

MATERIALS & PROCESSES

AEROSPACE MATERIALS AND TESTING
NEW TESTBED FOR
SUSTAINABLE AVIATION

P. 12

16

High Temperature
Functionally Graded Alloys
for Aerospace

21

ASM Data
Ecosystem

24

3D Printed Parts for
Hypersonic Rockets



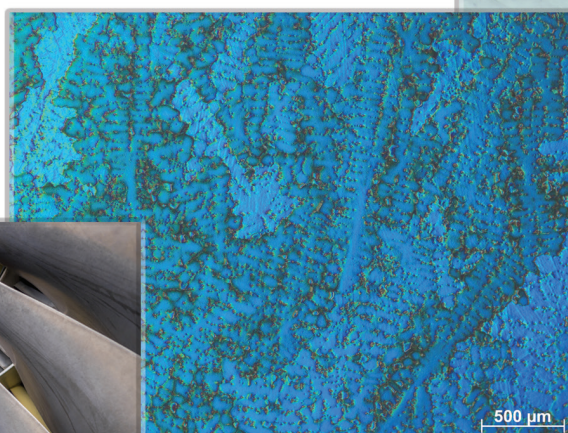
ASM
INTERNATIONAL

Sample Preparation Solutions for Aerospace Materials Including:

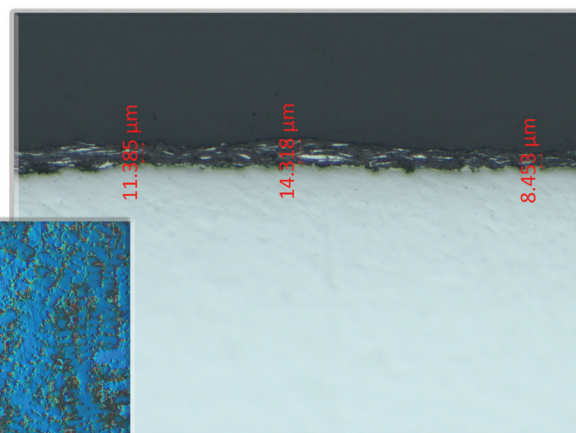
- Inconel
- Superalloys
- Titanium
- Carbon Fibers
- Ceramics
- Coatings



- Section/Mount/Grind/Polish



- Inspect & Image



- Analyze & Report



Allied equipment is designed &
manufactured in the USA

800.675.1118 US/Canada
310.635.2466 Worldwide

info@alliedhightech.com
www.alliedhightech.com

ADVANCED MATERIALS & PROCESSES

AEROSPACE MATERIALS AND TESTING
NEW TESTBED FOR
SUSTAINABLE AVIATION

P. 12

16

High Temperature
Functionally Graded Alloys
for Aerospace

21

ASM Data
Ecosystem

24

3D Printed Parts for
Hypersonic Rockets



ASM
INTERNATIONAL

SAVE THE DATE



INTERNATIONAL MATERIALS,
APPLICATIONS & TECHNOLOGIES

2022

SEPTEMBER 12-15 | ERNEST N. MORIAL CONVENTION CENTER, NEW ORLEANS, LA
EARLY BIRD REGISTRATION OPENS IN MAY!

IMAT, New Orleans...and all that jazz! New Orleans is home to Creole cuisine, rich with history, and offers unmatched southern hospitality. Come for IMAT, but stay for a little *lagniappe*!

This event offers a one-of-a-kind opportunity to network in “The Big Easy” with the “Big 3” in the materials world: Industry, Government, and Academia.

IMAT 2022 is where you will experience:

- The premier industry-focused conference surrounding the advancement of materials, processes, and their applications
- The only targeted exposition where you can showcase how your products and services improve the materials world
- Student events and competitions to develop connections with the next generation of materials scientists
- ASM International’s annual meeting

What you can expect:

- 2000 attendees
- Over 700 technical presentations, keynotes, and panel discussions
- 150 exhibitors
- 300 students
- 3.5 days of technical programming
- 2 days of expo

ORGANIZED BY:



OFFICIAL MEDIA SPONSOR:



ORGANIZING PARTNER:



CO-LOCATED WITH:



Visit imatevent.org for current information.



DECEMBER 6-8, 2022 | THE RITZ-CARLTON, NAPLES, FL

SAVE THE DATE!

Recharge in the company of visionaries, connect with other materials executives who share your fire about the future of the materials world, and unlock new thinking to spark innovation.

This year's summit will convene a powerful collection of groundbreaking innovators and top subject-matter experts, focused on the following domains:

- Materials 4.0 — Materials Genome Deployment
- Nexus of Data Science and Materials Science
- Industry 4.0 — the New Manufacturing Landscape
- Circular Economy — Materials Sustainability in the 21st Century

Plan today to join other materials executives and ASM leaders during this exclusive two-day summit, featuring keynotes, expert panel sessions, and numerous networking opportunities. Be sure to arrive early to relax and network with your peers during an informal golf outing!

REGISTRATION OPENS SUMMER 2022

asmsummitevent.org





12

NEW TESTBED HELPS DRIVE SUSTAINABLE FUTURE FOR AVIATION

Ann Bolcavage and Alistair Hobday

With the opening of Testbed 80, the largest engine testing facility in the world, Rolls-Royce plans to use its unique capabilities to accelerate the journey toward sustainable aviation technologies supported by the intelligent use of materials.

On the Cover:

Rolls-Royce's Testbed 80, in Derby, U.K., is the largest engine testing facility in the world. Courtesy of Rolls-Royce Corp.



28

AEROMAT SHOW PREVIEW

The 33rd AeroMat Conference and Exposition returns to Pasadena, Calif., in March.



43

ASM NEWS

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



56

3D PRINTSHOP

3D printing builds tailored parts using specialized materials such as "smart inks," antibacterial, and custom-designed alloys.

ADVANCED MATERIALS & PROCESSES

MARCH 2022 | VOL 180 | NO 2

FEATURES

16 EXPLORING GRADIENT PATHWAYS IN HIGH TEMPERATURE, FUNCTIONALLY GRADED ALLOYS

Soumya Nag, Brian Jordan, Ke An, Jaimie Tiley, Chuan Zhang, and Fan Zhang

A new approach aims to fabricate parts with targeted, site-specific properties for a wide range of applications in extreme environments within the aviation, space, and energy sectors.

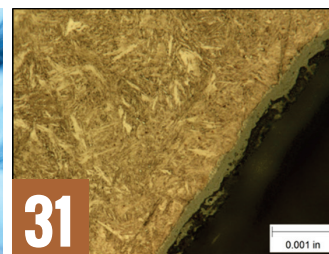
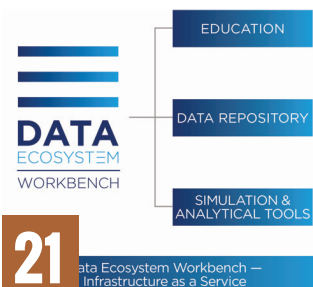
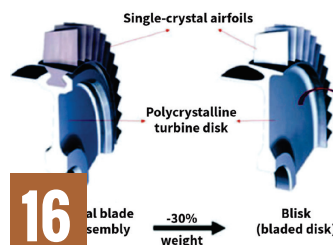
21 ASM DATA ECOSYSTEM

Raymond V. Fryan

Designed with key input from members, ASM International's new Data Ecosystem provides a digital platform to assist engineering design and manufacturing stakeholders working in the Materials 4.0 era.

24 TECHNICAL SPOTLIGHT QUALIFYING MATERIALS USING LASER POWDER BED FUSION

Ahead of formal certification, many advanced metals have been qualified for 3D printing, allowing for the creation of previously impossible aerospace parts including for the hypersonic environment.



31 HTPro

The official newsletter of the ASM Heat Treating Society (HTS). This supplement focuses on heat treating technology, processes, materials, and equipment, along with HTS news and initiatives.

TRENDS

- 4 Editorial
- 5 Research Tracks
- 6 Machine Learning

INDUSTRY NEWS

- 7 Process Technology
- 8 Metals/Polymers/Ceramics
- 10 Testing/Characterization

DEPARTMENTS

- 55 Editorial Preview
- 55 Special Advertising Section
- 55 Advertisers Index
- 56 3D PrintShop

Advanced Materials & Processes (ISSN 0882-7958, USPS 762080) publishes eight issues per year: January/February, March, April, May/June, July/August, September, October, and November/December, by ASM International, 9639 Kinsman Road, Materials Park, OH 44073-0002; tel: 440.338.5151; fax: 440.338.4634. Periodicals postage paid at Novelty, Ohio, and additional mailing offices. Vol. 180, No. 2, MARCH 2022. Copyright © 2022 by ASM International®. All rights reserved. Distributed at no charge to ASM members in the United States, Canada, and Mexico. International members can pay a \$30 per year surcharge to receive printed issues. Subscriptions: \$499. Single copies: \$54. POSTMASTER: Send 3579 forms to ASM International, Materials Park, OH 44073-0002. Change of address: Request for change should include old address of the subscriber. Missing numbers due to "change of address" cannot be replaced. Claims for nondelivery must be made within 60 days of issue. Canada Post Publications Mail Agreement No. 40732105. Return undeliverable Canadian addresses to: 700 Dowd Ave., Elizabeth, NJ 07201. Printed by Publishers Press Inc., Shepherdsville, Ky.

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



ASM International serves materials professionals, nontechnical personnel, and managers worldwide by providing high-quality materials information, education and training, networking opportunities, and professional development resources in cost-effective and user-friendly formats. ASM is where materials users, producers, and manufacturers converge to do business.

ADVANCED MATERIALS & PROCESSES

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

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

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

Frances Richards and Corinne Richards
Contributing Editors

Jan Nejedly, *Layout and Design*

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

Press Release Editor
magazines@asminternational.org

EDITORIAL COMMITTEE

Adam Farrow, *Chair, Los Alamos National Lab*
John Shingledecker, *Vice Chair, EPRI*
Somuri Prasad, *Past Chair, Sandia National Lab*
Beth Armstrong, *Oak Ridge National Lab*
Margaret Flury, *Medtronic*
Surojit Gupta, *University of North Dakota*
Nia Harrison, *Ford Motor Company*
Michael Hoerner, *KnightHawk Engineering*
Hideyuki Kanematsu, *Suzuka National College of Technology*
Ibrahim Karaman, *Texas A&M University*
Ricardo Komai, *Tesla*
Scott Olig, *U.S. Naval Research Lab*
Amit Pandey, *Lockheed Martin Space*
Satyam Sahay, *John Deere Technology Center India*
Kumar Sridharan, *University of Wisconsin*
Jean-Paul Vega, *Siemens Energy*
Vasishth Venkatesh, *Pratt & Whitney*

ASM BOARD OF TRUSTEES

Judith A. Todd, *President and Chair of the Board*
David B. Williams, *Vice President*
Diana Essock, *Immediate Past President*
John C. Kuli, *Treasurer*
Burak Akyuz
Ann Bolcavage
Elizabeth Hoffman
Navin Manjoooran
Toni Marechaux
U. Kamachi Mudali
James E. Saal
Priti Wanjara
Ji-Cheng Zhao
Sandra W. Robert, *Secretary and Executive Director*

STUDENT BOARD MEMBERS

Shruti Dubey, Andrew Ruba, David Scannapieco

Individual readers of Advanced Materials & Processes may, without charge, make single copies of pages therefrom for personal or archival use, or may freely make such copies in such numbers as are deemed useful for educational or research purposes and are not for sale or resale. Permission is granted to cite or quote from articles herein, provided customary acknowledgment of the authors and source is made.

The acceptance and publication of manuscripts in Advanced Materials & Processes does not imply that the reviewers, editors, or publisher accept, approve, or endorse the data, opinions, and conclusions of the authors.

GRAND ENDEAVORS



There is an ethereal beauty and majesty to the swirled floating lines of the Guggenheim Museum in Bilbao, Spain. Yet, the transition from design to construction proved to be a massive and perplexing undertaking. World-renowned architect Frank Gehry found the solution by adapting aerospace software. It provided the precise calculations his builders needed to be able to shape the titanium exterior into those trademark Gehry curves. Data saved the day.

And now, the newly launched ASM Data Ecosystem can provide similar guidance to the larger materials engineering community. This ambitious venture with an enormous scope provides engineers in design and manufacturing with a one-stop, digital platform for getting the data answers they need. Users will find that the collection of simulation and analytical tools in Release 1 represents a wide range of options from various partners. But there's much more to come. In this issue, Ray Fryan, ASM executive director of new product development, explains how the offerings in the Data Ecosystem will grow exponentially as more partners aggregate their data into the ASM platform. More partners = more data and tools = more options and solutions for the materials engineering community. The possibilities for users are enormous, exciting, and ever-expanding.



Guggenheim Museum Bilbao

And speaking of enormity of scale, it would be hard to miss the world's largest indoor testbed featured on the cover of this aerospace issue. The cavernous new facility in Rolls-Royce's Derby location literally brings turbine testing to new heights. Not only are the current capabilities impressive in their complexity and by the sheer numbers—the article is filled with astounding factoids—but the testbed also was designed to handle engines of the future (i.e., physically larger and either hybrid or all-electric). Read how the company's pillars of sustainable aviation were driving forces in their engineering decisions for the testbed. And they will serve as a type of control tower, guiding all related endeavors going forward. As an example, the company is committed to helping the industry work toward a specification for 100% sustainable aviation fuel. Certainly a lofty but critical goal.

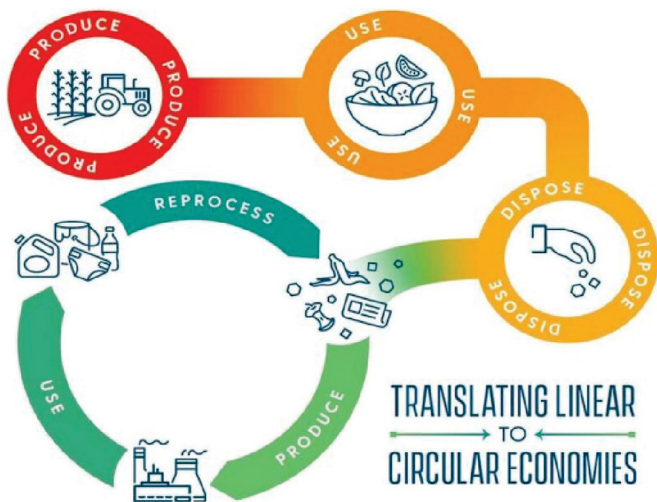
Specifications are also on the mind of the author from Velo3D. In the article, "Qualifying Materials using Laser Powder Bed Fusion for Additively Manufactured (AM) Aerospace Components," he presents a realistic picture of the state of standards and specs for AM parts. Some cutting-edge application examples cited include parts used in SpaceX's Raptor rocket engines as well as components utilized in hypersonic flight. Advancements in AM materials now allow for the creation of parts previously unheard of in these unique space environments.

For more on next-generation materials for aerospace, see our AeroMat Show Preview in this issue and then head to sunny Pasadena for the event. Starting this year, the combined aerospace signature events from ASM and SAE International will be offered in one location. There you'll hear firsthand—from a trio of keynote speakers addressing "Innovation, Engineered for the Era of Delivery"—how the future of avionics is shaping up. I'm sure it will be grand.

Joanne Miller

joanne.miller@asminternational.org

RESEARCH TRACKS



Courtesy of Dionisios Vlachos.

FROM BIOMASS TO PLASTIC

Researchers from the University of Delaware (UD) are teaming up with colleagues at the University of Kansas and Pittsburg State University to tackle plastic pollution. The National Science Foundation's Experimental Program to Stimulate Competitive Research awarded the group \$4 million toward this goal. Roughly \$1.4 million will go to UD to develop processes that will transform biomass such as agricultural byproducts into commercially viable plastics materials, and to chemically deconstruct the plastics so they can be reused. The project will concentrate on developing polymers that behave like polyethylene terephthalate (PET).

By focusing on biomass that is not edible, the team will try to prepare new building blocks for plastics that do not

compete with food sources, do not depend on fossil fuels, and can be easily assembled. Over the next four years, up to five UD graduate students will study the chemistry of the components and use machine learning to explore the existing literature and knowledge gaps. They will also study the economics of the new plastic materials. Their

work will closely examine how to deconstruct these new polymers to create a truly recyclable product. "If we succeed, we might be able to reduce, to some degree, the quantity of plastics or the amount of oil we consume," says chemical engineering professor Raul Lobo, who is leading the UD research effort. www.udel.edu.

RECORD-SETTING SOLAR CELLS

In a joint effort between Pavia University, Italy, and TU Dresden, Germany, researchers developed an innovative method to fabricate lead halide perovskite solar cells with record efficiency. Specifically, the new process significant-

ly improves the efficiency of inverted architecture solar cells. The new technique is based on modifying the interfaces of the perovskite active layer by introducing small amounts of organic halide salts at both the bottom and top of the perovskite layer. These organic halide salts, typically used to form 2D perovskites, led to suppression of microstructural flaws and passivation of defects in the perovskite layer.

Using this approach, the team achieved a power conversion efficiency of 23.7%—the highest reported to date for an inverted architecture perovskite solar cell. "The fact that our devices are fabricated at low temperatures of less than 100°C, and that our approach is fully applicable to the fabrication of large-area devices, takes us one step closer to large-scale utilization of perovskite solar cells," explains Professor Yana Vaynzof of TU Dresden. www.tu-dresden.de.

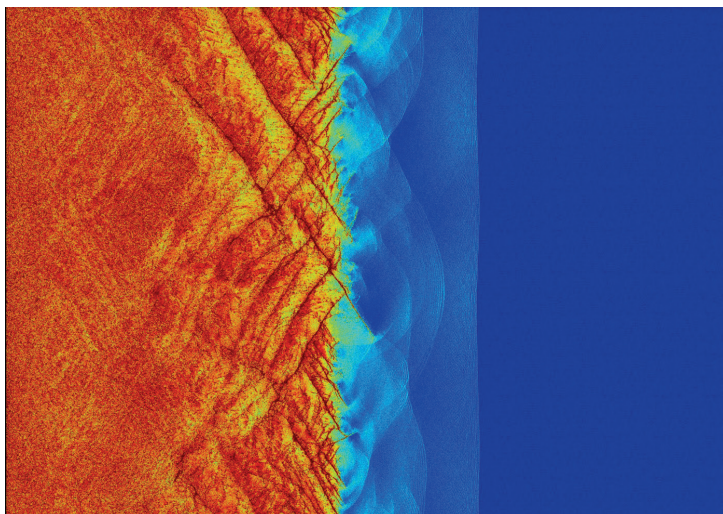


Nanomaterials of perovskite dispersed in hexane and irradiated by a laser. Courtesy of Luiz Gustavo Bonato.

BRIEF

Empa, the Swiss Federal Laboratories for Materials Science and Technology, received \$16.2 million from **The Werner Siemens Foundation**, Switzerland, in support of the lab's CarboQuant project. The goal is to lay the foundations for novel quantum technologies that could operate at room temperature, unlike most current methods that require cooling to near absolute zero. www.empa.ch.

MACHINE LEARNING | AI



Multibillion atom simulation of shockwave propagation into uncompressed diamond (blue) predicts that the final state (orange) is formed by recrystallization of amorphous cracks (red) that take shape in the light blue, green, and yellow compressed material.

SIMULATION CAPTURES DIAMOND MELTING

A supercomputer simulation model at Sandia National Laboratories, Albuquerque, N.M., called SNAP (spectral neighbor analysis potential) can rapidly predict the behavior of billions of interacting atoms. The model recently captured the melting of diamond when compressed by extreme pressures and temperatures. At several million atmospheres, the diamond's rigid carbon lattice is shown in the simulations to crack, melt into amorphous carbon, and recrystallize. Scientists say the work could lead to a better understanding of carbon-based exoplanets and have important implications for nuclear fusion efforts that use polycrystalline diamond.

"We can now study the response of many materials under the same extreme pressures," says SNAP creator Aidan Thompson. "Applications include planetary science, and it also opens the door to the design and manufacture of novel materials at extreme conditions."

SNAP used machine learning and other data science techniques to train

a surrogate model that accurately reproduced the correct atomic forces. These were computed using high-accuracy quantum mechanical calculations, which are only possible for systems containing a few hundred atoms. The surrogate model was then scaled up to predict forces and accelerations for systems containing billions of atoms. sandia.gov.

USING AI TO OPTIMIZE BATTERIES

Researchers working on flow batteries must find target molecules that offer the ability to both store a lot of energy and remain stable for long periods of time. To discover the right molecules, scientists at the DOE's Argonne National Laboratory, Lemont, Ill., are using artificial intelligence (AI) to search through a vast chemical space of over a million molecules. Chemist Rajeev Assary and his colleagues modeled anolyte redoxmers,

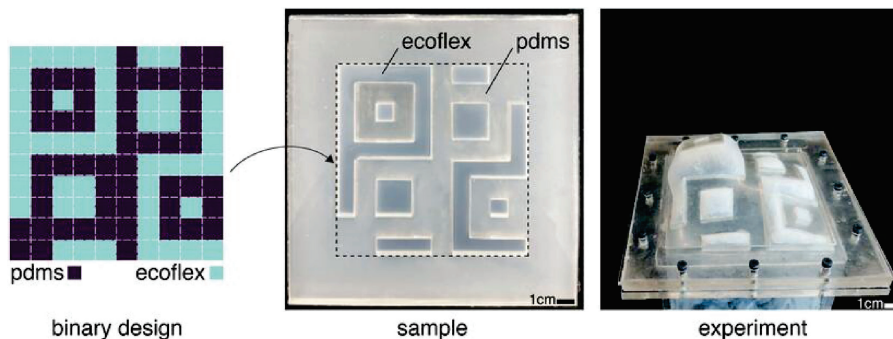
the electrically active molecules in a flow battery. For each redoxmer, the team identified three properties they wanted to optimize. The first two, reduction potential and solvation free energy, relate to how much energy the molecule can store. The third, fluorescence, serves as a self-reporting marker that indicates overall battery health.

Because it is extremely time consuming to calculate the properties of interest for all potential candidates, the team employed a machine learning and AI technique called active learning, in which a model can train itself to identify increasingly plausible targets. The researchers began with a fairly small sample—a dataset of 1400 redoxmer candidates whose properties they already knew from quantum mechanical simulations. By using this dataset as practice, they were able to see that the algorithm correctly identified the molecules with the best properties. Once they had explored the small dataset, the team expanded their search to more than a million different candidates. Through the model's iterative performance improvement, better and better molecules began to be identified for further study. According to Assary, the optimization algorithm could likely be applied to other types of batteries and other fields. anl.gov.



Researchers are using machine learning and AI to optimize new, potential chemicals for use in redox flow batteries that can modernize the electric grid.

PROCESS TECHNOLOGY



Regular grid (left) divides a membrane's domain into soft (blue) or stiff (purple) pixels; membrane (center) is fabricated as a continuous, flat material; after inflation, complex deformation (right) reflects stiff and soft pixels. Courtesy of Bertoldi Lab/Harvard SEAS.

PROGRAMMING MORPHABLE MATERIALS

Researchers from the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS), Boston, developed a platform that uses machine learning to program the transformation of 2D stretchable surfaces into specific 3D shapes.

The team began by dividing an inflatable membrane into a 10 x 10 grid of 100 square pixels that can either be soft or stiff. The soft or stiff pixels can be combined in an almost infinite variety of configurations, making manual programming extremely difficult. To meet the challenge, researchers used finite element simulations to sample the infinite design space. Next, neural networks used that sample to learn how the location of soft and stiff pixels controls the deformation of the membrane when pressurized. Then, they used the new design method to build

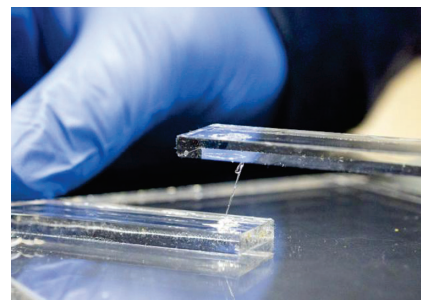
and test a device for mechanotherapy that can stimulate tissue around a scar to enhance healing and reduce recovery time. The platform can be used to design morphable surfaces at multiple scales for applications from medical devices to architecture. harvard.edu.

UPCYCLED PLASTIC ADHESIVES

Using polymer chemistry, researchers at the DOE's Oak Ridge National Lab transformed a common household plastic into a reusable adhesive with a rare combination of strength and ductility. The new adhesive is one of the toughest materials ever reported, and the work advances pathways to design a new class of tough adhesives with desirable features merged into a single material. The technology adapts to bear heavy loads, tolerate extreme stress and heat, and reversibly bond to various surfaces including glass, aluminum, and steel.

Researchers aimed at upcycling a commodity thermoplastic, polystyrene-b-poly(ethylene-co-butylene)-b-polystyrene, or SEBS, a rubbery polymer material that is easy to process but not engineered for tough adhesion. The team modified SEBS' chemical structure with dynamic crosslinking to make it more robust, as well as to create reuse pathways for plastics—beyond traditional recycling—that enhance their performance for new applications.

Results showed crosslinked bonds shift within the material to enable specific properties and adhere to surfaces so strongly that a thin square centimeter can hold roughly 300 pounds. The material was so tough in adhering to glass, in fact, that glass fractured before the sample debonded. The approach also enhanced thermal stability to 400°F, making the adhesive attractive for ambient and high-temperature applications. The development widens applications for aerospace, automotive, and construction adhesives. energy.gov.

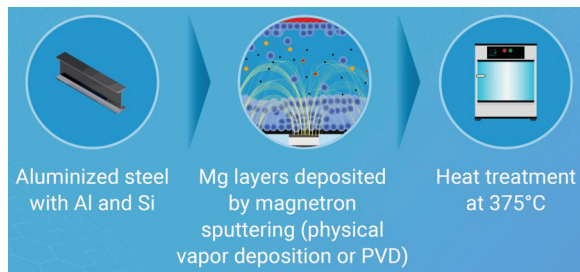


A common plastic was upcycled to develop a novel reusable adhesive. Courtesy of Carlos Jones/ORNL, U.S. DOE.

BRIEF

As part of a new merchant machining program for the aerospace industry, **Guill Tool & Engineering**, West Warwick, R.I., offers 5-axis machining centers, high precision machining, and full wire EDM capabilities including a 0.008-in. hole popper. Typical products include brackets, latches, engine components, fine hole cooling channels, and structural mechanisms. guill.com/aerospace.

METALS | POLYMERS | CERAMICS



Heat-treated Al-Mg-Si alloy coatings offer enhanced corrosion resistance to steel. Courtesy of KMOU.

PROTECTIVE STEEL COATING

The use of aluminum in marine applications is limited due to its tendency to react with chloride ions in sea water, leading to corrosion. The addition of other elements, such as magnesium and silicon, to form an alloyed coating is a promising way around this problem. But magnesium cannot be easily deposited as a coating using the conventional method of dipping the steel into a hot bath of metal salts. Now, scientists at the Korea Maritime and Ocean University (KMOU), South Korea, developed a new protocol for aluminum-magnesium-silicon coating of steel.

The researchers took aluminized steel and then plated it with magnesium using a technique called physical vapor deposition. Next, they exposed the coating to a high temperature of 375°C. They then characterized the coating film and performed corrosion testing in the form of a salt spray test. The scientists found that the corrosion products were formed in two layers—a surface layer made of primarily aluminum-based

corrosion products, and an inner corrosion layer made of aluminum, magnesium, and silicon-based products. Moreover, the inner layer of corrosion products produced a shielding effect, which further improved their anti-corrosion properties.

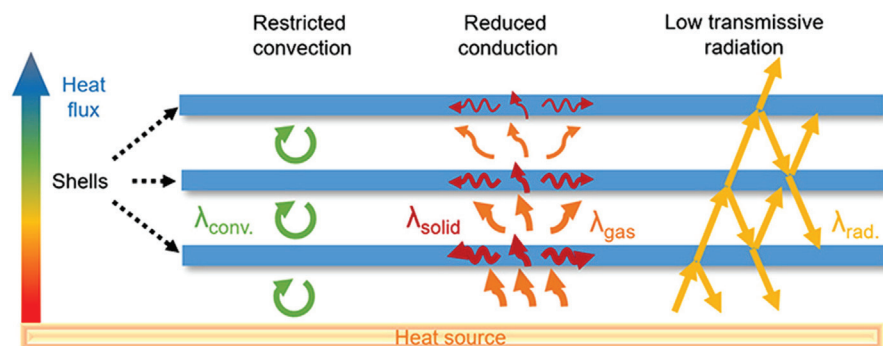
“Our research reveals how a highly corrosion-resistant steel can be produced using a simple change in the surface treatment protocol. This makes it very meaningful for conserving energy and environmental resources,” explains lead researcher Myeong-Hoon Lee. www.kmou.ac.kr/english/main.do.

SMART HEAT ISOLATOR

Effective thermal energy management is a key priority for green production. As such, developing an intelligent material that can automatically control heat transfer is a way to limit CO₂

emissions. Based on this goal, researchers from China’s Zhengzhou University and the Chinese Academy of Sciences created a smart material that combines hollow multishelled structure (HoMS) titanium dioxide and a heat-sensitive polymer in order to automatically control heat transmission. The objective of this intelligent material is to perform thermal insulation at relatively low temperatures while dissipating heat when the reaction system overheats.

According to the researchers, a hollow structure with multishells can provide more interfaces and thus further inhibit heat convection and transmission, making it more favorable for heat isolation. This new work shows that the thermally responsive polymer is a promising model for building thermal fields and reveals, for the first time, the mode of heat transfer through HoMS. This composite exhibits an unusual two-stage endothermic behavior whereby the direction of heat flow in the material matrix changes. The energy is



Graphical depiction of a multishelled structure embedded with a temperature sensitive polymer, which becomes effective at thermal accumulation and energy storage.

BRIEF

Vertellus, Indianapolis, acquired **Polyscope Polymers B.V.**, the Netherlands. Polyscope develops and manufactures styrene maleic anhydride copolymers used in applications across the electronic, automotive, and specialty coatings markets. vertellus.com.

accumulated in HoMS, which operates as a heat reservoir to regulate the thermal flow. The work provides a new avenue for designing smart reactors for the green chemical industry, thus creating more opportunities for heat-related applications and increasing the potential for efficient energy use. english.zzu.edu.cn, english.ipe.cas.cn/.

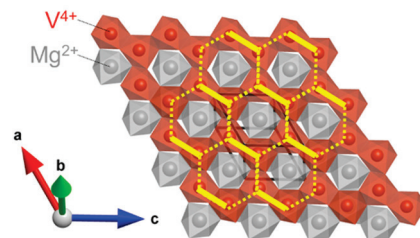
HONEYCOMB CRYSTAL DISCOVERY

Researchers from Tohoku University and Osaka Prefecture University, both in Japan, reported a rare structural change in a mineral-like crystal that could lead to the development of new functional materials if controlled. Until now, scientists had only observed a few examples of cation dimerization in 3D transition metals with honeycomb

lattice systems. 3D transition metals have specific properties and electrons that move about in the 3D orbital surrounding the atom.

The research team used high pressure to synthesize the simple oxide ilmenite-type magnesium vanadium trioxide, mimicking the conditions of mineral formation deep in the Earth's core. The team then used synchrotron x-ray experiments to analyze the crystal's structure and found that its honeycomb lattice developed vanadium-vanadium (V-V) dimers arranged in a ladder-like pattern at temperatures below 500 kelvin (227°C). Notably, the team also observed a magnetic to non-magnetic transition in the crystal's properties when the temperature fell below 600 K.

Next, the team plans to explore the control of the V-V dimer state with magnetic fields and pressure. "We might be able to use this to create new magnetic or electrical functions in this and similar materials," propose the researchers. www.tohoku.ac.jp/en.



The crystal structure of ilmenite-type magnesium vanadate (MgVO_3) with yellow lines defining the honeycomb lattice and thick lines indicating the location of V-V dimers. Courtesy of Hajime Yamamoto.

Education

Looking to enhance your knowledge within the aerospace community? Register today for an upcoming education course.

- Aluminum and its Alloys
March 22–24
- Additive Manufacturing 101
March 28–29
- Superalloys
April 11–13
- Corrosion
April 18–21
- Principles of Failure Analysis
May 2–4
- Titanium and its Alloys
July 11–14

Questions? Contact us today!
professionaldevelopment@asminternational.org

asminternational.org/exploreeducation

LOW CTE EPOXY

for PRECISE ALIGNMENT

Two Part EP30LTE-2

flowable system for bonding, potting & encapsulation

Very low CTE, 75°F
10–13 x 10⁻⁶ in/in/°C

NASA low outgassing
Per ASTM E595 standards

Electrically insulative
Volume resistivity, 75°F
>10¹⁵ ohm-cm

MASTERBOND®
ADHESIVES | SEALANTS | COATINGS

Hackensack, NJ 07601 USA • +1.201.343.8983 • main@masterbond.com

www.masterbond.com

TESTING | CHARACTERIZATION



Hard material DMA based on electro-mechanical impedance method. Courtesy of Peking University College of Engineering.

WORLD'S FIRST FOR HARD MATERIALS

A group of scientists from Peking University, China, invented a new instrument for high and low-temperature mechanical analysis in the fields of superalloys, composites, functional materials, and amorphous alloys. The instrument is the world's first dynamic mechanical analyzer (DMA) suitable for hard materials. It's based on the electro-mechanical impedance method which can quickly, accurately, and automatically measure Young's modulus, shear modulus, and corresponding internal friction of materials under variable temperature conditions.

Until now, there existed a lack of methods and instruments that could accurately measure material modulus and internal friction at the same time. Using their new DMA, the research group obtained the grain boundary sliding internal friction peak in polycrystalline pure aluminum under high-frequency

vibration (tens of kHz) for the first time, and the peak temperature reached nearly 500°C, which is much higher than the low-frequency internal friction peak (285°C) discovered by metal physicist Ke Ting-sui in 1947.

Next, they used the new DMA on titanium. The results of measuring the modulus and internal friction of TC4 titanium alloy from room temperature to

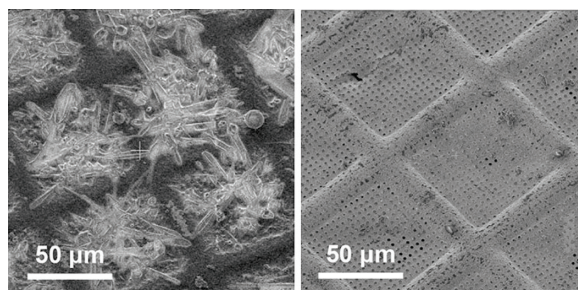
1200°C using the new DMA show that near 990°C, both moduli reach the minimum and both internal frictions peak, indicating that the material has undergone a solid-state phase transition. <https://en.coe.pku.edu.cn>.

HIGH-RES BATTERY PORTRAITS

The race to develop lithium metal batteries for next-gen electric vehicles, electronics, and other uses has begun. But a central challenge remains—understanding and manipulating a thin layer called the solid-electrolyte interphase or SEI, that forms when the electrolyte between battery electrodes corrodes the surface of the lithium metal anode. Although formation of SEI is believed to be inevitable, researchers hope to stabilize and control the growth of this layer in a way

that maximizes the battery's performance. Until now, there's never been a clear picture of what the SEI looks like when it's saturated with electrolyte, as it would be in a working battery.

Researchers from the DOE's SLAC National Accelerator Laboratory at Stanford University, Menlo Park, Calif., made the first high-res images of this layer in its natural plump, squishy state. This advance was made possible by cryogenic electron microscopy, or cryo-EM, a revolutionary technology that reveals details as small as atoms. According to the researchers, the results suggest that the right electrolyte can minimize the swelling and improve the battery's performance—giving them a potential new way to tweak and improve battery design. It also provides scientists with a new tool for studying batteries in their everyday working environments. Next, the researchers say they'd like to find a way to image these materials in 3D, and to



Left: Cryo-EM image of electrolyte clinging to holes in a sample grid shows excess electrolyte has formed crystals. Right: After blotting, the grid can clearly be seen and probed with beams of electrons. Courtesy of Weijiang Zhou/Stanford University.

BRIEF

Instron, Norwood, Mass., announces a capacity expansion for its 3400 and 6800 series universal testing systems. The new systems are successors to the company's 3300 and 5900 series and are available in force capacities to 300 kN. instron.com.

do so while they're still inside a working battery for the most realistic picture yet. slac.stanford.edu.

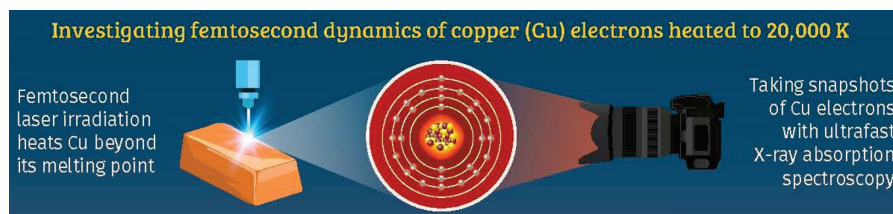
MELTING DYNAMICS DISCOVERY

A research team led by associate professor Byoung Ick Cho from the Gwangju Institute of Science and Technology (GIST), Korea, studied the warm dense matter state for copper created by using intense laser pulses. The optical pulse excitation created copper electrons with a temperature of ~20,000 K, which is similar to that of a giant planet's core. Then, right when the copper sample was about to melt, the researchers took snapshots of the electrons using ultrafast x-ray pulses from an x-ray free electron laser. This allowed them to analyze what happens in noble metals,

such as copper, when their bonding electrons are highly excited and the metals are about to melt.

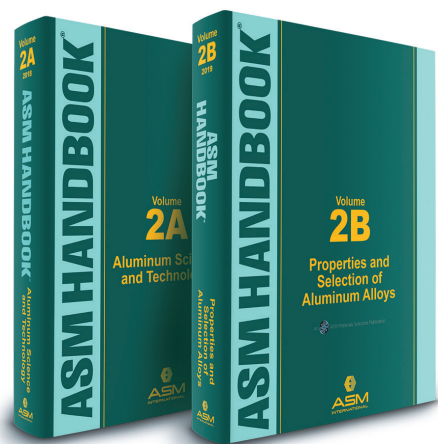
Notably, when heated quickly, the bonds between copper atoms first hardened for about one trillionth of a second before melting. The team carried out detailed theoretical analysis backed by simulations, which revealed that while some electrons were excited to higher energies at such high temperatures, some experienced a stronger

attraction toward the nucleus. These findings could have applications in contexts where materials are subjected to extremely high pressures and temperatures. "By capturing the precise moment when a material starts to melt or vaporize, we can generate new phases of matter or energy, which would be relevant to fields such as fusion, laser machining, and even nanosurgery," speculates Cho. www.gist.ac.kr/en.



Femtosecond x-ray snapshots of warm dense copper electrons can reveal elusive phenomena predicted over a decade ago. Courtesy of GIST.

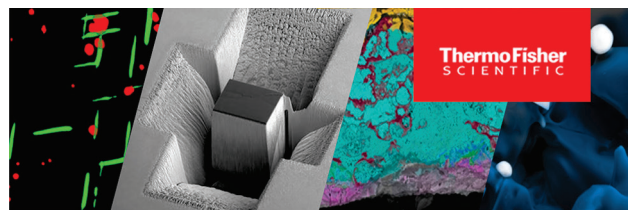
ASM HANDBOOK VOLUMES 2A & 2B ALUMINUM SET



PURCHASE THIS TWO-VOLUME SET AT A SPECIAL DISCOUNTED PRICE!

The set includes ASM Handbooks, Volume 2A: *Aluminum Science and Technology* and Volume 2B: *Properties and Selection of Aluminum Alloys*.

asminternational.org



Electron Microscopy

Enabling Next-Generation Aerospace Materials

Explore how Thermo Fisher Scientific can help you address your materials characterization challenges

- AI Driven Electron Microscopy
- 3D Characterization
- Surface Analysis

Visit us at AEROMAT 2022 Booth #408

Learn More at thermofisher.com/aeromat2022

NEW TESTBED HELPS DRIVE SUSTAINABLE FUTURE FOR AVIATION

Ann Bolcavage, FASM,* Rolls-Royce Corp., Indianapolis
Alistair Hobday, Rolls-Royce plc., Derby, U.K.

With the opening of Testbed 80, the largest engine testing facility in the world, Rolls-Royce plans to use its unique capabilities to accelerate the journey toward sustainable aviation technologies supported by the intelligent use of materials.

**Member of ASM International*

The transition to a low carbon global economy is a challenge that has been continually addressed by the aerospace industry. Emissions per passenger kilometer have been reduced by 80% since the first generation of commercial jet aircraft, and today aviation is currently responsible for about 2% of annual carbon dioxide emissions^[1] but recognizes the need to continue to decarbonize. Recently, the International Air Transport Association (IATA) approved a resolution for the global air transport industry to achieve net-zero carbon emissions by 2050^[2].

Propulsion for aerospace will play a fundamental role in enabling this transition, including emerging and disruptive products incorporating hybrid or fully electric and hydrogen technologies for the personal mobility and regional aircraft market. For larger aircraft engines however, fuel efficiency gains will come from improved gas turbine engine architectures and advanced materials for the foreseeable future. Additionally, the development of sustainable, non-fossil-sourced alternative fuels will have a critical role in decoupling carbon growth from market growth.

Demonstration of these novel technologies in current and future large gas turbine engines for civil aerospace constitutes a crucial step to verify performance and ensure safe operation. Before flight, ground-based testing provides essential information under a range of controlled conditions to better understand performance, operability, and reliability. In 2021, aircraft engine manufacturer Rolls-Royce officially unveiled Testbed 80 (Fig. 1), the world's largest and most advanced indoor aerospace test facility, to demonstrate the technologies that will improve propulsion efficiency and support the overarching objectives for sustainable aviation and the transition to a net-zero carbon future.

TESTBED 80 FACTS AND FIGURES

Testbed 80, located in Derby, U.K., was built at a cost of £90M (\$120M US) and took 4.5 years to design and

construct. The massive scale of the project (Fig. 2) can be appreciated by the following metrics:

- The internal area measures 7500 m² and the construction site required the removal of excavated earth to fill nearly 2000 trucks
- 27,000 m³ of concrete were poured for seven months and was poured for 60 days straight at the height of construction
- The surrounding walls of the test cell measure 1.5 to 1.7 m in thickness
- Over 3000 tons of steel were used in the construction
- The lift platform for engines can raise loads up to 10 tons to a height of 5.5 m

Aerodynamic design of the test cell incorporated lessons learned over the years from other facilities and was supported by aerodynamic and acoustic modelling done in collaboration with the National Research Centre in Ottawa. Augmented air within the test cell flows at a rate of 4.2 tons/s to simulate maximum take-off conditions with replenishment every 3 s. Turning vanes split the flow of air into the test bed and ensure it is evenly distributed. At the rear



of the test bed, a blast basket measuring 17 m long and 6.5 m in diameter dissipates the energy of the exhaust system.

Testbed 80 can accommodate several key tests crucial for ensuring safe operation of gas turbine engines, including fan blade-off, bird ingestion, sand ingestion, and core water ingestion. Other types of measurements required for regulatory approvals such as noise, emissions, and cabin air quality are also possible.

X-ray technology is used in the test cell to inspect geometrical clearances



Fig. 1 — Testbed 80, located at Rolls-Royce in Derby, U.K.

within the engine's turbomachinery and validate core architecture against the design intent. Details within 0.5 mm from any of the 20,000+ components that make up a modern gas turbine engine can be targeted. Up to 30 images can be captured per second with results instantaneously available to engineers who integrate this information with other data to understand the performance. The Testbed 80 x-ray generator produces 9 MeV of energy and can contain ionizing radiation up to 30 Gray.

During x-ray inspection, safety becomes the number one priority as the test bed becomes a bunker. The solid concrete walls in the cell provide shielding and an exclusion zone is defined within a certain radius of the building past which no one can enter. Furthermore, an elaborate procedure is conducted to ensure the facility is clear of personnel. A series of 45 search buttons located around the facility must be pushed in a specific order and within a given amount of time, ensuring that all areas are visually checked. After the devices have been found, a key is released which allows the inspector to leave the x-ray zone.

Physical data collected during testing is used to confirm aspects of engine performance predicted by digital models. To accomplish this, new acquisition systems capture nearly 200,000 samples of transient measurements at 0 to 200 Hz in each second of a test run, recording up to 1 terabyte/h and sending the data directly to a secure cloud. These new systems consist of loosely coupled architecture that is upgradable, extensible, and flexible. Additionally, improved controls and instrumentation enhance the cyclic capability built on a new throttle system along with a new supervisory system to conduct testing.

SUPPORT FOR ENABLING MATERIALS TECHNOLOGIES AND SAF FOR SUSTAINABLE AVIATION

Testbed 80 will play a crucial role in supporting several of the pillars in the corporate sustainability strategy at

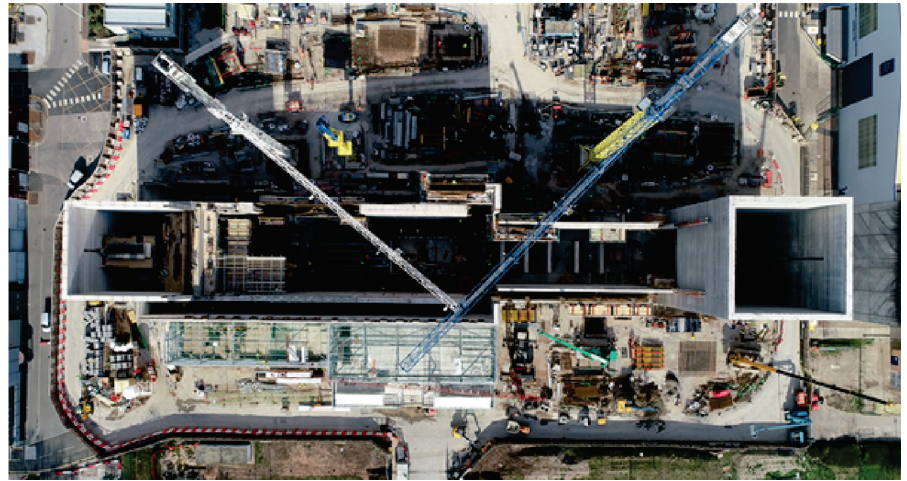


Fig. 2 — Testbed 80 construction in 2019, showing a plan-view look at the test cell.

Rolls-Royce. The first and most immediate impact will be made by technologies that reduce fuel burn and thus reduce carbon emissions. The facility has been designed to test current large civil aerospace engine products such as Trent 1000 and Trent XWB. However, more efficient engines of the future will be physically even bigger with increased bypass ratios and fan diameters. The massive size of the Testbed 80 facility was designed with these future products in mind, with the ability to handle engines up to 155 klbf thrust.

The next-generation geared-architecture UltraFan demonstrator, delivering a 25% efficiency gain compared to the first generation of Trent engine, will undergo testing in Testbed 80 in 2022. Building on a more efficient core and technologies from the Advance concept via incorporation of a geared intermediate pressure section, advanced materials will play a key role in the performance of UltraFan as these enable higher thermodynamic efficiency and lighter weight architectures^[3]. Examples include:

- Carbon composite/titanium (CTi) systems to form both fan blades and the fan casing (Fig. 3). Greater



Fig. 3 — UltraFan Demonstrator CTi fan blades and casing.

propulsive efficiency is achieved via weight reduction on twin-engine aircraft by 700 kg^[4].

- Ceramic matrix composite components. Consisting of silicon carbide continuous fiber within a silicon carbide matrix plus an environmental barrier coating system, these lightweight materials exceed the temperature capability of nickel superalloys and reduce the need for cooling air.

- Hybrid ceramic seals with higher durability and lowered oil consumption.
- Next-generation powder Ni disk alloy with improved damage tolerance and strength, as well as greater resistance to oxidation/corrosion, at temperatures up to 780 to 800°C.

Sustainable aviation fuels (SAFs), constitute the second pillar for sustainable propulsion. Their sustainability comes from how it is sourced and/or produced; any feedstocks must be non-food competing, and any biomass or forestry residues must not include deforestation specifically for the manufacture of jet fuel and must be from a waste stream. In principle, the carbon dioxide avoided and/or absorbed during the manufacturing process is approximately the equivalent to the amount released during combustion, therefore reducing the lifecycle carbon emissions of the fuel compared to fossil derived material.

The use of specific approved SAF product pathways is currently certified up to 50% by volume when blended with conventional jet fuel. Once blended, the fuel is recertified to an industry standard Jet A/Jet A-1 specification and considered a fully compliant “drop in” solution with no changes to engines, airframes, or refuelling equipment necessary. The use of 100% SAF is currently not certified for aviation, however there is significant activity both within Rolls-Royce and the aviation community to drive this forward and to develop a specification.

Rolls-Royce has made a commitment to demonstrate that all civil engines currently in production will be fully 100% SAF compatible by the end of 2023, with several engine and flight tests already successfully completed. The first run of the UltraFan engine in 2022 will be undertaken using 100% SAF in Testbed 80 (Fig. 4). The facility and infrastructure have been designed with specific consideration for SAF such that tests on different pathways and blends can be conducted effectively. For example, the facility is equipped with a 140,000 L fuel tank that



Fig. 4 — Testbed 80 will confirm engine operability using 100% sustainable aviation fuel on the UltraFan demonstrator in 2022.

can accommodate different fuel types where the potential for cross-contamination is designed out using intelligent fuel system architecture.

A pressing challenge to the broader implementation of SAFs is the near-term shortage based in part on the high cost of manufacture. Therefore, continued focus on engine efficiency gains will be essential to drive net-zero goals until SAFs are more widely available.

Finally, the testbed is designed to have the capability to test hybrid or all-electric flight systems of the future, constituting a third pillar of sustainable aviation.

Reducing fuel burn and overall carbon footprint is of vital strategic importance to all companies in the aerospace industry, driven by legislative requirements, customer demands, and competitive pressure. The investment made by Rolls-Royce in Testbed 80 demonstrates the company's commitment to meet these challenges and move toward a net zero future for carbon emissions. ~AM&P

For more information: Ann Bolcavage, engineering associate fellow - coatings, Rolls-Royce Corp., 420 S. Meridian St., Indianapolis, IN 46225-1103, ann.bolcavage@rolls-royce.com.

References

1. Decarbonizing Aviation: Cleared for Take-off, report available at www.shell.com.
2. Press Release No. 66, Net-Zero Carbon Emissions by 2050, IATA, www.iata.org/en/pressroom/2021-releases/2021-10-04-03.
3. F. Haselbach, A. Newby, and R. Parker, Concepts and Technologies for the Next Generation of Large Civil Aircraft Engines, ICAS, St. Petersburg, Russia, 2014.
4. G. Gardiner, Rolls-Royce Starts Manufacture of World's Largest Fan Blades, Made with Composites, for UltraFan Demonstrator, *Composites World*, Feb. 2020, www.compositesworld.com/news/rolls-royce-starts-manufacture-of-worlds-largest-fan-blades-made-with-composites-for-ultrafan-demonstrator.

EXPLORING GRADIENT PATHWAYS IN HIGH TEMPERATURE, FUNCTIONALLY GRADED ALLOYS

A new approach aims to fabricate parts with targeted, site-specific properties for a wide range of applications in extreme environments within the aviation, space, and energy sectors.

Soumya Nag, Brian Jordan, Ke An, and Jaimie Tiley, FASM*

Oak Ridge National Laboratory, Tennessee

Chuan Zhang and Fan Zhang

CompuTherm LLC, Middleton, Wisconsin

Additive manufacturing (AM) provides a tremendous opportunity to synergistically couple materials, design, and manufacturing strategies. One can strive toward fabricating parts with targeted properties by enabling site-specific metal-metal or metal-ceramic compositional transitions. Parts with site-specific composition and hybrid microstructures are relevant in an application space where certain sections of the component encounter considerably higher temperatures than others. For example, one may design composite parts with Nb-base refractory alloys for hotter sections (requiring increased high temperature strength and creep resistance) while opting for relatively low cost and low gamma prime containing IN718 at zones operating below 1400°F^[1-4]. Note that conventional welding and joining approaches are adopted to deal with parts operating at widely varying temperatures.

For example, Fig. 1 illustrates a commercial, bimetallic joined structure for an engine part where the performance requirements of the airfoils (SX material) and disk section are quite

different. Even within a turbine disk, the performance requirement for the outer rim of the disk needs material with a larger-grained microstructure that is creep resistant as opposed to the low cycle fatigue (LCF)-limited, fine-grained core of the disk^[5].

Although conventional joining processes are limited in their ability to create components comprised of multiple dissimilar materials, AM processing

provides an approach to circumvent these restrictions through compositionally grading materials. Considerations include:

Feasibility: The approach allows the transition from one terminal alloy composition to another, even when they are nonweldable^[4]. In this case, a gradual compositional gradation via an additive route makes such a transition feasible. In some cases, an intermediate

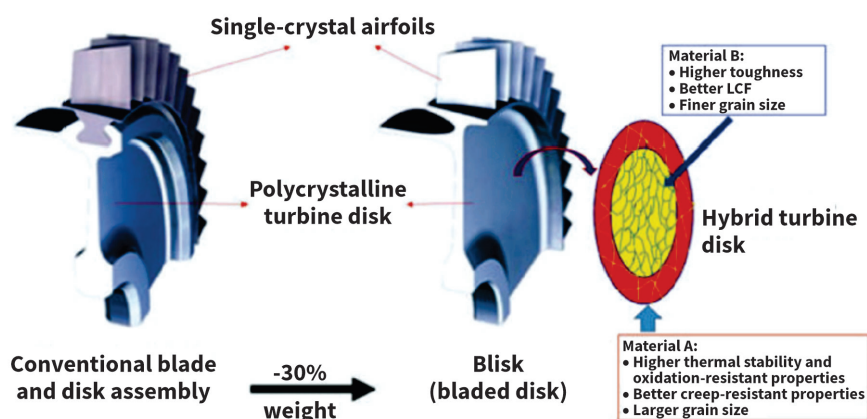


Fig. 1 — Illustration of site-specific property requirements in an aircraft engine part. The airfoil sees much higher temperature than the blade, hence the former is SX as opposed to PX disks. Within the disks there is a need for zone-based microstructures – LCF-limited core with finer grain size and creep-limited rim with coarser grains^[5].

*Member of ASM International

third alloy composition may be selected for nonlinear compositional gradient setup, similar to the use of strike coatings during metal plating operations.

Performance benefit: The goal is to eliminate abrupt property transitions at dissimilar interfaces along with alleviating residual stress across large structures. Apart from alleviating coefficient of thermal expansion (CTE)-driven thermal mismatch between different alloy systems, smooth compositional transitions can also exhibit performance benefits for static, dynamic, and high-speed impact property response. In short, the graded concept can help eliminate the weak link in dissimilar welded parts, which is often the weld zone itself.

Gradient design adapted for AM: While monolithic alloy use has been employed successfully, this is primarily due to the high strength and high temperature capabilities of nickel-base superalloys and refractory alloys. Further benefit for structural components may be realized when site-specific chemistry—tailored to desired performance requirements—is employed. Additional functionalities enabled by AM for topological optimization and manufacturing unitized components with complex geometries may be enhanced by coupling advanced design tools with fabrication of multi-material parts^[6].

Compared to conventional casting, the directed energy deposition (DED) additive modality reduces initial investment by not requiring casting molds. In addition, DED offers near-net shape structures, which significantly reduce machining and material waste compared to forging. High-speed printing via DED can also enable printing of large-scale structures at a fast production rate. The goal of this effort is to fabricate unitized parts with the proposed technology, with a reduction in part count to decrease supply chain costs. The unique challenges of additively manufacturing high temperature alloys involve crack sensitivity with regard to as-built process parameters and post-processing treatments. While the thermal gradients and cooling rates in and around the melt pool control aspects of the liquid-to-solid

phase transformation, spatially varied thermal cycles may result in residual stresses and distortion in solidified components (e.g., due to subsequent solid-state transformations)^[7,8].

Material properties and deformation characteristics also depend on the actual alloy class being studied. For example, low gamma prime Ni-base superalloys like IN718 and IN625 are readily weldable, and AM build parameters dictate thermal gradients and cooling rate dependencies on microstructure. However, the thermal gradient effect and cooling rate-dependent transformation kinetics are quite different for Nb-base refractory alloys like C103^[9,10]. Figure 2 is an illustration of varied operating temperatures among different alloy classes^[9]. Note that for monolithic builds, the alloy of choice restricts us, either by cost or performance, to operate within a specific temperature range. The proposed compositional transition from a high-temperature Ni-base superalloy (e.g., IN718) to an extreme temperature-capable Nb-base refractory alloy (e.g., C103) will allow fine-tuning of microstructures for zone-based performance over a wider temperature range.

In addition, this concept helps to simultaneously investigate the complex phase transformations, deformation mechanisms, and interrelationships across graded alloy chemistries. This effort is relevant to a wide range of applications in aviation (structural engine components), space (access, high

velocity) and energy fields (marine, nuclear, and renewables). For example, NASA and Boeing have adopted zone-based deployment of lightweight and high-temperature materials for the rocket nozzles and hypersonic air breathing structures (X-15, X-43A, and X-51A), respectively^[11,12].

APPROACH AND RESULTS

The proposed study of developing a graded structure from IN718 to C103 alloy may be broken down into the following categories: (a) find thermodynamically stable, kinetically feasible gradient pathways between terminal alloys from two different alloy classes—Ni-base superalloy (IN718) used for high temperature applications and Nb-base refractory alloy (C103) capable of operating at extreme temperatures; (b) adopt optimal build strategies to additively manufacture crack-free graded structures with hybrid microstructures; (c) understand phase transformation, microstructural evolution, and variation in residual stress as a function of thermal history (as-built and post-processed states); and (d) correlate these with the mechanical property response of graded specimens. Keep in mind that this is a work in progress and the current manuscript primarily deals with the first task, which is CALPHAD-based analyses of IN718 to C103 graded structures.

Design of the gradient pathway between two terminal alloys is a critical step as it ensures build compatibility, both thermodynamically and

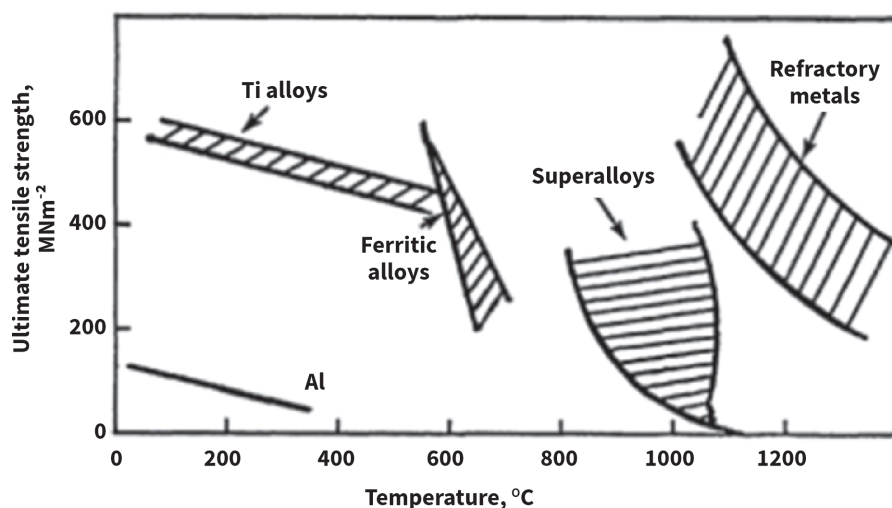


Fig. 2 — Tensile strengths of various alloy classes as a function of temperature^[9].

kinetically. For this study, Pandat (a CALPHAD-based thermodynamic software) was employed to understand the variations in solidus and liquidus temperatures within the two terminal alloys. Along with this, important parameters like gamma prime solvus temperature, equilibrium phase fractions as a function of temperature, and corresponding phase compositions were also determined. Initial trials involved identifying the major equilibrium phases in a pure Ni to pure Nb graded structure (Fig. 3).

For this calculation, 11 major phases, namely liquid (L), face centered cubic (fcc), body centered cubic (bcc), ordered bcc (B2), gamma prime (L1₂), gamma double prime, delta, mu, sigma, Laves, and AlNbNi₂, were selected. As shown in Fig. 3, the Ni-Nb binary phase diagram exhibits an fcc crystal structure on the pure Ni side, and a bcc crystal structure on the pure Nb end. There are also intermediate intermetallic phases—delta and mu, with possible compositions of Ni₃Nb and Ni₆Nb₇, respectively, coupled with associated eutectic reactions.

Subsequently, in the modeling effort for commercial IN718 and C103

alloys, a six-zone linear compositional gradation was chosen to predict the phase evolution of these 11 phases. Thus, if the compositional variations may be defined as (x*(Ni alloy) + y*(Nb alloy)), where x and y are weight fractions of the two terminal alloys and x + y = 1, then the gradient steps for six-zone linear compositional gradation were set up such that the unicompositional zones are with x = 1, 0.8, 0.6,

0.4, 0.2, and 0. Thus, the terminal alloy compositions were represented by x = 1 (IN718 with nominal composition of 54Ni-0.7Al-19Cr-17Fe-3Mo-5.3Nb-1Ti wt%) and x = 0 (C103 with nominal composition of 89Nb-10Hf-1Ti wt%).

CALPHAD-based thermodynamic predictions of this compositionally graded structure are compiled in Tables 1-3. Table 1 shows a tabulation of predicted solidus and liquidus

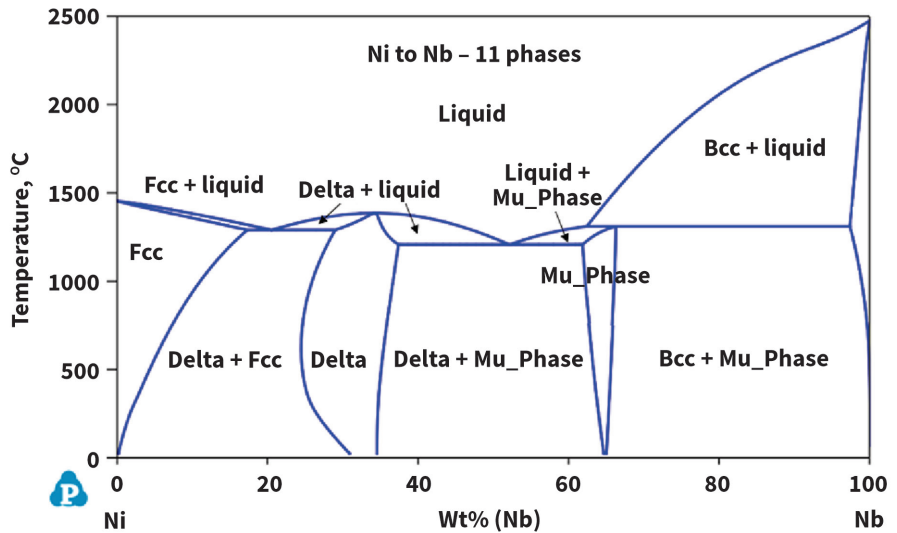


Fig. 3 — Ni-Nb binary phase diagram as predicted by Pandat software.

TABLE 1 – PREDICTED SOLIDUS, LIQUIDUS, AND FIRST PHASE TO SOLIDIFY FOR SIX-ZONE LINEAR COMPOSITIONALLY GRADED MODEL

Fraction of IN718 alloy	Fraction of C103 alloy	Liquidus temp, °C	Solidus temp, °C	Freezing range, delta °C	Primary solid phase to form in liquid
1	0	1330	1260	70	FCC
0.8	0.2	1279	939	340	Laves (C14)
0.6	0.4	1510	844	666	Laves (C14)
0.4	0.6	1533	1015	518	Laves (C14)
0.2	0.8	2019	1005	1014	BCC
0	1	2411	2372	39	BCC

TABLE 2 – PHASE PREDICTION AND CORRESPONDING PHASE FRACTION AT 25°C FOR SIX-ZONE LINEAR COMPOSITIONALLY GRADED MODEL

Compositional gradient		Predicted phase and phase % at 25°C							
Fraction of IN718 alloy	Fraction of C103 alloy	FCC	Gamma prime, L1 ₂	Delta	Laves, C14	Mu	AlNbNi ₂	BCC	Other minor phases
1	0	45	11.6	19.7		5.6		18.1	
0.8	0.2			53.7	4.8	5.1	5.2	28	3.2
0.6	0.4			26.6	62.2		4.3	2.3	4.6
0.2	0.8				27.5	12.5	1.5	52.1	6.4
0	1							92.7	7.3

TABLE 3 – PHASE PREDICTION AND CORRESPONDING PHASE FRACTION AT 1000°C FOR SIX-ZONE LINEAR COMPOSITIONALLY GRADED MODEL

Compositional gradient		Predicted phase and phase % at 1000°C							
Fraction of IN718 alloy	Fraction of C103 alloy	Liquid	FCC	Delta	Laves, C14	Mu	B2	BCC	Other minor phases
1	0	2.2	97.8						
0.8	0.2	2.2	30.4	38.7	21.7			7	
0.6	0.4	6.8		6.2	85.5				1.5
0.4	0.6				49.3	27.5	6.9	16.3	
0.2	0.8				27.5	11.5	8.4	52.6	
0	1							100	

temperatures for each unicompositional zone in the six-zone linear compositionally graded model. The table clearly shows a significant variation in freezing range, which is the difference between liquidus and solidus temperatures. This is also an indication of how quickly a liquid solidifies: (i) in a layer-by-layer fashion for materials having smaller freezing ranges (e.g., eutectics), or (ii) for an extended period of time resulting in elongated grains and possibly with enhanced hot tearing tendencies in alloys that have relatively large freezing ranges.

Similar to the CALPHAD results for pure Ni-Nb gradation, these predictions also indicate the formation of fcc and bcc phases for two terminal alloy compositions. However, for intermediate compositions, a C14 Laves phase is predicted as the first phase to solidify. Pandat software was also used to predict equilibrium phase fractions at both room (25°C) and elevated (1000°C) temperatures, as compiled in Tables 2 and 3, respectively. These tables indicate that as the composition of a block is altered from IN718 to C103 in a stepwise manner, the primary phase with the highest phase fraction changes from fcc to intermediate delta and C14 Laves phases, and finally to a bcc crystal structure.

It is evident that these equilibrium thermodynamic predictions point toward considerable challenges—such as hot cracking and distortion due to residual stress—associated with additively building a IN718 to C103 graded structure. However, a blown powder DED modality provides a unique opportunity

to regulate the deposition rates of terminal alloys via a multi-hopper powder feed system, along with the potential to regulate the substrate and surrounding temperature. Note that prior studies have discussed the nuances of laser-processed microstructures and defect distribution in Ni-base superalloys^[13-16] and Nb-base refractory alloys^[17-20]. Based on the above calculations, Fig. 4 shows a schematic of IN718 to C103 graded block that will be used for initial build trials.

As indicated in the figure, the build height of two terminal compositions will be approximately 40 mm, while each of the intermediate four layers will be 5 mm tall. The overall block size of 100 x 25 x 10 mm may be subsequently machined to extract specimens for characterization and testing of composite builds. Based on the literature, at least two or three build trials will likely be required to identify overlapping process parameters between the terminal alloys, as well as to conduct post-build analyses to ensure defect-free builds. A successful gradient build via one combination of gradient step size and pathway would be considered a sufficient criterion to move forward with post-build characterization. During this step, thermodynamic predictions could be validated, and heat treatment and mechanical property response could also be investigated.

CONCLUSION

The proposed research effort delves into one of the many unique AM functionalities, by using a combi-

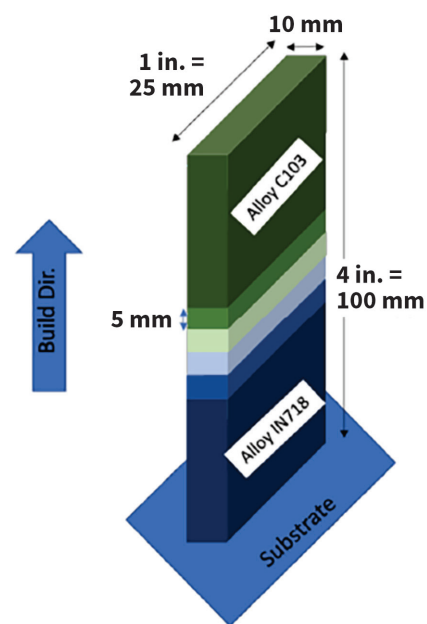


Fig. 4 — Schematic of a six-zone compositionally graded structure with approximate block dimension.

national approach to generate hybrid microstructures tailored for site-specific property response. This material-agnostic concept is currently being studied on alloys that are used for high temperature and extreme environment applications—namely Ni-base superalloys (IN718) and Nb-base refractory alloys (C103), respectively. Preliminary CALPHAD-based thermodynamic predictions show significant variations in freezing ranges and primary phases to form within the individual unicompositional zones in a six-zone linear compositionally graded model. The equilibrium phase fractions at both room (25°C) and elevated (1000°C) temperatures point toward essentially

different solidification and solid-state transformation routes at the intermediate unicompositional steps.

Based on this data, a plan was developed to additively build a graded structure with a defined gradient step size and pathway. Future research includes post-build characterization coupled with a fundamental evaluation of phase transformation and deformation mechanisms in these graded structures. This approach provides a critical path toward a broader vision of employing breakthrough AM functionalities with integrated design, manufacturing, and materials evolution criteria. ~AM&P

Acknowledgment

This work was sponsored by ORNL Director's Research and Development Fund (#10700) under Strategic Hire Initiative.

For more information: Soumya Nag, Materials Science and Technology Division, Oak Ridge National Laboratory, 1 Bethel Valley Rd., Oak Ridge, TN 37830, 865.241.9586, nags@ornl.gov.

Notice

This manuscript has been authored by UT-Battelle LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy (DOE). The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. government purposes. DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (<http://energy.gov/downloads/doe-public-access-plan>).

References

1. T.M. Pollock and S. Tin, Nickel-Based Superalloys for Advanced Turbine Engines: Chemistry, Microstructure and Properties, *J. Propuls. Power*, Vol 22(2), p 361-374, 2006.
2. M. Rappaz, et al., Development of Microstructures in Fe-15Ni-15Cr Single Crystal Electron Beam Welds, *Metall Mater Trans A*, Vol 20(6), p 1125-1138, 1989.
3. M. Rappaz and C.A. Gandin, Probabilistic Modelling of Microstructure Formation in Solidification Processes, *Acta Mater.*, Vol 41(2), p 345-360, 1993.
4. M. Henderson, et al., Nickel Based Superalloy Welding Practices for Industrial Gas Turbine Applications, *Sci. Technol. Weld. Join.*, Vol 9(1), p 13-21, 2004.
5. <https://www.mri.psu.edu/mri/newspubs/focus-materials/advanced-manufacturing/fast-%E2%80%93-penn-state%E2%80%99s-manufacturing-scale-fast>.
6. J. Smith, et al., Linking Process Structure Property and Performance for Metal-Based Additive Manufacturing: Computational Approaches With Experimental Support, *Comput. Mech.*, Vol 57(4), p 583-610, 2016.
7. P. Rangaswamy, et al., Residual Stresses in Components Formed by the Laser-Engineered Net Shaping Process, *J. Strain. Anal. Eng. Des.*, Vol 38(6), p 519-527, 2003.
8. T. DebRoy, et al., Additive Manufacturing of Metallic Components – Process, Structure and Properties, *Prog. Mater. Sci.*, Vol 92(5), p 112-224, 2018.
9. <https://www.totalmateria.com/page.aspx?ID=CheckArticle&site=kts&NM=355>.
10. A. Basak and S. Das, Additive Manufacturing of Nickel-Base Superalloy R N5 Through Scanning Laser Epitaxy (SLE) – Material Processing, Microstructures, and Microhardness Properties, *Adv. Eng. Mater.*, Vol 19(3), p 1600690, 2017.
11. P.R. Gradl, et al., Lightweight Thrust Chamber Assemblies Using Multi Alloy Additive Manufacturing and Composite Overwrap, https://www.nasa.gov/sites/default/files/atoms/files/2020_aiaa_rampt_multimetallc_compositechambers-final.pdf.
12. <https://www.flightglobal.com/analysis/analysis-3d-printing-brings-scramjet-engines-closer-to-reality/133652.article>.
13. A. Reichardt, et al., Advances in Additive Manufacturing of Metal-Based Functionally Graded Materials, *Int. Mater. Rev.*, Vol 66(1), p 1-29, 2021.
14. V.A. Popovich, et al., Functionally Graded Inconel 718 Processed by Additive Manufacturing: Crystallographic Texture, Anisotropy of Microstructures and Mechanical Properties, *Mater. Des.*, Vol 114, p 441-449, 2017.
15. L.D. Bobbio, et al., Additive Manufacturing of a Functionally Graded Material from Ti-6Al-4V to Invar: Experimental Characterization and Thermodynamic Calculations, *Acta Mater.*, Vol 127, p 133-142, 2017.
16. Y. Chen and F. Liou, Additive Manufacturing of Metal Functionally Graded Materials: A Review, *Proc. of the 29th Annual Int. Solid Freeform Fabrication Symposium*, p 1215, 2018.
17. <https://techport.nasa.gov/view/94980>.
18. T.G. Nieh and J. Wadsworth, Recent Advances and Developments in Refractory Alloys, *Materials Research Society*, Vol 1, 1993.
19. O. Mireles, et al., Additive Manufacturing of Refractory Alloy C103 for Propulsion Applications, AIAA Propulsion and Energy 2020 Forum, <https://doi.org/10.2514/6.2020-3500>.
20. N.R. Philips, M. Carl, and N.J. Cunningham, New Opportunities in Refractory Alloys, *Metall. Mater. Trans. A*, Vol 51, p 3299-3310, 2020.

ASM DATA ECOSYSTEM

Designed with key input from members, ASM International's new Data Ecosystem provides a digital platform to assist engineering design and manufacturing stakeholders working in the Materials 4.0 era.

Raymond V. Fryan,* ASM International, Materials Park, Ohio

The impact that Industry 4.0, with interconnected cyber-physical systems, has on our materials, engineering, and manufacturing capabilities needs, has thrust advanced materials-related modeling and curated, high-quality materials data into the spotlight for many ASM members. Materials 4.0 represents those increased expectations of the Industry 4.0 world in which we all operate. This more predictive side of engineering and optimization is affecting new materials development, functional and mechanical design, manufacturing, supply chain, and sustainability in ways the STEM community would have thought not possible even a few decades ago. ASM International has developed the Data Ecosystem over the past two years, addressing the need for better products, created and manufactured more cost effectively, and launched more quickly. This convenient digital platform, Data Ecosystem Workbench, will serve the materials, engineering, scientific, manufacturing, and supply chain stakeholders in the ASM sphere of influence. Data Ecosystem will also launch with pragmatic education courses aimed at teaching the fundamentals of data management, advanced analytics, and materials processing that will expand the adoptability of Materials 4.0 in our highly competitive landscape (Fig. 1).

INTRODUCTION TO THE ASM DATA ECOSYSTEM

The ASM International team developed a concept based on a simple structure recognizing the criticality of high-quality materials data in the Materials 4.0 era. We discovered strong leadership resonance that the world's

largest society of materials professionals should help accelerate adoption of digital ways of working in our membership. As we further refined the concept into a working prototype, we also found that data management and data management education was a key foundational element that would make the concept grow faster and more effectively. In summary, the Data Ecosystem provides the materials data our members need to succeed, analytical tools that leverage those data, and the pragmatic education on how members can capture more value in this Materials 4.0 environment.

A MEMBER-BASED INITIATIVE DESIGNED AROUND MEMBER INSIGHTS

Taking the initial concept and creating a functioning product line took many months of member engagement and significant assessment of unserved and underserved materials community needs. This challenge was addressed by an ASM staff-led market research effort we called "Member Market Insights." The layers of this effort started with a foundation of extracting needs from over two dozen member experts. These themes progressed into a member survey with significant member response, and then product categories and features were further refined through member focus groups.

The themes that emerged as critical to ASM stakeholder success included reduced barriers for adoption

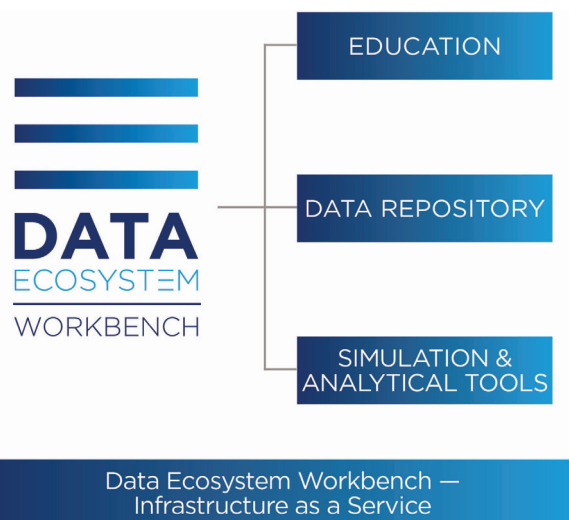


Fig. 1 — Schematic of ASM Data Ecosystem.

of Materials 4.0 capabilities, expanding the availability of high-quality materials data, particularly for usage in design, engineering, manufacturing, and supply chain activities, with applicability to a broad cross-section of our membership (Fig. 2). The Materials 4.0 capabilities that showed the greatest member interest in the survey included pragmatic data management and data management education, machine learning, and uncertainty quantification. This led to an initial Release 1 offering based on the survey results and initial high-level themes identified:

- Data management fundamentals and materials processing simulation courses as the first two classes in the ASM Data Ecosystem Education portfolio
- Dante Solutions heat treat process simulation desktop toolset, with practical heat treat development and optimization graphical tools
- Pandat Materials Phase Diagram desktop simulation module with

*Member of ASM International

five popular Pandat databases, used in materials design and optimization

- ASM Global Materials Platform, a database and data tools platform based on Key to Metals' Total Materia product, including powerful workflow, export, visualization, search, compliance, and standards-based engineering scale materials data
- ASCENDS Machine Learning tool (graphic user interface), an easy to learn, easy to use machine learning tool for the non data scientist
- SmartUQ, a powerful desktop analytical platform that allows complex, system-level design and optimization by incorporating advanced design of experiments, statistical variation, feeding advanced, computationally efficient, machine-learning-based emulator models
- ASM Materials Platform for Data Science, the largest phase and crystal system-specific compendium of highly curated materials data, with advanced searching, application program interface, and other advanced data visualization features

2022 CURRENT SITUATION

As of early 2022, the Data Ecosystem is in launch mode; the platform and digital products will scale and will incrementally improve using agile development methods and frequent engagement of dedicated focus group

volunteers. The initial product offering will create immediate impact for pragmatic ASM stakeholder needs and will enable advancement of ASM International's strategic plan including digital, international, diversity-equity-inclusion, and interdisciplinary themes.

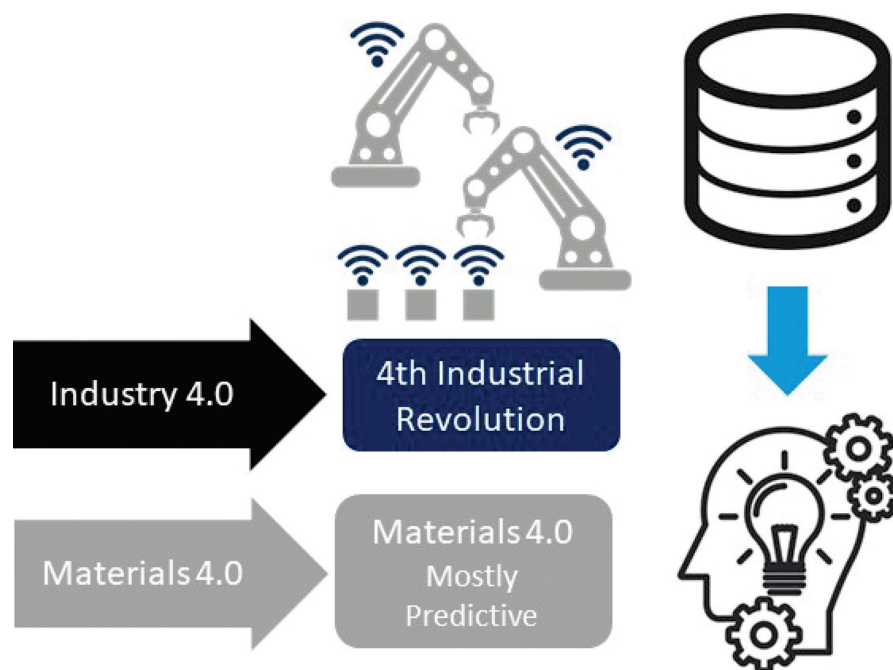


Fig. 2 — Predictive challenges of Industry 4.0 and Materials 4.0.

AI-ML MICROSTRUCTURE TOOLKIT

NASA Glenn Research Center and ASM International are co-partners in producing an artificial intelligence (AI)/machine learning (ML) enhanced Microstructure Toolkit. The main purpose of the Microstructure Toolkit is to quantify the relationship between processing, structure, property, and performance (PSPP) with the objective of accelerating alloy development and increasing material performance.

The resulting toolkit will efficiently combine the resources of ASM International Micrograph Database, Image Processing via MIPAR and its deep learning algorithms, a Python interface created by Materials Data Management Inc. (MDMI), and the Machine Learning algorithm created by NASA Glenn, which is trained based on more than 100,000 NASA micrographs.

The Microstructure Toolkit will leverage the AI/ML algorithms to automatically extract and quantify microstructure features from micrographs of different alloy classes. The components of the toolkit will interact with the Granta MI information management system to store/retrieve and make accessible materials data such as processing, property, micrograph images, extracted microstructure features, and machine learning derived relationships.

The project was initiated in January of this year and is a two-year venture. At the end of the project, the resulting Microstructure Toolkit will find its way into the ASM International Data Ecosystem for the benefit of Society members and the materials community at large. Based on input from members, ASM strongly believes that deciphering (decoding) microstructure is of tremendous importance for the entire materials community, all involved engineering groups, manufacturers, and industrial applications. The post project evolution of the microstructure toolkit will depend directly on feedback received from users.

The International Metallographic Society, as an affiliate society of ASM International, will promote this project's results and convey to members the toolkit benefits while encouraging feedback and suggestions for further improvement.

RELEASE 1: JUST THE BEGINNING...

The Release 1 products and classes represent a good start. Additional simulation tools covering key materials and processing steps in typical supply chains will complement the current initial tools, including more materials data and additional manufacturing processes, such as forging and solidification. The expansion of existing data platforms like ASM-Global Materials Platform and the ASM Materials Platform for Data Science will be enhanced through both incremental, periodic additions

to the data, as well as large expansions of materials system coverage through innovative and sustainable data business models engaging partners in industry, academia, and government. Our growth will be guided by dedicated volunteer thought leaders in the ASM membership representing the best insights of those segments. This growth, over time, will anchor ASM International, The Materials Information Society, as a preeminent materials data resource in the Materials 4.0 world, and beyond. We eagerly look forward to better serving our members and their stakeholders through the Data Ecosystem. ~AM&P

Acknowledgments

The author would like to thank Afina Lupulescu, senior new product developer at ASM International, for her contribution of the AI-ML Microstructure Toolkit and Adhesives Project sections of this article.

For more information: Raymond V. Fryan, executive director – new product development, ASM International, 9639 Kinsman Rd., Materials Park, Ohio 44073, 440.671.3834, ray.fryan@asminternational.org.

ADHESIVES PROJECT

ASM International's involvement in an innovative Adhesives Project, conceptually implemented by the Army Research Laboratory (ARL), assures the convergence of technology interests of defense, commercial markets, data science, and the materials community. This project also facilitates a novel approach to building materials standards (specifically ARL's MIL-PRF-32662), while assuring the full and continuous participation of the manufacturing community (i.e., PPG Industries as a prime contractor for the project). The critical data management disciplines will include data processing and visualization, developed by the Data Science Department at Worcester Polytechnic Institute (WPI), using an advanced analytics approach incorporating machine learning and design of experiments.

The purpose of this two-year project is to implement the Adhesives database MIL-PRF-32662 (initially created by an ARL/WPI/PPG

collaborative effort) into the ASM Data Ecosystem. The Adhesives database will be managed by ASM International and will be both publicly and privately accessible through the ASM Data Ecosystem to generate the largest impact for the scientific community. The Data Ecosystem will become a sustainable business model combining open sources (e.g., national laboratories) and private sources (e.g., industry partners like PPG) to feed data to the Data Lake as well as using specific tools for processing and curating data.

In this model, ASM will implement the database into the Data Ecosystem, and will also consider feeding the database continuously with new supplier data. This feed will be made possible by the involvement of PPG and other adhesives manufacturers who are ready to establish contact with their consumers by using the ASM Data Ecosystem as a neutral venue to facilitate product and performance dialog. This approach will benefit all participants and the broader materials and standards communities as well. In addition to gathering

adhesives data via a chosen data management platform, ASM will focus on:

- the best practices of building a database while combining the best of data management and data science concepts
- the best practices for building and updating standards, significantly reducing the timeline for standards development
- creating a vivid platform with continuous involvement and contributions of/from suppliers
- creating a continuous interaction between our qualified volunteers and suppliers
- involving ASM International interns (i.e., undergraduate students)
- developing a fruitful dialog between materials, suppliers, and standards communities
- developing a sustainable, unique business model that captures relevant materials data from both open and private sources

GET ENGAGED, GET INVOLVED, GET CONNECTED

ASM has recently launched a new Technical Committee on Materials Data Management and Analytics with David Furrer, FASM, as chair. It has already spawned two subcommittees, one on Artificial Intelligence and Machine Learning (Amra Peles, chair; Afina Lupulescu, co-chair/liaison), and the second on Materials Certification Data (Heath Riewe, chair). These committees will be useful for guiding the future direction of the Data Ecosystem. To get involved, visit the ASM Connect home page at connect.asmiinternational.org, search for the committee or subcommittee name, and get into the conversation!

QUALIFYING MATERIALS USING LASER POWDER BED FUSION FOR ADDITIVELY MANUFACTURED AEROSPACE COMPONENTS

Ahead of formal certification, many advanced metals have been qualified for 3D printing, allowing for the creation of previously impossible aerospace parts including for the hypersonic environment.

Certified parts that are additively manufactured (AM) using laser powder bed fusion (L-PBF) technology are already in flight in aerospace and defense applications. As these industries continue to innovate, they are encouraged by the high quality of 3D-printed parts made with titanium, aluminum, and nickel-based alloys—and are asking AM equipment makers to qualify an ever-broadening roster of other materials (Fig. 1).

It's perhaps no surprise that aerospace and defense have been the primary drivers of advancements in additive manufacturing. The benefits of the technology are tangible and competitive: novel designs that couldn't be manufactured any other way, lighter-weight components with consolidated parts and optimized topologies, often greater strength and durability than conventionally manufactured parts, and significant performance boosts in aircraft engines, heavy-lift rockets, drone turbines, and satellite launchers.

But qualifying a particular metal alloy for L-PBF can be a highly exacting journey. While the specifications for

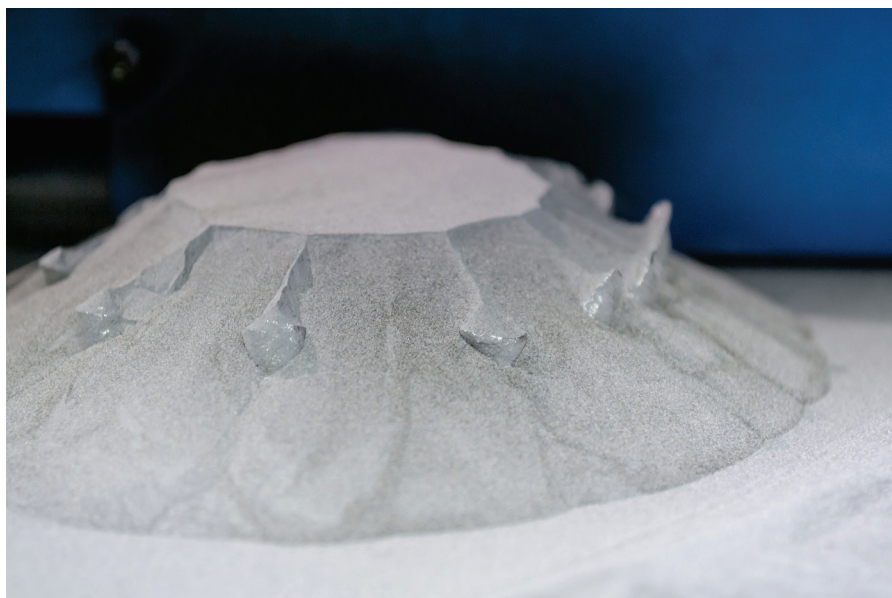


Fig. 1 — Metal powder cloaks a part on an AM build platform after 3D printing.

conventional manufacturing methodologies of the same alloy have existed for years (through SAE International, ASTM, or similar regulatory bodies worldwide), the number of specifications for L-PBF have been sparse, and have hindered its adoption. As L-PBF has matured, specifications have started to be issued with the participation of

regulatory agencies, aerospace OEMs, and L-PBF machine producers. This has been critical for the continued, successful adoption of AM in aviation and aerospace. While industry creates specs and standards for the materials being used in production today, L-PBF equipment manufacturers are paying keen attention to customer requests and overall

market trends as they prioritize which materials to qualify next.

AN EXPENSIVE JOURNEY TOWARD CERTIFICATION OF AM MATERIALS

Beyond adherence to specifications, flight certification is the holy grail for L-PBF parts in manned aircraft. Up to now, the major commercial aircraft manufacturers (and the larger suppliers that serve them) have gone it alone, developing proprietary internal material specifications for producing AM parts certified for flight. Part of the reason that L-PBF has been limited to major aerospace manufacturers is due to the massive cost of material characterization; the other part is limitations in the regulations.

For example, FAA 14 CFR 21.1 only permits airframe, engine, and propeller type certificate holders to create their own material specs and allowables. For everyone else there are no FAA-recognized specs or allowables. Regardless of the fidelity of the data provided, MRO providers and smaller aviation-related companies encountered significant cost and certification challenges that held back the widespread adoption of AM.

However, a robust data set—*MMPDS Volume 2 for Additive Materials*—is soon to be released, enabling companies of all sizes to embrace AM without going to such lengths of time and expense. The FAA, DOD, and NASA all recognize MMPDS (Metallic Materials Properties Development & Standardization) as an industry-based source for design allowables referencing a material spec, typically AMS (Aerospace Material Specifications, from SAE International), that can be used for parts and repairs. The initial alloy to be certified for additive applications by MMPDS is Alloy 718 (an Inconel), the workhorse material in jet engines that's proved its worth in traditional manufacturing for years. (Next up are likely titanium and aluminum.)

The first L-PBF equipment maker to have submitted initial data for Alloy 718 to MMPDS consideration is Velo3D. The list of material properties that is being characterized is comprehensive

and includes tensile and compressive strength (including stress-strain curves), elongation, as-printed fatigue, bearing strength, shear, and creep/stress-rupture. For tensile, modulus, and fatigue properties, these will not only be at room temperature, but up to the typical maximum operating temperatures. This will create a data set comparable to what exists in MMPDS Volume 1 for wrought Alloy 718.

EXPLORING THE VALUE OF MATERIALS FOR AM AHEAD OF FORMAL CERTIFICATION

Although this level of exactitude is desirable for any application involving flight, unmanned rocket, drone, and satellite-launch companies are already enthusiastic about the robustness of the parts they're seeing emerge from the more-advanced L-PBF systems. Ahead of MMPDS certification, a variety of materials are being successfully qualified and employed by these users: Titanium 6Al-4V (in drone engines for light weight and strength), Aluminum F357 (ideal for heat exchangers), and Hastelloy X (Hast-X, employed in combustion-zone gas turbine engines to resist high-temperature stress-corrosion cracking and oxidation) (Fig. 2).

For example, SpaceX, which owns numerous Sapphire AM systems from Velo3D, produces multiple 3D-printed parts for the Raptor rocket engines that will power its flagship launch vehicle,

the Starship. The Starship is planned to deliver supplies to the International Space Station, launch the Starlink constellation, and carry missions to the Moon and Mars.

Boom Supersonic, a project that's reinvigorating supersonic jet travel at a more technically sophisticated level than the previous Concorde aircraft, is 3D printing vanes, ducts, louvers, and more from titanium.

And back on planet Earth, Purdue University's Zucrow Laboratories are using 3D-printed parts in a giant experimental burner that's creating a hypersonic-flow environment in a ground-test cell. Researchers are proving-out a variety of injector geometries for a combustor made out of Hast-X, one of the few high-strength, high-temperature superalloys that can withstand the extremes of the hypersonic environment.

THE ALUMINUM F357 EXAMPLE

Developing an optimum L-PBF compatible material for such exploits can take some doing, as demonstrated by the journey that L-PBF has taken over the years to arrive at Aluminum F357.

Some of the original success in 3D printing aluminum came with AlSi₁₂, an alloy that is 12% silicon, a fairly high proportion. The Si serves to increase the flowability of the AM meltpool (where the laser meets the metal powder), and also to decrease the amount

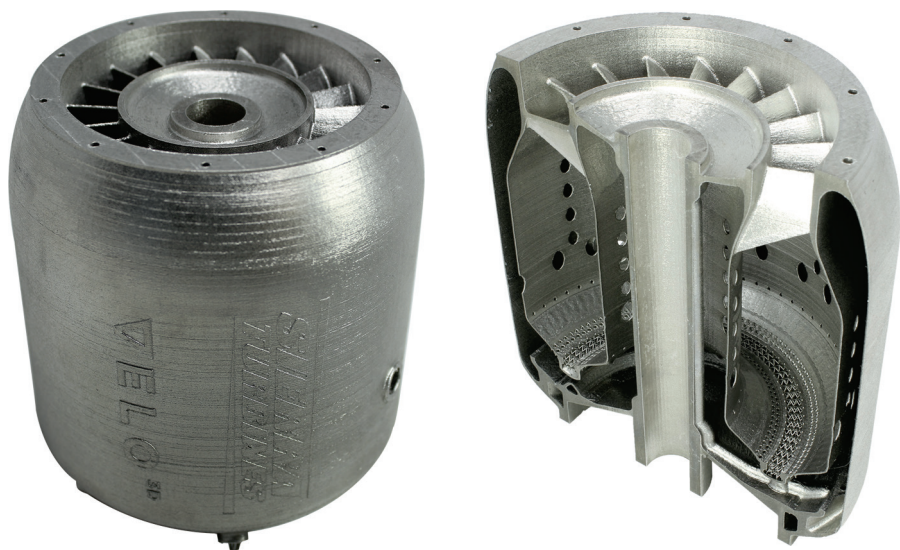


Fig. 2 — Whole and cut views of Sierra Turbines' microturbine, 3D printed in Hastelloy X.

of contraction as the meltpool solidifies. But for mechanical properties, a high silicon content was less desirable, so the proportion of silicon in the alloy was reduced from 12 to 10% and magnesium was added to increase the strength.

The result was $AlSi_{10}Mg$, but parts printed with it still didn't meet many of the mechanical requirements of the final applications. One solution was to add more magnesium to A356, an alloy widely used in casting, which created A357, a stronger material that could be heat treated to better properties.

But there was a catch: A357 also contains 0.04 to 0.07% beryllium. The alloy can be toxic to humans, especially if it is inhaled, which can happen during the powder-handling and post-processing that occur with additive manufacturing production. The final step? Eliminate beryllium from the alloy, with the result being the now "best" aluminum for AM, F357 (think F for "free of beryllium").

Since then, F357 has become the L-PBF alloy of choice in aerospace (Fig. 3). Chief engineers like it because it's been used for decades in the field. Swapping an A356 casting for an F357 L-PBF part is a relatively low technical risk for system material compatibility and corrosion. Additionally, the lower silicon content over $AlSi_{10}Mg$ makes it able to be anodized.

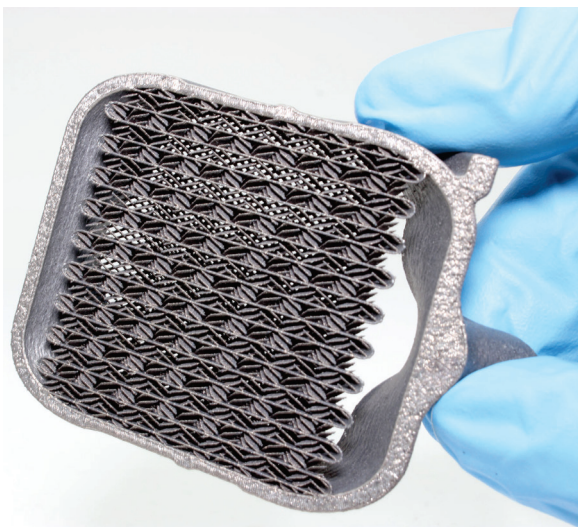


Fig. 3 — Heat exchanger 3D printed in Aluminum F357.

PICKING THE OPTIMAL MATERIAL FOR AM APPLICATIONS

Typically, an aerospace company that is already exploring AM and is thinking about expanding their internal resources with new materials capabilities—or, alternatively, one that outsources to a full-service contract manufacturer (CM) that provides start-to-finish AM services—has a new part design that can't be made any other way besides AM. They have a specific alloy in mind to give them the desired heat, strength, ductility, or other characteristics they require, and they've developed their own internal specifications that must be met.

An existing material already qualified for use on an advanced AM system (like Alloy 718) may fit the bill for them. In that case, it may just be a matter of accessing a dedicated machine; it's considered best-practice to assign a particular material to a specific piece of equipment, to avoid cross-contamination, as well as customize atmospheric conditions during printing.

But if the need is for a completely new alloy to be qualified for 3D printing, the AM-equipment maker will work closely with the customer, and/or a CM, to prove-out the material on the actual machine system. This involves identifying the customer's application-specific requirements, securing the material from a reputable vendor, and developing the process parameters and recipes required to print in that material.

The printer must then achieve or exceed established criteria for porosity, ultimate tensile strength, surface roughness, and dimensional accuracy. Skin and core samples are tested, along with sophisticated processes like zero-degree printing (which only the most advanced AM systems can achieve). It's also common to perform a design of experiments on

thermal treatments of the printed material to achieve the desired mechanical properties.

STRENGTH VERSUS TEMPERATURE REQUIREMENTS: A BALANCING ACT

Some of the most recently qualified alloys for use in advanced metal AM systems include the aluminum alloy Scalmalloy, and the nickel-based superalloys Amperprint 0233 Haynes 282 (HS282), and Inconel 625 (IN625).

Corrosion can be a challenge with aluminum alloys. Currently the highest-strength aluminum alloy for AM is Scalmalloy, developed by APWorks at Airbus for, among other uses, critical structural aviation applications such as airframe parts or engine mounts. Achieving high strength in aluminum generally involves adding alloying elements that may be detrimental to corrosion behavior. In the case of Scalmalloy, APWorks used a strengthening mechanism of precipitated ceramic phase Al_3Sc that enables retention of excellent corrosion resistance of 5000 series alloys and has been proven through numerous corrosion tests (Fig. 4).

Nickel-based superalloys, on the other hand, are more corrosion resistant than aluminum alloys. The primary driver for advanced nickel-based materials has been a demand for parts that can withstand higher temperatures that

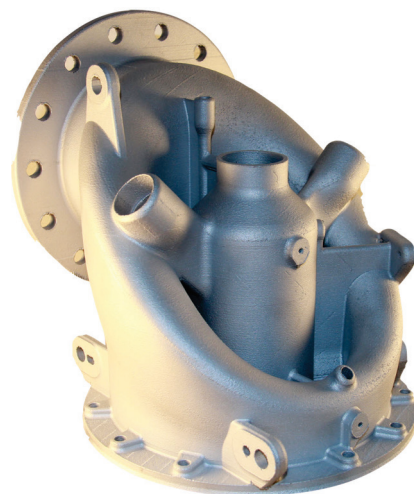


Fig. 4 — Manifold 3D-printed using L-PBF with Scalmalloy.

allow for more efficient thermal cycles in engine applications. Parts made from the nickel-based alloys also exhibit high strength, as well as corrosion, oxidation, and creep resistance.

As operating temperatures rise, especially above 1100°F, it is important to consider the stresses experienced by the individual parts as well as the duration of those stresses. For precipitation-hardened alloys, over-aging can occur at high temperatures over time, and material properties can degrade. Long term temperature exposure can also lead to embrittlement as the phases that once strengthened the alloy breakdown with exposure at evaluated temperatures. Additionally, corrosion and oxidation also become more of a concern at higher temperatures even for nickel-based alloys.

GOING BEYOND 'WORKHORSE' ALLOY 718

There has been good reason for Alloy 718's reputation as a workhorse. It offers superior strength at low-to-intermediate temperatures, with its strength primarily coming from precipitation hardening via the γ'' (Nb) & γ' (Ti & Al) phases during the aging cycle of post printing heat treatment. Of Alloy 718, IN625, Hast-X, and HS282, Alloy 718 offers the highest strength in operating ranges of 1200° to 1300°F.

However, with significant time at temperatures above 1200°F, Alloy 718 becomes over-aged as the precipitates decompose. Embrittlement can occur as well as microstructural damage from corrosion and oxidation.

Therefore, for higher temp/high strength applications, Amperprint 0233 Haynes 282 (HS282) has been developed (Fig. 5). This precipitation-hardened alloy is γ' strengthened (Ti & Al) and can be used with operating temperatures up to 1700°F. Above 1200°F, HS282 offers higher strength and higher creep-resistance than Alloy 718.



Fig. 5 — Cut view of a test ramjet engine, additively manufactured with laser powder bed fusion (L-PBF) using Haynes 282 superalloy, a material that can survive the temperature extremes of hypersonic flight.

The duration of exposure to high temperatures must also be taken under consideration when choosing a superalloy for AM. Solution-strengthened alloys such as IN625 and Hast-X are chosen for applications with prolonged exposure to high temperatures because they avoid over-aging, since they do not have γ' precipitates that will degrade with time. Both maintain good strength, ductility, and creep after thousands of hours at high operating temperatures, but these alloys lack the strength of the HS282 and Alloy 718 discussed above.

IN625 and Hast-X both exhibit exceptionally high ductility, which is advantageous in operating environments with high thermal stresses such as heat exchangers. When comparing the two, IN625 provides higher strength and creep resistance below 1400°F, where

Hast-X provides superior creep resistance in the 1400° to 1600°F range. Hast-X also provides additional corrosion resistance at higher temperatures—especially above 1600°F. Velo3D is actively developing the nickel-based alloys discussed above for specific applications with their partners in the jet engine and space industries.

SEEDING THE GROUND FOR THE NEXT NEW AM MATERIAL

The development of new material capabilities for L-PBF applications is providing aerospace design engineers with unprecedented opportunities to realize much greater design freedom than they've experienced with traditional manufacturing methodologies. The ground is now seeded for even more impressive material-plus-application synergies moving forward. The challenges of a lack of specifications, and not having MMPDS allowables, are actively being addressed by the industry. As the groundwork is laid, these will become stepping stones in the progress to flight certification.

Robust material specifications are just the starting point. Tight additive manufacturing process control is key to ensuring that the latest high-performance alloys live up to their potential to produce flight-critical 3D-printed parts. More robust, consistent AM processes are allowing engineers to fully realize the advantages of these new materials. The most advanced AM systems that are now available are meeting and exceeding the industry's high expectations—and producing parts that have already achieved liftoff. ~AM&P

For more information: Will Hasting, director of solutions engineering, Velo3D, 511 Division St., Campbell, CA 95008, 408.610.3915, info@velo3d.com, www.velo3d.com.

AEROMAT | 2022

MARCH 15-17 | PASADENA CONVENTION CENTER | PASADENA, CALIFORNIA

SHOW PREVIEW

Plan now to attend the 33rd AeroMat Conference and Exposition, the premier aerospace materials conference presented by top leaders in this field. With the theme Research and Development Enabling Next-Generation Aerospace Materials, this year's AeroMat brings together hundreds of aerospace professionals and exhibiting companies to discuss and display the latest advancements in materials and processes for aerospace applications.

With more than 160 presentations, the technical program of the 2022 conference is one of the top reasons aerospace professionals attend AeroMat. This year's program will focus on innovative aerospace materials and process developments, along with implementation of those technologies in new and legacy platforms to cost-effectively improve performance of aerospace structures and engines. Keynote sessions on the show floor will complement the technical programming and provide attendees with a comprehensive view of the industry.

Returning this year is the highly successful interactive forum. An expert panel during the Wednesday forum will address sustainability as an imperative in the aerospace industry.

Starting this year, ASM International and SAE International will combine signature aerospace conferences, providing an unparalleled industry event. Attendees will benefit from an expanded technical program and exhibit hall, all in one location in sunny Pasadena!

EDUCATION WORKSHOPS

Monday, March 14 | 8:30 a.m. – 4:30 p.m.

RESIDUAL STRESS: FRIEND OR FOE?

Instructor: Jeff Bunn

This course is an introduction to residual stress and residual stress characterization methods, including mechanical release methods as well as diffraction methods.

METAL ADDITIVE MANUFACTURING FOR AEROSPACE

Instructor: Frank Medina

This course will provide details on powder bed fusion, directed energy deposition, and binder jetting technologies and how they have been used successfully in aerospace applications.

FATIGUE AND FRACTURE IN AEROSPACE

Instructor: Kumar V. Jata, FASM

Attendees will learn about fatigue and fracture principles in structural materials to aid in the prevention of failures from manufacturing defects and service-induced damage.

PLENARY SPEAKERS

TUESDAY, MARCH 15



Dr. Sylvain Henry

*Vice President Research and Development
Constellium*

3:30 – 4:15 p.m.



Dr. Claudio Dalle Donne

*Head of Materials, Process, and Testing
Airbus Airframe Engineering*

4:15 – 5:00 p.m.

WEDNESDAY, MARCH 16



Dr. Markus Heinimann

*Vice President — Technology & Quality
Howmet Aerospace*

3:00 – 4:00 p.m.

INDUSTRY PARTNER:



CORPORATE SPONSORS:



Constellium



Quaker
Houghton



Thermo-Calc
Software

SPONSOR:



AMERICAN
ELEMENTS

THE ADVANCED MATERIALS MANUFACTURER®

AEROMAT 2022 SCHEDULE-AT-A-GLANCE

MONDAY, MARCH 14

8:30 a.m.–4:30 p.m. | Education Workshop: Fatigue Fracture in Aerospace (additional fee)

8:30 a.m.–4:30 p.m. | Education Workshop: Metal Additive Manufacturing for Aerospace (additional fee)

8:30 a.m.–4:30 p.m. | Education Workshop: Residual Stress: Friend or Foe (additional fee)

TUESDAY, MARCH 15

7:00 a.m.–6:00 p.m. | Registration Open

8:00–10:00 a.m. | Technical Programming

10:00–10:30 a.m. | Refreshment Break

10:00 a.m.–6:30 p.m. | Exhibits Open

10:30 a.m.–12:00 p.m. | Technical Programming

12:00–1:00 p.m. | Lunch (included in registration)

1:00–3:00 p.m. | Technical Programming

3:00–3:30 p.m. | Refreshment Break on Show Floor

3:30–5:00 p.m. | Keynote Sessions on Show Floor

5:00–6:30 p.m. | Expo Welcome Reception (included in registration)

WEDNESDAY, MARCH 16

7:30 a.m.–5:00 p.m. | Registration Open

8:00–10:00 a.m. | Technical Programming

9:30 a.m.–5:00 p.m. | Exhibits Open

10:00–10:30 a.m. | Refreshment Break on Show Floor

10:30 a.m.–12:00 p.m. | Joint Panel Discussion with AeroTech: Sustainability— an Aerospace Imperative

12:00–1:00 p.m. | Lunch on Show Floor (included in registration)

1:00–2:30 p.m. | Technical Programming

2:30–3:00 p.m. | Refreshment Break on Show Floor

3:00–4:00 p.m. | Keynote Session on Show Floor

4:00–5:30 p.m. | Technical Programming

THURSDAY, MARCH 17

7:30 a.m.–1:00 p.m. | Registration Open

8:00–10:00 a.m. | Technical Programming

10:00–10:30 a.m. | Refreshment Break

12:00–1:30 p.m. | Lunch (included in registration)

1:30–5:15 p.m. | Technical Programming

3:00–3:15 p.m. | Refreshment Break

EXHIBITION HOURS*

TUESDAY, MARCH 15

10:00 a.m. – 6:30 p.m.

WELCOME RECEPTION WITH EXHIBITORS

TUESDAY, MARCH 15

5:00 – 6:30 p.m.

WEDNESDAY, MARCH 16

9:30 a.m. – 5:00 p.m.

**TIMES ARE SUBJECT TO CHANGE.*

**FOR EVENT DETAILS AND TO REGISTER, VISIT
AEROMATEVENT.ORG**

EXHIBITORS

Allied High Tech Products

Bruker Nano Analytics

Carr Lane Mfg Co

Centrix Inc

Curtiss-Wright Surface Technologies

ERG Aerospace

Innovative Test Solutions

IPG Photonics

JR Automation

Leica Microsystems

Luxfer Magnesium Rolled Products

MAGMA Foundry
Technologies, Inc.

Proto Manufacturing

Quaker Houghton

SAE Industry Technologies
Consortia

SAE International

SINTX Technologies

The Boeing Company

Thermo-Calc Software Inc.

Thermo Fisher Scientific

Westmoreland Mechanical
Testing & Research, Inc.

*Note: Exhibitors list current as of
February 15.*

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



AEROMAT 2022 EXHIBITOR SHOWCASE

VISIT THESE KEY EXHIBITORS AND MORE AT AEROMAT IN PASADENA, CALIFORNIA

EXHIBITION HOURS

Pasadena Convention Center

Tuesday, March 15 • 10:00 a.m. – 6:30 p.m.

Wednesday, March 16 • 9:30 a.m. – 5:00 p.m.



For over 39 years, **Allied High Tech Products Inc.** has provided sample preparation products for microscopic evaluation to the aerospace industry. Allied manufactures cutting-edge equipment at its California headquarters where all design, manufacturing, and assembly takes place in-house to ensure the highest quality equipment is produced. Items on display include Allied's state-of-the-art TechCut 5x sectioning saw, MetPrep 3 polishing system, and Zeiss microscopes. A range of consumable products will also be shown.



display include Allied's state-of-the-art TechCut 5x sectioning saw, MetPrep 3 polishing system, and Zeiss microscopes. A range of consumable products will also be shown.

alliedhightech.com — Booth 202



Boeing is the world's largest aerospace company and leading manufacturer of commercial jetliners, defense, space, and security systems, and service provider of aftermarket support. As America's biggest manufacturing exporter, the company supports airlines and U.S. and allied government customers in more than 150 countries.

Boeing products and tailored services include commercial and military aircraft, satellites, weapons, electronic and defense systems, launch systems, advanced information and communication systems, and performance-based logistics and training.

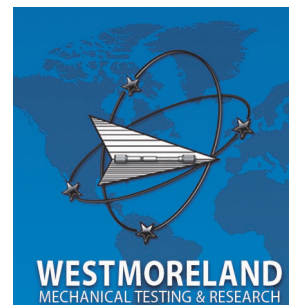
boeing.com — Booth 303

Quaker Houghton helps the world's aerospace manufacturers overcome the toughest challenges in machining and heat treating of highly engineered aerospace materials by increasing overall productivity and throughput, while improving environmental and safety impact. Our innovative range of products includes metal forming, removal, cleaners, heat treatment fluids, specialty hydraulic fluids, industrial lubricants, greases and more. Our comprehensive process fluid portfolio together with our equipment and sensor technology, QH FLUIDTREND real-time fluid monitoring software, and expert engineering services deliver the ultimate fluid optimization solution for Industry 4.0, QH FLUID INTELLIGENCE.



home.quakerhoughton.com/aerospace — Booth 307

Westmoreland Mechanical Testing & Research Inc. is a world-renowned materials testing facility for the additive manufacturing, aerospace, automotive, composites, medical, and power generation industries. With over five decades of custom, high volume and quick materials testing experience, our comprehensive testing services provide innovative, customizable, and reliable analytical results to fit the most complex engineering needs, both large and small.



wmtr.com — Booth 306

HTPRO

**BUSINESS AND TECHNOLOGY FOR
THE HEAT TREATING PROFESSIONAL**

CONTROLLED GAS QUENCHING
FOR DIFFICULT GEOMETRIES

4

BASICS OF HEAT TREATING
MAGNESIUM ALLOYS

8

SAVE THE DATE

HEAT TREAT / TRATAMIENTO TÉRMICO



7-9 DE MARZO DE 2023 | MARCH 7-9, 2023 | MONTERREY, MEXICO

Save the date for this biennial global conference that will attract maintenance supervisors, metallurgists, and production engineering staff. This unique conference is designed to provide a bridge for relevant new technology for thermal processing and how it is applied to the production environment in Mexico.

Website Coming Soon!

HEAT TREAT | 2023

OCTOBER 17-19, 2023 | DETROIT, MICHIGAN

Heat Treat is the event that bridges
RESEARCH with **INDUSTRY!**

Heat Treat is the premier conference and expo for heat treating professionals, attracting the who's who of the heat treating industry. Innovators, influencers, and decision makers in the heat treating industry from around the world will be at Heat Treat 2023.

heattreatevent.org

CO-LOCATED WITH:



INTERNATIONAL MATERIALS,
APPLICATIONS & TECHNOLOGIES
2023

ORGANIZED BY:



EDITOR

Victoria Burt

TECHNICAL ADVISORS

HTS R&D Committee

PRODUCTION MANAGER

Madrid Tramble

NATIONAL SALES MANAGER

Kelly Johanns

440.318.4702

kelly.johanns@asminternational.org

HEAT TREATING SOCIETY EXECUTIVE COMMITTEE

Lesley Frame, *President*

Eric L. Hutton, *Immediate Past President*

Benjamin Bernard, *Vice President*

EDITORIAL OPPORTUNITIES FOR HTPRO IN 2022

The editorial focus for HTPRO in 2022 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

July/August

Thermal Processing in
On/Off Highway Applications

November/December

Atmosphere & Vacuum
Heat Treating

To contribute an article to an upcoming issue, contact Vicki Burt at vicki.burt@asminternational.org.

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

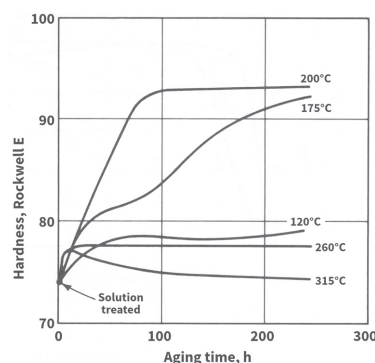


4

MINIMIZING DISTORTION DURING HIGH-PRESSURE GAS QUENCHING, PART II

Justin Sims, Zhichao (Charlie) Li, and
B. Lynn Ferguson

The second article in this series looks at materials testing, microstructural evaluation, mechanical testing, and residual stress and distortion using the DANTE Controlled Gas Quenching process.



8

THE BASICS OF HEAT TREATING MAGNESIUM ALLOYS

Three types of thermal treating processes are commonly applied to magnesium alloys, including annealing, solution heat treatment, and precipitation, or aging.

DEPARTMENTS

2 | EDITORIAL

3 | HEAT TREATING SOCIETY NEWS

ABOUT THE COVER

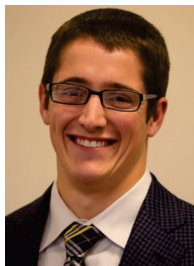
An eccentric bore coupon used to evaluate out-of-round distortion. Courtesy of DANTE Solutions Inc.

HTPro is published three times per year by ASM International®, 9639 Kinsman Road, Materials Park, OH 44073, 440.338.5151, asminternational.org. Vol. 10, No. 1, Copyright © 2022 by ASM International®. All rights reserved.

The acceptance and publication of manuscripts in HTPRO does not imply that the editors or ASM International accept, approve, or endorse the data, opinions, and conclusions of the authors. Although manuscripts published in HTPRO are intended to have archival significance, authors' data and interpretations are frequently insufficient to be directly translatable to specific design, production, testing, or performance applications without independent examination and verification of their applicability and suitability by professionally qualified personnel.

HTS ONLINE MEMBER COMMUNITY: LET'S KEEP THE DISCUSSION GOING!

If you are an active member of the Heat Treating Society's On-line Member Community (HTSOMC) on ASM Connect, you may have noticed an increase in activity in recent months, especially in the weeks leading up to and after the Heat Treat 2021 conference in St. Louis. Over the past six months, the HTS Membership Committee has prioritized promoting the HTSOMC because:



Russell

- It is a relatively new membership benefit that we expect to offer increasing value moving forward.
- According to the 2020 ASM membership survey, networking opportunities and access to industry news and trends are two of the most valuable benefits of membership. As a place to meet new people, share industry news, and have technical discussions with technical experts, the HTSOMC should provide additional value in both of these key areas.
- Professional societies such as ASM's HTS—both the organization and its members—benefit from dialog, and the HTSOMC provides an additional platform for such dialog.



If you have not already, I encourage you to create an ASM Connect account at connect.asminternational.org. Your Connect account will be linked to your existing ASM International account and, as an HTS member, you will automatically have access to the HTSOMC. We expect activity to continue increasing in the coming months and we would love for you to be a part of it!

The HTS Membership Committee is also looking to expand to better represent our diverse membership and gain new perspectives and ideas. If you are interested in joining the committee, please contact Nicole Hale (nicole.hale@asminternational.org) or Collin Russell (crussell@lanl.gov).

Collin Russell

R&D Engineer, Los Alamos National Laboratory,
New Mexico

The views expressed in this article are his own and do not represent the views of the Laboratory. This work was approved for public release under LA-UR-21-32210.

JUST FOR FUN: What is the coolest thing you've encountered in thermal processing?

Follow



Collin Russell 09-01-2021 16:31

There are lot of very cool physical phenomena, processes, and components encountered in the field of...

1. JUST FOR FUN: What is the coolest thing you've encountered in thermal processing?

1 Recommend



Collin Russell

Actions

Posted 09-01-2021 16:31

Reply

There are lot of very cool physical phenomena, processes, and components encountered in the field of thermal processing. What's the coolest thing you've seen?

To start, I'll throw out a couple of my own:

- 1) Press "stretch": The (sometimes quite significant) elastic deformation of forging presses that occurs under load. In some cases, engineers have to compensate for this phenomena in the design of tooling.
- 2) Induction levitation melting: Simultaneously levitating and melting materials using electromagnetic induction. It's so cool (figuratively, not literally), it looks like magic!

Now that the ball is rolling, please share your own experiences!

Collin Russell
Research & Development Engineer
Los Alamos National Laboratory
Los Alamos NM
(505) 664-0949

ASM HEAT TREATING SOCIETY NAMES COMMITTEE CHAIRS FOR 2021-2022 TERM

The ASM Heat Treating Society (HTS) board appointed chairs to each of its committees for the 2021-2022 term. **Lesley Frame**, assistant professor, University of Connecticut, serves as president of HTS. **Benjamin Bernard**, VP international sales, Surface Combustion Inc., serves as vice president of HTS. **Eric Hutton**, VP operations, Bodycote, serves as HTS immediate past president and treasurer, as well as chair of the HTS Awards & Nominations and the HTS Finance Committees. **Timothy De Hennis**, senior metallurgist, Boeing, and **Chuck Faulkner**, commercial development manager, Quaker Houghton, continue to serve as co-

chairs of the HTS Exposition Subcommittee. **Roger Jones**, **FASM**, CEO emeritus, Solar Atmospheres Inc., was named chair of the HTS Technology & Programming Committee. **Mohammed Maniruzzaman**, engineering specialist, Caterpillar Inc., continues as chair of the HTS Education Subcommittee. **Michael A. Pershing**, senior technical steward, Caterpillar Inc., continues as chair of the HTS Research and Development Committee. **Collin Russell**, research & development engineer, Los Alamos National Laboratory, continues as chair of the HTS Membership Subcommittee. If you are interested in serving on an HTS committee, contact the respective committee chair, or email maryanne.jerson@asminternational.org.



Frame



Bernard



Hutton



De Hennis



Faulkner



Jones



Maniruzzaman



Pershing



Russell

HTS SEEKS BOARD NOMINATIONS

The ASM HTS Awards and Nominations Committee is seeking nominations for one vice president and one secretary for a two-year term and three Directors for a three-year term, as well as candidates to fill the positions of Student Board Member and Emerging Professional Board Member for a one-year term. Candidates must be an HTS member in good standing. Nominations should be made on the formal nomination form and can be submitted by a chapter, council, committee, HTS member, or an affiliate society. The HTS Awards and Nominations Committee may consider any HTS member, even those who have served on the HTS Board previously. **Nominations for board members are due March 15.**

For more information and the nomination form, visit the HTS website at hts.asmiinternational.org and click on Membership and Networking and then Board Nominations; or contact Mary Anne Jerson at 440.671.3877, maryanne.jerson@asminternational.org.

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

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

Paper submission deadline has been extended to March 15. For nomination rules and forms for the awards, visit the Heat Treating Society website at hts.asmiinternational.org and click on Membership & Networking and Society Awards. For additional information, or to submit a nomination, contact Mary Anne Jerson by email at maryanne.jerson@asminternational.org.

MINIMIZING DISTORTION DURING HIGH-PRESSURE GAS QUENCHING, PART II

The second article in this series looks at materials testing, microstructural evaluation, mechanical testing, and residual stress and distortion using the DANTE Controlled Gas Quenching process.

Justin Sims,* Zhichao (Charlie) Li,* and B. Lynn Ferguson, FASM*

DANTE Solutions Inc., Cleveland

In the November/December 2021 issue of *HTPro* magazine, part I of this article series described a process, termed DANTE Controlled Gas Quenching (DCGQ), by which the martensitic phase transformation is controlled during gas quenching. The process was devised in response to large distortion during high-pressure gas quenching of complex geometries and is a method to control distortion. Part I described the equipment design, construction, operation, and characterization. This article discusses material property testing, microstructural evaluation, and mechanical testing.

MATERIALS TESTING RESULTS

The previous article showed that the temperature of quench gas, at atmospheric pressure, could be controlled within the range of martensitic formation for high hardenability steels. However, doubt still existed as to whether or not a martensitic structure formed over such a long time period could perform as well as a standard high-pressure gas-quenched structure. Therefore, a testing program was launched to compare DCGQ to a standard high pressure gas quenching process.

Ferrium C64 was chosen as the candidate alloy, due to its high hardenability, use in high-stress powertrain applications, and high-tempering temperature. And because the martensite transformation occurs slowly using DCGQ, self-tempering may occur during quench if the tempering temperature is less than the martensite start temperature (MS). Further testing is needed to evaluate this effect. All comparative testing was performed on identical coupons machined from one, 100 mm diameter bar. For tests which required carburization, a single LPC process was executed by Solar Atmospheres in Souderton, Pa., on all coupons as one batch using a predefined LPC

recipe. The HPGQ coupons were processed first, at Solar Atmospheres, and the austenitizing step was analyzed such that the time the coupons spent in the austenite phase was noted and duplicated with the DCGQ coupons. This was done to ensure any additional carbon diffusion occurring during austenitizing was similar between the two sets of coupons. All processed coupons, DCGQ and HPGQ, were also subjected to cryogenic and tempering treatments. The testing included, on carburized coupons, microstructural evaluation, hardness, and residual stress and on noncarburized coupons, tensile, impact strength, and distortion.

MICROSTRUCTURAL EVALUATION

Previous experiments had been conducted on base carbon Ferrium C64 prior to the design and construction of the DCGQ prototype unit to evaluate a slow transformation rate on C64's microstructure. Those preliminary results showed no noticeable difference between slowly and rapidly transformed martensitic microstructures. Figure 1 shows the microstructure, magnified 1000x, of a carburized (a) DCGQ processed coupon and (b) HPGQ processed coupon. As with previous experiments, there is no discernable difference between the two microstructures. The thin gray film on the DCGQ coupon is oxidized copper, which was removed prior to testing. The microhardness profiles

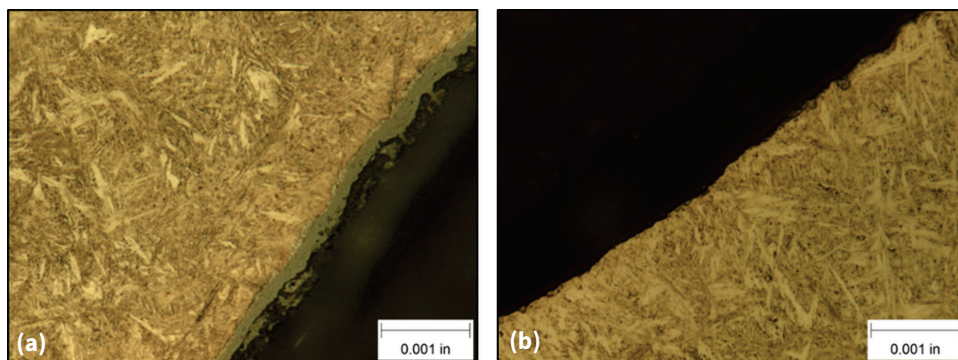


Fig. 1 — Microstructure of a carburized coupon processed using (a) DCGQ and (b) HPGQ, magnified 1000x.

*Member of ASM International

for the coupons are shown in Fig. 2 and confirm that the slow transformation rate did not alter the microstructure of the DCGQ processed coupons, compared to coupons processed using a standard 2-bar HPGQ process.

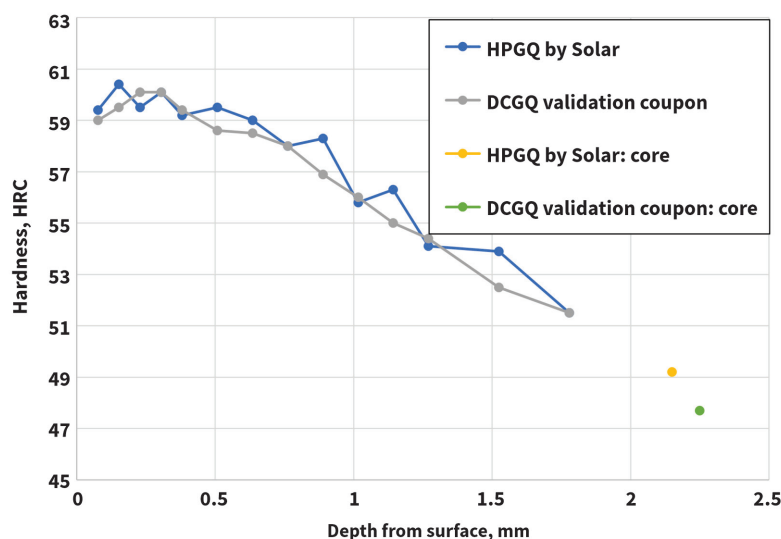


Fig. 2 — Hardness profile comparison of carburized coupons processed using DCGQ and HPGQ.

MECHANICAL TESTING

Tensile testing and Charpy V-notch impact testing were conducted at room temperature to compare the mechanical properties of DCGQ processed C64 and HPGQ processed C64. Table 1 shows the results from these tests and reveals equivalent tensile and yield strengths, elongation and reduction of area, and impact energy for Ferrum C64 processed using HPGQ and DCGQ. These tests are promising, as they indicate that a slow martensitic transformation can be used for Ferrum C64 without degrading the microstructure or mechanical properties. Materials with similar MS and tempering temperatures should also be suitable for DCGQ, though further testing is required.

RESIDUAL STRESS AND DISTORTION

Residual stress profiles for a carburized coupon were compared between the two processes, at two locations, and are shown in Fig. 3. There is no significant difference be-

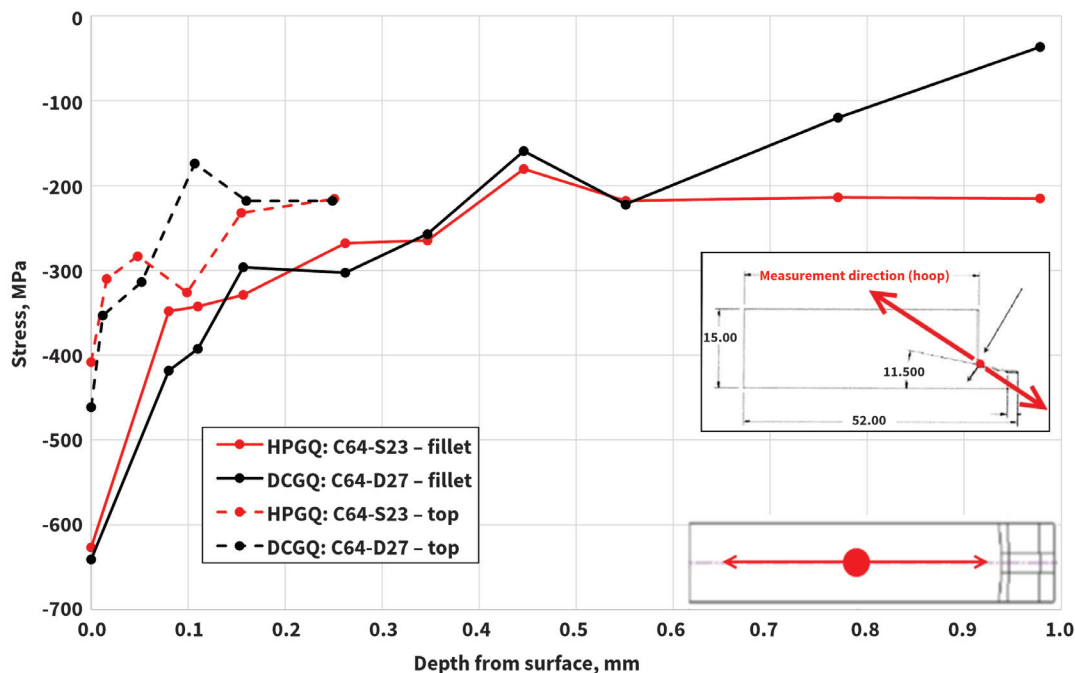


Fig. 3 — Residual stress profile comparison of carburized coupons processed using DCGQ and HPGQ.

TABLE 1 – TENSION AND CHARPY IMPACT RESULTS FOR FERRIUM C64 COUPONS

	Tensile strength, MPa	Yield strength, MPa	Elongation, %	RA, %	CVN energy, J
DCGQ	1627	1405	17.75	71.2	25.35
HPGQ	1625	1401	16.75	71.0	24.00

tween the residual stress profiles. This, combined with the microstructural and mechanical property evaluations, bode well for fatigue performance being similar between parts subjected to the two different processes.

Bend fatigue testing was conducted during this work; however, the results were impacted by surface oxidation on the DCGQ bend fatigue coupons. The oxidation was caused by the DCGQ coupons requiring open air processing with the prototype unit and was verified by SEM; production equipment can eliminate this problem by operating in a protective atmosphere. Although the DCGQ coupons were copper plated, the integrity of the copper was not maintained throughout the complete cycle, with damage likely occurring during the 1000°C austenitizing step, and subsequently worsened during the 500°C tempering cycle. The DCGQ coupons which did not fail after a few hundred cycles due to crack initiation at an oxide, would runout with stress levels comparable to HPGQ. Therefore, operating DCGQ under a protective atmosphere for all processing steps should not render a decrease in in-service performance compared to HPGQ processed components.

The above discussion focused on showing that certain materials, particularly those which are tempered at temperatures below their MS, have the potential to acquire

a similar structure and properties after a relatively slow transformation from austenite to martensite, compared to a rapid transformation from austenite to martensite. However, the benefit of DCGQ is its capability to significantly reduce and control distortion of difficult-to-quench geometries. One such geometry was designed by DANTE Solutions to maximize nonuniform cooling and create large distortion. The coupon, shown in Fig. 4, was used to show the distortion reducing capabilities of DCGQ compared to HPGQ.

Out-of-round distortion was the chosen mode of distortion to evaluate, due to its ease of measurement. A 50 mm eccentric bore was drilled through a disc having a 100 mm diameter and 100 mm height, creating a 6 mm thin section and 44 mm thick section. A bore gauge is used to compare the measurements of the bore at the location between the minimum and maximum thicknesses and at 90° to this location. The two measurements are made at five points along the height, as shown in Fig. 4.

Two eccentric bore coupons were processed using HPGQ and two using DCGQ. These coupons were processed alongside the mechanical test coupons. The out-of-round distortion results for the four coupons at the five axial locations, along with the average for each coupon, are shown in Table 2.

For the given geometry and distortion mode, DCGQ reduced the distortion by 100 μm , or 50%, compared to HPGQ. This is significant, as the DCGQ recipe used was designed for the bend fatigue coupon, which has a thinner and more uniform cross-section. The recipe was designed as such to ensure testing was conducted using a DCGQ recipe representative of the geometry being tested. Slowing the DCGQ process down would

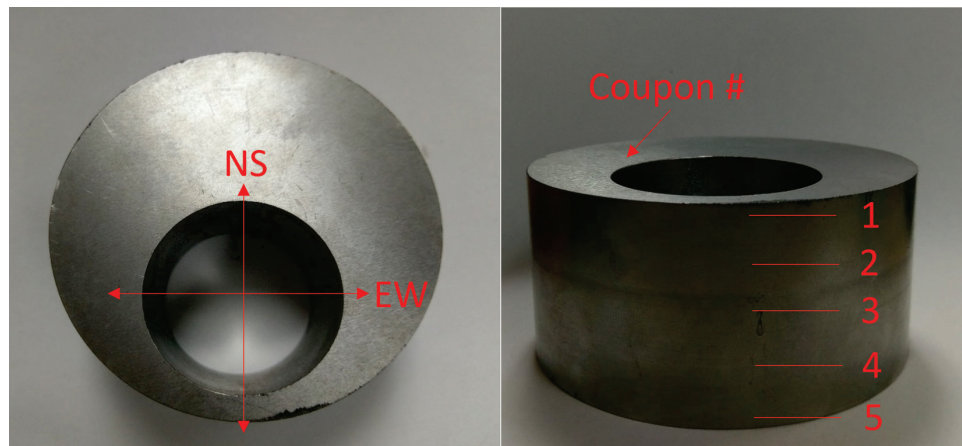


Fig. 4 — Eccentric bore coupon used to evaluate out-of-round distortion, showing the two directions used to define out-of-round (left) and the five axial measurement points (right).

TABLE 2 – OUT-OF-ROUND DISTORTION RESULTS FOR FERRIUM C64 COUPONS

Axial position	Coupon DCGQ 4, mm	Coupon DCGQ 5, mm	Coupon HPGQ 1, mm	Coupon HPGQ 2, mm
1	0.11	0.09	0.15	0.23
2	0.09	0.11	0.21	0.21
3	0.07	0.11	0.23	0.21
4	0.08	0.12	0.22	0.20
5	0.11	0.09	0.25	0.23
Average	0.092	0.104	0.212	0.216

yield less distortion of the eccentric bore geometry. Regardless, a 50% reduction in distortion was achieved when compared to the currently used processing conditions for Ferrium C64.

DANTE simulations have been conducted on various geometries, using various DCGQ recipes, and it has been shown that it is possible to design a DCGQ recipe that completely eliminates the shape change distortion, with only the uniform volumetric size change from the initial to final volume microstructure occurring. Generally, this recipe takes too much time to be practical. However, the processing time can be reduced to determine acceptable distortion and processing time; the DCGQ recipe used to reduce distortion in the eccentric bore coupon by 50% was executed in one hour, where the recipe resulting in no shape change of this geometry, determined by DANTE modeling, requires seven hours to complete.

CONCLUSIONS

The DANTE Controlled Gas Quenching (DCGQ) process has the potential to handle difficult-to-quench part geometries without the use of expensive press quench tooling and reduce the amount of post-heat treatment processing required. The work presented here concluded that it is possible to control the temperature of quench gas entering a quench vessel, at atmospheric pressure, in order to follow a time-temperature recipe required to control the martensitic transformation rate in high hardenability steel alloys. The prototype unit constructed was able to achieve great control within the temperature range of 400 to 100°C, using varying rates of temperature change. The work further concluded that for Ferrium C64, the relatively slow transformation rate from austenite to martensite did not alter the microstructure, mechanical properties, or residual stress when compared the current standard quenching process. Furthermore, DCGQ was shown to significantly

reduce distortion in a difficult-to-quench geometry when compared to HPGQ.

Besides having the capability to significantly reduce distortion for difficult-to-quench part geometries, DCGQ has also been shown, through the use of DANTE modeling, to be less sensitive to nonuniform convective cooling conditions created by equipment design. The DCGQ process can also result in more dimensionally consistent components. All of DCGQ's benefits are a result of controlling the martensitic transformation. By controlling the martensitic transformation throughout the part, it is possible to reduce the nonuniform cooling effect created by geometry and equipment design, ensuring that the transformation proceeds in a consistent way, part after part. Consistent and predictable distortion allows the part's pre heat treatment configuration to be redesigned such that the post-heat treated shape is within design tolerances and a minimal amount of post-heat treatment processing is required.

~HTPro

For more information: Justin Sims, senior engineer, DANTE Solutions Inc., 7261 Engle Rd. Ste. 105, Cleveland, OH 44130-3479, 440.234.8477, justin.sims@dante-solutions.com, dantesolutions.com.

Acknowledgments

The authors wish to acknowledge the U.S. Army Combat Capabilities Development Command Aviation & Missile Center (DEVCOM AvMC) for their support of this work. The authors also wish to acknowledge Solar Atmospheres for heat treating the experimental coupons using LPC and HPGQ, Akron Steel Treating for hosting the prototype DCGQ unit and conducting the experiments using DCGQ, and Tensile Testing Metallurgical Laboratory for mechanical property testing.

Interested in advertising with the ASM Heat Treating Society?
Contact Kelly "KJ" Johanns at kelly.johanns@asminternational.org.

THE BASICS OF HEAT TREATING MAGNESIUM ALLOYS

Three types of thermal treating processes are commonly applied to magnesium alloys, including annealing, solution heat treatment, and precipitation, or aging.

Magnesium alloys are produced in both wrought and cast product forms. Cast alloys are much more widely used, and die castings constitute the largest segment. Well over 90% of magnesium alloys are used for high-pressure die casting, but heat treatment plays a small role in die casting. The emphasis here is on gravity-cast alloys.

WROUGHT MAGNESIUM ALLOYS

A relatively limited number of magnesium alloys are available in wrought form, because magnesium is somewhat more expensive than aluminum, and aluminum is also much more easily cold formed. The lower ductility of magnesium alloys is due to the hexagonal close-packed structure of magnesium, which offers only three slip systems. This is also true of zinc, but the c/a ratio of zinc allows mechanical twinning in tension and new slip systems, which leads to great ductility (e.g., 50%) in zinc alloys. In contrast, the c/a ratio of magnesium allows only mechanical twinning in compression. Thus, magnesium alloys invariably have low (e.g., less than 10%) ductility in tension, although magnesium alloys can be fabricated by forming operations with a compression component (e.g., rolling, extrusion).

The basic temper designations used to designate the various types of heat treatment for magnesium alloys are shown in Table 1.

TABLE 1 – MAGNESIUM ALLOY TEMPER CODES

Code	Description
F	As-fabricated
O	Annealing
H10, H11	Slightly strain hardened
H23, H24, H26	Strain hardened and partially annealed
T	Heat treated to produce stable tempers other than F, O, or H
T2	Annealed (cast products only)
T3	Solution heat treated and cold-worked
T4	Solution heat treated
T5	Artificially aged only
T6	Heat treated and artificially aged
T7	Solution heat treated and stabilized
T8	Solution heat treated, cold-worked, and artificially aged
T9	Solution heat treated, artificially aged, and cold-worked

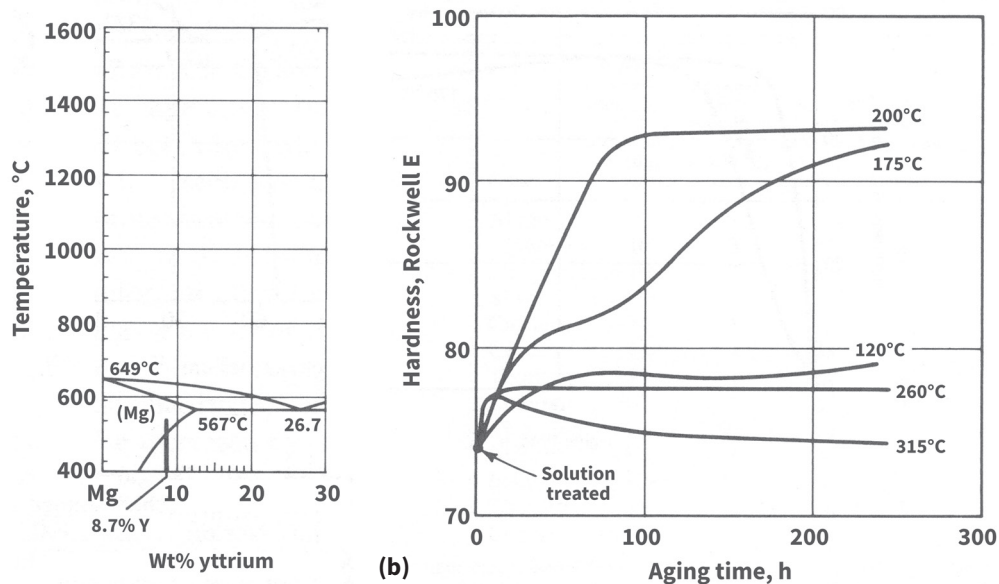


Fig. 1 — Phase diagram (a) and age hardening response (b) of magnesium-yttrium alloy. Source: Ref. 1.

Heat treatment can improve the mechanical properties of most magnesium casting alloys. In most wrought alloys, maximum mechanical properties are developed through strain hardening, and these alloys generally are either used without subsequent heat treatment or merely aged to a T5 temper. Occasionally, however, solution treatment, or a combination of solution treatment with strain hardening and artificial aging, will substantially improve mechanical properties.

Three basic types of thermal treating processes are commonly applied to magnesium alloys: annealing, solution heat treatment, and precipitation or aging. In addition, stabilizing and stress-relieving treatments are used in practice. The former is a type of precipitation, and the latter is related to annealing. Precipitation occurs in many magnesium alloys, but precipitation does not always re-

sult in hardening. In many alloys, lattice coherence (and lattice straining) is lost early in the formation of precipitates. Some examples of significant hardening that does occur from precipitation include magnesium-aluminum alloys, magnesium-yttrium alloys (Fig. 1), and magnesium-zinc alloys.

CAST MAGNESIUM ALLOYS

The cast alloys are used in the as-cast, annealed, or precipitation-hardened conditions. In terms of strengthening by heat treatment, many of the cast alloys can be age hardened. The most common precipitation-hardening treatments for cast magnesium alloys are solution treating and natural aging (T4), natural aging after casting (T5), and solution treating and artificial aging (T6).

CAUSES AND PREVENTION OF PROBLEMS COMMONLY ENCOUNTERED IN HEAT TREATMENT OF MAGNESIUM ALLOYS

Oxidation

Cause: Heat treating without use of protective or inert atmosphere; can lead to local weakening of the metal part, and even to burning of the metal in the furnace

Prevention: Heat treat in a controlled atmosphere containing approximately 1.5% SO₂, or 0.2 to 0.5% SF₆^(*) or HFC-134a in dry air, CO₂, nitrogen, or argon atmosphere. Ensure that furnace is clean and completely dry.

Fusion voids

Cause: Use of improper rate of heating from 260° to 370°C (500° to 700°F) for Mg-Al-Zn alloys, or exceeding recommended temperature in solution heat treating of these alloys or of the alloys that contain zinc, thorium, and rare earth metals as major alloying elements. Fusion voids are not normally observed when the solidus temperature of the alloy is exceeded. In this instance, grain-boundary phase will run along the grain boundary, forming long, narrow regions. This is normally accompanied by grain coarsening.

Prevention: Charge furnace with Mg-Al-Zn alloys at 260°C (500°F) and then heat gradually to solution-treating temperature over a period of 2 h. Control solution temperature so as not to exceed designated temperature by more than 6°C (10°F).

Warping

Cause: Lack of support of castings during heat treatment; uneven distribution of heat

Prevention: Support long spans of thin cross section; use jigs for intricate shapes. Distribute load in furnace to obtain good circulation of atmosphere.

Grain coarsening

Cause: Occurs in HK31A as a result of delay in attaining solution temperature or of holding at solution temperature for an excessive period

Prevention: Prior to solution treating of HK31A, furnace should be at temperature; castings should be loaded quickly, and the loaded furnace should be closed and brought to temperature as rapidly as possible. Time at temperature should be controlled.

Germination

Cause: Grain growth, which occurs in AM 100A, AZ81A, AZ91C, and AZ92A toward the end of the solution-treating cycle

Prevention: Use antigermination heat treating schedules.

Inconsistent properties

Cause: Insufficient or excessive furnace temperature, inadequate circulation of heat in the furnace, faulty temperature control, very slow cooling from the solution-treating temperature, or inadequate solution-treating time for heavy sections

Prevention: Check temperature at various positions in furnace with standardized thermocouple. Distribute castings in furnace to provide adequate circulation of heat. Check temperature controls often and ensure that controls are located so as to provide uniformity of temperature. Increase solution-treating time to allow complete homogenization.

(*) SF₆ is banned in some jurisdictions due to its high global-warming potential.

Solution heat treating is used with cast alloys to reduce the brittle eutectiferous networks that form during casting. Solution heat treating is conducted at 390° to 530°C (730° to 980°F). Solution-heat-treated castings have a more uniform matrix, which improves both strength and ductility. The aging treatment normally does not improve the tensile strength very much, but the yield strength is increased along with some reduction in ductility. However, the ductility decrease still leaves enough ductility for most casting applications.

Some wrought alloys also can be hardened by heat treatment. Magnesium alloys AZ80 and ZK60 are commonly hardened by heat treatment. In general, wrought magnesium alloys that can be strengthened by heat treatment are grouped into five general classes according to composition:

- Magnesium-aluminum-zinc (example: AZ80A)
- Magnesium-thorium-zirconium (example: HK31A)
- Magnesium-thorium-manganese (examples: HM21A, HM31A)
- Magnesium-zinc-zirconium (example: ZK60A)
- Magnesium-zinc-copper (example: ZC71A)

Six common problems that may be encountered in heat treating magnesium alloys are oxidation, fusion

voids, warpage, grain coarsening, germination, and inconsistent properties. A summary of the causes and prevention of problems encountered in heat treatment of magnesium alloys is described in the sidebar. Magnesium alloys are usually solution treated in a protective atmosphere with special temperature monitor and control devices to prevent magnesium fires, which are very difficult to extinguish. The parts are then air quenched and aged. For more specific information on heat treating, see Ref. 2. ~HTPro

Note: This article is an excerpt from the book *Practical Heat Treating, Basic Principles* by Jon L. Dossett. It is adapted from Chapter 12, Heat Treatment of Aluminum and Other Nonferrous Alloys. The book is available in print and in the ASM Digital Library at doi.org/10.31399/asm.tb.phtbp.9781627083263.

References

1. C.R. Brooks, *Heat Treatment, Structure and Properties of Nonferrous Alloys*, American Society for Metals, 1982.
2. T. Abbott, Heat Treating of Magnesium Alloys, *Heat Treating of Nonferrous Alloys*, Vol 4E, *ASM Handbook*, ASM International, 2016, p 640–649.

Vertical Vacuum Oil Quench Furnace for Large Parts

ecm-usa.com/products/pfth



ECM USA
VACUUM FURNACES

PFTH VACUUM FURNACE

**AERONAUTICAL &
LARGE EQUIPMENT APPLICATIONS**
INCLUDING LANDING GEAR & SHAFTS

Low Pressure Carburizing (LPC) or Hardening
of large, heavy loads and long shafts

Significantly reduce cycle time of deep case parts

High efficiency oil quenching tank
with integrated agitation



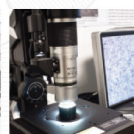
Furnace Systems



Automation



Service & Parts



Synergy Center

9505 72nd Avenue, Suite 400, Pleasant Prairie, WI 53158
262.605.4810 | www.ecm-usa.com | info@ecm-usa.com



LADOS TO CHAIR 2022 NOMINATING COMMITTEE

Members of the 2022 Nominating Committee have been selected and **Prof. Diana Lados, FASM**, Milton Prince Higgins II Distinguished Professor at Worcester Polytechnic Institute (WPI), was elected to serve as chair by the ASM Board of Trustees. Dr. Lados has been a member of ASM International since 2000 and served as ASM trustee in 2018-2021. She earned her B.S./M.S. in mechanical engineering from Polytechnic University of Bucharest in 1997, her second M.S. in mechanical engineering from Southern Illinois University in 1999, and her doctorate in materials science and engineering from WPI in 2004. Lados is also founder and director of the Integrative Materials Design Center (iMdc), an industry-government-university consortium established at WPI in 2007, dedicated to advancing the frontiers of sustainable materials-process-component design and manufacturing for high-performance and reliability. Lados is credited with significant research contributions in the areas of materials design, characterization, evaluation, and computational modeling for fatigue, fatigue crack growth, and high-temperature performance, as well as for her original work in materials processing and advanced manufacturing. Lados is actively engaged in several professional societies, including ASM, where she has organized symposia and served on several committees including the Awards Policy Committee, Technical Committees and Academic Engagement Task Force—which she launched, DEI Task Force, Emerging Professionals Committee, and is an active member of the Central Massachusetts Chapter of ASM. Additionally, Lados is president of Alpha Sigma Mu, the international honor society for the field of materials science and engineering. Lados received the ASM Silver Medal in 2012 and was installed as an ASM Fellow in 2017.



Lados

ASM Officers Appoint Members

In accordance with the ASM International Constitution, ASM president **Dr. Judith A. Todd, FASM**, vice president

Dr. David B. Williams, FASM, and immediate past president **Diana M. Essock, FASM**, appointed nine members to the Nominating Committee from among candidates proposed by chapters, committees, councils, and ASM Affiliate Society boards. This year, the committee is responsible for selecting a nominee for senior vice president-trustee (one-year term), a nominee for vice president-trustee (one-year term), and for nominating three trustees (three-year terms). Members do not select a candidate for president of the Society, because Article IV, Section 8c of the Constitution states that the office of president shall be filled for a period of one year by succession of the senior vice president. The 2022 Nominating Committee's nominee for senior vice president will serve as ASM's president in 2024.

2022 Nominating Committee Members Include:

Daniel Brinkley, staff engineer, Accident Reconstruction Analysis, Raleigh, N.C. (nominated by the Carolinas Central Chapter); **Dr. Jeffrey R. Bunn**, neutron instrument scientist, Oak Ridge National Laboratory, Tenn. (nominated by the Emerging Professionals Committee); **Jean A. Mozolic, FASM**, president and founder, The Mozolic Group, Londonderry, N.H. (nominated by the Boston Chapter); **Dr. Donald R. Muzyka, FASM**, president and CEO (retired), Special Metals Corp., Reading, Pa. (nominated by the ASM Finance Committee); **Dr. Mary K. O'Brien**, Glenn T. Seaborg Post-Doctoral Fellow, Los Alamos National Laboratory, N.M. (nominated by the IDEA Committee); **Dr. Ryan M. Paul**, R&D associate, Oak Ridge National Laboratory, Tenn. (nominated by the Cleveland Chapter); **Jatinder (J.P.) Singh, FASM**, technical integration engineer, General Motors, Warren, Mich. (nominated by the Detroit Chapter and ASM Chapter Council); **Dr. Tirumalai Sudarshan, FASM**, president, Materials Modification Inc., Fairfax, Va. (nominated by the ASM Investment Committee); and **Dr. Ashok Kumar Tiwari**, director, Manufacturing, Chemi-Chem, Mumbai, India (nominated by the Awards Policy Committee).

The Nominating Committee will meet on April 20 and its recommended slate of officers will be published in the May/June issue of *ASM News*.

In This Issue

43

Lados Chairs
Nominating
Committee

44

Affiliate Societies
Name
Committee Chairs

47

Strategic Plan
Highlights

49

Executive
Director
Corner

53

Chapter
News

» HIGHLIGHTS AFFILIATE COMMITTEE CHAIRS

AFFILIATE SOCIETIES NAME COMMITTEE CHAIRS FOR 2021-2022 TERM

The boards of the Electronic Device Failure Analysis Society (EDFAS), Failure Analysis Society (FAS), Heat Treating Society (HTS), International Metallographic Society (IMS), and Thermal Spray Society (TSS) have appointed chairs to each of their committees for the 2021-2022 term. Chairs for ASM Society and General Committees and Councils appeared in the January/February 2022 issue of *ASM News*. The purpose of each committee is stated on its affiliate society website under the Membership and Networking tab.

Electronic Device Failure Analysis Society (EDFAS)

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

Felix Beaudoin, FASM, PMTS yield engineer, Global-Foundries, serves as vice president/finance officer of EDFAS.

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

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

Tom Schamp, principal consulting scientist, Materials Analytical Services, was named chair of the EDFAS Membership Subcommittee.

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

Zhigang Song, senior engineer, IBM, was named chair of the EDFAS Events Committee.

Failure Analysis Society (FAS)

Daniel Dennies, FASM, principal and CEO, Dennies Metallurgical Solutions Inc., serves as president of FAS.

Andrew (Tony) Havics, director, pH2 LLC, serves as vice president of FAS.

James Lane, director, materials science practice, Rimkus Consulting Group Inc., serves as immediate past president and chair of the FAS Awards & Nominations Committee.

Jake Auliff, senior manager, Danfoss Power Solutions, was named chair of the FAS Programming Committee.

Elvin Beach, associate professor of practice in MSE, The Ohio State University, was named chair of the Journal of Failure Analysis and Prevention Editorial Committee.



Demarest



Beaudoin



Knauss



Antoniou



Schamp



Sood



Song



Dennies



Havics



Lane



Auliff



Beach

AFFILIATE COMMITTEE CHAIRS HIGHLIGHTS

Failure Analysis Society (FAS) (cont'd)

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

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

Erik Mueller, materials research engineer, National Transportation Safety Board, continues to serve as chair of the FAS International Relations Committee.

Heat Treating Society (HTS)

See page 3 of *HTPro* in this issue for the HTS committee chairs.

International Metallographic Society (IMS)

Michael Keeble, U.S. labs and technology manager, Buehler, a Division of ITW, serves as president of IMS.

Laura Moyer, professor, Lehigh University, serves as vice president of IMS.

Daniel Dennies, FASM, principal and CEO, Dennies Metallurgical Solutions Inc., serves as IMS immediate past president and chair of the IMS Awards & Nominations Committee.

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

Johnathon Brehm, laboratory support technologist, Sandia National Laboratories, was named chair of the IMS Membership Subcommittee.

Dana Drake, lab engineer-metals, EOS of North America, continues to serve as chair of the IMS Micrograph Database Committee.

Brett Leister, engineer, Naval Surface Warfare Center, continues to serve as chair of the IMS Education Subcommittee.

Evans Mogire, EMEA technologies and laboratory manager, ITW Test and Measurement – Buehler, was named chair of the IMS Buehler Technical Paper Award Committee.

Joseph Quinn, principal materials consultant, Materials FACT, was named chair of the IMS Annual Meeting/Events Committee.

Ellen Rabenberg, AST Aerospace metallic materials, NASA Marshall Space Flight Center, continues to serve as chair of the IMS International Metallographic Contest Committee.

David Rollings, vice president, sales and marketing, Ted Pella Inc., continues to serve as chair of the IMS Corporate Sponsorship Committee.



Bradley



Connelly



Mueller



Keeble



Moyer



Dennies



Bagnall



Brehm



Drake



Leister



Mogire



Quinn



Rabenberg



Rollings

» HIGHLIGHTS AFFILIATE COMMITTEE CHAIRS

Thermal Spray Society (TSS)

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

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

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

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

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

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

Milad Rad, University of Alberta, was named chair of the TSS Membership, Marketing, and Outreach Subcommittee.

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

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



Lenling



Lima



McDonald



Azarmi



Fowler-Hutchinson



Miller



Rad



Vassen

ASM Seeks Vice President and Board of Trustees Nominations

ASM is seeking nominations for the position of vice president as well as three trustees. In conjunction with the Constitutional amendments approved at the 108th ASM Annual Meeting, a senior vice president will also be nominated for 2022-2023 to begin the reintroduction of the second vice president role, as part of the Society's updated governance structure. The Society's 2022 senior vice president, vice president, and trustee elects will serve as a voice for the membership and will shape ASM's future through implementation of the ASM Strategic Plan.

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

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

Guidelines: Nominees for vice president must have previously served on the ASM Board or served as the president of an ASM Affiliate Society Board. Those selected to serve as trustees should be capable of someday assuming the ASM presidency.

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

A DECADE OF OPPORTUNITY *inspired by the* ASM STRATEGIC PLAN

ASM International's strong strategic plan has led to more digital-first products, new frontiers in data science, and increased global partnerships. To read the plan in full, visit www.asminternational.org/about/strategicplan.

Judith A. Todd, FASM, ASM President

On July 27, 2021, the ASM Board of Trustees, Affiliate Society Presidents, recent Past Presidents, Interim Managing Director, and members of the ASM staff, convened virtually for the annual strategic planning retreat. We reflected on the progress made to date in achieving our goals of increasing membership and enhancing engagement; technical excellence; and strategic partnerships and collaborations; and considered the next steps forward in advancing ASM's four key strategic initiatives: developing a digital-first platform; establishing an interdisciplinary collaboration framework; creating a global professional network; and embracing a foundational culture of diversity, equity, and inclusion (DEI), Fig. 1. A lively discussion was had by all. This article highlights some of the remarkable accomplishments ASM has made toward our vision of being the *leading global resource for materials information* at a time of unprecedented change in the way we work, communicate, support each other, adapt, and advance our Society. With our dedicated staff as our anchor, ASM is truly well positioned for **A Decade of Opportunity**.

STRATEGIC PLAN IN ACTION

To set the stage, ASM's digital initiatives enabled us to pivot rapidly to virtual and hybrid communication platforms and conferences as COVID-19 evolved. Such experiences will enhance our traditional, in-person events in the future. ASM made prudent financial investments in new technologies that stabilized our financial position, while continuing to digitize our materials content. The *ASM Handbook* series is now digital-first, with searchable content—a significant member benefit. Our members can now participate in Chapter meetings, webinars, tutorials, committee service, and leadership and educational programs across the globe. Indeed, on the global and DEI fronts, it was my privilege to join the Pune Chapter in India to celebrate International Women's Day in March 2021. ASM's Board and Committee meetings now regularly comprise members from the U.S. (including Hawaii), Europe, India, Asia, and Australia. We applaud the fortitude and dedication of our international late-night and early-morning members.

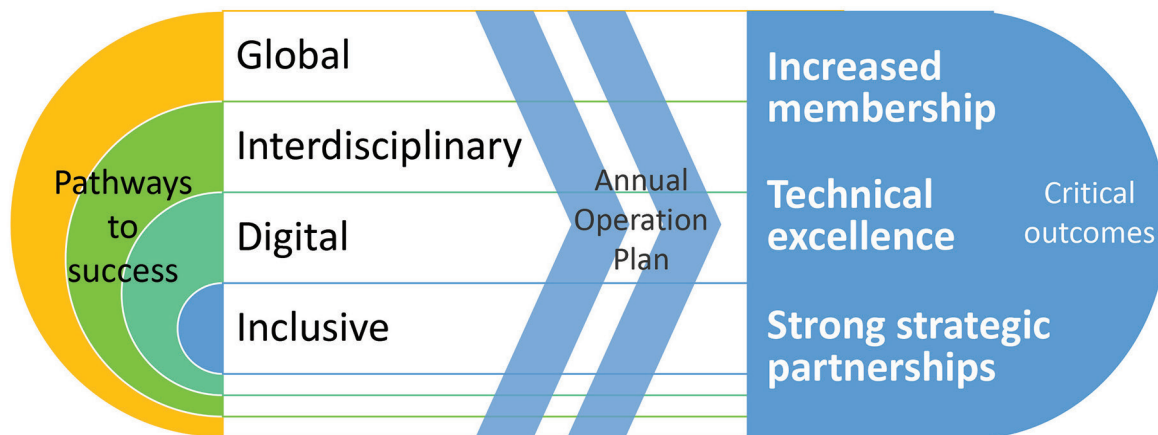


Fig. 1 — Vision, mission, and key strategic initiatives of ASM's 2020-2025 Strategic Plan.

» ASM INTERNATIONAL

On the materials data sciences front, ASM has established partnerships with Japanese, European, and U.S. industries, as well as governmental (NASA) and academic institutions. ASM's Digital Task Force is working with ASM's recently formed committees on Materials Data Management and Analytics; Materials and Processes Modeling; and Residual Stress. Together they are charting new frontiers for ASM in the data sciences, machine learning, and artificial intelligence arenas. ASM has a wealth of data to contribute to the interdisciplinary arena. Our potential for providing ASM's materials information to members of other societies in the engineering, sciences, medical, educational, and disciplines far beyond is embryonic. Even greater is our opportunity to provide educational materials and tools for non-materials experts to use our data. ASM is developing partnerships in the U.K., France, Germany, India, and beyond to advance these areas for future strategic opportunities.

As an academic leader with faculty from 16 different disciplines within my department, I clearly see the role that materials play within the engineering, science, medicine, life sciences, health, social science, humanitarian, environmental, ethics, and educational disciplines, and far beyond. Consequently, it was my greatest pleasure to see that the next highest priority to emerge from our strategic planning discussions was the importance our group placed on **Sustainability**. We had an immediate opportunity to act on this initiative through a joint webinar last November with the Institute of Materials, Minerals and Mining (IOM3) U.K., spearheaded by John Wolodko, FASM. The event represented the first pilot launch of our new ASM/IOM3 joint membership. ASM members can now join IOM3 at a reduced joint membership rate and can access a wealth of programs in the U.K. and Europe. IOM3 has reciprocal relationships with ASM—a benefit to all our members.

Volunteer for Service on an ASM Committee/Council

ASM depends on its members to volunteer their time and expertise to carry out the mission and vision of the organization, and to keep moving forward in the field of material science and engineering. If you are looking to enrich your ASM experience in a new and rewarding way, now is your chance! We are looking for volunteers for ASM Committee/Council appointments for 2022-2023. There are limited openings (2-3 per committee/council), and qualifications will be considered.

STRATEGIC PLAN

SUMMARY

As we look toward the future, ASM is expanding our horizons globally, interdisciplinarily, and culturally as we embrace our diverse membership. Our digital platforms promise to benefit all.

As an ASM member, you have an important role to play in ASM's future. Please review ASM's strategic plan at asminternational.org/about/strategicplan and send your comments to asmstrategicplan@asminternational.org. Even better, let us know how you can contribute to our future by serving on one of our committees or as a Society officer. We are excited to hear from you. You are a valued member of our Society and your opinions count.

Thank you for your loyal service and for being an important advocate for ASM's future. I look forward to hearing from you and am honored to serve as your President.

ASM STRATEGIC PLAN

VISION: To be the leading global resource for materials information.

MISSION: To gather, process, and disseminate materials information globally through education, networking, and professional development for members, organizations served by our members, and the materials community at large. ~AM&P

ASM DATA ECOSYSTEM LAUNCH

Read about Release 1 of the new ASM Data Ecosystem and plans for future data product enhancements on page 21 in this issue. The product, designed around member insights, is a tangible outgrowth of ASM's Strategic Plan.

Visit ASM's Volunteer Center at <https://connect.asminternational.org/volunteeroportunities/about-volunteering> to view ASM's committee/council purpose statements, roles and responsibilities, and the open volunteer opportunities available. While there, take a moment to "manage your volunteer profile" so that your expertise and interests can best be matched with the appropriate committee/council for future appointment and interaction as well. **Deadline for submitting your interest in volunteering for the open volunteer positions is March 29.** For more details contact: christine.hoover@asminternational.org.

EXECUTIVE DIRECTOR CORNER

Getting to Know You

As we advance into 2022, I want to share my excitement in coming aboard ASM International as your Executive Director. This is my third executive role leading a STEM organization, and I love the work that I do. I have a deeply held passion for manufacturing engineering, and a strong layman's knowledge of materials science that I look forward to building out as I interact with you. My father is a guild silversmith who has chased sterling and pure silver for more than 60 years, as well as titanium, which he discovered is a lot harder to shape! I married into a toolmaking family, with the third generation of toolmakers now working in the shop started by my father-in-law after WWII.



Robert

Associations provide the bridge to ongoing technical education, publishing, and knowledge transfer, and they are the engine for professional development. As ASM International, your professional society, continues to adapt and evolve to the "new normal" ushered in during the pandemic, we are here to serve your professional needs in new ways. Throughout this year, you will see enhancements to our website functionality, making it easier to find resources, and ensuring additional security measures. We will phase in the Data Ecosystem, which you can read about in Ray Fryan's article on page 21, and which will provide you with easy access to powerful digital tools.

As we get to know each other, I thought I would use a customized version of the Proust Questionnaire, a set of questions originally designed as a parlor game by 19th century French writer Marcel Proust, to share a bit more about myself. James Lipton, the host of *Inside the Actors Studio*,

and *Vanity Fair* magazine have also adapted the questionnaire for use as an interview framework. I hope you'll discover some additional aspects of who I am beyond the dimensions of the work environment.

1. What is your idea of perfect happiness?
Spending a couple of weeks in Normandy with a pile of books and a bicycle
2. What is your favorite word? *Infinity*
3. What profession(s) other than your own calls to you?
Engineer and film director
4. Who is your historical hero? *Abraham Lincoln*
5. Who is your modern-day hero? *Dolly Parton*
6. Dogs or cats? *DOGS in all caps!*
7. What movie or TV character would you be?
Walt Longmire
8. What unique skill do you have that people may not recognize? *Plumbing copper*
9. What recent education have you had and why was it meaningful? *Preparing the University of South Florida Diversity, Equity, and Inclusion in the Workplace certificate program because it expanded my thinking and leadership practice*
10. What do you want to accomplish in your first year at ASM International? *I want to support the successful launch of our Data Ecosystem, which I see as a revolutionary tool for engineers everywhere.*

I'll be traveling to our ASM events this year and look forward to meeting you along the way. Please feel free to reach out with your questions and feedback.

Sending best wishes from the Dome.

Sandy Robert, CAE

Executive Director, ASM International
sandy.robert@asminternational.org

SEEKING NOMINATIONS FOR EDFAS AWARDS

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

EDFAS Lifetime Achievement Award

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

EDFAS President's Award

The EDFAS President's Award recognizes exceptional

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

For complete rules and nomination forms, visit the EDFAS website at asminternational.org/web/edfas/societyawards; or contact Mary Anne Jerson at 440.671.3877, maryanne.jerson@asminternational.org.

Nomination deadline for both awards is March 15.

» HIGHLIGHTS NOMINATIONS DUE

ATTENTION STUDENTS: 2022 ASM International Student Paper Contest Deadline April 1

The ASM International Student Paper Contest is designed to increase interest and awareness in materials science and engineering, and provide recognition for outstanding student efforts in the field. The contest is open to all Material Advantage student members who are enrolled at a college or university offering courses in materials science and engineering. The winner will receive a cash prize of \$500, plus up to \$500 toward travel expenses to attend IMAT 2022. In addition, a full set of ASM Handbooks (or an ASM Handbooks Online subscription) will be presented to the school or student chapter of the winning entry. For contest rules, past recipients, and a sample form, visit asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination form link.

Payam Emadi, a Ph.D. student at Ryerson University, was the 2021 Best International Paper Award winner.



2022 Bradley Stoughton Award for Young Teachers

Winner receives \$3000

Deadline March 15

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

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

Nominate a colleague for the 2022 award by contacting christine.hoover@asminternational.org.

Engineering Materials Achievement Award Deadline March 15

This award recognizes an outstanding achievement in materials or materials systems related to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product. Do you know of an innovative, cutting-edge scientific achievement that has distinctly impacted industry, technology, and society within

the past 10 years? If so, consider submitting a nomination for the 2022 award. View sample forms, contest rules, and past recipients at asminternational.org/membership/awards/nominate. To submit a nomination, contact christine.hoover@asminternational.org for a unique nomination form link.



Canada Council Award Nominations due April 30

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

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

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

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

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

ASM-IIM Visiting Lecturer Program Seeks Applicants

Deadline March 15

The cooperative Visiting Lecturer Program of ASM International and the Indian Institute of Metals (IIM) is seeking applicants for 2022. View rules, past recipients, and criteria at asminternational.org/membership/awards.

FROM THE FOUNDATION HIGHLIGHTS

Mark Your Calendar: Upcoming Award Deadlines

March 15 – ASM-IIM Visiting Lecturer

March 15 – Bradley Stoughton
Young Teachers Award

March 15 – Engineering Materials
Achievement Award – EMAA

April 1 – ASM International Student Paper Contest

April 30 – Canada Council Awards

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

Accepting Nominations through March 15 for the following ASM Awards:

Distinguished Life Membership*

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

Medal for the Advancement of Research*

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

Honorary Membership*

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

*ASM membership not required

Bronze Medal

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

Revised Self-Study Course

The ASM self-study course *Principles of Metallography* has been revised and updated by the International Metallographic Society (IMS) and is now available on the ASM website. This course is intended to provide instruction in proper metallographic preparation techniques and the principles

FROM THE FOUNDATION

Onsite Camps Invite Your Assistance

ASM Materials Education Foundation is moving back to in-person programming this summer; both staff and volunteers are working hard to get everything in place. After nearly three years since ASM Materials Camps were last in these locations, we need all hands on deck to recruit teachers to attend, refresh the labs to meet health and safety guidelines, as well as assess equipment and supply needs. Our staff is working with Master Teachers to be sure everyone is comfortable with returning to the lab for the full ASM Materials Camp curriculum. There is much to be done, but everyone is excited to return to programming that has received such great reviews from teachers and students.



Wilson

We would love your help too! Please help us connect with teachers or school districts in your area. If you'd like to volunteer at an ASM Materials Camp, please let us know where you are able to help. And, of course, our in-person



ASM Materials Camps will return to in-person labs this summer.

ASM Materials Camps are more expensive to run and offered at no charge to the teachers who attend. Your financial support at asmfoundation.org will be greatly appreciated.

As always, the ASM Foundation values its partnership with ASM chapters and members. Working together is the way the ASM Foundation will continue to grow its reach to more teachers and students. And it's the way we will all engage the next generation in materials science and engineering. Thank you!

Carrie Wilson

Executive Director

ASM Materials Education Foundation

on which they are based. It describes methods of viewing structures and analyzing the constituents that are present. ASM self-study courses give learners the opportunity to study at their own pace in the location of their choice. Learn more by visiting <https://bit.ly/3B6ljGL>.

» HIGHLIGHTS VOLUNTEERISM COMMITTEE

OPPORTUNITIES FOR STUDENTS AND TEACHERS

Undergraduate Scholarships

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

Technical and Community College Scholarships

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

Undergraduate Design Competition

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

Student Chapter Grants

These grants support Material Advantage student chapters in their outreach activities. Five grants of \$500 each. **Deadline November 15.**

ASM Materials Camp - Students

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

ASM Materials Camp - Teachers

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

Kishor M. Kulkarni Distinguished High School Teacher Award

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

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

Provides support for K-12 teachers to develop and implement science teaching activities. Award: 20 grants of \$500 each. **Deadline: March 31.**

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

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Alexandra Merkouriou, project manager, Project Daedalus at University of Connecticut and Ph.D. student in materials science



Merkouriou

Meet Alexandra Merkouriou and you'll quickly learn of two passions in her life: materials science and helping others. In her education, career, and as an ASM volunteer, she fulfills both.

Merkouriou's fascination with materials began in high school at the University of Connecticut's Explore Engineering program. "They showed me a superconductor and I was hooked. I've been set on materials science and engineering ever since!"

Pursuing her bachelor's at the University of Connecticut (UConn), she joined ASM's Material Advantage chapter, serving as president her junior and senior years. "It was an opportunity to connect students, faculty, and industry. My goal was helping students figure out how to get internships and jobs while we were still focused on classes."

In the GE Edison Engineer program, she rotated through electrical and mechanical engineering to "learn their language" and build her leadership skills. It also confirmed her attraction to tangible applications and the broad scope of materials science, from the atomic to the macro.

While earning her master's degree, Merkouriou worked in R&D for M Cubed Technologies. This inspired her to pursue a Ph.D. and led to her role as project manager for UConn's Project Daedalus, with three contracts totaling \$18 million to develop transformative technologies for the Air Force Research Labs.

Merkouriou is involved in her local ASM chapter but is excited to help on a grander scale with the national Emerging Professionals Committee. "Our goal is to have a global audience, helping people get internships and jobs, handle difficult situations at work, and share opportunities. We have so many different voices reaching out to help students and professionals see where their careers can go."

She encourages members to volunteer, even simply offering to give a talk or suggest a chapter event. "We get stuck thinking we need a leadership role to be involved. Maybe you plan a meeting once a year. That's awesome and a huge help. The beauty of ASM is you can participate in any way you have time for."

CHAPTERS IN THE NEWS HIGHLIGHTS

CHAPTERS IN THE NEWS

Ontario Hosts Mercedes Engineer

The ASM Ontario Chapter held an exciting virtual event on February 2 as part of their World Class Speaker Series. They hosted Stephen Edge, the senior materials engineer of Mercedes High Performance Powertrains, to provide them with a rare look into the materials engineering that exists under the hood of the Mercedes F1 car. In his talk, Edge also conveyed the fast-paced world that the materials engineers at the company operate in. At top speed, they develop new engineering processes as well as characterize and introduce new materials to the powertrain.



Cleveland Hears about Battery Material

Members of the Cleveland Chapter learned about “The Role of Graphite in Lithium-Ion Batteries” during their online technical meeting on January 18. The speaker, Ryan Paul, is a carbon materials scientist in the Carbon and Composites group at Oak Ridge National Laboratory. Paul described the fundamental role that graphite has in the workings of a lithium-ion battery and explained why graphite will not be soon replaced at large scale. The implications of natural and synthetic graphite availability and recyclability were also discussed.



Paul



Upcoming Chapter Meetings

Stay informed of future chapter meetings through announcements in ASM Connect. ASM members are welcome to attend any virtual/hybrid meetings of chapters even outside their geographic area. Learn more at connect.asminternational.org.



*Congratulations to these
ASM Chapters
celebrating milestones
of serving local members!*

Akron—75 Years

Bangalore—15 years

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

MEMBERS IN THE NEWS

Mudali Receives IIM Platinum Medal

U. Kamachi Mudali, FASM, was awarded the prestigious Platinum Medal for 2021 from the Indian Institute of Metals (IIM) for his outstanding contributions to the metallurgical profession over the past four decades. Mudali served as president of IIM, with its more than 10,000 members, during 2019-2020. He is listed among the top 2% of scientists from India working in the field of materials based on an analysis by Stanford University. He is vice chancellor of VIT Bhopal University. Mudali is currently a trustee of ASM International, serving from 2021 to 2024. He was previously chair of the ASM Chennai Chapter 2015-2017 and received their Distinguished Achievement Award. He is a fellow of 12 societies.



Mudali

Liu Named Fellow of TMS

Zi-Kui Liu, FASM, Dorothy Pate Enright Professor of MSE at Penn State, has been named a Fellow of the Minerals, Metals and Materials Society (TMS), the society's highest honor. Liu is renowned for his seminal contributions to the fundamentals of thermodynamics and for developing computational approaches and tools for predictions of properties and design of materials. He was president of ASM International from 2019 to 2020 and received ASM's J. Willard Gibbs Phase Equilibria Award in 2014. Liu earned a bachelor's degree in metallurgy from Central South University in China, a master's degree in MSE from the University of Science and Technology Beijing, and a doctorate in physical metallurgy from the Royal Institute of Technology in Sweden.



Liu

» HIGHLIGHTS MEMBERS IN THE NEWS

Kamaraj Elected INAE Fellow

Prof. Muthuswamy Kamaraj, **FASM**, was named a Fellow of the Indian National Academy of Engineering (INAE). He is currently a professor in the department of metallurgical and materials engineering at Indian Institute of Technology Madras, Chennai, India. He has made outstanding research contributions in tribological behavior of coatings and dissimilar welded joints of advanced materials for automobile, aerospace, and power plant applications. Kamaraj has 254 publications, including journal articles, conference proceedings, and book chapters. His research has been cited over 4200 times and he was named among the top 2% of scientists from India in materials (2020). Kamaraj now serves as chair of the ASM Chennai Chapter and was appointed to the 2021 ASM Nominating Committee.



Kamaraj

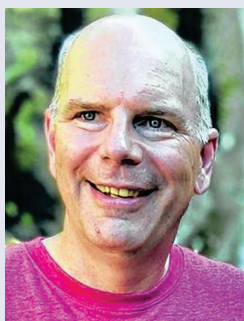
Prucha Wins AFS Gold Medal

Thomas Prucha is the 2022 winner of the William McFadden Gold Medal from the American Foundry Society (AFS). He will receive the society's highest honor at the annual banquet at CastExpo 2022, April 23-26, in Columbus, Ohio. The award honors Prucha's "outstanding achievements, service, and contributions to the metalcasting industry and his visionary leadership steering the industry toward new technological horizons on the global level." Prucha is editor-in-chief of the *International Journal of Metalcasting* and president of Metal Morphosis LLC. In 2021, he was a Hoyt Memorial Lecturer at the virtual Metalcasting Congress. Prucha is a member of the ASM Detroit Chapter.



Prucha

IN MEMORIAM



Witting

Peter R. Witting, of Buffalo, N.Y., passed away on November 13, 2021, at age 55. He was a member of the board of the ASM Buffalo Chapter. He also was a member of ASM's Heat Treating Society (HTS) and was active on the HTS Research & Development Committee since 2016. Witting had a Ph.D. from SUNY Buffalo and worked as a mechanical engineer for Harper International.

ADVANCED MATERIALS & PROCESSES EDITORIAL PREVIEW

APRIL 2022

Materials Testing & Characterization

Highlighting:

- Integrating Materials Characterization and Informatics
- Ultrasonic Fatigue Testing
- ITSC and SMST Show Previews

Advertising Bonus and Distribution:

Show issue for ITSC 2022 and SMST 2022

- ITSC: May 4-6, Vienna
- SMST: May 16-20, San Diego

Special Supplements:

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

Advertising closes March 7

MAY/JUNE 2022

Materials for Energy/Automotive/Power Generation

Highlighting:

- Green Steel Production
- Sustainable Materials for Electric Vehicles
- IMAT Program Highlights

Advertising Bonus and Distribution:

- Advertising and Webinar Specials

Advertising closes April 20

Subscriptions/Customer Service:

800.336.5152

MemberServiceCenter@asminternational.org

Information on Advertising and Sponsorships:

Kelly Johanns

440.318.4702

kelly.johanns@asminternational.org

Download the Media Kit at:

asminternational.org/advertise-webform

MATERIALS TESTING SPECIALIST



WMT&R is recognized as the world leader in Fracture Toughness, Fatigue Crack Growth, Stress Corrosion, High Cycle, and Low Cycle Fatigue Testing. Over 300 Servo-Hydraulic Test Frames support quick turnaround on your projects, as does on-site Heat Treatment and Machining of specimens.

WMT&R Inc. 221 Westmoreland Drive Youngstown, PA 15696-0388 USA, tel: 724-537-3131; fax: 724-537-3151 Email: admin@wmtr.com Web www.wmtr.com

WMT&R LTD. 19 Wildmere Road, Banbury, Oxon, OX163JU UK, tel: +44(0)1295 261211; fax: +44(0) 1295 263096; Email: admin@wmtr.co.uk Web:www.wmtr.co.uk



Journal of Thermal Spray Technology

The only English-language critically reviewed journal on advances in thermal spraying. Combines new R&D with the latest engineering applications. Covers processes, feedstock manufacture, testing, and characterization.

Customer Service

Springer New York, LLC

P.O. Box 2485

Secaucus, NJ 07094-2485

tel: 800/777-4643 or 212/460-1500

fax: 201/348-4505

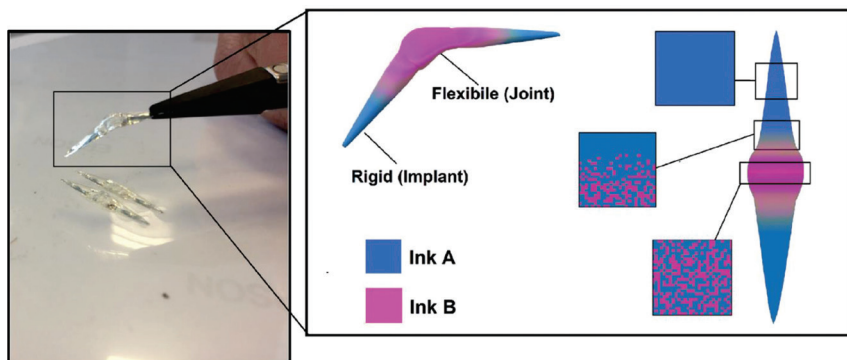
journals-ny@springer.com

AD INDEX

Advertiser	Page
Allied High Tech Products Inc.	30, BC
Boeing	30
ECM USA Inc.	42
Master Bond Inc.	9
Quaker Houghton	30
Thermo-Calc Software AB	IBC
Thermo Fisher Scientific	11
Westmoreland Mechanical Testing & Research Inc.	30, 55

The ad index is published as a service. Every care is taken to make it accurate, but *Advanced Materials & Processes* assumes no responsibility for errors or omissions.

3D PRINTSHOP



A bacteria-repelling artificial finger joint with customized strength distribution made with the multi-material 3D print process. Courtesy of University of Nottingham.

'SMART INK' ALLOWS FOR REVERSIBLE 4D PRINTING

A researcher from Eindhoven University of Technology has developed a “smart ink” that is light-sensitive, paving the way for 4D applications. The basis of the ink lies in the use of liquid crystals. Currently, various smart materials are used for 4D printing. As a rule, these are shape-memory polymers or hydrogels. The disadvantage of the former is that the movements are not reversible. While form changes can take place in the air, they are one-time events. Hydrogels offer the opportunity to switch the form back and forth, but then only underwater. “What we didn’t yet have was a more flexible material, capable of reversing its shapeshifting in various environments in response to stimuli. Now, we can adapt liquid crystals in multiple ways. We can play with not only the chemical composition, but also the molecular arrangement,” explains Marc del Pozo Puig.

Thus, materials can be designed that are responsive to humidity or temperature and whose movement can be precisely controlled. And by combining materials with different functionalities, printed objects can be organized to form a communicating system.

He describes another application, a minuscule flower that changes color in response to del Pozo’s breath. “The flower, as small as a red blood cell, has been created with a liquid crystal ink. When I breathe on the flower, which is under a microscope, the ambient humidity changes. And with it, the color of the flower. A color change like this can be used as a sensor to register form change, a check that a certain movement has taken place.” www.tue.nl.

CUSTOM MEDICAL DEVICES FIGHT BACTERIA

By optimizing the stiffness of materials that also prevent build-up of bacterial biofilm, University of Nottingham

researchers have discovered how to tailor-make artificial body parts and other medical devices. For example, the method could be adapted to create a highly bespoke one-piece prosthetic limb or joint to replace a lost finger or leg that can fit the patient perfectly to improve their comfort and the prosthetic’s durability; or to print customized pills containing multiple drugs, known as polypills, optimized to release into the body in a pre-designed therapeutic sequence.

For this study, the researchers applied a computer algorithm to design and manufacture, pixel by pixel, 3D-printed objects made up of two polymer materials of differing stiffness. By optimizing the stiffness in this way, they successfully achieved custom-shaped and sized parts that offer the required flexibility and strength. www.nottingham.ac.uk.



A micro-butterfly, printed by del Pozo. The width is around 70 micrometers. Courtesy of Eindhoven University of Technology.

BRIEF

A paper published in *Materials Today* by researchers at Washington State University says that 3D printing is rapidly changing how materials can be developed. The paper is a roadmap for industry and academics to use 3D printing to design new alloys. “With additive manufacturing you can make a structure for your needs on-demand with not only chemistry or composition control, but also with your desired functionalities at limited cost, time, and maintaining a smaller manufacturing footprint,” says Susmita Bose, FASM, a co-author. wsu.edu.



Researchers have led efforts to use 3D printing for designing alloys. Courtesy of Washington State University.

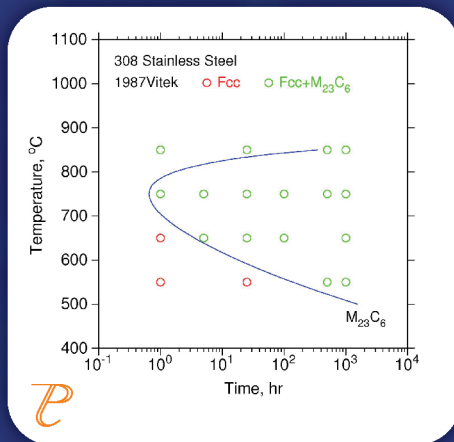
Thermo-Calc Software

Empowering Metallurgists, Process Engineers and Researchers

What if the materials data you need doesn't exist?

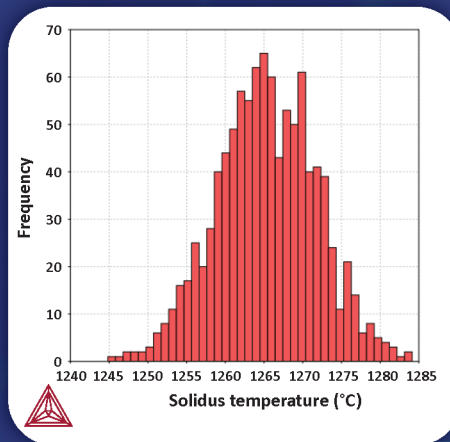
Gain insight into materials processing

Precipitation



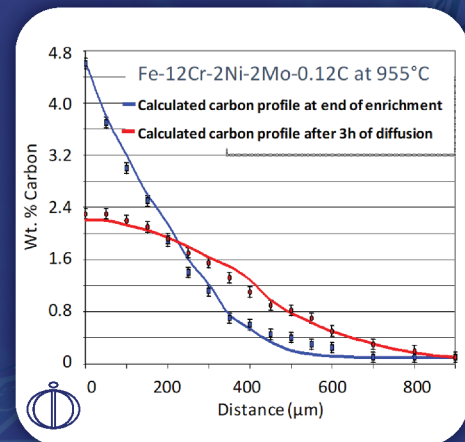
Time temperature precipitation of M₂₃C₆ in 308 stainless steel

Solidification



Solidus variation within Alloy 718 specification (Gaussian, n=1000)

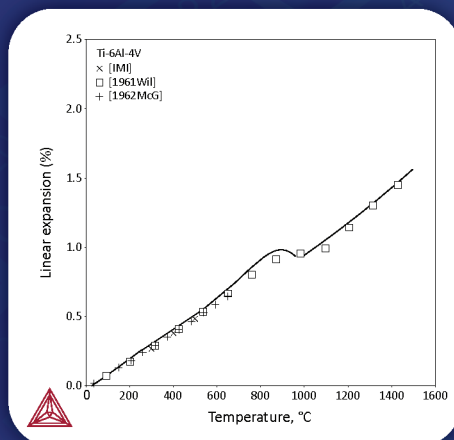
Diffusion



Carbon diffusion profile near surface during carburization of a martensitic stainless steel

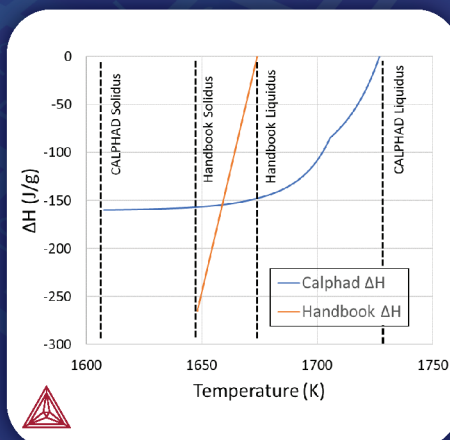
Predict a wide range of materials property data

Thermophysical Data



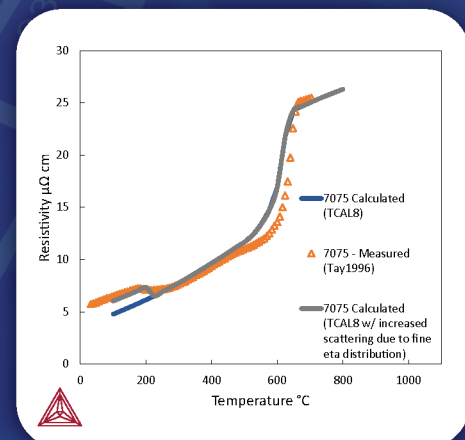
Linear expansion vs temperature for Ti-6Al-4V

Thermodynamic Properties



Calculated latent heat compared to handbook values for a specific 316L stainless steel chemistry

Electrical Resistivity



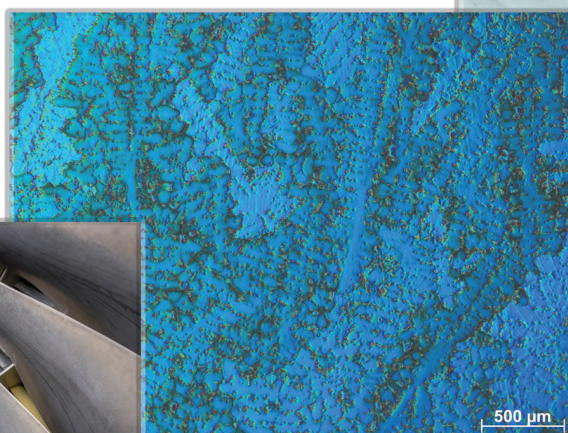
Calculated electrical resistivity of aluminum alloy 7075

Sample Preparation Solutions for Aerospace Materials Including:

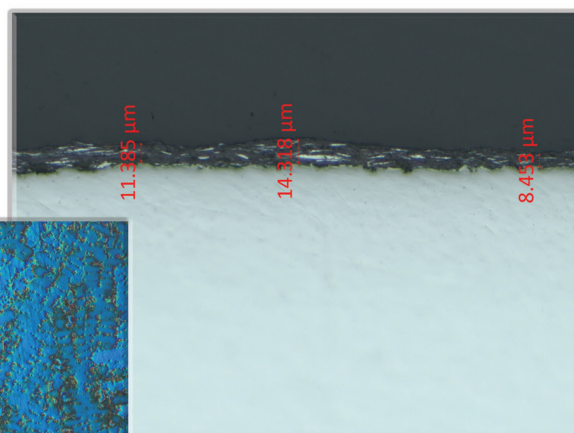
- Inconel
- Superalloys
- Titanium
- Carbon Fibers
- Ceramics
- Coatings



- Section/Mount/Grind/Polish



- Inspect & Image



- Analyze & Report



Allied equipment is designed &
manufactured in the USA

800.675.1118 US/Canada
310.635.2466 Worldwide

info@alliedhightech.com
www.alliedhightech.com