N	2019
Accounts Payable and Accrued Expenses	$534		$1,146
Borrowings Under the Line of Credit	$382,245		$460,707
Deferred Revenue (Future Camps)	0		0
Debt Owed to ASMI	0	4/	$892
TOTAL CURRENT LIABILITIES	**$382,779**		**$462,743**
LONG-TERM LIABILITIES			
Long-Term Liabilities	$69,217		$67,882
Deferred Interest Income	0		0
TOTAL LONG-TERM LIABILITIES	**$69,217**		**$67,882**
NET ASSETS			
Unrestricted Net Assets	$1,885,618		$1,217,818
Operating	$1,557,354		$2,032,700
Unrealized gain (loss) on investments	$1,124,121	5/	$2,282,269
TOTAL UNRESTRICTED NET ASSETS	**$4,567,093**		**$5,532,788**
RESTRICTED NET ASSETS			
Temporarily Restricted	$1,370,980		$1,099,825
Permanently Restricted (Adjusted)	$2,162,758	6/	$1,008,521
Board Designated Restricted	$6,493,429		$6,553,921
TOTAL RESTRICTED NET ASSETS	**$10,027,167**		**$8,662,267**
TOTAL NET ASSETS	**$14,594,260**		**$14,195,055**
TOTAL LIABILITIES & NET ASSETS	**$15,046,257**		**$14,725,681**

FOOTNOTES

1/ Accruals of contributions and pledges.

2/ Market value of the investment portfolio, variance to statement due to rounding.

3/ ASMI debt to ASMMEF - See #4 and #5 below.

4/ ASMMEF debt to ASMI - Payments processed quarterly. Do not anticipate a balance here until after Summer Camp programs are complete.

5/ This represents difference between market value and cost value of the investment portfolio reflecting the overall market growth in the portfolio.

6/ Permanently restricted funds - adjusted for shortfalls

THANK YOU TO OUR 2020 DONORS!

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CHiMaD Project - Northwestern University

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TSS Thermal Spray Society
ASM INTERNATIONAL

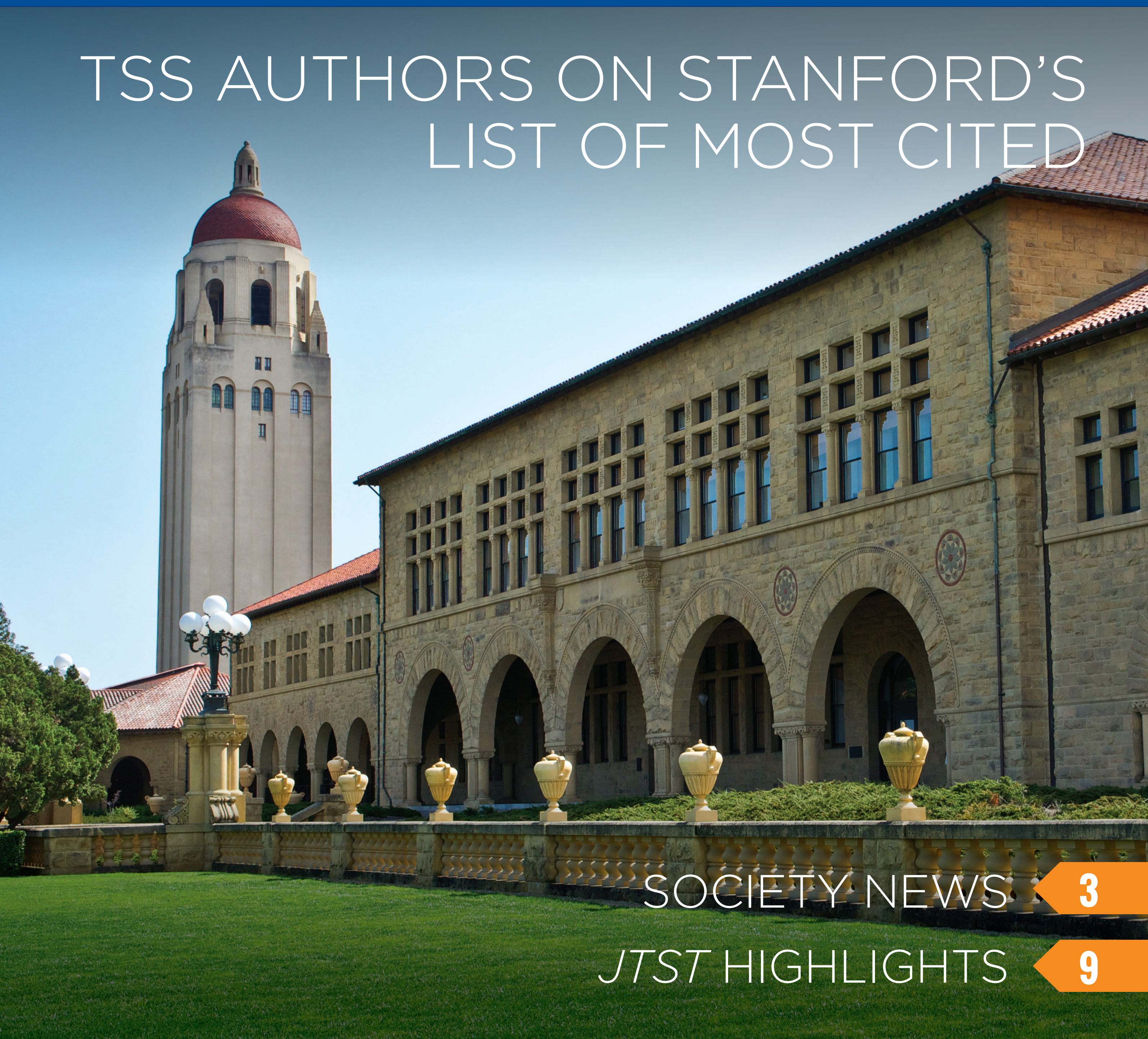
JULY/AUGUST 2021 | VOL. 16 | ISSUE 2

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

TSS AUTHORS ON STANFORD'S LIST OF MOST CITED



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tss.asminternational.org

SAVE THE DATE

COLD SPRAY
NORTH AMERICAN COLD SPRAY CONFERENCE 2022

SEPTEMBER 13-14, 2022 | NEW ORLEANS, LA

The participation of international speakers, attendees, and exhibitors at TSS events continues to increase, allowing for the advancement of content, solutions, and networking within the community. Because ASM Thermal Spray Society events are truly global, the decision has been made to postpone the 2021 North American Cold Spray Conference based on current international travel restrictions.

We hope you will join us in New Orleans for this two-day, multidisciplinary program. The schedule will include invited presentations from prominent speakers from industry, government, and academia. Attendees will gain technical insight on new technologies, exciting applications, and cutting-edge research.

coldsprayevent.org

NEM-TS 2022
New and Emerging Markets for Thick Film Coatings: Unconventional Uses of Thermal Spray

SEPTEMBER 13-14, 2022 | NEW ORLEANS, LA

Save the date for "New and Emerging Markets for Thick Film Coatings: Unconventional Uses of Thermal Spray (NEM-TS 2022)," a new topical event organized by the ASM Thermal Spray Society.

This exciting symposium will explore the unconventional application of thermal spray technology in new and emerging markets, including solid oxide fuel cells, semiconductors, electrical insulation, heating elements, functional coatings/sensors, hydrophobic coatings, PVD and CVD targets, and other industries exploring the use of thermal spray for new applications.

Event website coming soon!

Both events will be co-located with
IMAT 2022, ASM's annual meeting.

TSS
Thermal Spray Society
ASM INTERNATIONAL

JULY/AUGUST 2021 | VOL. 16 | ISSUE 2

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

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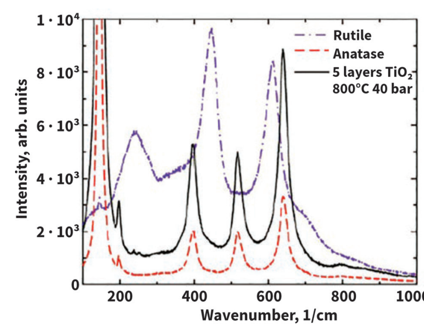
4

MEMBERS OF TSS COMMUNITY ARE AMONG TOP 2% OF MOST-CITED WORLD SCIENTISTS

7

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS



EDITORIAL OPPORTUNITIES FOR *iTSSe* IN 2022

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

April:
Aerospace Industry and Military Applications

July/August:
Energy and Power Generation

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

DEPARTMENTS

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ABOUT THE COVER

The picturesque campus of Stanford University in Palo Alto, Calif.

GROWTH AHEAD FOR THERMAL SPRAY AND AEROSPACE INDUSTRIES

What was life like for you before the arrival of COVID-19 and the resulting changes in the way we work and travel? I thought about this while virtually attending the recent ITSC 2021 meeting. In prior year's conferences, I would register and choose interesting sessions and exhibitors to visit for each day, make airline and hotel reservations, and even carefully carve out some free time to enjoy the sights of the host city. And though this year's conference shined with many interesting and highly relevant presentations and events focused on the theme "Versatile Surface Engineering for Environmental Solutions," I certainly missed the personal interactions with colleagues and students that typically make this event so meaningful.

Although dark clouds continue to linger over the aerospace industry and a full recovery may not be realized until 2024[1], there are early signs of improvement in some sectors despite huge losses and the threat of new travel restrictions. Furthermore, the past year and near future offer several opportunities to prepare for a market bounce-back and future growth within both the aerospace and thermal spray industries. These were described in a unique keynote lecture by Mitchell Dorfman, FASM, from Oerlikon Metco. Incorporating video commentary from over 30 interviews with technology leaders and specialists across the aerospace supply chain, Dorfman described the following challenges and opportunities to ensure the industry emerges with greater vitality:

Changing market conditions: The current lull in business, although worrying, is actually the perfect time to invest in adaptive and capable infrastructure as well as in the development of the next wave of thermal spray specialists to prepare for the eventual rebound.

Sustainability: Coatings will continue to be a key enabling technology for durable and fuel-efficient gas turbine engines, including wear-resistant coatings and calcium-magnesium-alumino silicate-resistant advanced thermal barrier coatings for sandy environments, environmental barrier coatings for lightweight ceramic matrix composite components, and new clearance-control coatings. Chromium replacement for aircraft structural parts will continue, driven by environmental regulations. The thermal spray industry should keep its eyes on future mobility and propulsion systems incorporating hybrid and electric designs that will reduce carbon footprint.


Bolcavage

Technology and cost of ownership: Digital transformation will support the full lifecycle of component design, manufacturing, and aftermarket service. Innovations include physics-based life models to predict coating performance in the relevant environment, as well as advanced sensor technologies to monitor thermal spray processes and adapt to Industry 4.0 initiatives. There will also be more widespread adoption of SPS, HVAF, and cold spray for OEM and MRO applications.

Workforce: The loss of skilled engineers and operators with their accumulated knowledge is a huge concern. Although the digitally enabled factory will augment some of this loss, there is a recognized urgency to train and develop workers' skills across the supply chain.

The keynote lecture and the many presentations certainly underscored the fact that while the industry grapples with business and market challenges unlike those ever seen, the pace of innovation and scientific understanding in thermal spray materials and manufacturing continues accelerating. It is still an exciting time in the aerospace industry, and it's my firm hope that come 2022, we will gladly look forward to booking our flights for ITSC and meeting face-to-face with our global colleagues.

Ann Bolcavage, FASM
Rolls-Royce

Reference

1. Accenture Commercial Aerospace Insight Report: Prepare for Takeoff, April 2021. https://www.accenture.com/_acnmedia/PDF-151/Accenture-Commercial-Aerospace-Insight-Report-2021.pdf#zoom=40.

SEEKING NOMINATIONS FOR THERMAL SPRAY HALL OF FAME

The Thermal Spray Hall of Fame, established in 1993 by the Thermal Spray Society of ASM International, recognizes and honors outstanding leaders who have made significant contributions to the science, technology, practice, education, management, and advancement of thermal spray. For a copy of the rules, nomination form, and list of previous recipients, visit tss.asminternational.org or contact maryanne.jerson@asminternational.org.

Nominations are due September 30 of this year for recognition in 2022.

TSS ANNOUNCES 2021 HALL OF FAME RECIPIENTS

The ASM Thermal Spray Society (TSS) is pleased to welcome the following 2021 honorees into the TSS Hall of Fame: Robert Unger and Kesong Zhou.

Robert Unger began his career in thermal spray as vice president of sales for TAFA in 1983. He was fortunate to be mentored by Merle Thorpe, a thermal spray pioneer and an inaugural ASM TSS HoF recipient. Unger was instrumental in TAFA's growth by establishing arc spray as the process of choice for dimensional restoration of aircraft engines, boiler tube protection, and countless other applications.

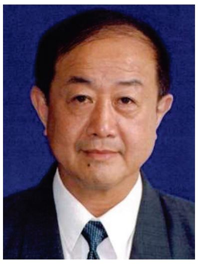

Unger

In 2004, he left TAFA and joined Polymet Corp. in Cincinnati, where he continues to serve as thermal spray sales manager. There he has been instrumental in the development and marketing of new amorphous alloys for wear protection by arc spray.

Unger has served on the ASM TSS Board of Directors, as well as chairing and serving on numerous TSS committees. He has also served as his company's representative to the International Thermal Spray Association since 1983. He has authored numerous papers and articles for ITSC and industry publications, particularly in the areas of corrosion protection and boiler tube protection. In addition, he authored the Thermal Spray Coatings chapter of ASM International's *Metals Handbook, Ninth Edition,* Vol. 13: *Corrosion.*

Unger was recognized "for enduring commitment and sustained service to the thermal spray community together with critical technical contributions fostering the development and acceptance of twin-wire arc and liquid-fuel HVOF thermal spray processes."

Kesong Zhou is a professor at the Institute of New Materials, Guangdong Academy of Sciences, and an academician of the Chinese Academy of Engineering.


Zhou

Zhou graduated from Tsinghua University in 1965. He worked at the Guangzhou Research Institute of Non-ferrous Metals since 1971 and was appointed as its president from 1992 to 2002. He was a Visiting Scholar from 1980 to 1982 at the State University of New York at Stony Brook.

His research interests include the design of novel thermal spray process systems, coating deposition behaviors, and coating microstructure design of VPS, PS-PVD, APS, and HVO/AF coatings. He also focuses his research on the applications of wear resistant coatings, corrosion resistant coatings, oxidation resistant coatings, seal coatings, and TBCs in many fields including aviation, nuclear fusion, petrochemical engineering, advanced equipment manufacturing, and the iron and steel industry.

His citation reads, "Prof. Zhou has promoted the development and dissemination of thermal spray technology and its industrial applications within China and around the world."

JOURNAL OF THERMAL SPRAY TECHNOLOGY VOLUME 29 BEST PAPER AWARDS

The *Journal of Thermal Spray Technology* (*JTST*) is pleased to announce the winners of the *JTST* Volume 29 Best Paper Awards, as chosen by an international committee of expert judges. The awards were acknowledged during this year's virtual International Thermal Spray Conference and Exposition, held May 24-28.

The Editorial Committee of the journal believes it is important to evaluate the quality of engineering and scientific contributions published in *JTST* and to provide recognition of excellent work and its publication. Each paper is reviewed and evaluated on its merits for scientific and engineering content, originality, and presentation style. The *JTST* Editorial Board and the ASM Thermal Spray Society Executive Board of Directors extend their congratulations to the winning authors:

Best Paper Award

"Plasma Spraying of $CaCO_3$ Coatings from Oyster and Mussel Shell" by Steve Matthews and Alec Asadov, The University of Auckland.


Matthews


Asadov

Best Paper Honorable Mention

"Thermal Swing Evaluation of Thermal Barrier Coatings for Diesel Engines" by John Saputo, Hwasoo Lee, and Sanjay Sampath, Stony Brook University; Gregory Smith, Stony Brook University and Naval Research Laboratory; and Eric Gingrich and Michael Tess, U.S. Army Ground Vehicle System Center.

MEMBERS OF TSS COMMUNITY ARE AMONG TOP 2% OF MOST-CITED WORLD SCIENTISTS

Thermal spray community identifies many in its ranks on Stanford's list of the top 2% of scientists worldwide based on citation data.

Rogerio S. Lima, TSS VP, National Research Council of Canada, QC, Canada*
Christopher C. Berndt, FASM, TSS-HoF, Swinburne University of Technology, Australia*

BACKGROUND

A study led by Stanford University and published in 2020 in *PLOS Biology* (a peer-reviewed open-access journal) provided a comprehensive list that identified the top 2% of scientists worldwide. The paper, led by Prof. John P. A. Ioannidis, is titled "Updated Science-wide Author Databases of Standardized Citation Indicators" (https://bit.ly/357Gl9y).

Stanford University Main Quad. Courtesy of Wikipedia Commons.

According to Prof. Ioannidis, "*There is no large-scale database that systematically ranks all the most-cited scientists in each and every scientific field to a sufficient ranking depth.*" Moreover, according to Prof. Ioannidis, "*Google Scholar allows scientists to create their profiles and share them in public, but not all researchers have created a profile. Clarivate Analytics provides every year a list of the most-cited scientists of the last decade, but the scheme uses a coarse classification of science in only 21 fields, and even the latest, expanded listing includes only about 6000 scientists. We have tried to offer a solution to overcome many of the technical problems and provide a comprehensive database of a sufficiently large number of most-cited scientists across science.*"

The large database was created from data from Scopus. The study analyzed data from papers published from 1996 to 2019, covering nearly 7 million scientists across various disciplines. Finally, "*For papers published from 1960 until 1995, the citations received in 1996–2017 are also included in the calculations, but the citations received up to 1995 are not. Therefore, this version provides a measure of long-term performance, and for most living, active scientists, this also reflects their career-long impact or is a very good approximation thereof.*" More specifically, the authors were classified into 22 scientific fields and 176 subfields. The Stanford team sought to provide a comprehensive database of a sufficiently large number of the most-cited scientists.

The research team used common citation indicators, including H-index, co-authorship, and a composite indicator for career-long impact to create the dataset. This top 2% list—which corresponds to 159,683 people of ~7 million—can be found online. Download the file Table-S6-career-2019.xlsx from this link: https://bit.ly/2UlyCSM.

STATUS OF THERMAL SPRAY RESEARCHERS

This information brings an important parameter for the status of thermal spraying across the globe. Thermal spray is a well-recognized industrial process worldwide. There are many successful applications in the aerospace, power generation, anti-wear & corrosion, textile, pulp & paper, oil & gas, and mining fields. Nonetheless, it needs to be highlighted that this news has a particular and immense impact in the thermal spray scientific community (i.e., universities and research centers). In the table provided in this article, it is possible to observe many TSS members and awardees within the Top 2% list.

Citation metrics are exceedingly important for scientists and are often used as indicators to determine the relevance and importance of a given research topic. The presence of many thermal spray researchers in this list shows the *tremendous impact that thermal spray R&D* has been playing in the big picture of the science around the world. Besides recognizing the valuable contributions of past and present thermal spray-

**Member of ASM International*

ers, it also serves as a valuable incentive and inspiration to the next generation of professionals in the area. For sure, young professors, junior scientists, post-docs, and students have a great chance to pursue bright careers in thermal spray technology and make a lasting impact in science and technology. **~iTSSe**

For more information: Dr. Rogerio S. Lima, TSS VP, Senior Research Officer, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, QC, J4B 6Y4, Canada, rogerio.lima@cnrc-nrc.gc.ca.

TABLE 1 – MEMBERS OF TSS COMMUNITY ON STANFORD'S TOP 2% MOST-CITED WORLD SCIENTISTS

Author Name	Institute Name	Country Code
Agarwal, Arvind, FASM	Florida International University	USA
Anderson, Iver, FASM	Iowa State University	USA
Barbezat, Gérard	Sulzer Ltd.	CHE
Berger, Lutz Michael	Fraunhofer Institute for Ceramic Technologies and Systems IKTS	DEU
Berndt, Christopher C., FASM, TSS-HoF	Swinburne University of Technology	AUS
Bobzin, K.	Rheinisch-Westfälische Technische Hochschule Aachen	DEU
Bolelli, Giovanni	Università degli Studi di Modena e Reggio Emilia	ITA
Boulos, Maher, TSS-HoF	University of Sherbrooke	CAN
Champagne, Victor K., FASM	U.S. Army Research Laboratory	USA
Chandra, S.	University of Toronto	CAN
Coddet, C., TSS-HoF	Université de Technologie Belfort-Montbéliard	FRA
Dearnley, Peter A.	Boride Services Ltd.	GBR
Deevi, S. C., FASM	Virginia Commonwealth University	USA
Ding, Chuanxian, TSS-HoF	Shanghai Institute of Ceramics Chinese Academy of Sciences	CHN
Faber, Katherine, FASM	Northwestern University	USA
Fauchais, P., FASM, TSS-HoF	Universite de Limoges	FRA
Fukumoto, Masahiro, FASM, TSS-HoF	Toyohashi University of Technology	JPN
Gadow, Rainer	Universität Stuttgart	DEU
Gell, Maurice, FASM	University of Connecticut	USA
Gross, Kārlis A.	Riga Technical University	LVA
Guilemany, J.M.	Universitat de Barcelona	ESP
Haynes, J. Allen	Oak Ridge National Laboratory	USA
Heberlein, Joachim V.R., TSS-HoF	University of Minnesota	USA
Herman, Herbert, FASM, TSS-HoF	Stony Brook University	USA
Ilavsky, Jan	The Advanced Photon Source (Argonne National Lab)	USA
Jodoin, B.	University of Ottawa, Canada	CAN
Jordan, Eric H.	University of Connecticut	USA
Joshi, Shrikant, FASM	Högskolan Väst	SWE
Kesler, Olivera	University of Toronto	CAN
Khanna, A.S., FASM	The Society for Surface Protective Coatings	IND
Khor, K.A.	School of Mechanical and Aerospace Engineering	SGP
Klassen, Thomas	Helmholtz-Zentrum Geesthacht - Zentrum für Material- und Küstenforschung GmbH	DEU
Kreye, H., TSS-HoF	Helmut Schmidt University - University of the Federal Armed Forces Hamburg	DEU
Kuroda, Seiji, FASM, TSS-HoF	National Institute for Materials Science	JPN
Lee, Changhee, FASM	Hanyang University	KOR
Lee, Kang N.	NASA Glenn Research Center	USA
Li, Chang Jiu, FASM, TSS-HoF	Xi'an Jiaotong University	CHN
Liao, H.L.	Université de Technologie Belfort-Montbéliard	FRA
Lima, Rogerio S.	National Research Council Canada	CAN

(continued)

TABLE 1 – MEMBERS OF TSS COMMUNITY ON STANFORD'S TOP 2% MOST-CITED WORLD SCIENTISTS (continued)

Author Name	Institute Name	Country Code
Lugscheider, E., FASM, TSS-HoF	Institut fuer Oberflaechentechnik	DEU
Matthews, Allan	University of Manchester	GBR
McCartney, David Graham	University of Nottingham	GBR
McPherson, R., TSS-HoF	Commonwealth Scientific and Industrial Research Organization	AUS
Miller, Robert A., TSS-HoF	Vantage Partners, LLC (NASA GRC Contractor)	USA
Moreau, Christian, FASM, TSS-HoF	Concordia University	CAN
Mostaghimi, Javad, FASM, TSS-HoF	University of Toronto	CAN
Munroe, Paul	University of New South Wales (UNSW) Australia	AUS
Padture, Nitin P.	Brown University	USA
Pawłowski, Lech, TSS-HoF	Universite de Limoges	FRA
Rybicki, Edmund F., FASM	FNACE (University of Tulsa)	USA
Sampath, Sanjay, FASM, TSS-HoF	Stony Brook University	USA
Schadler, Linda S., FASM	University of Vermont	USA
Sohn, Yongho, FASM	University of Central Florida	USA
Stöver, Detlev, TSS-HoF	Forschungszentrum Jülich (FZJ)	DEU
Sundararajan, G., FASM	International Advanced Research Centre for Powder Metallurgy and New Materials, Hyderabad	IND
Teixeira, Vasco	Universidade do Minho	PRT
Tillmann, Wolfgang	TU Dortmund University	DEU
Vaßen, Robert, FASM, TSS-HoF	Forschungszentrum Jülich (FZJ)	DEU
Vasudevan, A.K., FASM	Technical Data Analysis, Inc.	USA
Villafuerte, Julio	CenterLine (Windsor) Ltd.	CAN
Vuoristo, Petri, FASM, TSS-HoF	Tampereen Yliopisto	FIN
Xiao, Ping	University of Manchester	GBR
Yang, Guan Jun	Xi'an Jiaotong University	CHN
Yue, Stephen, FASM	McGill University	CAN
Zhu, Dongming, FASM	NASA Glenn Research Center	USA

Note: Names listed are identified as having an association with the Thermal Spray Society and its broader community. Refer to the original source to uncover inadvertent errors of omission. Institutions are as listed on the Stanford study and may not be the current affiliation. Key to the Country Codes: AUS: Australia; CAN: Canada; CHE: Switzerland; CHN: China; DEU: Germany; ESP: Spain; FIN: Finland; FRA: France; GBR: United Kingdom; IND: India; ITA: Italy; JPN: Japan; KOR: Korea; LVA: Latvia; PRT: Portugal; SGP: Singapore; SWE: Sweden; and USA: United States.

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—RAMAN SPECTROSCOPY, OXYGEN ANALYSIS, AND SURFACE ROUGHNESS MEASUREMENT

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

Dheepa Srinivasan

Raman spectroscopy is a structural characterization tool used to evaluate the arrangement of bonding in a material. An intense monochromatic light beam is applied to the sample, resulting in the electrical field of the incident radiation distorting the electron clouds that make up the chemical bonds in the sample, which have a particular energy. On reversal of the field, the wave passes, the distorted electron clouds relax, and the stored energy is reradiated. Most of the stored energy is reradiated at the same frequency as the incident exciting light; this phenomenon is called Rayleigh scattering. However, a small portion is transferred to the sample itself, exciting vibrational modes that appear as weak side bands in the spectrum at frequencies less than the incident beam. These are the Raman lines characteristic of the material.

Kliemann et al. carried out micro-Raman spectroscopy to detect phase transitions in ceramic TiO_2 coatings. Figure 1 shows the intensities obtained from a cold spray coating of TiO_2 starting with an anatase powder. The presence of both rutile and anatase forms of TiO_2 in the starting powder is clearly established, the two forms being distinguished by their individual patterns in the Raman spectrum. However, the 100% anatase structure is evident in the cold spray coating, regardless of gas temperature.

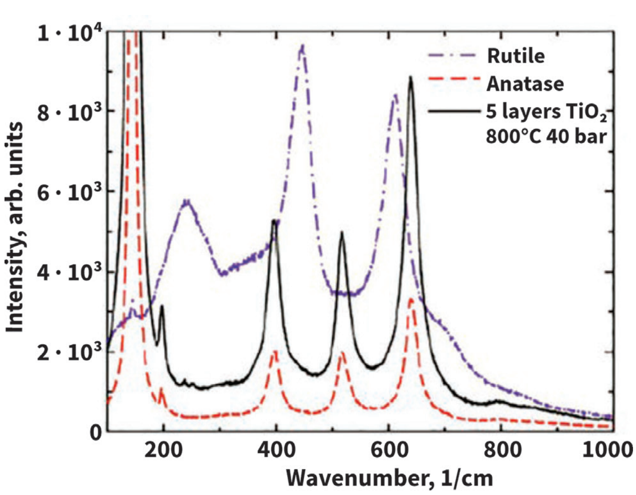


Fig. 1 — Raman shift of TiO_2 coating sprayed using nitrogen at 4 MPa (580 psi) compared with Raman spectra of rutile and anatase.

OXYGEN ANALYSIS

One of the key features that distinguishes cold spray from thermal spray is the lack of oxidation during the spray process. However, if the starting powders contain oxygen, then it becomes difficult to avoid subsequent oxidation in the coating. It is therefore important to characterize the oxygen content in the coating—starting with the powders—prior to any spraying.

A LECO analyzer is specifically designed to estimate very minute (5 to 10 ppm) traces of oxygen, nitrogen, and hydrogen in samples. It is imperative to characterize for oxygen levels, especially with materials and alloys prone to oxygen pickup such as titanium alloys. Because titanium can dissolve up to 13 wt% oxygen, it is important to know how much oxygen exists in the coating in order to interpret the mechanical properties as well as bonding characteristics with the substrate. Figure 2 shows an example of the measured oxygen levels in both warm and cold spray coatings, using the inert gas fusion method.

Other practitioners have detected the oxygen using high-resolution energy-filtered transmission electron microscopy and have found that most of the oxygen exists near the

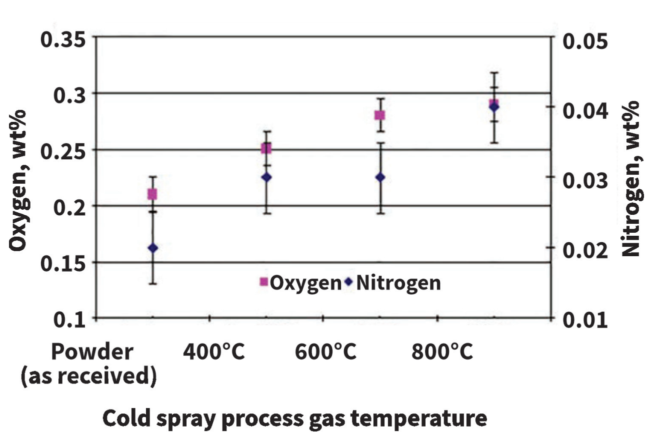


Fig. 2 — LECO analysis of oxygen and nitrogen at different cold spray gas temperatures in titanium and Ti-64.

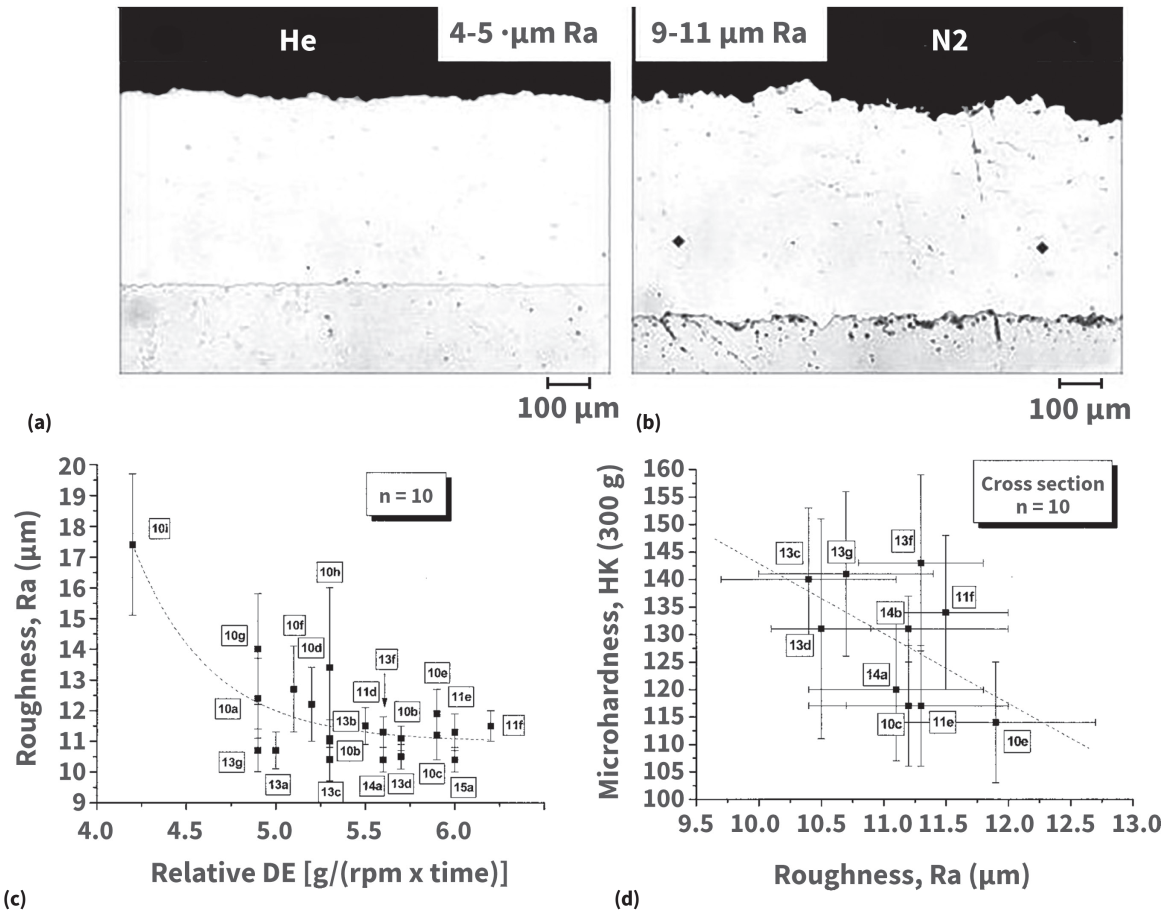


Fig. 3 — Root mean square surface roughness (Ra) measurements: (a, b) Optical micrographs showing variation in surface roughness from a helium-sprayed (4 MPa, or 580 psi, and 600°C, or 1110°F) versus nitrogen-sprayed (5 MPa, or 725 psi, and 800°C, or 1470°F) IN625 coating on AISI steel. Insets in the micrographs indicate the average surface roughness measurement; (c) roughness versus deposition efficiency (DE) of a cold spray titanium coating; and (d) microhardness versus roughness for a titanium coating.

interface of the substrate/particle or particle/particle boundaries. Inert gas fusion is also used to determine the oxygen content in the coatings. Typically, the oxygen content of the cold spray coating is largely determined by the oxygen content of the original powder.

SURFACE ROUGHNESS

The first step in any coating process is characterization of the surface. Roughness (Ra) is the average of the deviation from the average height of a surface profile. This can be measured using a simple handheld surface profilometer (a mechanical profiler with a spring-loaded stylus) or by more sophisticated methods such as interferometry (using an optical profiler), atomic force microscopy, or scanning tunneling microscopy. Simple to use, a profilometer run on a cold spray coating is an indirect indicator of the extent of deformation and bonding of the powder particles in the coating. In many instances, nitrogen coatings have a higher roughness than helium sprayed ones, as shown in Fig. 3b.

Coating surface roughness is a combination of many factors, such as powder size distribution and morphology, as well as the specific process parameters. Surface roughness is considered an indirect indicator of coating density and coating process integrity and is often used as a characterization tool during process optimization. Figures 3c and 3d show the variation of coating roughness with deposition efficiency and microhardness, respectively, for a cold spray titanium coating. Another consideration, especially in applications that involve direct use of cold spray coatings without any machining, is that coating roughness could play an important role in determining the reliability of both coating life and fatigue properties. **~iTSSe**

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

The *Journal of Thermal Spray Technology* (*JTST*), the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal spray information transfer, its mission is to synergize the rapidly advancing thermal spray industry and related industries by presenting research and development efforts leading to advancements in implementable engineering applications of the technology. Articles from the February and April issues, as selected by *JTST* Editor-in-Chief Armelle Vardelle, are highlighted here. The April issue is a special issue containing selected and expanded papers based on presentations at the 10th Asian Thermal Spray Conference (ATSC 2020). The last three articles highlighted below are from this special issue. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

INFLUENCE OF PROCESS PARAMETERS ON THE AEROSOL DEPOSITION (AD) OF YTTRIA-STABILIZED ZIROCNIA PARTICLES

Tarini Prasad Mishra, Reeti Singh, Robert Mücke, Jürgen Malzbender, Martin Bram, Olivier Guillon, and Robert Vaßen

Aerosol deposition (AD) is a novel deposition process for the fabrication of dense and rather thick oxide films at room temperature. The bonding of the deposited ceramic particles is based on a shock-loading consolidation, resulting from the impact of the ceramic particles on the substrate. However, the deposition mechanism is not fully understood. In addition, many technical challenges have been observed for achieving a successful deposition of the oxides with higher efficiency. In this work, the influence of different processing parameters on the properties of the deposited layer is studied. Proof of concept was done using 8 mol.% yttria-stabilized zirconia (8YSZ) powder as starting material. The window of deposition with respect to carrier gas flows for successful deposition was identified. (Fig. 1)

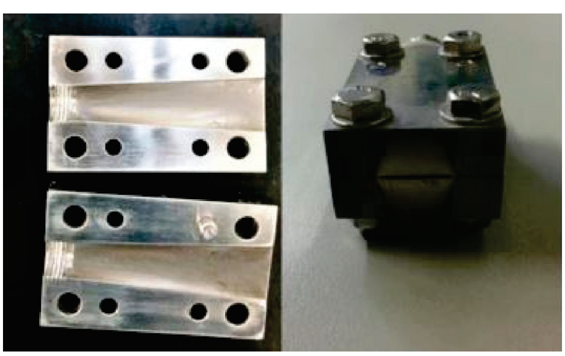


Fig. 1 — Image of the inside view and front view of the nozzle used in the current work.

A SELF-CONSISTENT SCHEME FOR UNDERSTANDING PARTICLE IMPACT AND ADHESION IN THE AEROSOL DEPOSITION PROCESS

Robert Saunders, Scooter D. Johnson, Douglas Schwer, Eric A. Patterson, Heonjune Ryou, and Edward P. Gorzkowski

Aerosol deposition (AD) is a thick-film deposition process that can produce films tens to hundreds of micrometers thick with densities greater than 95% of the bulk at room temperature. However, the precise mechanisms of bonding and densification are still under debate. To better understand and predict deposition, a self-consistent approach is employed that combines computational fluid dynamics (CFD), finite-element (FE) modeling, and experimental observation of particle impact to improve the understanding of particle flight, impact, and adhesion in the AD process. First, deposition is performed with a trial material to form a film. The process parameters are fed into a CFD model that refines the particle flow and impact velocity for a range of sizes. These values are in turn used to

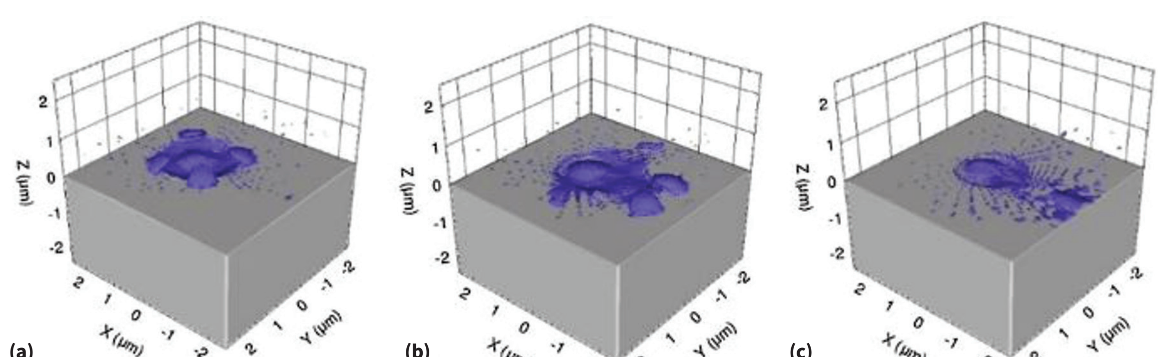


Fig. 2 — Particle state after 25 ns for oblique impacts of (a) 2.5°, (b) 15°, and (c) 30° for an Al_2O_3 particle onto an Al_2O_3 substrate.

inform the FE parameters to model the fracture and adhesion of the particle on the substrate. (Fig. 2)

SLIDING WEAR OF CONVENTIONAL AND SUSPENSION SPRAYED NANOCOMPOSITE WC-CO COATINGS: AN INVITED REVIEW

R. Ahmed, O. Ali, C.C. Berndt, and A. Fardan

This paper provides an expert review of the tribological considerations that dictate the sliding wear performance of thermal spray WC-Co coatings. Structure–property relationships and failure modes are discussed to grasp the design aspects of WC-Co coatings for tribological applications. Recent developments of suspension sprayed nanocomposite coatings are compared with conventional coatings in terms of performance and failure mechanisms. The dependency of coating microstructure, binder material, carbide size, fracture toughness, post-treatment, and hardness on sliding wear performance and test methodology is discussed. Semiempirical mathematical models of wear rate related to the influence of tribological test conditions and coating characteristics are analyzed for sliding contacts. Finally, advances for numerical modeling of sliding wear rate are discussed. (Fig. 3)

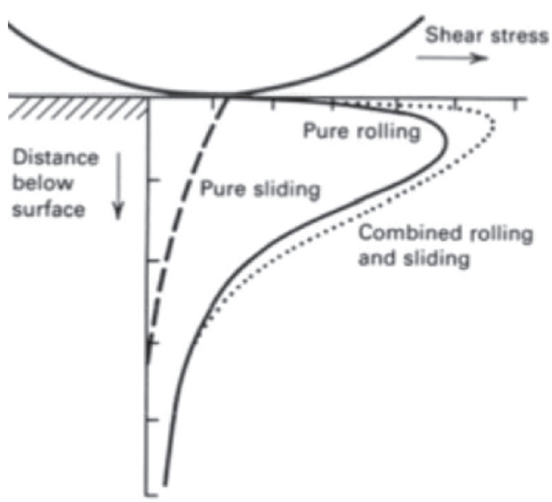


Fig. 3 — Shear stress distribution under pure rolling and pure sliding conditions (R. Ahmed, Rolling Contact Fatigue, *ASM Handbook,* Vol 11: *Failure Analysis and Prevention,* 2002).

ESTABLISHING A COLD SPRAY PARTICLE DEPOSITION WINDOW ON POLYMER SUBSTRATE

Jung-Ting Tsai, Semih Akin, Fengfeng Zhou, David F. Bahr, and Martin Byung-Guk Jun

A set of processing conditions for cold spray deposition of an embedded particle layer on a polymer substrate has been established using a dynamic impact model and verified experimentally. This research utilizes a three-network polymer model based on high strain-rate impact tests to capture the nonlinear and time-dependent response of polymer deformation during the cold spray impact with both rigid and deformable particles. The particle's material properties, particle velocity, and particle size were systematically studied to obtain the polymer deformation's various responses from finite element analysis. Particle impact velocity was experimentally measured with a double disk rotary system. (Fig. 4)

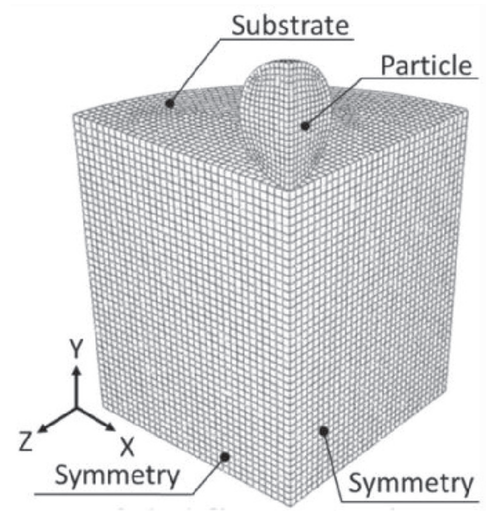


Fig. 4 — Mesh geometry and the schematic view of the FE model.

PS-PVD ALUMINA OVERLAYER ON THERMAL BARRIER COATINGS AGAINST CMAS ATTACK

Yiqian Guo, Liangliang Wei, Qing He, Yangpi Deng, Wenting He, and Hongbo Guo

Glassy deposits mainly comprising of calcium–magnesium–alumina–silicate (CMAS) accelerate the spallation of thermal barrier coatings (TBCs). In this work, an Al_2O_3 layer was produced on yttria-stabilized zirconia (YSZ) coating by plasma spray–physical vapor deposition (PS–PVD). The effects of processing parameters during PS–PVD process on the microstructures of the deposited Al_2O_3 coatings were investigated. A homogeneous Al_2O_3 coating with porosity less than 1% was deposited at the spray distance of 1400 mm, which is much denser than the coating produced by atmospheric plasma spray (APS) and other PS–PVD coatings sprayed at 1000 and 1900 mm. (Fig. 5)

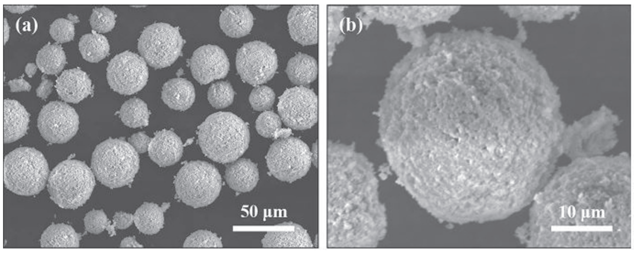


Fig. 5 — Surface morphologies of feedstock powder for spraying Al_2O_3 coatings: (a) lower magnification and (b) higher magnification.

ASMNEWS

ASM ANNOUNCES 2021 AWARD PROGRAM RECIPIENTS

The ASM International Board of Trustees has named award program recipients for 2021. The awards program recognizes achievements of members of the materials science and engineering community. ASM had hoped to present awards in person in St. Louis, however the Awards Banquet held in conjunction with IMAT 2021 will not take place this year. Therefore, ASM will present these awards, along with awards from 2020, at the ASM Awards Banquet to be held at IMAT 2022, scheduled for September 13-16, 2022, in New Orleans. ASM looks forward to celebrating all the award winners from 2020-2022 in a big way in New Orleans. We promise it will be worth the wait!

Distinguished Life Membership


Goyal

Mr. Pradeep V. Goyal, FASM, chairman and managing director, Pradeep Metals Lmt., Navi Mumbai, India, will receive this year's award "for his continuous lifelong dedication to promoting industrial activities in materials science and serving as a mentor to many underprivileged children at all levels." Distinguished Life Membership was established in 1954 and is conferred on those leaders who have devoted their time, knowledge, and abilities to the advancement of the materials industries.

Honorary Membership


Ravindran

Prof. C. Ravi Ravindran, FASM, professor, mechanical and industrial engineering, Ryerson University, Toronto, will receive this year's award "for unique contributions to innovative processes and materials development, energy conservation and improved efficiency of powertrain systems, development of materials engineers through university-industry partnerships, and being a role model for students, researchers, engineers, and the materials community." Honorary Membership in the Society was established in 1919 to recognize distinguished service to the materials science and engineering profession, ASM strategic plan and initiatives, and the progress of mankind.

Engineering Materials Achievement Award

Dr. Jason T. Sebastian, Mr. Chris Kern, Mr. Jeff Grabowski, Mr. Kerem Taskin, Dr. Thomas S. Kozmel, and **Prof. Gregory B. Olson, FASM,** from **QuesTek Innovations LLC,** Evanston, Ill., will receive this year's award "for the design and commercialization of novel high-performance carburizable steels enabling more durable, lighter weight transmission gears with increased power density." Established in 1969, this award recognizes an outstanding achievement in materials or materials systems relating to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product.


Sebastian


Kern


Grabowski


Taskin


Kozmel


Olson

Albert Sauveur Achievement Award

Prof. Enrique J. Lavernia, FASM, distinguished professor, department of materials science and engineering, University of California, Irvine, will receive this year's award "for sustained and pioneering studies on the fundamental

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Submit news of ASM and its members, chapters, and affiliate societies to Joanne Miller, editor, ASM News | ASM International
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HIGHLIGHTS 2021 AWARD PROGRAM RECIPIENTS


Lavernia

mechanisms that govern the interrelationship between processing, microstructure, and mechanical behavior of structural materials." Established in 1934 in honor of a distinguished teacher, metallographer, and metallurgist, the award recognizes pioneering materials science and engineering achievements that have stimulated organized work along similar lines to such an extent that a marked basic advance was made in the knowledge of materials science and engineering.

William Hunt Eisenman Award


Clauer

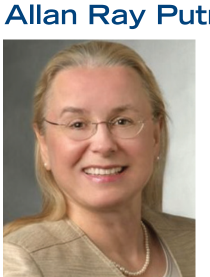
Dr. Allan H. Clauer, FASM, chief metallurgist, retired, LSP Technologies, Dublin, Ohio, will receive this year's award "for development of laser shock peening from an intriguing concept to a widely practiced technology that improves products and safety, and saves lives." The award was established in 1960, in memory of a founding member of ASM, and its first and only secretary for 40 years. It recognizes unusual achievements in industry in the practical application of materials science and engineering through production or engineering use.

J. Willard Gibbs Phase Equilibria Award


Ågren

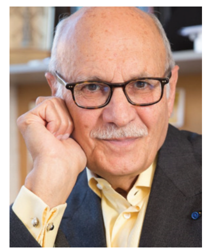
Prof. John Ågren, FASM, professor, Royal Institute of Technology, Stockholm, Sweden, will receive this year's award "for pioneering work in the field of computational thermodynamics and kinetics and their application to materials design and process improvement." The award honors J. Willard Gibbs, one of America's greatest theoretical scientists. In addition to many other contributions, Gibbs laid the thermodynamic foundations of phase equilibria theory with his brilliant essay "On the Equilibrium of Heterogeneous Substances," published in 1876 and 1878 in the *Transactions of the Connecticut Academy.*

Allan Ray Putnam Service Award


Collins

Prof. Sunniva R. Collins, FASM, professor, Case Western Reserve University, Cleveland, will receive this year's award "for her leadership of ASM International, at the chapter and national levels, supporting the Society in its goals and objectives with over three decades of committed volunteer service." Established in 1988, the award recognizes the exemplary efforts of various outstanding members of ASM International on behalf of the Society to further its objectives and goals. The purpose of this award is to recognize those individuals whose contributions have been especially noteworthy and to whom the Society owes a particularly great debt of appreciation.

Albert Easton White Distinguished Teacher Award


Apelian

Prof. Diran Apelian, FASM, distinguished professor, department of materials science and engineering, University of California, Irvine, will receive this year's award "for his legacy of excellence in teaching and innovation and being a visionary role model and inspirational mentor to two generations of students – now leaders in academia and industry." The award was established in 1960 in memory of an outstanding teacher and research engineer, who was a founding member and president of ASM in 1921. It recognizes unusually long and devoted service in teaching, as well as significant accomplishments in materials science and engineering and an unusual ability to inspire and impart enthusiasm to students.

Gold Medal Award


Ritchie

Dr. Robert O. Ritchie, FASM, professor, department of materials science and engineering, University of California, Berkeley, will receive this year's award "for seminal contributions to the micromechanical modeling and mechanistic understanding of the failure, by fracture and fatigue, of a wide range of engineering and biological materials." The medal was established in 1943 to recognize outstanding knowledge and great versatility in the application of science to the field of materials science and engineering, as well as exceptional ability in the diagnosis and solution of diversified materials problems.

Silver Medal Award


Frame

Dr. Lesley D. Frame, assistant professor, University of Connecticut, Storrs, will receive this year's award "for noteworthy research and collaborations that merge experiment and characterization of materials, materials behavior modeling, and data analytics; along with her unwavering support of diversity, equity, and inclusion within ASM International."

Rowan

Dr. Olga K. Rowan, engineer specialist, Caterpillar Inc., Dunlap, Ill., will receive this year's award "for contributions in the field of carburizing and heat treating."

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

Bronze Medal Award

Gibbs

Ms. Meghan J. Gibbs, research and development engineer 2, Nuclear Materials Science, Los Alamos National Laboratory, N.M., will receive this year's award "for excellence in process modeling, manufacturing science, and professional service impacting the U.S. steel industry and product qualification for U.S. nuclear deterrence."

Hargather

Dr. Chelsey Z. Hargather, assistant professor, New Mexico Institute of Mining and Technology, Socorro, will receive this year's award "for technical contributions to materials science and engineering through dissemination of her scientific work and graduating students; and for developing herself and her students professionally through her service to ASM."

Established in 2014, the honor recognizes members of ASM International who are in early-career positions, typically 0 to 10 years of experience, for significant contributions in the field of materials science and engineering through technical content and service to ASM and the materials science profession.

Bradley Stoughton Award for Young Teachers

Titus

Prof. Michael Titus, associate professor, Purdue University, West Lafayette, Ind., will receive this year's award "for excellence in coupling computational and experimental methods to enhance student learning across all levels, particularly focusing on processing-structure-property relationships in high temperature materials." This award, accompanied by $3000, was established in 1952 in memory of an outstanding teacher in metallurgy and dean of engineering who was president of ASM in 1942. The award recognizes young teachers of materials science, materials engineering, and design and processing, by rewarding them for their ability to impart knowledge and enthusiasm to students. The recipient must be 35 years of age or younger by May 15 of the year in which the award is made.

Henry Marion Howe Medal

Anna Jarzębska, Magdalena Bieda, Łukasz Maj, Robert Chulist, Daniel Wojtas, Martyna Strąg, Bartosz Sułkowski, Sylwia Przybysz, Wacław Pachla, and **Krzysztof Sztwiertnia** will receive this year's award for their paper

Jarzębska

Bieda

Maj

Chulist

Wojtas

Strąg

Sułkowski

Przybysz

Pachla

Sztwiertnia

entitled "Controlled Grain Refinement of Biodegradable Zn-Mg Alloy: Effect of Magnesium Alloying and Multi-pass Hydrostatic Extrusion Preceded by Hot Extrusion." Published in *Met. Trans. A,* Vol. 51A, 2020. The award was established in 1923 in memory of a distinguished teacher, metallurgist, and consultant, to honor the author(s) whose paper was selected as the best of those published in a specific volume of *Metallurgical and Materials Transactions.*

ASM Historical Landmark Designation

Oregon Iron Furnace, City of Lake Oswego, Ore., has been selected as a 2021 Historical Landmark, and the citation reads, "For being the first company in the United States to smelt pig iron west of the Rocky Mountains." In 1969, the ASM Historical Landmarks Designation was established to permanently identify the many sites and events that have played a prominent part in the discovery, development, and growth of metals and metalworking. In 1987, the scope of this award broadened to include all engineered materials.

ASM Student Paper Contest

Emadi

Mr. Payam Emadi, is recognized for his paper entitled "The Influence of High Temperature Ultrasonic Processing Time on the Microstructure and Mechanical Properties of AZ91E Magnesium Alloy," published in the *J. Mat. Eng. Perform.,* Vol. 30, 2021. The contest was established in 1985 as a mechanism for student participation in Society affairs. The award recognizes the best technical paper with a graduate or undergraduate student as first author that is published in an ASM-sponsored publication during the year.

Emerging Professionals Achievement Award

Dr. Sumedh Gostu, senior research scientist, Hydrometallurgy Air Liquide, Newark, Del., will receive this year's award "for groundbreaking contributions in the chemical processing of red mud and other secondary metallurgical waste materials and enduring contributions through the ASM International Hybrid Chapter Taskforce and devising innovative networking strategies to increase emerging professional involvement with ASM." Established in 2010, the award recognizes and honors extraordinary ASM volunteers who are less senior individuals, i.e., 0-5 years of experience post-graduation, who have made a significant impact on ASM International through devoted service and dedication to the future of the Society.

Gostu

Official ASM Annual Business Meeting Notice

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

Monday, September 13
4:00 - 5:00 p.m.
Register for the virtual meeting online at:
https://bit.ly/ASMAnnualMeeting

The purpose of the ASM Annual Business Meeting is the election of officers for the 2021-22 term, approval of proposed changes to the ASM Constitution, and transaction of other Society business.

Nominations Sought for 2022 ASM/TMS Distinguished Lectureship in Materials & Society

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

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

Qualifications of the lecturer include:

- A person experienced in national or industrial policymaking in the field of materials science and engineering.
- An eminent individual who has an overview of technology and society in which technology and society are affected by development in materials science and engineering.

- A person associated with government, industry, research, or education.

Nominations may be proposed by any member of either Society. **Submit your nominations by September 1 for consideration.** Recommendations should be submitted to the headquarters of either Society.

View sample forms, rules, and past recipients at http://www.asminternational.org/membership/awards/nominate. To nominate someone for any of these awards, contact christine.hoover@asminternational.org for a unique nomination link. You may also contact Deborah Hixon at TMS Headquarters, hixon@tms.org.

2021 LECTURERS ANNOUNCED

2021 Alpha Sigma Mu

Monday, September 13 | 3:00 – 4:00 p.m.

Prof. Sudipta Seal, FASM

MSE, AMPAC

University of Central Florida, Orlando

"Innovation through Design Strategy: A Material's Journey from Coatings to Biomedical Intervention"

Seal

Nanoparticles in a variety of forms continue to grow in importance for fundamental research and medical applications. Rare earth metals/oxides in nanoscale are widely studied for their use in catalysis, energy, environmental, and biomedical applications. Recently, nanoceria, a redox active material in the rare earth family, is being used as a high-temperature coating and as additives for chemical mechanical planarization (CMP) slurries in microelectronics. The morphologies of nanoceria play an important role in determining their redox and catalytic performances. Our research involves examination of the synthesis design strategies of CMP with various shapes and sizes and their effect on surface chemistry. While high-resolution TEM (HRTEM) is used to follow the particle structure-morphology evolution, the defected surfaces are studied using high resolution x-ray photoelectron spectroscopy (XPS). Atomistic computer simulations were used to help rationalize how the synthetic design impacts particle chemistry. Recently, we also discovered the unique antioxidant properties of the same rare earth ceria nanoparticles, where it protects mammalian cells against damage caused by increased reactive oxygen or nitrogen species and has been shown to act as an effective superoxide dismutase mimetic in vitro. This lecture will provide an overview of the biomedical applications of these redox active nanostructures.

2021 ASM/TMS Distinguished Lectureship in Materials and Society

Tuesday, September 14 | 11:00 a.m. – 12:00 p.m.

Prof. Ian M. Robertson, FASM

University of Wisconsin-Madison

"Hydrogen as an Energy Carrier"

Robertson

To meet the goals of increasing the amount of energy generated from renewable sources and decreasing CO_2 emissions, several challenges must be overcome. First, the disparity in prime locations for renewable energy production and high-use regions such as large cities or industrial sites needs to be addressed. Second, there is a need for efficient energy storage systems to mitigate the difference in peak energy production periods to peak demand times. One option for a large-scale storage system is to use the produced energy to generate hydrogen from water and to deploy hydrogen gas as the energy carrier. Hydrogen can then be used to fuel the transportation sector, and to provide energy for buildings and various industries. This talk will look at the potential benefits of using hydrogen gas as an energy carrier and will identify the challenges associated with producing sufficient quantities of hydrogen to meet the needs and delivering it safely to the consumer.

2021 Edward DeMille Campbell Memorial Lecture

Tuesday, September 14 | 9:40 – 10:40 a.m.

Prof. Elizabeth A. Holm, FASM

Carnegie Mellon University, Pittsburgh

"Computational Materials Science: Past, Present, Future"

Holm

Materials science and engineering calculations were among the first applications of digital computing, and the field of computational materials science has grown in proportion to computational power—which is to say, exponentially. We shall review the history of computing in support of materials research and observe how increases in computer capacity enable scientific advances with examples drawn from multiscale modeling in support of microstructural science. The transformative impact of integrated computational materials engineering and the Materials Genome Initiative will be discussed, along with the current focus on artificial intelligence, machine learning, and data science. Finally, we will make some predictions about where computational materials science will and will not take us in the next decade.

FROM THE PRESIDENT'S DESK

Unique Times—Unique Perspectives


Essock

ASM International is a member-driven, volunteer-based, technical Society focused on materials science and engineering. Our volunteers are the driving force of ASM. Opportunities are available for volunteers to have an impact at the local, national, and global level. Members can match their interests with the needs of the ASM materials community through ASM Connect, an online member service that features groups seeking volunteers and fosters connections with like-minded members.

Volunteering is one of the most democratic activities a member can undertake. All members are welcome to participate and encouraged to share their areas of interest and concern; volunteers need not fit into a certain mold to have their influence felt. Bringing together diverse members with unique skills and perspectives strengthens our Society.

We are in a unique time; and no, in this case I am not referring to the pandemic. This year, women have been elected to presidential positions in each of the major U.S.-headquartered materials engineering technical societies. This is a first for our materials community. Though the societies have one-year presidential terms like ASM, many also have women serving as vice president. In addition to myself and our ASM Vice President Prof. Judith Todd, FASM, The Pennsylvania State University, these leaders are:

- TMS President Dr. Ellen Cerreta, FASM, division leader, Los Alamos National Laboratory
- ACerS President Dr. Dana Goski, vice president R&D, Allied Mineral Products, and ACerS Vice President Prof. Elizabeth Dickey, North Carolina State University
- MRS President Prof. Cherie Kagan, University of Pennsylvania and MRS Vice President Dr. Carolyn Duran, vice president, Intel Corp.

In my outreach to these women leaders, we found much common interest and a shared sense of purpose to advance materials engineering and ensure diverse voices are heard in our community.

Internationally, women lead materials engineering societies in countries including France, Brazil, Germany, Slovenia, Lithuania, and Latvia. International Women in Engineering Day was celebrated on June 23, and we, in the materials community, should commemorate the diversity, equity, and inclusion advances we have collectively made. But in order to elevate our community to the highest levels, it is vital that we encourage all underrepresented minorities to become active volunteers and join our leadership ranks. In the words of Gloria Steinem, "Clearly no one knows what leadership has gone undiscovered in women of all races, and in black and other minority men." To *all* of our members from our unique and diverse communities and to their supporters—be the change agent! Today is your opportunity to help build the best tomorrow.

ASM President Diana Essock, FASM
diana.essock@asminternational.org

International Metallographic Contest at IMAT

Deadline: September 3

The International Metallographic Contest (IMC), an annual contest cosponsored by the International Metallographic Society (IMS) and ASM International to advance the science of microstructural analysis, will take place on September 12 as part of IMAT 2021. The conference is scheduled for St. Louis, September 13-16. Six different classes of competition—including a new video class—cover all fields of optical and electron microscopy:

Class 1: Light Microscopy—All Materials

Class 2: Electron Microscopy—All Materials

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

Class 4: Artistic Microscopy (Color)—All Materials

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

NEW—Class 6: Video Entry

The new video class is aimed at engaging undergraduate students who may be unable to get into the laboratory due to COVID-19 restrictions.

Best-In-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of $3000. For more information, visit metallography.net or contact IMC chair, Ellen Rabenberg at ellen.m.rabenberg@nasa.gov.

Congressional Visits Day

The 2021 Material Advantage Student Program's Virtual Congressional Visits Day (CVD) was held on April 20-22. The annual CVD provides students an opportunity to visit Washington to educate Congressional decision makers about the importance of funding for basic science, engineering, and technology. Unable to be held in D.C. this year, the program was offered virtually. Including talks, breakout sessions, and online networking with ASM and ACerS members from the D.C. Chapters, the event was attended by 27 students and faculty from 11 universities.

HIGHLIGHTS 2021 STUDENT BOARD MEMBERS

Student Board Members for 2021-2022 Announced

The ASM Board of Trustees values the insights, ideas, and participation of Material Advantage students. The Student Board Member program provides the opportunity to attend four board meetings where the students will meet and work with leading technical professionals and gain leadership skills that will benefit them throughout their career. The next deadline for submissions is February 15, 2022. Details can be found on the ASM website.

Dubey

Shruti Dubey
Indian Institute of Technology, Kanpur, India

Shruti Dubey is a doctoral scholar in the department of materials science and engineering at Indian Institute of Technology (IIT), Kanpur, U.P., India. She earned her master's degree, also from IIT Kanpur, in July 2018. With interests in thermal protection systems, she is developing thermally stable isotactic polypropylene and SiC composite nanofibers via electrospinning technology. She plans to fabricate thermal and flame retardant fibers that can be utilized as protective clothing for firefighters and defense personnel, in automotive applications, and more. She is the chair of the Material Advantage IIT Kanpur Chapter and a student delegate in ACerS, President's Council of Student Advisors.

Ruba

Andrew Ruba
Iowa State University

Andrew Ruba is a junior, pursuing a degree in materials science and engineering at Iowa State University with specializations in metals and polymers, as well as minors in English and nondestructive evaluation. In the fall, he will serve as chair of the Iowa State Material Advantage Chapter for the second consecutive year. Recently, he was the lead writer for an undergraduate-led grant application for a project aiming to recycle waste plastic and 3D print it into musical instruments. In January, he started working as a polymer co-op engineer at Mercury Marine in Fond Du Lac, Wis.

Scannapieco

David Scannapieco
Case Western Reserve University

David Scannapieco is a third-year Ph.D. student in materials science and engineering at Case Western Reserve University under Dr. John Lewandowski in the Advanced Manufacturing and Mechanical Reliability Center, where he also completed his B.S. in materials science and engineering. Scannapieco has strong interests in advanced alloy processing and mechanical characterization of materials. His current projects include developing a novel alloying technique for Cu-Cr-Nb alloys using additive manufacturing and a method of optimizing additive manufacturing parameters using mechanical properties. His technical goals include exploring new age manufacturing techniques and developing innovative materials that exploit the unique aspects of these processes.

MD CORNER

Midyear Progress Report

Aderhold

As we move into the second half of 2021, it's helpful to reflect back on our goals for the year. First, we wanted to minimize the effects of the COVID-19 pandemic-driven economic downturn for ASM and our members. Second, continue to focus on our strategic plan initiatives, and lastly, maintain the momentum of our multiyear digital transformation. At the ASM Dome, we just completed our mid-year review, and I am happy to say that we have made tremendous progress on all three goals. For example, our events are an excellent place to gather with colleagues, network, and learn about the newest advancements in materials. Throughout the pandemic, we held smaller virtual events to help keep everyone connected. This September, we are co-locating Heat Treat 21, IMAT—the International Materials, Applications, and Technologies conference, and the Motion + Power Technology Expo in St. Louis. We will have over 600 technical presentations, keynotes, and panel discussions, 250 exhibitors, and more than 300 students interested in materials engineering. Registration is open now, so do not miss this opportunity to reconnect with your peers.

One of our strategic plan focus areas is to create a global professional network with technical and professional societies through joint activities including webinars, workshops, conferences, education, and publications. Today we're working with the Japanese Institute of Metals, SF2M (France), IOM3 (U.K.), and societies in Brazil and India. You will hear more about these new partnerships in the coming months.

We began our digital transformation three years ago by creating the ASM Digital Library that gives our members easy access to our world class collection of handbooks, journals, books, and conference proceedings. Today we're continuing to transform by building an industrywide repository of materials data, tools, and education, as well as new technical committees focused on materials and process modeling, residual stress, machine learning and artificial intelligence, and materials data management and analytics. This powerful combination of people, processes, and technology will help prepare you for new challenges and opportunities ahead. Our goal is to release version one of our Data Ecosystem by the end of the year.

As always, I welcome your feedback, let me know what you're thinking.

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

Centennial Metallograph

Hallie Chavez, ASM Lab Technician

The metallograph shown here and displayed in the lower lobby of ASM International's headquarters at Materials Park, Ohio, turns 100 years old this year! Presented to ASM by the Wisconsin Electric Power Company (now We Energies), the 1921 Bausch & Lomb photometallograph could magnify samples about 1500 times. While no longer in use, the instrument serves as a testament to the ingenuity of 19th-century scientists as well as the advancement of technology throughout the last century. Though modern microscopes are much smaller and faster than the vintage Bausch & Lomb, it remains a celebrated piece of history. Read the full story on ASM's website at https://bit.ly/2TGCm1s.

FROM THE FOUNDATION

From a Volunteer's Perspective: Benefits of Volunteering with Camps

Mueller

Through my experience with materials science, I developed a belief that my knowledge should be passed on. One of the ways I found to do this is by volunteering with Eisenman Materials Camps for students. This annual camp, held at the ASM Dome, teaches failure analysis and materials science to high school students who may otherwise never be exposed to our fields. They get to personally sand cast tin, blacksmith wrought iron, and use optical and electron microscopes. Even if they do not choose to study materials engineering, they learn how materials impact their lives and what engineering life is like. In addition, I get to work with other dedicated mentors who teach me new concepts and demonstrate the true camaraderie that comes from membership in a professional society.

In 2020, the global COVID-19 pandemic threatened to derail the camps. However, with assistance from the Master Teachers, we were able to successfully convert the Eisenman Materials Camp into three weeklong virtual camps, where students could experiment with an at-home materials kit. The Master Teachers created hands-on activities for the students to perform from home, no matter where they were in the world. Many mentors dedicated their time to rapidly transition the program to a virtual medium, and staff at the Dome were able to live stream use of the ASM equipment at the teaching labs to provide as immersive an experience as possible.

The ASM Foundation volunteers and staff are looking forward to another three weeks of online ASM Materials Camps for students this summer—and they are already filled beyond initial capacity. We have found that seeing students make connections to the world around them while gaining an appreciation for the field we all care about is rewarding in any setting.

I want to personally say thank you to all those who have helped make the Eisenman Materials Camp and other ASM Materials Camps for students possible. The Master Teachers, mentors, and staff look forward to bringing this experience to even more students this year. If you would like to join us and help out, please let us know!

Erik Mueller
Mentor, Eisenman Materials Camp, 2014-present
Curriculum Leader, Eisenman Camp, 2017 and 2018
Leader, Materials Camp for Students, 2020 and 2021

Winners of the First ASM Materials Student Challenge Announced

The ASM Materials Education Foundation is pleased to announce the winners of the first ASM Materials Challenge for Students.

First prize goes to **Steven Gidaro** of Floyd E. Kellam High School, Virginia Beach, Va., for his "Testing Rig" entry. He receives $500 and a certificate.

Second prize goes to **Scout Skaggs** of Granbury High School, Granbury, Texas, for his "A Hybrid Bioplastic and Its Properties" entry. He receives $300 and a certificate.

Third prize goes to **Noah Quick and Jackson Speerhas** of Landstown High School, Virginia Beach, Va., for their "Testing the Strength of 3D Printed Objects" entry. They receive $200 and a certificate.

The ASM Materials Challenge for Students was launched in fall 2020, open to all U.S. high school students to exhibit their knowledge of materials science and engineering. Challenge specifics include:

- Students should build something with their own hands, e.g., a testing or measurement device for structural comparison of materials for a specific purpose.
- The device should be testing using data that can be shown.
- Findings should be presented in a two-page essay and in a three-minute video aimed at middle school students.

Congratulations to these inaugural winners!

EMERGING PROFESSIONALS

Compelling EPC Session at IMAT

Punnathat Bordeenithikasem, NASA Jet Propulsion Laboratory, California Institute of Technology

IMAT 2021 Session Organizer, Perspectives for Emerging Materials Professionals

Bordeenithikasem

As we transition from the unprecedented times of the global pandemic toward normalcy, ASM is planning its first ever in-person International Materials, Applications, & Technologies (IMAT) conference and exhibition. Co-located with the Heat Treating Society Conference, IMAT 2021 will be held in St. Louis, September 13-16. IMAT 2021 will feature technical sessions organized by the ASM Programming Committees, AeroMat Committee, Emerging Professionals Committee (EPC), as well as other ASM affiliated societies, in addition to informational courses, keynotes, networking events, and an exhibit floor.

The EPC symposium for IMAT 2021 titled "Perspectives for Emerging Materials Professionals" consists of nine invited speakers at different points in their careers, spanning from academia to industry to intellectual property law. The speakers are asked to share their life stories navigating the world of materials science and engineering and provide insight to the emerging professionals regarding their own career paths. The symposium ends with a panel discussion where the speakers collectively answer questions from the audience.

For the emerging professional, IMAT 2021 will provide the opportunity to keep up to date with the field of materials science and engineering in both the technical aspects and networking. It is a great chance to get introduced to new topics, learn more about what your peers are working on, and meet people who may become future collaborators, mentors, and friends. For students, IMAT 2021 is a glimpse into the materials world beyond the degree. Talking to conference attendees who represent multiple universities, companies, and institutions will offer key insights into what the future can hold. For all other attendees, IMAT 2021 is a wonderful occasion to remain current and connected, especially as we move forward from the aftermath of COVID-19.

To see the latest news about IMAT 2021, visit imatevent.org or follow ASM International on social media.

WOMEN IN ENGINEERING

*This profile series introduces materials scientists from around the world who happen to be females. Here we speak with **Caitlin Walde,** senior materials engineer, Solvus Global, Worcester, Mass., and Boston Chapter Chair.*

Walde

What part of your job do you like most?

I love the variety. I work with a variety of materials for a variety of applications with a variety of customers and colleagues. No day is ever boring and there's something new and exciting every day.

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

Never! Both of my parents are engineers and I excelled at math and science in grade school, so I never gave anything other than engineering another thought. It was just a matter of which field of engineering.

What is the best career advice you've received?

The best advice I've been given is to be stubborn about your goals and flexible about your methods. That really resonates with me from my experiences training for races and is something I can translate into my professional career.

What are you working on now?

I earned my Ph.D. researching processing of aluminum powders for cold spray applications. Now I work on a much wider range of materials, from aluminums to steels to refractory metals, still in the cold spray field. I used to do a lot of microscopy and TEM but am more focused now on bulk powder properties and consolidated mechanical properties and microstructures. I also spend more time writing proposals than I ever imagined.

Are you actively engaged with ASM?

I am actively involved in the Boston ASM Chapter—currently as chair, and as vice chair and secretary before that. I was also actively involved in WPI's Material Advantage program during grad school.

Hobbies?

Running, baking, cooking, and renovating my home.

Favorite motto or quote?

The journey of a thousand miles begins with the first step.

Last book read?

The Answer Is… by Alex Trebek.

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

ASM Digital Short Course – Basics of Welding

ASM presents a new digital short course entitled *Basics of Welding.* This is an ideal first short course for anyone who needs a working understanding of the basic principles of welding and welding techniques. Students move at their own pace in this self-guided digital course aided by helpful visuals, narrated animations, and interactive quizzes. It has been designed for those with no previous training in welding, such as technical, laboratory, and sales personnel; engineers from other disciplines; management and administrative staff; and non-technical support staff such as purchasing and receiving agents. The course teaches the basic principles of arc, electroslag, oxyfuel gas, and resistance welding processes and touches on other welding methods. Visit www.asminternational.org/basicsofwelding.

ASM Librarian Remembered

Eleanor Mary Baldwin, of Cuyahoga Falls, Ohio, served as the trusted and resourceful librarian at ASM International for 25 years, retiring in 1993. ASM recently learned that Baldwin passed away on February 27 at the age of 85. She had a love of books and was always eager to assist members by locating materials information and data for them. She also enjoyed traveling to London to archive rare books on ASM's behalf.

Former ASM librarian Eleanor Baldwin stands in front of a special atmosphere-controlled cabinet that housed some of William Hunt Eisenman's rare book collection, including such treasurers as *De Re Metallica,* written by Georgius Agricola in 1556. Photo circa 1991.

MEMBERS IN THE NEWS

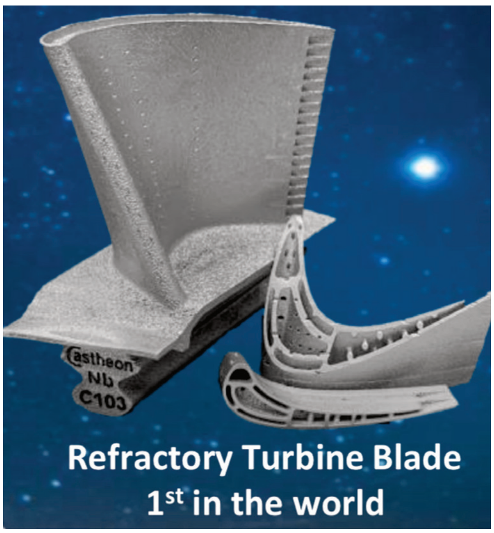
Hussain Receives Fellowship

Hussain

Tanvir Hussain, associate professor in materials engineering at the University of Nottingham, U.K., has secured over £2.1 million to develop new coatings for use in aerospace that could cut jet plane CO_2 emissions and help spacecraft built for humans venture further into our solar system. The five-year fellowship funded by the Engineering and Physical Sciences Research Council is to find modeling and processing techniques that will overhaul the design and manufacture of advanced ceramic materials for the next generation of air and space travel. The long-term vision is to build a Center of Excellence in Ceramic Coatings at the University.

Gao's 'First-in-the-World' Development

Youping Gao, founder and president of Castheon Inc., Thousand Oaks, Calif., has proven to be a pioneer in the additive manufacturing sector. He successfully 3D printed the world's first refractory alloy advanced turbine blade. Inspired by the Advanced Research Projects Agency-Energy's (ARPA-E) Ultrahigh Temperature Impervious Materials Advancing Turbine Efficiency (ULTIMATE) call, he set out to overcome the traditional challenges of refractory alloys, known for their poor manufacturability. Using additive manufacturing allowed him to develop a high quality, fully dense refractory alloy, Nb C103, in 3D laser powder bed fusion printing. Gao now serves on the industry advisory board in support of Penn State Team's ARPA-E ULTIMATE project, led by ASM immediate past president Zi-Kui Liu, FASM.



Sohn Named Engineer of the Year


Sohn

Yongho Sohn, FASM, received the 2020 Engineer of the Year Award from the Korean-American Scientists and Engineers Association (KSEA), presented by the Korean Federation of Science and Technology Societies (KOFST). His contributions to the development of metallic alloys for 3D printing and low-enriched metallic nuclear fuels were cited for the award. At the award ceremony, held virtually during the 2020 US-Korea Conference (UKC-2020), Sohn noted his sincere appreciation to KOFST for recognizing the accomplishments of U.S. scientists and engineers with Korean heritage. Sohn is currently Pegasus Professor and Lockheed Martin Professor of Engineering at the University of Central Florida.

CHAPTERS IN THE NEWS

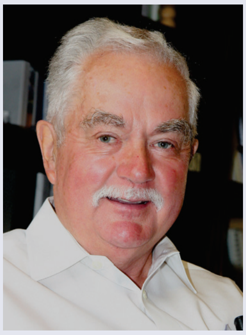
Cleveland Hand-Delivers Awards

After months of virtual meetings, ASM Cleveland Chapter leaders decided to surprise eight of their members with special in-person visits. They hand-delivered the plaques for chapter awards bestowed on their members for 2021. Here is a sampling of those visits.

The ASM Cleveland Chapter established The Cleveland Chapter Technical Educator Award to recognize a teacher or mentor in the Northeast Ohio region who has made a substantial contribution to technical education methods and/or is considered to have uniquely inspired students to pursue technical fields. Prof. Tushar Borkar (left), Cleveland State University, is the 2021 recipient. The award was presented by John Pickens, vice chair, Materials & Process Innovation.

The ASM Cleveland Chapter Outstanding Company Support Award recognizes a company that has clearly demonstrated over the years sustained, unselfish contributions to the Chapter and ASM International. Mager Scientific is the recipient of this Award. Dave Kovarik (left), chair, NSL Analytical Services, presented the 2021 Award to Steve Glancy, Mager Scientific.

IN MEMORIAM



Froes

Francis H. "Sam" Froes, FASM, of Tacoma, Wash., passed away on May 19 at age 81. An alumnus of Sheffield University, U.K., (D.Eng., engineering), he had an M.Sc. and Ph.D. in physical metallurgy. He served as an institute director and department head of materials science and engineering at the University of Idaho. Froes was involved in the titanium field with an emphasis on powder metallurgy (PM) for more than 40 years. He was leader of the titanium group at Crucible Steel Co. and later program manager on a U.S. Air Force contract on titanium PM in Dayton, Ohio. He presented keynote addresses in more than 40 different countries. A member of the Russian Academy of Science, he received the Distinguished Service to Powder Metallurgy award from the Metal Powder Industries Federation. He published more than 800 papers, held 60 patents, and edited 15 books. Froes was a frequent instructor at ASM's headquarters and contributor to ASM's *AM&P* magazine.

Hamilton

Bruce McCoy Hamilton, FASM, passed away on April 2 in his 101st year. Graduating in metallurgy from Queen's University in 1943, Hamilton embarked on a successful career in the steel industry, gaining valuable management experience at Atlas Steel and Crucible Steel. He had a distinguished career, rising to the position of president and CEO at Slater Steel Company, Ontario. Later, he served as the CEO of Sydney Steel Corp., in Nova Scotia. He was a past chair of ASM's Ontario Chapter and a recipient of the ASM Canada Council Lectureship (1982). Hamilton was awarded the Distinguished Life Membership of ASM in 1998.

Smith

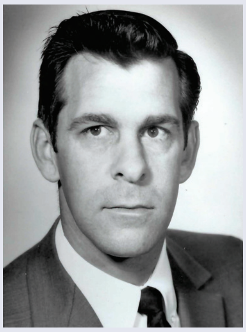
Darrell W. Smith, FASM, of Chassell, Mich., age 83, passed away on June 4. He was a professor emeritus at Michigan Technological University. He began his teaching career in 1970 in the department of metallurgical engineering at Michigan Tech, retiring in 1999. He earned his M.S. and Ph.D. from Case Western Reserve University while working at GE in Cleveland. Active in the Metal Powder Industries Federation, he received the MPIF Distinguished Service to Powder Metallurgy Award in 1997 and became a Fellow of APMI International in 2001. Smith was a past ASM trustee and member of the ASM Saginaw Valley Chapter as well as the ASM Heat Treating Society. He also taught metallurgy courses at ASM headquarters after his retirement.

Helmus

Michael Helmus, of Worcester, Mass., passed away in June at age 67. A longtime member and contributor to the biomaterials community, Helmus was most recently a consultant at his company, Medtech, and research professor of mechanical engineering at Worcester Polytechnic Institute. Previously he worked as a consultant at Exponent and was vice president of Amulet Pharmaceuticals in addition to executive research roles at Advance Nanotech, Boston Scientific, and Edwards Lifesciences. His research interests included cardiovascular devices, 3D surgical printing, biomaterials, and nanotechnology. He had 44 U.S. patents. After growing up in Philadelphia, Helmus received a B.S. in metallurgy and materials science from Lehigh University in 1975. He then earned his M.S. and Ph.D. at Case Western Reserve University in 1980. Helmus was an instrumental contributor to the joint ASM International and Granta Design effort to develop the ASM Medical Materials Database.

(continued)

IN MEMORIAM (continued)



Henry

Wiliam "Bill" Henry, 89, of Bedminster Twp., Pa., died on April 9. He was employed for 47 years at Tinius Olsen where he became their top sales leader in testing equipment, retiring in 1998. A past chair of the ASM Philadelphia Chapter (1975-1976), he was a passionate supporter of the Society, volunteering both locally and nationally. The diligence with which he maintained the Chapter membership list (in precomputer times on 3 x 5 cards in shoe boxes with metal address plates), assured the accuracy and timely publication of the Yearbook, and his recruitment of Sustaining Members is legendary. He was awarded the ASM Allan Ray Putnam Service Award in 1997, making him only one of two Philadelphia Chapter members ever to receive the award. Henry also received awards from his chapter including the Delaware Materials Person of the Year award in 1989, Adolph Schaefer Special Achievement Award in 1995, the first Chapter President's Award in 1971, the Philadelphia Chapter Distinguished Service Award in 1986, and the Meritorious Service Award in 2001.

Howard

Stanley M. Howard, of Rapid City, S.D., died on May 15 at age 75. He was professor in the department of materials and metallurgical engineering at South Dakota School of Mines and Technology. His B.S and Ph.D. in metallurgical engineering were from the Colorado School of Mines. He was also a registered professional engineer. Howard served as president of Mintech Inc., and Group V Metals Inc. Prior to his academic career, Howard gained industry and government experience at Caterpillar, Oak Ridge National Laboratory, and the U.S. Department of Navy. He was president of The Metals, Materials, and Minerals Society in 2016 and served on its board of directors for many years prior. Howard received the AIME Outstanding Educator Award in 2004 and his university's Benard A. Ennenga Faculty Award and Presidential Award, both in 1994.

Modi

Suresh Chand Modi, 71, managing director of Metallizing Equipment Company, India, passed away on May 28. Born in Jodhpur, India, he graduated in 1971 from the University of Jodhpur with a degree in mechanical engineering. He joined his family business and developed surface engineering technology there, in particular, thermal spraying, shot peening, and abrasive blasting. He developed a world-class, ISO-accredited thermal spray laboratory in India, training his staff from the ground up. He attended nearly all International Thermal Spray Conferences held in the past 40 years and developed close connections with the thermal spray community worldwide. He also was a supporter of ASM's Thermal Spray Society publications, including the *International Thermal Spray & Surface Engineering* supplement to *AM&P* magazine.

Waldeck

Frank J. Waldeck, 98, of Lake Forest, Ill., died on February 12. Waldeck retired from Lindberg Corp. as executive vice president and director in 1989 and subsequently served as a management consultant. Waldeck was project manager and board member of the Executive Service Corps of Chicago, which provided consulting services to non-profit organizations. He earned a B.B.A. from Case Western Reserve University in 1946 and an M.B.A. in 1962 from the University of Chicago. In addition, he was CPA certified in Ohio and Illinois. A past ASM trustee, Waldeck served as the Society's treasurer 1985-1988. He also was chair of the ASM Investment Committee and chair of the ASM Finance Committee.

Word has been received at ASM Headquarters of the death of Life Member **Ted Lundquist,** of Fremont, Calif. He was CTO of DCG Systems Inc. and active in the EDFAS/ISTFA community. He passed away on June 9 at age 74. A complete obituary will be included in the next issue of *Advanced Materials & Processes.*

ADVANCED MATERIALS & PROCESSES

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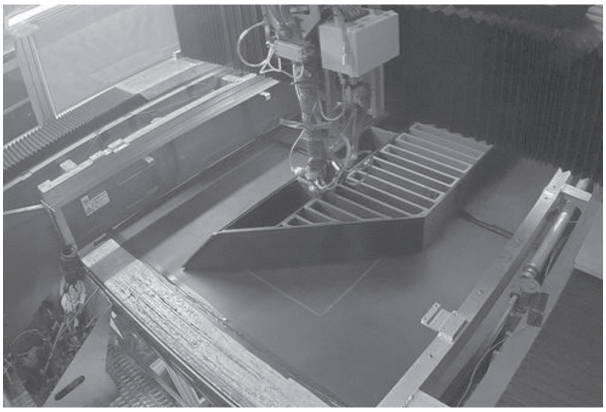
3D PRINTSHOP



Large-scale mold printed with recycled thermoplastic composite and syntactic foam.

BIGGER, YET LIGHTER BUILDS USING RECYCLED MATERIALS

Oak Ridge National Laboratory researchers, in collaboration with Cincinnati Inc., demonstrated the potential for using multimaterials and recycled composites in large-scale applications by 3D printing a mold that replicated a single facet of a precast concrete tool.

The team added a dual feed system to the Big Area Additive Manufacturing (BAAM) machine, a large format tool developed by ORNL and Cincinnati Inc. This enabled printing with multiple materials in a single build using one extruder. Within seven hours, the large 3D printer produced a 400 lb mold measuring 10 ft in length made of recycled carbon fiber reinforced thermoplastic and syntactic foam. BAAM's goal is to 3D print large, near-net shape parts as quickly as possible.

Large-scale printing with multimaterials and recycled composites is anticipated to lower the cost of tooling and open opportunities for printing structures with lightweight cores and tailored properties. "New mechanical responses can be achieved with multimaterial printing such as soft and rigid segments within a part and impact resistant structures," says ORNL's Vidya Kishore. *ornl.gov.*

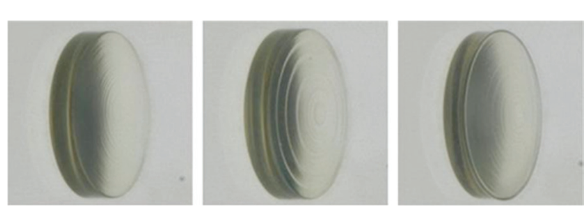
3D-PRINTED COMPLEX MICRO-OPTICS

Researchers from the University of Stuttgart, Germany, have shown that 3D printing can be used to make highly precise and complex miniature lenses with sizes of just a few microns. The microlenses can be used to correct color distortion during imaging, enabling small and lightweight cameras that can be designed for a variety of applications.

"The ability to 3D print complex micro-optics means that they can be fabricated directly onto many different surfaces such as the CCD or CMOS chips used in digital cameras," says Michael Schmid, a member of the research team. "The micro-optics can also be printed on the end of optical fibers to create very small medical endoscopes with excellent imaging quality."

The study, published in the Optical Society journal, *Optics Letters,* details how they used a type of 3D printing known as two-photon lithography to create lenses that combine refractive and diffractive surfaces. They also show that combining different materials can improve the optical performance of these lenses.

"3D printing of micro-optics has improved drastically over the past few years and offers a design freedom not available from other methods," says Schmid. "Our optimized approach for 3D printing complex micro-optics opens many possibilities for creating new and innovative optical designs. *osa.org.*



Researchers used 3D printing to make highly precise and complex apochromatic miniature lenses that can be used to correct color distortion during imaging. Courtesy of Michael Schmid/University of Stuttgart.

EB-BASED PRINTING FOR VARIABLE PROPERTIES

Dr. Carolin Körner from Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, has been awarded an Advanced Grant from the European Research Council for her work in additive manufacturing of high-performance components using high-energy electron beams.

Electron beam-based additive manufacturing allows voxel-based material design; in other words, the highly precise tuning of local material properties, with the term voxel derived from pixel-based resolution of 2D images. This process makes it possible for various areas within a component to be given different properties.

The project, Voxel-Based Material Design: Amalgamation of Additive Manufacturing and Scanning Electron Microscopy, AMELI for short, hopes to open up pioneering new possibilities for component manufacturing. "The groundbreaking combination of locally adjustable material properties and freedom of construction shifts the limitations of components made from high-performance alloys," explains Körner. As a result, additive manufacturing is becoming increasingly interesting for the aviation industry, and may also be able to contribute to increasing the effectiveness of land-based gas turbines or accelerating the expansion of hydrogen production facilities. *www.fau.eu.*