

APRIL 2018 | VOL 176 | NO 3

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

MATERIALS CHARACTERIZATION TITANIUM PART II

P.18

25

Ceramic Reinforced
Metal Matrix
Composites

30

Sample Preparation
for EBSD

35

ASM Reference
Publications
Catalog

Celebrating **35 Years** of Providing
Quality Metallographic Sample Preparation
Equipment & Consumables!



2376 E. Pacifica Place
Rancho Dominguez, CA 90220

310.635.2466 Worldwide
800.675.1118 Canada / US

info@alliedhightech.com

APRIL 2018 | VOL 176 | NO 3

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

MATERIALS CHARACTERIZATION TITANIUM PART II

P.18

25

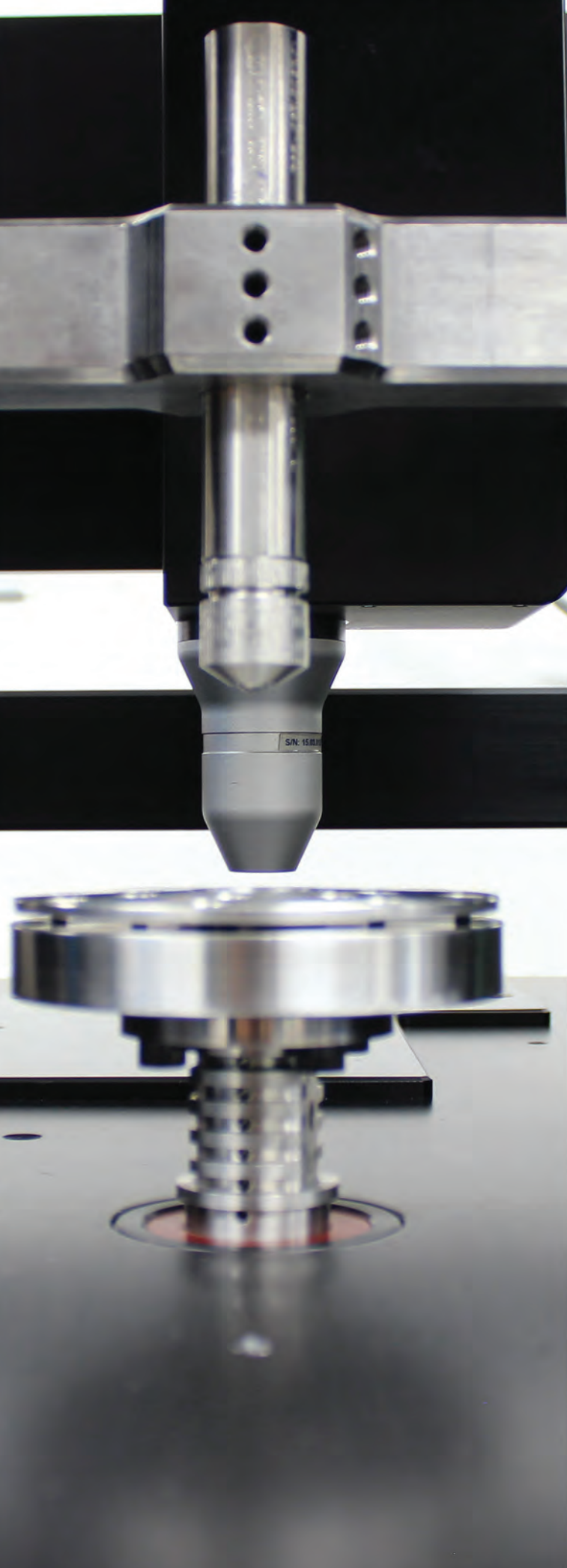
Ceramic Reinforced
Metal Matrix
Composites

30

Sample Preparation
for EBSD

35

ASM Reference
Publications
Catalog



It's About Time

TRIBOLOGY TESTING IS ABOUT TO IMPROVE

The Nanovea T2000 is the worlds first dual controlled load Tribometer providing vertical force oscillation at frequencies up to 150Hz. It combines advanced pneumatic technology with a state of the art linear electromagnetic stage to provide controlled loading from 1mN to 2000N during rotative and linear testing. Pneumatic is used from 5 to 2000N offering multiple advantages compared with age old spring/motor technologies used on other systems. With spring/motor technologies, the load sensor is typically placed behind the spring. This means that it is not measuring the actual variation of load applied on the surface during the test. The T2000 measures the load by a direct connection between the ball holder and the actual load cell. This ensures that the load measured is actually the load applied on the surface.

The linear electromagnetic loading system of the T2000 can apply a vertical force of 0.2 to 20N at frequencies up to 150Hz. As an example, the normal load can be increased from 0 to 100N with the pneumatic technology and then the linear motor can vary the load from 90 to 110N and up to 150 times per second. This gives the unique capability of superposing a control fatigue or vibration level to the main constant force applied by the pneumatic system. This electromagnetic linear stage can also apply directly very low loads from 1mN to 5N to complete the full range.

- **1mn - 2000n controlled load range**
- **Vertical force oscillation up to 150hz**
- **Friction measured direct not by torque**
- **In-situ point or line sensor scanning**
- **Auto wear calculation of ball or pin**
- **Multiple environment options**

Learn more
nanovea.com

ISTFA/2018 PHOENIX, AZ OCT 28 - NOV 1, 2018



1ST TIME, CO-LOCATION WITH INTERNATIONAL TEST CONFERENCE

FAILURES WORTH ANALYZING

CALL FOR PAPERS

SUBMIT AT **ISTFA.ORG**
BY APRIL 21, 2018

Share your experiences and advance the industry and your career at the 44th International Symposium for Testing and Failure Analysis, the premier event for the microelectronics failure analysis community. We invite you to submit your work for publication and to present to the industry in Phoenix, Arizona, for the 44th year of ISTFA.

TOPICS INCLUDE:

- Emerging FA Techniques and Concepts
- Future Challenges of FA
- Fault Isolation (Thermal, Lock-in thermography, static and dynamic laser stimulation, static and dynamic emission microscopy, Laser Voltage Probing and imaging ...)
- 3D devices Failure Analysis (stacked dies, TSV ...)
- FA Techniques Addressing the Challenges of Heterogeneous Systems in Package
- Organic Electronic (OLED...)
- Wireless, Self-Powered, Sensors, MEMS Failure Analysis
- Detecting Counterfeit Microelectronics
- Alternative Energy (Photovoltaics, Solid State Lighting, etc...)
- FA Process
- Packaging and Assembly Level FA
- Diagnostic Testing, Scanning and Debug
- Board and System Level FA
- Metrology and In-line Device Characterization
- Power, Discretes and Optoelectronic Device FA
- Electronic Device Materials Characterization (SIMS, RBS, XPS, Auger, etc...)
- Microscopy (SEM, TEM, FIB, etc.)
- Circuit Edit (Laser, FIB, etc.)
- Sample Preparation and Device Deprocessing
- Scanning Probe Analysis
- Yield and Reliability Enhancement
- Nanoprobe, Electrical Characterization
- Competitive Analysis and Reverse Engineering
- FA use cases

Organized by:

EDFAS
Electronic Device Failure Analysis Society
ASM INTERNATIONAL

ASM
INTERNATIONAL



18

TITANIUM: A HISTORIC AND CURRENT PERSPECTIVE PART II

Francis H. (Sam) Froes and Ashraf Imam

Among the structural materials developed in the 20th century, titanium and its alloys have played a leading role in improving component performance.

On the Cover:

The U.S. Navy's George H.W. Bush CVN 77 aircraft carrier uses a significant amount of titanium for its mainmast platforms.



33

SMST SHOW PREVIEW

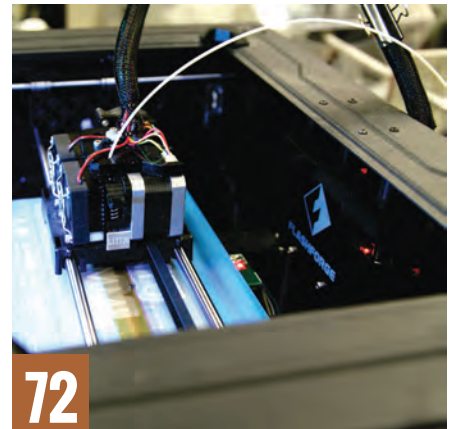
Experts from around the world are headed to SMST 2018 in Ireland to review and assess recent advances and future directions in shape memory and superelastic technology.



59

ASM NEWS

The monthly publication about ASM members, chapters, events, awards, conferences, affiliates, and other Society activities.



72

3D PRINTSHOP

Learn what's new in additive manufacturing from the NYU Tandon School of Engineering and the DOE's SLAC National Accelerator Laboratory.

FEATURES

25 INTRODUCING NANOSCALE CERAMIC PARTICLES INTO METAL MATRICES

Rishi Raj

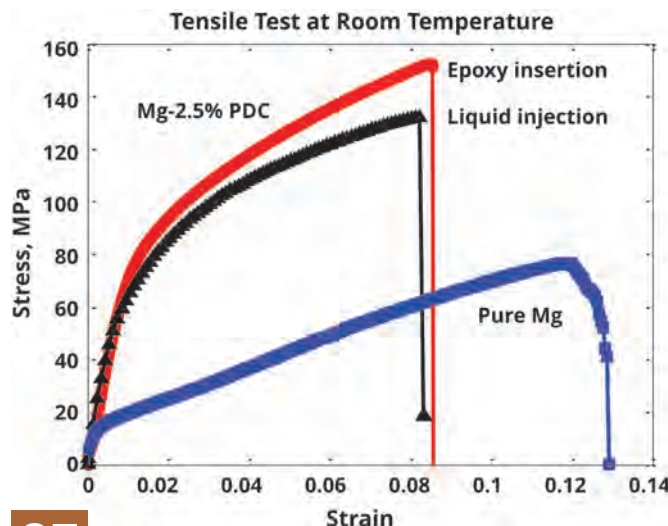
Melt-injection of organic precursors may result in revolutionary technologies for producing ceramic reinforced metal matrix composite castings.

30 TECHNICAL SPOTLIGHT SAMPLE PREPARATION FOR EBSD

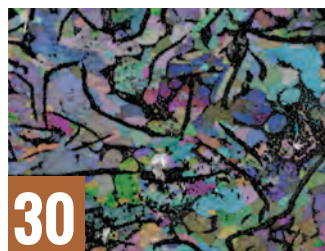
Because electron backscatter diffraction (EBSD) is a surface-sensitive technique, preparing the sample surface so that it is smooth and free of defects is crucial to successful analysis.

35 ASM REFERENCE PUBLICATIONS CATALOG

Our vast, authoritative reference library offers the most comprehensive and up-to-date information.



25



30



35

TRENDS

- 4 Editorial
- 6 Feedback
- 7 OMG!

INDUSTRY NEWS

- 8 Metals/Polymers/Ceramics
- 10 Testing/Characterization
- 12 Process Technology
- 13 Emerging Technology
- 14 Energy Trends
- 16 Surface Engineering

DEPARTMENTS

- 69 Stress Relief
- 69 Classifieds
- 71 Advertisers Index
- 71 Special Advertising Section
- 71 Editorial Preview
- 72 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. 176, No. 3, APRIL 2018. Copyright © 2018 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: \$475. Single copies: \$51. POSTMASTER: Send 3579 forms to ASM International, Materials Park, OH 44073-0002. Change of address: Request for change should include old address of the subscriber. Missing numbers due to "change of address" cannot be replaced. Claims for nondelivery must be made within 60 days of issue. Canada Post Publications Mail Agreement No. 40732105. Return undeliverable Canadian addresses to: 700 Dowd Ave., Elizabeth, NJ 07201. Printed by Publishers Press Inc., Shepherdsville, Ky.

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

ADVANCED MATERIALS & PROCESSES

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

Frances Richards, *Editor-in-Chief*
frances.richards@asminternational.org

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

Ed Kubel, Larry Berardinis, and Erika Steinberg,
Contributing Editors

Jim Pallotta, *Creative Director*
jim.pallotta@asminternational.org

Jan Nejedly, *Layout and Design*

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

Ellen Cerreta, *Board Liaison, Los Alamos*

National Lab

Tomasz Chojnacki, *Caterpillar Inc.*

Mario Epler, *Carpenter Technology Corp.*

Surojit Gupta, *University of North Dakota*

Nia Harrison, *Ford Motor Company*

Yaakov Idell, *NIST*

Hideyuki Kanematsu, *Suzuka National College*
of Technology

Scott Olig, *U.S. Naval Research Lab*

Anand Somasekharan, *Los Alamos National Lab*

Kumar Sridharan, *University of Wisconsin*

Jaimie Tiley, *U.S. Air Force Research Lab*

ASM BOARD OF TRUSTEES

Frederick E. Schmidt, Jr., *President and Chair*
of the Board

David U. Furrer, *Vice President*

William E. Frazier, *Immediate Past President*

Craig D. Clauser, *Treasurer*

Prem K. Aurora

Ellen K. Cerreta

Ryan M. Deacon

Larry D. Hanke

Roger A. Jones

Thomas M. Moore

Sudipta Seal

Judith A. Todd

John D. Wolodko

William T. Mahoney, *Secretary and*
Chief Executive Officer

STUDENT BOARD MEMBERS

Mari-Therese Burton, Olga Eliseeva,
Jonathan Healy

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.

SPRING HAS SPRUNG AT ASM



Welcome to the spring edition of *AM&P*! We hope April finds you in a state of thaw. Here in the Midwest, we're in the midst of either the spring of deception or third winter, depending on the day. Our seasons are as follows: winter, fool's spring, second winter, spring of deception, third winter, mud season, actual spring, summer, false fall, second summer (one week), and actual fall. Don't worry though—the nasty weather is not putting a damper on our productivity.

For starters, we hope you enjoy the second half of the titanium perspective that began last issue. Authors Sam Froes and Ashraf Imam do a terrific job in summarizing the development of titanium into one of the most important structural materials of the 20th century and beyond. Their article also gives us a nice excuse to run some beautiful Navy images of the George H.W. Bush CVN 77 aircraft carrier, which uses a goodly amount of titanium in its mainmast plat-forms. Seeing the wide range of real-world applications for titanium and all of the other innovative materials we write about is truly the most fascinating part of this job. As the engineers and scientists who make these applications possible through painstaking research and sheer trial and error, we salute you.



On the opposite end of the spectrum is Rishi Raj's forward-looking article on introducing nanoscale ceramic particles into metal matrices. As an emerging technology very much in the early stages of development, the final outcome may be revolutionary—super strong and versatile ceramic reinforced metal-matrix composite castings. We look forward to keeping tabs on this technology.

Finally, we hope you'll take a few moments to page through our beautiful spring catalog beginning on page 35. We have several new and exciting offerings along with the tried and true materials information that is the lifeblood of ASM. If you need to round out your materials knowledge, you've come to the right place.

Among our new offerings is the highly anticipated labor of love, "The History of Metals in America" by Charles Simcoe. As you may recall, Simcoe wrote more than 40 "Metallurgy Lane" articles for *AM&P* over the past few years. This historical department became one of our most popular magazine series ever. Simcoe then added to this material and completed his book just before passing away at the age of 93. For anyone interested in the development of American industry or the science of metallurgy, this book is a must read. Simcoe's series begins in Massachusetts in 1645, in the British Colonies at the Saugus Iron Works. These early days of ironmaking were the precursors of our domestic steel industry and Simcoe does a fantastic job of chronicling this history over the next 350 years. With more than 150 images, the new book is also a pleasure to look at. Check out page 7 in the catalog for more information. As always, feel free to contact us with any questions or comments.

F. Richards

frances.richards@asminternational.org

Saphir X-Change

Fully Automated Materials Sample Preparation



Affordable Automation

MAGER

magersci.com
shopmager.com

sales@magersci.com
800.521.8768

FEEDBACK

INFECTION-FIGHTING COPPER NOT A RELIC OF THE PAST

It was with keen interest that I read the “Feedback” letter from Chuck Dohogne [January issue] sent in response to my co-authored article, “Copper Alloys Resurface as an Antimicrobial Force” [October 2017]. I am pleased to respond with facts rather than resort to glib comments and misleading opinions, as this writer does. Dohogne states that copper “was very high tech—3500 years ago!” Copper is not a relic residing only in the periodic table. Copper alloys continue to be widely used in large quantities in the modern era due to unique properties such as high electrical and thermal conductivity, corrosion resistance, ease of fabrication, and their ability to kill bacteria and prevent hospital-acquired infections.

He further states that copper alloys “would make for lots of new jobs polishing all that brass.” However, a tarnish-resistant copper-nickel alloy was used in the clinical trial. It is in the same family of alloys that coat the surfaces of U.S. coins (nickels, dimes, and quarters). These copper-nickel alloys do not normally tarnish and typically are not polished.

Dohogne then cites my “recurring mention of 99% (reduction of live bacteria in laboratory testing)” as meaning “absolutely nothing.” As an aside, the reduction in bacteria was only mentioned once and it is 99.9% rather than 99%. More importantly, the writer apparently fails to appreciate that a nearly two orders of magnitude reduction of infectious bacteria is significant and not trivial. It should be noted that copper alloys have the ability to keep killing bacteria and protecting humans when the surface is re-contaminated, all without human intervention.

He also states that, “Instead of stainless steel, the comparison should have been made with something that

works, say titanium?” Note that stainless steel is mandated as the experimental control material by the U.S. EPA and is widely used in microbiology labs. Stainless steel, like titanium, has no inherent ability to kill bacteria and thus neither “works.” Dohogne goes on to say, “A bit of UV light and everything is gone, bacteria, viruses, mold spores, and biofilms.” The oxide that naturally forms on the surface of titanium is titanium dioxide,

a photocatalytic material. When titanium is exposed to UV, it oxidizes and kills bacteria. Thus, the combination of titanium surfaces and UV is antimicrobial. Titanium by itself has no antimicrobial effect. More importantly, without UV, oxidized titanium surfaces are immediately re-contaminated after being touched with a contaminated glove or hand. UV light can be highly effective on all materials, including copper, even if they are not photocatalytic. However, in contrast to the combination of titanium and UV, copper alloys keep reducing bacteria on a 24/7 basis without requiring hospital staff time.

Dohogne further states that, “Materials cost means nothing for medical applications.” This may be true for surgical joint implants covered by insurance. However, hospital administrators are very conscious about the cost of components that come out of their budgets. In a multi-hospital clinical trial, six components made of copper alloys were placed in random patient rooms. Although the copper alloy components comprised less than 10%



A typical patient room retrofitted with copper alloy components. Four of the six copper retrofits are visible, including the over-the-bed table, IV pole, data input device (touch screen bezel), and caps on the bed rails.

of the surface area of the rooms, these components were the most frequently touched items. The trial continued until the results were deemed to be statistically significant. A remarkable 58% reduction in infection was achieved compared to infection rates measured in the control rooms—much better than “almost nothing.”

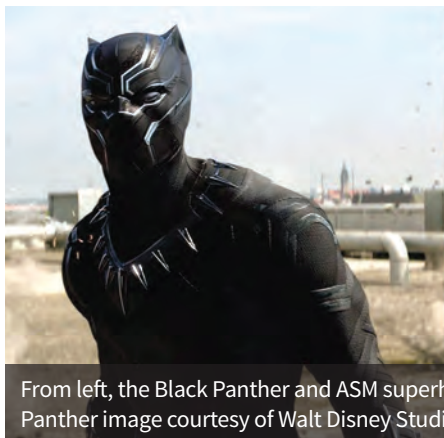
A multipronged approach is needed to fight hospital infections. It should include good hygienic and infection control practices—as well as new technologies such as copper alloys and UV light—in order to achieve optimum results. Sooner or later, most of us wind up in the hospital. If and when you are a patient, I hope that copper alloys are one of the tools used by your hospital to protect you from infections. They really work.

*Harold T. Michels
ASM Life Member*

We welcome all comments and suggestions. Send letters to frances.richards@asminternational.org.

OMG!

OUTRAGEOUS MATERIALS GOODNESS



From left, the Black Panther and ASM superhero Suveen Mathaudhu, FASM. Panther image courtesy of Walt Disney Studios Motion Pictures.



ASM SUPERHERO VETS VIBRANIUM

The latest Marvel Studios film “Black Panther” hit the big screen on February 16 and once again showcased the fictional supermaterial *vibranium*. Previously, in the 2016 Marvel film “Captain America: Civil War,” Black Panther demonstrated his powers by leaving scratches on Captain America’s nearly indestructible shield. This makes sense because Black Panther’s suit and weapons and Captain America’s shield are all made of vibranium, which is only available in Black Panther’s kingdom of Wakanda. Vibranium is a fictional metallic element that can store and release energy, making it a highly versatile material in Marvel’s cinematic universe.

For more details on both real and imagined strategic materials, ASM superhero Suveen Mathaudhu, FASM, frequently speaks about the scientific phenomena underpinning various elements such as vibranium. Mathaudhu, assistant professor of materials science and mechanical engineering at the University of California, Riverside, also addresses the complex global issues in strategic materials availability for advanced technologies. As an avid comic book and superhero fan, Mathaudhu regularly provides scientific consultation to the entertainment industry. An

active panelist at comic conventions, he recently appeared on a StarTalk Live! panel at AwesomeCon/Smithsonian FutureCon with the late great Stephen Hawking to discuss advanced materials capable of taking humanity to Mars and beyond.

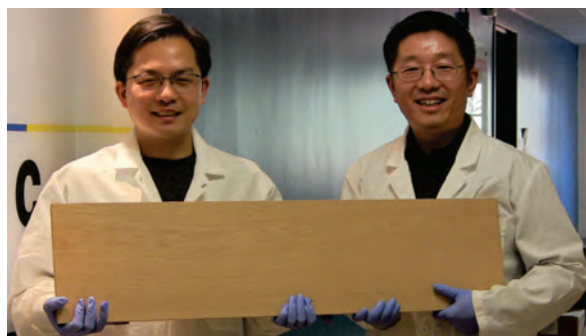
“Vibranium as a structural and functional material offers the epitome of materials advancement. In the same way that Black Panther’s suit can both protect him and provide power for his feats, future vehicles could be made with structural frames that are also batteries, allowing them to collect from renewable energy sources,” says Mathaudhu. “As scientists and engineers, we are trying to develop real metallic materials that mimic these properties.” *For more information:* smathaudhu@engr.ucr.edu, www.ucr.edu.

TIMBER AS STRONG AS TITANIUM

Engineers at the University of Maryland, College Park (UMD) recently discovered how to make wood more than 10 times stronger and tougher than ever before, creating a natural substance that is reportedly stronger than

many titanium alloys. “This new way to treat wood makes it 12 times stronger than natural wood and 10 times tougher,” says research leader Liangbing Hu of UMD’s A. James Clark School of Engineering. “This could be a competitor to steel or even titanium alloys. It’s also comparable to carbon fiber, but much less expensive. This kind of wood could be used in cars, airplanes, buildings—any application where steel is used.” The team also tested the new wood material and natural wood by shooting bulletlike projectiles at it. The projectile blew straight through the natural wood while the treated wood stopped the projectile partway through.

“The most outstanding observation, in my view, is the existence of a limiting concentration of lignin, the glue between wood cells, to maximize the mechanical performance of the densified wood. Too little or too much removal lowers the strength compared to a maximum value achieved at intermediate or partial lignin removal. This reveals the subtle balance between hydrogen bonding and the adhesion imparted by such a polyphenolic compound. Moreover is the fact that wood densification leads to both increased strength and toughness, two properties that usually offset each other,” explains Orlando Rojas, a professor at Aalto University in Finland. umd.edu.



From left, Liangbing Hu and Teng Li discovered a way to make wood more than 10 times stronger and tougher than ever before. Courtesy of UMD.

METALS | POLYMERS | CERAMICS



Postdoctoral research associate Sichuang Xue, left, and doctoral student Qiang Li work on creating super-strong aluminum alloys. Courtesy of Purdue University/Marshall Farthing.

SUPERMAN, MAN OF... ALUMINUM?

Researchers at Purdue University, West Lafayette, Ind., demonstrated methods to alter the microstructure

of nanograined aluminum to create aluminum alloys with the strength of steel along with increased ductility and thermal stability. The new super-strong metal is produced by introducing nanotwins and a 9R phase, two types of “stacking faults,” or distortions in the crystal structure—a goal that has stumped scientists in the past due to aluminum’s high stacking fault energy. A collaborating research group at Rice University, Houston, bombarded ultrathin aluminum films with tiny micro-projectiles of silicon dioxide, yielding a shock-induced 9R phase in aluminum. The laser-induced projectile impact testing technique, which ejects the particles at 600 m/s, resulted in a deformation-induced 9R phase just tens of nanometers in width. The Purdue team also used a procedure called magnetron sputtering to induce

a 9R phase by introducing iron atoms into aluminum’s crystal structure. The resulting nanotwinned aluminum-iron alloy coatings proved to be one of the strongest aluminum alloys ever created, comparable to high-strength steels. The discovery could find application in wear and corrosion-resistant aluminum alloy coatings for the electronics and automobile industries. purdue.edu.

DRIVING UP RECYCLING RATES

A study conducted by researchers at Tohoku University, Japan, reveals that sorting scrap car parts into eight categories could hike recycling rates of alloy elements to over 97% in Japan, saving steelmakers in that country \$287 million on raw materials and cutting associated greenhouse gas emissions. While Japan mandates automobile recycling, parts are usually lumped together for iron, leaving specific alloy elements—such as manganese, chromium, nickel, and molybdenum—out of the loop. Researchers determined that 94-99% of these elements in automotive scrap could be recycled and used in nine specific steel alloys. The recovered elements, which could be melted in electric arc furnaces (EAFs)

BRIEFS

Sandvik, Sweden, will invest over \$2.4 million in a new plant to manufacture titanium and nickel fine metal powders for its Sandvik Materials Technology division. The facility will be located in Sandviken, Sweden, near the company’s in-house titanium raw material supply and center for additive manufacturing. Production will begin in 2020. www.home.sandvik/en.

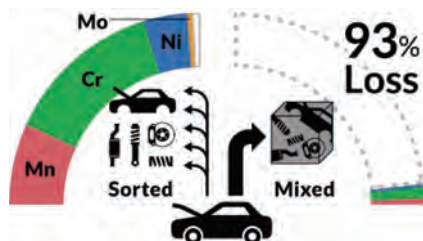
AZZ Inc., Fort Worth, Texas—a provider of metal coating services, welding solutions, electrical equipment, and engineered services to the power industry—acquired all assets and outstanding shares of **Rogers Brothers Co.**, Rockford, Ill. Rogers provides galvanizing services to a multi-state area in the Midwest. azz.com.

Researchers at **Oak Ridge National Laboratory**, Tenn., developed a super-tough renewable plastic with improved manufacturability for additive manufacturing and packaging applications. The team created the new polymer by adding tiny amounts of silicon-based materials called silanes to polylactic acid—a biobased plastic used in packaging, and 3D printing. ornl.gov.



Halil Tekinalp combines silanes and polylactic acid.

and incorporated into products such as coils, plates, and bars, could ultimately replace about 10% of the new material used by EAF steelmakers. This small percentage translates into a big impact: Steelmakers could save up to 15.2% currently spent on alloys and reduce greenhouse gas emissions associated with the new material by 28.3%. www.tohoku.ac.jp.



Schematic compares recycling of sorted and non-sorted scrap car parts in terms of recovering alloy elements.

RECORD-SMASHING MAGNETIC ALLOY HAS ITS MOMENT

Scientists from Montana State University, Bozeman, and Lawrence Berkeley National Laboratory, Calif., developed a stable thin film made of iron, cobalt, and manganese with an average atomic moment potentially 50% greater than the Slater-Pauling limit. The ternary bcc alloy's magnetization density of 3.25 Bohr magnetons per atom busts through the previously accepted ceiling of 2.45. To make the film, researchers used molecular beam epitaxy, a technique where individual metal atoms are meticulously applied to a substrate and layered into a 10-20 nm film of Fe₉Co₆₂Mn₂₉. As a thin film, roughly 60% of the available compositions kept the bcc struc-

ture—critical for high magnetism—compared to only 25% in bulk. When scientists previously combined iron-cobalt binary alloys with high-magnetic-moment transition metals, the loss of much of their bcc structure resulted.

When the alloy's composition and structure are examined with x-ray absorption spectroscopy and reflection high-energy-electron diffraction, the x-ray magnetic circular dichroism results show an average atomic moment of 3.25 Bohr magnetons per atom. Conventional vibrating sample magnetometry registers a value of 2.72—lower, but still well above the Slater-Pauling limit. The advance could expand possibilities in the growing field of spintronics, which exploits electron spins rather than charge to prolong battery life in solid-state devices. montana.edu, lbl.gov.

ATS APPLIED TEST SYSTEMS
THE MARK OF RELIABILITY

Superior quality for results you can trust.

ATS Series 1100 Universal Testing Machines

ATS Series 1100 Universal Testing Machines (UTMs) provide an affordable solution to precision tension, compression, shear, and flexure tests. With a diverse selection of models available, the UTMs in this series can accommodate a wide variety of test specimens and are used in a diverse range of testing applications, from production to quality control and high end research. Both bench top and floor models feature a large testing area, which allows for a multitude of different sample sizes. Series 1100 Universal Testing Machines have been designed with a simple, yet highly accurate software interface, allowing for user friendly training and operation.

Contact Applied Test Systems Today to Upgrade Your Test Lab

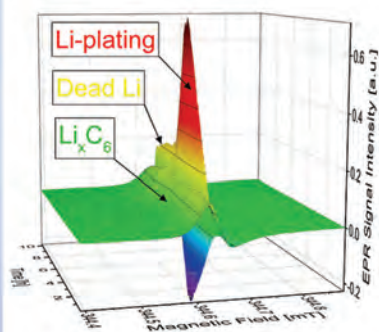
+1-724-283-1212 | sales@atspa.com | www.atspa.com



TESTING | CHARACTERIZATION



Left, EPR spectroscope. Right, EPR measurement detects lithium plating. Courtesy of TUM/FZ Jülich.



FLIPPING OUT OVER QUICK-CHARGING BATTERIES

Scientists at the Technical University of Munich and the Jülich Institute of Energy and Climate Research, both in Germany, developed a new process that allows direct observation of lithium plating in lithium-ion batteries for the first time. During rapid charging, lithium ions can accumulate as a solid metallic layer on the outside of a Li-ion battery anode, reducing battery capacity and lifespan, and even causing batteries to short circuit or ignite. To develop their new electron paramagnetic resonance (EPR) spectroscopy method of observation, the researchers designed a test

cell that was both compatible with EPR spectroscopy and exhibited good electrochemical properties. Electrons were placed in an externally applied, static magnetic field, and unpaired electrons in the sample were “sounded out” using microwaves. This stimulated the electrons to flip, and the phenomenon was measured by the associated drop in microwave radiation intensity.

The new observation method can differentiate between metallic lithium plating and the lithium embedded in graphite anodes, and the cell’s unique rod-shaped geometry allows a sample to be exposed to the magnetic field but not the electric field. The new process, which allows researchers to determine the maximum charging current before lithium plating sets in, could lead to development of more functional quick-charging batteries. www.tum.de/en, fz-juelich.de/portal/en.

CRUDE OIL CHARACTERIZATION COMBATS CORROSION

Researchers at Chevron, San Ramon, Calif., and the University of Saskatchewan, Canada, developed a method of x-ray spectroscopy to identify and characterize the specific sulfur compounds in crude oil that can corrode equipment. The results of their ongoing experiments at the Stanford Synchrotron Radiation Lightsource (SSRL) will allow scientists to better anticipate corrosion rates and improve oil industry guidelines.

To develop their new method, researchers started with sulfur K-edge x-ray absorption spectroscopy, then tuned the energy range to just the “tender x-rays”—those that occupy the middle ground between high and low energy. This allowed the scientists to untangle the overlapping information



Using x-ray techniques, scientists are developing an analysis tool to more accurately predict how sulfur compounds in a batch of crude oil might corrode equipment. Courtesy of iStockphoto.com/SLAC.

BRIEFS

Verder Scientific, Germany, acquired the majority of hardness testing machine manufacturer **Qness**, Austria. Qness specializes in custom test lines and its machines—which comply with recognized standards like Brinell, Vickers, Knoop, and Rockwell—are used for both industrial applications and materials research. verder-scientific.com.

Nordson Corp., Westlake, Ohio, acquired **Sonoscan Inc.**, Elk Grove Village, Ill., a designer and manufacturer of acoustic microscopes and micro imaging systems. Sonoscan equipment is used in microelectronic, automotive, aerospace, and industrial electronics assembly applications. nordson.com.

generated by similarities in the sulfur compounds and characterize the compounds separately. This is essential because different compounds exhibit different reactivity and total sulfur concentration does not directly correlate with corrosiveness. Because crude oil contains a large number of sulfur compounds, each subtly different from the others, past results from less sensitive characterization techniques have been difficult to interpret. The x-ray absorption spectroscopy work at SSRL allows the scientists to see a precise description of the crude oil's sulfur chemistry. chevron.com, www.usask.ca.

IMPROVED TESTING ENABLES BETTER BODY ARMOR

Scientists at the National Institute of Standards and Technology (NIST), Gaithersburg, Md., developed a new characterization method to investigate the high-performance fibers used in modern body armor, providing insight that could lead to development of more dependable and comfortable bulletproof gear. After the failure of protective gear made of second-generation ballistic fibers led to the death of a police officer in 2003, tests revealed that the creasing experienced during normal use caused significant degradation of the fibers' critical mechanical properties, such as stiffness, tensile strength, and strain-to-failure. The team's new materials characterization tool examines the structural and chemical differences in fibers that cause some ballistic materials to break down during folding and others to maintain their quality.



First responders are among those whose lives depend on body armor—and the ballistic fibers inside of them. Courtesy of Shutterstock/NIST.

Developed using the intense positron beam facility at North Carolina State University's PULSTAR Nuclear Reactor, the new method uses positron annihilation lifetime spectroscopy (PALS) to provide a molecular-level view of the structure of materials. By injecting positrons into ballistic fibers, researchers first determined if any voids smaller than 5 nm were created during folding. Then using PALS, researchers discovered that void levels are very sensitive indicators of folding

damage: A larger population of voids means a higher chance of fiber failure. Past analyses using small-angle x-ray scattering measurements were inconclusive because they were less sensitive to voids smaller than 5 nm. The new results could lead to development of alternatives to current body armor technologies or help fine-tune the amount of fibers currently used for these products, leading to more comfortable gear. nist.gov.



Stay Ahead of Your Analysis

You need a smoothly running lab to efficiently analyze your samples, and LECO has you covered. We offer reliable metallographic and optical solutions that seamlessly come together to give you results you can count on. Our support after the sale further streamlines your lab's productivity and helps to keep you one step ahead.

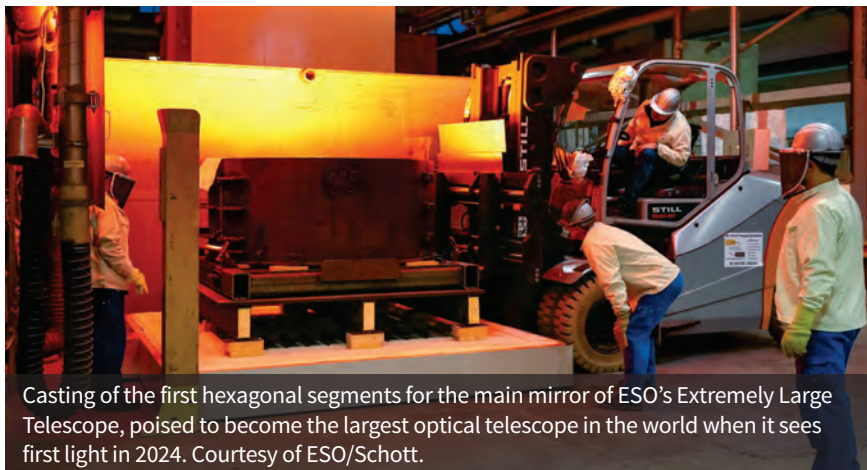
Tell us about your samples and we'll show you a solution for success at www.leco.com.



Delivering the Right Results

Phone: 1-800-292-6141 | info@leco.com
www.leco.com | © 2017 LECO Corporation

PROCESS TECHNOLOGY



Casting of the first hexagonal segments for the main mirror of ESO's Extremely Large Telescope, poised to become the largest optical telescope in the world when it sees first light in 2024. Courtesy of ESO/Schott.

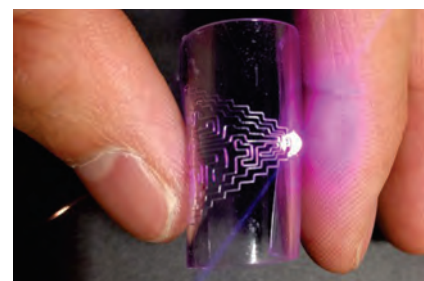
SMALL STEPS TOWARD EXTREMELY LARGE TELESCOPE

The first six hexagonal segments for the main mirror of what will become the world's largest optical telescope were cast by the German company Schott at their Mainz facility. The 1.4-meter hexagons, made of Schott's low-expansion ceramic material Zerodur, are the first of 798 individual segments that will form the primary mirror of the European Southern Observatory's Extremely Large Telescope (ELT), currently under construction atop a mountain in Chile. Schott will manufac-

ture the blanks for the first four ELT mirrors, along with a set of 133 spare segments, ramping up to one segment a day at full production speed. After casting, the blanks will undergo a slow cooling and heat treatment sequence. Following these processes, French company Safran Reosc will grind them to shape and polish them to a consistent thickness of 15 nm before conducting additional testing. The 39-meter-diameter primary mirror—which will collect tens of millions of times as much light as the human eye—will be the largest ever made for an optical-infrared telescope. eso.org.

electrohydrodynamic printing technology common to many manufacturing processes, but instead of functional inks, molten metal alloys with melting points as low as 60°C are printed onto a substrate. Compatible with multiple metals and substrates, the technique has already been demonstrated using three different alloys printed onto four different materials including glass, paper, and two stretchable polymers.

When testing the resilience of the circuits on one of these polymer substrates, the researchers found that the circuit's conductivity was unaffected after being bent 1000 times, and the circuits remained electrically stable even when stretched to 70% of tensile strain. The team also discovered that the circuits can heal themselves after being bent or stretched too far. Heating the damaged area to around 70°C melts the metal, which flows back together to repair the breach. The circuits are functional too: Researchers used the new technology to create a high-density touch sensor, fitting a 400-pixel array into one square centimeter. ncsu.edu.



Prototype demonstrates the potential of a new technique for printing flexible stretchable circuits.

BRIEFS

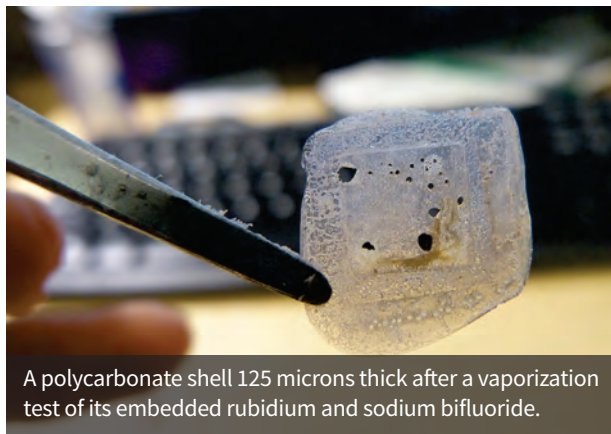
Global Advanced Metals Pty. Ltd., Waltham, Mass., commissioned **Tekna** Teksphero plasma spheroidization equipment for a new process development facility at its Boyertown, Pa., location. The facility will produce spherical tantalum and other refractory metal powders for advanced additive manufacturing and metal injection molding. Using a variety of tantalum feed materials, the equipment creates spherical powders with particle sizes from 10-100 µm and standard oxygen content from 600-1000 ppm. globaladvancedmetals.com.

PRINTED CIRCUITS GO WITH THE FLOW

Scientists at North Carolina State University, Raleigh, invented a process to directly print metal circuits, charting a course to flexible electronics that sidesteps traditional masks, etching, and molds. The new technique uses existing

Maxion Wheels, India, the world's largest wheel manufacturer, is forming a new legal entity, **Maxion Wheels Aluminum India Pvt. Ltd.** The company will initially build a 25,000 sq-m facility in Pune, India, with annual production capacity of two million wheels, and plans a subsequent plant expansion that will double annual output to four million wheels. Production is expected to begin in the third quarter of 2019. maxionwheels.com.

EMERGING TECHNOLOGY



A polycarbonate shell 125 microns thick after a vaporization test of its embedded rubidium and sodium bifluoride.

CIRCUITS GO POOF AT THE PUSH OF A BUTTON

Researchers from Cornell University, Ithaca, N.Y., and Honeywell Aerospace, Phoenix, developed a new technique to vaporize electronics via remote control, allowing devices—and their sensitive data—to vanish into thin air in the event of a security breach. The ability to self-destruct is at the center of an emerging technology known as transient electronics, in which circuits or portions of circuits can be made to disintegrate. While current transient architectures require specific moisture levels or temperatures to operate, the new system can be triggered remotely using radio waves.

The new system consists of a silicon-dioxide microchip attached to a polycarbonate shell containing microscopic cavities filled with rubidium and sodium bifluoride. When radio waves are used to open the graphene-on-nitride valves that keep the chemicals

sealed in cavities, the rubidium oxidizes vigorously, releasing heat to vaporize the polycarbonate shell and decompose the sodium bifluoride. Finally, the sodium bifluoride releases hydrofluoric acid, which eats away the electronics. In addition to data security applications, the technology can serve as a scalable micro-power

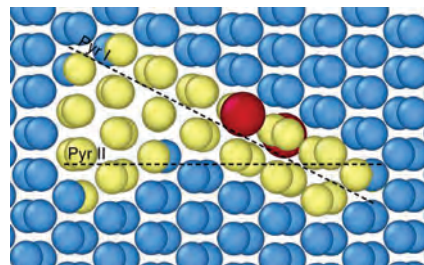
momentum and electricity source, delivering high peak powers for robotic actuation. cornell.edu, aerospace.honeywell.com.

MODELING MAGNESIUM MALLEABILITY

Scientists at the École Polytechnique Fédérale de Lausanne (EPFL), Switzerland, developed an atomic-scale model to predict changes in magnesium's ductility when alloyed with different elements. Because magnesium is abundant and four times lighter than steel, it has long been a metal of interest for automotive and aerospace designers on a quest to build lighter vehicles. It has incredibly low ductility, however, so it must be alloyed for use in industrial applications. "Magnesium becomes much more malleable if you add a few atoms of rare-earth metals, calcium, or manganese," says William Curtin, a professor at EPFL's School of Engineering. "We wanted to understand

what's going on in these alloys at an atomic level, so that we can identify which elements to add and in what amounts to make the metal pliable."

Researchers have long known that magnesium's low ductility is caused by its small number of moveable dislocations—linear defects that induce plastic flow and decrease brittleness. The EPFL team discovered that certain alloy atoms substantially increase the number of moveable dislocations, "canceling out" the mechanism that makes magnesium hard to shape. Armed with this insight, they turned to EPFL's high performance computing system to calculate via quantum mechanics which combinations of atoms result in the highest ductility. Specific alloys are still in the modeling stage. www.epfl.ch.

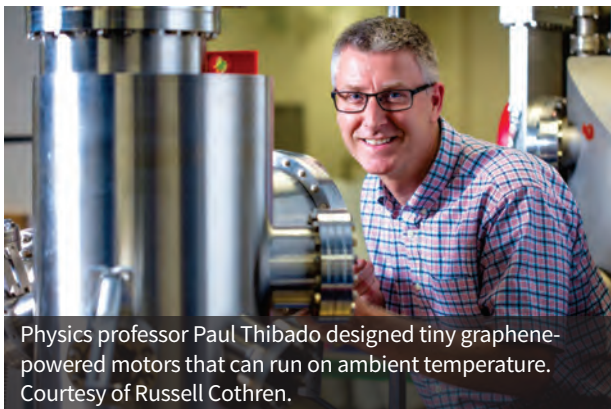


Final atomic configuration of the "cross-slip" process in the presence of two yttrium atoms. Blue Mg atoms are in a nearly perfect Mg crystal environment; yellow Mg atoms are far from being in the perfect Mg crystal environment, and so indicate the structure and atoms involved in the dislocation defect. Red atoms indicate two Y solutes.

BRIEF

In collaboration with an international team of physicists, researchers at the **US Naval Research Laboratory Center for Computational Materials Science**, Washington, showed that cesium lead halide perovskite nanocrystals emit light much faster than conventional light emitting materials. This property enables more efficient lasers and LEDs with larger emission power at lower energy use as well as faster switching for communication and sensors. nrl.navy.mil.

ENERGY TRENDS



Physics professor Paul Thibado designed tiny graphene-powered motors that can run on ambient temperature. Courtesy of Russell Cothren.

CONJURING ENERGY OUT OF THIN AIR

Scientists at the University of Arkansas, Fayetteville, demonstrated that perpetual clean energy could be harvested from the minute motions of 2D materials. The researchers made their discovery while observing the behavior of graphene mounted on a copper grid. Using a high-powered microscope, they observed that the freestanding graphene has a rippled structure, and each ripple flips up and down in response to the ambient temperature. Inspired, the team designed a device called a *vibration energy harvester*—a negatively charged sheet of graphene suspended between two metal electrodes. When the graphene flips up, it induces a positive charge in the top electrode, and when it flips down, it positively charges the bottom one, creating an alternating current. Graphene samples in Paul Thibado's lab measure about 10 μm across, and while each ripple measures just $10 \times 10 \text{ nm}$,

it could yield as much as 10 pW of power. As a result, each of these miniscule membranes could potentially power a wristwatch, and because they produce energy from ambient heat, they would never need charging.

Supported by nanotechnology company NTS Innovations, East Peoria, Ill., which licensed the technology, researchers plan to produce a proof of concept device capable of charging a capacitor using only ambient heat and the motion of graphene. The work could ultimately lead to sustainable, decentralized energy systems, especially in places where the energy grid is underdeveloped or nonexistent. It could also be applied in biomedical devices, enhanced solar and wind production, and remote sensing devices. uark.edu.

SMART WINDOWS JUST GOT SMARTER

An international collaboration led by scientists from Lawrence Livermore National Laboratory, Calif., discovered that a form of perovskite can be used in smart windows to allow them to convert solar radiation into useable energy. The researchers discovered the unique capabilities of this type of inorganic perovskite while investigating the phase transition of the material: When it changes its crystal structure, it shifts

from transparent to nontransparent. While typical smart windows absorb or reflect sunlight without harnessing its energy, the new photovoltaic windows could capture solar energy to power technologies found in buildings, automobiles, and information displays, for example. The new windows could also toggle between transparent and nontransparent states without deterioration of their electronic properties. Previous smart window research used materials that cannot switch between transparent and nontransparent phases without degrading. The distinctive properties, high photovoltaic efficiency, and ease of processing of metal halide perovskites—compounds with formula ABX_3 that have the crystal structure of the mineral perovskite—have numbered them among the most promising materials in solar technology in recent years. lbnl.gov.



Lawrence Livermore researchers and collaborators are using a new material that enables smart windows to generate electricity. Courtesy of LLNL/iStock.

BRIEF

Supported by \$59 million from **The Faraday Institution**, UK, a team of leading battery experts from universities across Great Britain are launching a three-year initiative to advance next-gen battery technology. The work will encompass four initial projects: solid-state electrodes, battery modeling, degradation, and recycling. Academic partners include **Oxford University, Imperial College London, Lancaster University, University College London, University of Bath, University of Cambridge, University of Glasgow, University of Liverpool, University of Southampton, University of Strathclyde, University of St. Andrews**, and the **University of Warwick**. www.faraday.ac.uk.



THERMAL PROCESSING IN MOTION

Including the 4th International Conference on Heat Treatment
and Surface Engineering in Automotive Applications

June 5-7, 2018 | Spartanburg, South Carolina



Don't miss your opportunity to learn more about the latest innovation and research in thermal processing and its critical role for the safe and efficient operation of aircraft, rail and automotive transportation.

WHY SHOULD YOU ATTEND?

THE PRICE IS RIGHT!

Full Conference registration includes:

- 2 ½ Days of Technical Programming
- 2 Days of Access to Networking with Exhibitors
- Welcome Reception with Exhibitors (Monday Evening)
- Lunch on Tuesday and Wednesday
- Morning and Afternoon Refreshments with Exhibitors (Tuesday/Wednesday)
- Access to Online Conference Proceedings

COMPREHENSIVE TECHNICAL PROGRAMMING

This conference will bring together international experts from around the globe to present the latest innovations and research in thermal processing. More than 50 technical presentations will be offered during sessions focused on Advances in Thermal Processing; Additive Manufacturing; Phase Transformations; Microstructure/Property Relationships; Quenching and Quenchants; Thermomechanical Thermal Processing; Surface Hardening; and MUCH MORE!

SPECIAL KEYNOTE PRESENTATIONS

Don't miss important updates from well-known industry leaders, including:

- "Metallurgical Aspects of Aluminum Power Driven Components," presented by Dr. Rafael Colas Ortiz, FASM, Professor and Metallurgist Engineer, Faculty of Mechanical and Electrical Engineering, UNIVERSIDAD AUTONOMA DE NUEVO LEON
- "Challenges and Opportunities for the Heat Treating Community: Threats, Risks and Benefits," presented by Dr. Richard D. Sisson, FASM, George F. Fuller Professor of Mechanical Engineering and Director of Manufacturing and Materials Engineering, Worcester Polytechnic Institute
- "NTSB and its Materials Laboratory," presented by Joe Epperson, Recently Retired Senior Metallurgist for the NTSB

GAIN EXPOSURE

Don't miss out on the opportunity to reach the movers and shakers in the Thermal Processing Market! Exhibit your products or services or gain additional exposure with sponsorships and advertising! Tabletop display rental packages start at \$1,200 USD.

For more information contact: exposales@asminternational.org.

Online registration is now open!

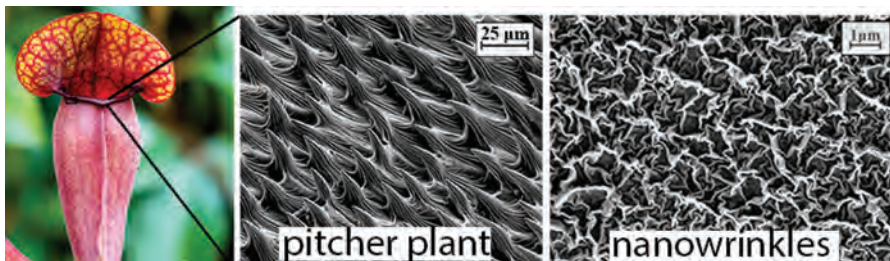
Please visit the link below for additional information and to register.

ORGANIZED BY:



www.asmiinternational.org/web/thermal-processing-in-motion

SURFACE ENGINEERING



The *Nepenthes* pitcher plant traps a lubricating layer in the structure of its peristome. Newly developed nanowrinkles work the same way, trapping a lubricating layer that stops the adhesion of bacteria and other marine organisms.

SLIP AND SLIDE COATING RESISTS FOULING

Since the banning of toxic tributyltin, demand is mounting for environmentally friendly methods to prevent marine fouling, and scientists from the University of Sydney Nano Institute, Australia, have responded with a new surface coating that uses nanostructuring—not toxins—to prevent bio-buildup. The coating incorporates nanowrinkles modeled on the tiny structures around the rim of the carnivorous *Nepenthes* plant that trap water, creating a slick surface that sends insects sliding into the plant's pitcher to be digested. Similarly, the new coating creates a slippery surface that prevents initial adhesion of bacteria, thereby inhibiting formation of biofilms, which are a precursor to the buildup of fouling organisms.

In the lab, surfaces treated with the new coating resist almost all fouling from a common species of marine bacteria, while control Teflon samples are completely fouled. When test surfaces

were attached to swimming nets at Watsons Bay baths in Sydney Harbor for a period of seven weeks, the surfaces with the new coating were very efficient at resisting fouling. The new coatings are moldable and transparent, making their application suitable for underwater cameras and sensors. In addition, their slippery surface could reduce drag on marine vessels, upping energy efficiency. www.sydney.edu.au.

COATING KEEPS COOL UNDER FIRE

Researchers from Nanyang Technological University and industrial developer JTC, both in Singapore, invented a new fire protection coating for steel building structures that is 50% more cost effective to apply than conventional intumescent coatings. The new paint, called FiroShield, requires just five layers to achieve a standard two-hour fire rating—enough time for building occupants to evacuate—while conventional coatings can require more than 15 layers for similar protection. In addition, because sand blasting is not

required to prepare a surface for FiroShield, overall application time and related labor costs are reduced by half. The paint's superior performance can be ascribed in part to a unique endothermic ingredient that absorbs heat from a fire, triggering a chemical reaction that causes the coating to adhere more firmly to the steel.

"In a fire, our coating forms a compact charred layer that acts as a protective barrier," explains assistant professor Aravind Dasari. "While typical fire coatings will also form a charred layer, those are thick and foam-like, which can fall off easily and leave the steel exposed." In addition, the new coating provides corrosion protection—something no other fire coating currently offers—and withstands weathering. In lab tests, its performance barely dipped by 2% when subjected to weathering, while conventional coatings showed up to a 75% performance drop. FiroShield meets similar performance standards when applied to construction materials such as reinforced concrete and laminated timber, and it can even be tinted like traditional paint. www.ntu.edu.sg, jtc.gov.sg.



Scientists from Nanyang Technological University and JTC display steel plates coated with different shades of FiroShield.

BRIEF

AkzoNobel, the Netherlands, donated more than 1600 gallons of military-grade International Marine Coating to repaint the 873-ft USS Hornet Sea, Air & Space Museum docked in Alameda, Calif. Decommissioned in 1970, the USS Hornet was named a National Historic Landmark in 1991 and was converted into a museum in 1998. The new paint job will allow museum visitors to see what the Hornet looked like when it was commissioned in 1943. akzonobel.com.



USS Hornet Sea, Air & Space Museum.

CO-LOCATED EVENT

AEROMAT 18
29th CONFERENCE AND EXPOSITION

ITSC2018
INTERNATIONAL THERMAL SPRAY
CONFERENCE AND EXPOSITION

May 7-10, 2018

Gaylord Palms Resort &
Convention Center |
Orlando, Florida, USA

This year, AeroMat 2018 and the International Thermal Spray Conference and Exposition (ITSC) are co-located in Orlando, FL.

Attendees will receive **2x** the technical program, **2x** the exhibiting companies, **2x** the connections, and **2x** the content on additive manufacturing for the price of one!

SPECIAL JOINT KEYNOTES:

- Richard Noble, Project Director, The Bloodhound Project
- James Ruud, Senior Principal Scientist, GE Global Research
- Tommaso Ghidini, Head of Structures, Mechanisms and Materials Division, European Space Agency
- Dr. Marvi Matos, Chemical Engineer, Product Group Lead, Blue Origin "Materials Reusability: A key to having millions of people living and working in space."
- Prof. Dr.-Ing. Michael Kupke, Professor, The German Aerospace Center (DLR) "Structures and Production of Future Commercial Aircraft – Challenges and Opportunities"

OVER 50 Presentations
on Additive Manufacturing

OVER 200 Exhibits

OVER 500 Technical
Presentations

INTERACTIVE FORUMS

MATERIALS DEVELOPMENT:

New Technologies and Market Trends

ADDITIVE MANUFACTURING PANEL

SESSION: Metallic Materials Qualification
and Component Certification

Post-Processing World Roundtable

Be at the forefront of the
additive manufacturing
industry by attending
AeroMat and ITSC!

www.asminternational.org/conferences/main

Organized by: **TSS**
Thermal Spray Society
ASM INTERNATIONAL

ASM
INTERNATIONAL

DVS GERMAN WELDING
SOCIETY



TITANIUM:

A HISTORIC AND CURRENT PERSPECTIVE

PART II

Francis H. (Sam) Froes, FASM,* Consultant

Ashraf Imam, George Washington University

*Member of ASM International

Among the structural materials developed in the 20th century, titanium and its alloys have played a leading role in improving component performance.

Part I of this article (February/March 2018) discussed historical aspects of titanium discovery and processing, growth and current status of the industry, and traditional manufacturing aspects. This article discusses development of new production techniques, specifications, economic aspects, and applications.

PRODUCTION AND PROCESSING R&D

The Kroll process is a slow batch process, making it very expensive. In the 1950s, DuPont, Horizons Titanium Corp., Kennecott Copper, Monsanto, and National Research Corp. invested heavily in developing new processes without success. Subsequent attempts by Dow-Howmet, RTI, and other companies led to incremental improvements, but nothing replaced the Kroll process. Along with the metallurgical difficulties, volatility of the economic market for titanium made heavy investment in experimental technologies difficult.

The batch sponge process accounts for less than 40% of the final mill product cost. The next step in production is pressing and/or forging, both time-consuming processes, which explains why a replacement for the batch process alone will not bring the price down sufficiently to make titanium use commonplace. It also explains the interest in titanium powder metallurgy (PM) technology^[1,2], which would lower the final cost by greatly reducing the number of processing steps compared with the conventional ingot metallurgy technique (Fig. 1), opening the metal to a wider range of applications. PM produces near-net-shape parts directly. However, problems associated with PM include contamination, danger of explosion, and difficulties in making large parts.

Research on replacing or modifying the Kroll process has increased since the 1990s, focusing mostly on PM. Oak Ridge National Laboratory (ORNL) and industry partners are developing a non-melt consolidation process that could reduce the energy and costs required to make titanium PM parts by up to 50%. The process includes roll compaction for directly fabricating sheet from powder, press and sinter techniques to produce net-shape components, and extrusions. Research in Japan is concentrating on a high-speed continuous process using subhalide reduction in a titanium container.

Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia, developed a technology to produce cost-effective commercially pure (CP) titanium using a continuous fluidized bed in which TiCl_4 is reacted with magnesium (TiRO process)^[1]. This technology is enabled by Australia's large mineral sand deposits. Continuous production of a wide range of alloys including aluminides, Ti-6Al-4V, and a number of Ti-Al alloys has been demonstrated on a large laboratory scale. Ti powder has been used to fabricate extrusions, thin sheet by continuous roll consolidation, and cold sprayed

complex shapes including ball valves and seamless tubing. Commercialization of the process is in the planning stage, to be followed by a pilot plant in the future.

Scientists at Cambridge University, UK, developed an approach (Fray-Farthing-Chen Cambridge or FCC Cambridge process) that uses titanium as an efficient cathode, made possible by the removal of oxygen from the cathode^[1]. The process extracts metals from their solid oxides by molten salt electrolysis (generally with a CaCl_2 electrolyte). Using titanium dioxide as an example, the sequence for TiO_2 is TiO_2 (solid, cathode) $\rightarrow$ molten salt electrolysis $\rightarrow$ Ti (cathode) + O_2 (anode). Metalysis, South Yorkshire, UK, is commercializing the process.

In the U.S., several initiatives for industrially scalable methodologies were funded by Defense Advanced Research Projects Agency (DARPA). In 2003, the first goal was to establish a U.S.-based, high volume, low cost, environmentally benign production capability. The second goal was to develop and demonstrate unique, previously unattainable titanium alloys, microstructures, and properties that enable new high-performance applications. DARPA also set a goal to produce high-quality titanium with a price of $<\$9/\text{kg}$ ($<\$4/\text{lb}$) for billet with 500 ppm max O_2 ; O_2 content in CP titanium is approximately 2000 ppm.

One DARPA-funded project was the Armstrong process developed by International Titanium Powder LLC (ITP), Lockport, Ill.^[1]. In 2008, ITP was acquired by Cristal USA Inc., Ashtabula, Ohio, a wholly owned subsidiary of Cristal Global, UK, which has extensive experience in the manufacture of TiCl_4 and has been supplying the chemical to titanium sponge producers for more than 20 years. The Armstrong process is continuous and uses molten sodium to reduce TiCl_4 (the Hunter process), which is injected into it as a vapor^[3-5]. The powder requires no further purification and can be used in traditional melt-to-billet

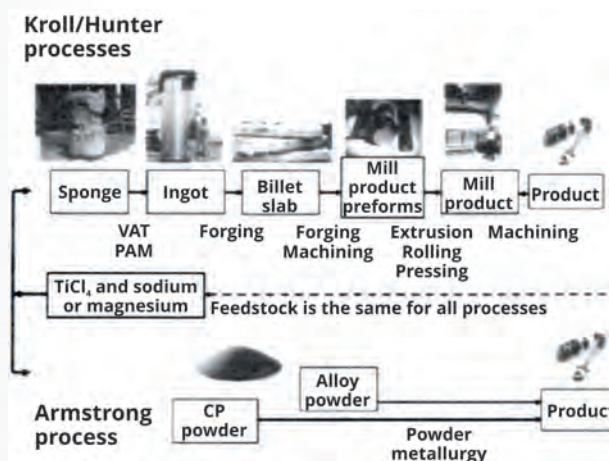


Fig. 1 — The titanium powder metallurgy approach (Armstrong process, bottom row) would reduce final product cost by greatly decreasing the number of processing steps compared with the conventional ingot-metallurgy technique^[1].

processes, allowing use of the product in the current value chain. However, the powder is better used in direct non-melt consolidation to final end product, eliminating the need to process sponge, thereby reducing supply chain cycle time, energy consumption, manufacturing costs, and environmental impact. An advantage of the process is its ability to produce a range of alloys (including Ti-6Al-4V) as a high-quality homogeneous powder suitable for many applications. The Lockport facility provides limited quantities of materials necessary to successfully complete solid-state consolidation development activities. ITP also broke ground on a 4 million lb/yr facility in Ottawa, Ill., to produce CP Ti and Ti-6Al-4V alloy powder. Independent research shows the use of low-grade TiCl_4 leads to higher part density due to the difference in sintering behavior that affects the entrapment of volatiles within the sintered body. As of late 2017, the full-scale facility had not yet entered production.

Materials and Electrochemical Research Corp. (MER) and DuPont are developing an electrolytic powder process that uses a composite anode of TiO_2 (reducing agent) and an electrolyte mixed with fused halides^[1]; Ti is deposited at the cathode. Ti production is projected at significantly lower cost than the Kroll process.

Advanced Materials (ADMA) Products, Hudson, Ohio, is developing a powder process in which sponge titanium is cooled in a hydrogen atmosphere rather than conventional inert gas. The

hydrogenated sponge is easily crushed and can be compacted in the hydrogenated condition to a higher density than that of conventional low-hydrogen sponge. Reportedly low levels of remnant chloride content of the hydrogenated sponge helps to avoid porosity and enhance weldability.

Fang et al.^[6] studied the use of hydrogen-assisted reduction of TiO_2 with magnesium and production of low-cost spherical meltless Ti powder.

ECONOMIC ASPECTS

Figure 2 shows the uses of Ti raw material. U.S. imports for consumption of titanium pigment were nearly 290,000 metric tons in 2006. U.S. exports of titanium by class (scrap, unwrought, wrought, ferrotitanium and ferrosilicon titanium, ores and concentrates, and pigment) were 581,000 metric tons in 2006. Regarding titanium pigment shipments, roughly 57% were used in paint, 26% in plastics and rubber, 12% in paper, and 4% in other applications^[9].

In 2007, titanium sponge producers in the U.S. included ATI, Titanium Metals Corp. (Timet), and The Alta Group (part of Honeywell Electronic Materials Inc.). ATI's sponge plant capacity increased to 7260 metric tons/yr, and the company began construction of a new premium-grade sponge plant in Rowley, Utah. ATI began construction of a sponge plant in Hamilton, Miss., to be operational by 2010. Timet increased its sponge capacity and brought a new EB furnace and several VAR furnaces online in 2008. However, the economic

downturn later that year led to a severe slowing of plant construction across the industry. ATI idled its Albany, Ore., sponge plant (Wah Chang unit) and delayed bringing the Rowley facility online until late 2009. Prior to the downturn, production of titanium metal products rose to record levels; U.S. ingot production reached 59,200 metric tons, an 11% increase over 2006^[10].

Before 1970, more than 90% of titanium products were used in aerospace applications, which fell to about 70-80% by 1982. Military use also declined through the late 1990s^[10]. However, industrial demand for titanium continued to increase through the late 1990s and into the new millennium. While the destruction of the World Trade Center in New York City on September 11, 2001, had a marked negative effect on commercial aerospace, Boeing and Airbus began to receive orders for their new planes, the 787 Dreamliner and A380, respectively, both of which contain between 130 and 150 tons of titanium components per unit. Also, production of the U.S. Air Force F-22 Raptor began in 2003. Simultaneously, there was a price surge in titanium, more than doubling between 2003 and 2006. The recession beginning in 2008 reversed the cycle with cancellations outnumbering orders of new planes. Production of the F-22 came to an end, replaced by production of the F-35 Lightning II.

The breakup of the former Soviet Union drastically reduced internal consumption of titanium, leaving a large volume available for export. Throughout the 1990s, VSMPO-AVISMA upgraded its quality standards so its products could be used in aerospace applications, completing its transformation by 2000. By 2009, the company was exporting 70% of its products, with the remainder supplied to the domestic market.

GRADE, SPECIFICATIONS, QUALITY CONTROL

Commercially important titanium grades and pertinent specifications are shown in Table 1. In addition, every

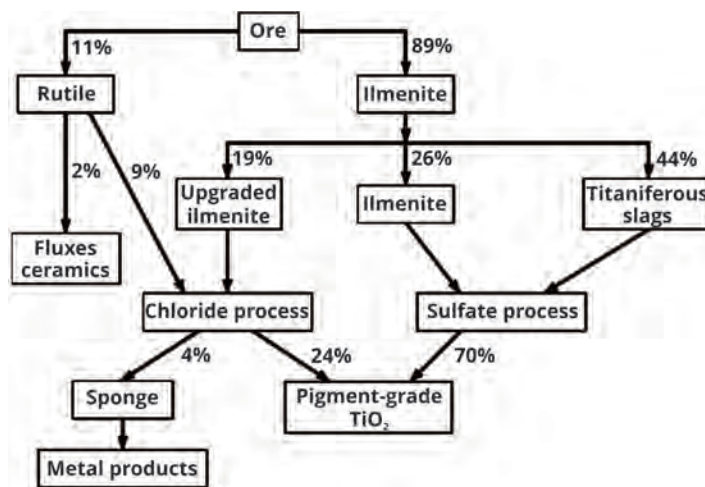


Fig. 2 — U.S. titanium raw material use^[7,8].

large aircraft company has its own set of alloy specifications. The alloy name in the U.S. can include a company name or trademark in conjunction with the alloy composition or strength, i.e., ultimate tensile strength for TIMET and yield strength for other U.S. producers, for unalloyed titanium.

Because titanium alloys are used in a variety of applications, several different material and quality standards are specified. Among these are ASTM, ASME, Aerospace Materials Specifications (AMS), U.S. military, and a number of proprietary sources. The correct chemical composition is basic to obtaining mechanical and other properties required for a given application. Minor elements controlled by specification

include carbon, iron, hydrogen, nitrogen, and oxygen. In addition, control of thermomechanical processing and subsequent heat treatment is vital to obtaining the desired microstructure and mechanical properties. In critical applications, such as rotating parts in aircraft gas turbines, raw materials, melting parameters, composition, thermomechanical processing, heat treatment, testing, and finishing operations must all be closely controlled at each step to ensure that products have the required characteristics^[11-14].

RECYCLING AND ENVIRONMENTAL CONCERNS

Due to the high buy-to-fly ratio (as high as 9:1), recycling of titanium

(revert) is an economic necessity. Recycling companies come into play at both the beginning and end of the process. Scrap is readily available at high manufacturing rates, which is purchased by the recycler, processed, and sold to an ingot producer.

Until the 1980s, use of scrap was limited because it was difficult to remove impurities. High density inclusions, such as the broken tungsten-rich tool bits from aerospace manufacturing production had to be removed from turnings to preclude being melted into the ingot, which could lead to defects resulting in failure of aerospace engine parts. With the removal of impurities, titanium turnings became an essential component of premium quality ingot.

TABLE 1—CHEMICAL COMPOSITION AND SPECIFICATIONS FOR COMMON TI ALLOYS

Nominal composition, wt%	Common name	UNS No.	Aerospace Materials Specification (AMS)	ASTM Standard B265	U.S. Military Specification
Alpha (α) alloys					
99.5 Ti	Ti	R50250	4591E	Grade 1	Mil-T-9046J
99.2 Ti	Ti	R50400	4902E	Grade 2	Mil-T-9046J
99.1 Ti	Ti	R50550	4900J	Grade 3	Mil-T-9046J
99.0 Ti	Ti	R50700	4901L	Grade 4, 7, and 11	Mil-T-9046J
99.8 Ti	Ti-0.2 Pd	R52400, R52250	-	-	-
Ti-5Al-2.5Sn	Ti-5-2.5	R54520	4926H	Grade 6	Mil-T-9047J
Ti-5.8Al-4Sn-3.5Zr-0.7Nb-0.5Mo-0.35Si	IMI 834	-	-	-	-
Ti-8Al-1Mo-1V	Ti-811	R54810	4972C	-	Mil-T-9047G
Ti-6Al-2.7Sn-4Zr-0.4Mo-0.45Si	TiMetal 1100	-	-	-	-
Alpha-beta (α-β) alloys					
Ti-3Al-2.5V	Ti-3-2.5	R56320	4943D	Grade 9	Mil-T-9047G
Ti-6Al-2Sn-4Zr-2Mo-0.1Si	Ti-6242S	R54620	4976C	-	Mil-T-9047G
Ti-6Al-4V	Ti-6-4	R56400	4911F	Grade 5	Mil-T-9046G
Ti-4Al-4Mo-2Sn-0.5Si	Ti-550	-	-	-	-
Ti-6Al-6V-2Sn	Ti-662	R56620	4918F	-	Mil-T-9046J
Ti-6Al-2Sn-2Zr-2Mo-2Cr-0.1Si	Ti-6-2222S	-	-	-	-
Ti-6Al-2Sn-4Zr-6Mo-2Cr-0.1Si	Ti-6246	R56260	4981B	-	-
Ti-4.5Al-3V-2Mo-2Fe	SP700	4899	-	-	-
Ti-5Al-2Sn-2Zr-4Mo-4Cr	Ti-17	R58650	4955	-	-
Beta (β) alloys					
Ti-10V-2Fe-3Al	Ti-10-2-3	-	4984	-	-
Ti-15V-3Cr-3Al-3Sn	Ti-15-3	-	4914	-	-
Ti-3Al-8V-6Cr-4Mo-4Zr	Beta C	R58640	4957	Grade 19	Mil-T-9046J
Ti-3Al-2.8Nb-15Mo-0.2Si	TiMetal21S	R58210	-	-	-
Intermetallics					
Ti ₃ Al	Alpha 2	-	-	-	-
TiAl	Gamma	-	-	-	-

Several environmental concerns associated with titanium production include waste disposal, air quality, fire hazards, and others. Residuals containing heavy metals in the chlorination of rutile to TiCl_4 present a disposal problem. The potential for leaking Cl_2 and TiCl_4 also exists. Transport of TiCl_4 to sponge producers that have no TiCl_4 production is done by rail, which is a concern, as is the handling of Cl_2 , which is generated but not consumed. Sponge production is leached or washed, and there is a concern with effluent from these operations.

Pickling is intrinsic to most titanium mill operations, especially those that make flat products. Acid baths build up dissolved metal ion content, so disposal of the liquid is a significant problem especially because it contains fluorine ions. The industry is evaluating ways to minimize or eliminate hydrofluoric acid pickling where possible.

Further, there is always the potential for titanium fires in the sponge plant and chip plant as well as in powder metallurgy operations. This is more of a safety issue than an environmental problem.

APPLICATIONS

Over the past 40 years, titanium use in military, commercial, and consumer applications has continued to grow, depending in part on fabricability and cost^[10]. Product requirements for titanium alloys in each market segment are based on specific needs of the particular application. For example, jet engine requirements focus primarily on high-temperature tensile and creep strength, as well as thermal stability at elevated temperatures. Second-tier property considerations include fatigue strength and fracture toughness. Airframe applications require high tensile strength combined with good fatigue strength and fracture toughness. Ease of component fabrication is also an important consideration. Industrial applications demand good corrosion resistance in a variety of media as a prime consideration as well as adequate strength, fabricability, and competitive cost relative to other types

of corrosion-resistant materials. The high cost of titanium alloy often limits its application. Thus, a lot of research is aimed at reducing component cost while maintaining acceptable mechanical property levels; approaches include near-net-shape techniques and lower cost alloy formulation.

The use of titanium in terrestrial military vehicles leads to high-performance attack systems that are strong, lightweight, fast, and readily deployable with cost penalties being resolved by single melt and near-net-shape fabrication. However, the aerospace industry dominates the use of titanium in engines and airframes. Fan and compressor blades, discs, and hubs made of titanium account for about 30% of the weight of a gas turbine engine.

Titanium offers high strength-to-weight ratio, strength at moderate temperatures, and good resistance to creep and fatigue. In the airframe, titanium brings about weight reduction in highly stressed parts. According to the International Titanium Association, engines account for about 42% of U.S. titanium demand and 37% in Europe^[10]. Figure 3 shows the power unit for the F-35 Lightning, which contains a substantial amount of titanium. The Boeing 777 uses 13,000 lb forging weight of Ti-10V-2Fe-3Al in the landing gear. The Boeing 787 requires at least 120 tons forging weight of titanium per aircraft including the engines.

U.S. Navy ships CVN 77 and CVN 78 use 38 tons of Ti-6Al-4V alloy per ship for mainmast platforms (Fig. 4) in the

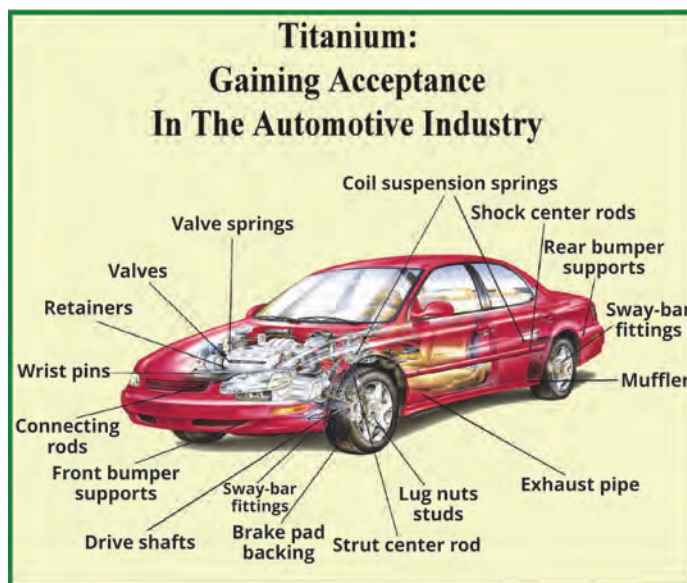


Fig. 3 — Current and potential applications of titanium in passenger cars.

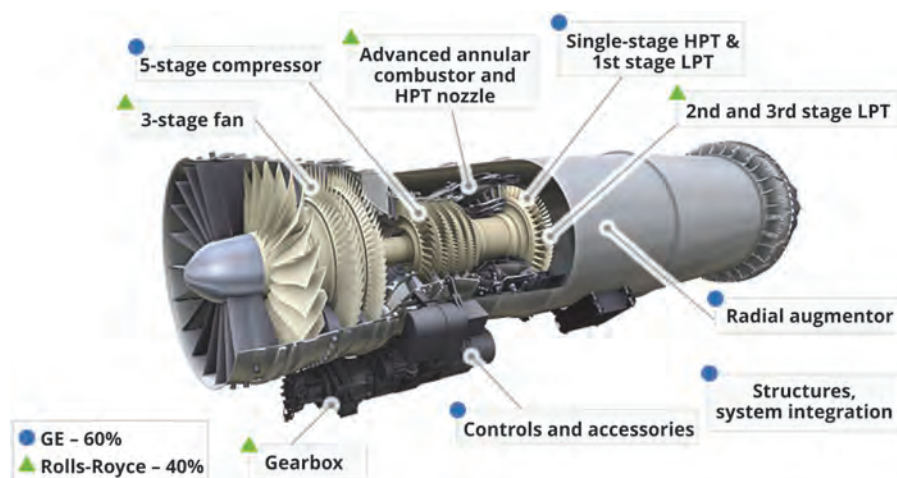


Fig. 4 — The Lockheed Martin F-35 Lightning II engine contains a substantial amount of titanium.

form of thick plate welded structures. The mainmast is the most visible, exposed structure on the ship. Use of titanium can provide topside weight savings and lower life-cycle costs due to reduced maintenance.

A wide variety of nonmilitary/aerospace applications include medical (artificial knees and hips, pacemaker cases, dental implants, and surgical devices), marine (deep-sea submersibles, off-shore oil platforms, and seawater piping), chemical processing (heat exchangers, vessels, pipe, and tubing), coatings (electrically conducting diffusion barriers,

interconnects, and antireflective coatings), automotive components, and eyeglass frames (Fig. 5 and Table 2). In addition, titanium is also used as cladding on art museums and cultural institutions, where its gray luster not only adds beauty, but also corrosion resistance to air pollution in urban environments. ~AM&P

For more information: Professor Sam Froes is a consultant to the additive manufacturing and titanium industries. He may be reached at 253.517.3034 or ssfroes@comcast.net.



Fig. 5 — The U.S. Navy's George H.W. Bush CVN 77 aircraft carrier uses a significant amount of titanium for its mainmast platforms.

TABLE 2 – TITANIUM COMPONENTS IN AUTOMOBILES

Component	Material	Manufacturer	Model
Connecting rods	Ti-3Al-2V-RE	Honda	Acura NSX
Connecting rods	Ti-6Al-4V	Ferrari	All 12 cylinder
Wheel rim screws	Ti-6Al-4V	Porsche	Sport wheel option
Brake-pad guide pins	Ti grade 2	Daimler	S-Class
Brake sealing washers	Ti grade 1s	Volkswagen	All
Gearshift knob	Ti grade 1	Honda	S2000 Roadster
Connecting rods	Ti-6Al-4V	Porsche	GT3
Valves	Ti-6Al-4V and PM Ti	Toyota	Altezza 6-cylinder
Turbocharger wheel	Ti-6Al-4V	Daimler	Truck diesel
Suspension springs	TiMetal LCB	Volkswagen	Lupo FSI
Wheel rim screws	Ti-6Al-4V	BMW	M-Technology option
Valve spring retainers	β-titanium alloys	Mitsubishi	All 1.8 L-4 cylinder
Turbocharger wheel	Gamma TiAl	Mitsubishi	Lancer
Exhaust system	Ti grade 2	General Motors	Corvette Z06
Wheel rim screws	Ti-6Al-4V	Volkswagen	Sport package GTI
Valves	Ti-6Al-4V and PM Ti	Nissan	Infiniti Q45
Suspension springs	TiMetal LCB	Ferrari	360 Stradale

materials testing trusted

Let our one-stop, Independent Testing Laboratory assist you with commercial dedication or failure analysis of your materials.

Visit us at
NSLanalytical.com/lab
or call 877.560.3875



Trust | Technology | Turnaround

4450 Cranwood Parkway, Cleveland, OH 44128
877.560.3875 | ISO/IEC 17025



References

1. F.H. Froes, Titanium Powder Metallurgy: Developments and Opportunities in a Sector Poised for Growth, *PM Rev.*, Vol 2, No. 4, p 29-43, 2013.
2. B. Dutta and F.H. Froes, Additive Manufacturing of Titanium Alloys, Elsevier/Butterworth-Heinemann, 2016.
3. K.S. Weil, et al., Effect of TiCl_4 Purity on the Sinterability of Armstrong-Processed Ti Powder, *J. Alloys and Compounds*, Vol 473, Issues 1-2, April 2009.
4. K.L. Housley, Kroll Process May Be on the Verge of Replacement or Modification, *Titanium News*, Metal Management Aerospace Inc., Hartford, CT, summer 2007.
5. Summary of Emerging Titanium Cost Reduction Technologies, Study for U.S. DOE and ORNL by EHK Technologies, January 2004.
6. P. Sun, et al., A Novel Method for Production of Spherical Ti-6Al-4V Powder for Additive Manufacturing, *Powder Technol.*, 301, p 331-335, 2016.
7. H.B. Bomberger, et al., Titanium Technology: Present Status and Future Trends, Titanium Devel. Assoc., p 3-18, 1985.
8. F.H. Froes and I.L. Caplan, Titanium 92 Science and Technology, TMS, 1993.
9. Mineral Commodity Summaries, Department of Interior Geological Survey and Bureau of Mines, Washington, 1996.
10. Titanium Facts, Intl. Titanium Assoc., 2007.
11. Titanium Technology: Present Status and Future Trends, F.H. Froes, D. Eylon, and H.B. Bomberger (eds.), Intl. Titanium Assoc., 1985.
12. Materials Property Handbook: Titanium Alloys, R. Boyer, G. Welsch, and E. Collings (eds.), ASM Intl., 1994.
13. M.J. Donachie, Titanium: A Technical Guide, ASM Intl., 1988.
14. I.J. Polmear, Light Alloys, Metallurgy of the Light Metals, 3rd ed., E. Arnold, London, 1996.



Tinius Olsen

Whatever the material –
Tinius Olsen
has the
solution

- Sub-micron resolution
- Multiple modules
- Non-contacting
- Record, playback
- Post-process functionality
- Strain mapping/DIC
- Scaleable LED lighting

All tests can be performed in accordance with ISO, BS, ASTM and industry specific standards

www.tiniusolsen.com
sales@tiniusolsen.com
 215 675 7100

✓ COMPOSITES ✓ METALS ✓ PLASTICS

INTRODUCING NANOSCALE CERAMIC PARTICLES INTO METAL MATRICES

Melt-injection of organic precursors may result in revolutionary technologies for producing ceramic reinforced metal-matrix composite castings.

Rishi Raj

University of Colorado, Boulder

Sintering is used to fabricate ceramics with high melting points, where densification occurs by solid-state diffusion. The high sensitivity of sintering rate to particle size^[1] led to commercial development of fine nanometer-scale ceramic powders. Van der Waals forces cause the fine powders to form hard particles^[2], which have gained consideration for use as reinforcements in metal-matrix composites (MMCs).

High volume fractions of ceramics enhance the modulus of the composite, which depends mostly on the volume fraction of the ceramic phase. This concept is applied to SiC-reinforced aluminum matrix composites^[3]. However, enhancement of yield strength and creep resistance requires nanoscale dispersion of the ceramic particles, which is approximately given by the Orowan stress:

$$\sigma_y = \frac{Gb}{\lambda} \quad (1)$$

where σ_y is shear yield stress, G is shear modulus, b is the Burgers vector (essentially equal to the lattice parameter), and λ is the interparticle spacing. Therefore, to achieve a yield stress that is 1% of G requires that λ is equal to roughly 100 times the lattice parameter (~15-20 nm). Assuming the particles are in the form of cubes (different particle shapes lead to minor differences in a numerical factor) of size p , the spacing

between adjacent particle edges is given by^[4]:

$$\lambda = p \left(\frac{1}{f_v^{1/3}} - 1 \right) \quad (2)$$

For example, λ is equal to $4p$ for a volume fraction (f_v) of 0.01. If $\lambda = 20$ nm, the particle size must be just a few tens of nanometers. The influence of particle dispersion on creep resistance is more complex, but essentially follows a similar guideline. If particles coarsen at elevated temperatures, such as with precipitation-strengthened alloys, creep resistance degrades with increasing particle size. Therefore, inert particles, which have little or no solubility in the metal matrix, are required for good creep resistance. ODS alloys made of nickel and thoria particles by deformation processing are an example of such optimized design of MMCs^[5].

Thus, the goal in creep-resistant MMCs is to be able to disperse essentially inert nanoscale ceramic particles. One approach has been to mix readily available fine ceramic particles into a metal by mechanical methods. However, the fine particles form hard agglomerates, which must be broken down by mechanical stirring. Ultrasonic methods have been used, but have yet to show commercial potential^[6]. Processes where second phases are produced by in-situ reactions with the host metal have also been explored^[7]. This work

differs in that the chemistry of the ceramic phase is contained entirely within the organic precursors, which imparts simplicity and versatility to the polymer route.

WHY THE POLYMER ROUTE?

Conversion of organics into ceramics is a relatively new field^[8]. Typically, organics convert into ceramics at low temperatures in the range of 400° to 800°C, increasing the possibility of in-situ production of fine ceramic particles within a metal matrix. The organics are self-contained, i.e., they decompose by themselves to produce the ceramic without needing to react with the metal host. There are two classes of the organics (generally known as polymer-derived ceramics, or PDCs): volatile (generally called alkoxides^[9]) and those that remain in a condensed state until converting into the ceramic phase^[10,11]. PDCs include:

- Type A are usually liquid at ambient temperature, but develop significant vapor pressure above ~400°C. Vapor pressure depends on monomer molecular weight; larger hydrocarbon side groups increase molecular weight and lower vapor pressure. These yield oxides.
- Type B have networks like oligomers (large 3D molecules built around silicon) or linear chains made of Si backbones. These nonvolatile compounds cross-link into epoxy-like

polymers at $\sim 350^\circ\text{C}$, which are relatively stable in air up to $\sim 600^\circ\text{C}$, but then decompose into ceramics. These fall into two subclasses, B1 and B2.

- Type B1 includes silicones and silazanes that yield amorphous ternary ceramics constituted from Si, C, and N/O, which have the composition SiCO (SiCN), and are inert and stable above 1200°C .
- Type B2 includes carbosilanes that yield binary SiC , which is normally nanocrystalline with some residual carbon at the grain boundaries. They are linear chain polymers built on silicon backbones, which can be drawn into fibers.

The fabrication of in-situ PDC-MMCs is carried out by introducing the raw precursor into the metal matrix in a fine dispersion, followed by in situ conversion of the polymer into the ceramic phase by heating to between 700° and 800°C . If the melting point of the host metal is above the pyrolysis temperature, the polymer must be introduced by milling the metal powders with the polymer powders, followed by hot consolidation with traditional powder metallurgy methods. The polymer pyrolyzes during hot consolidation of the powders. This approach is used with a Cu metal matrix.

If the metal melts below 700°C , the polymer can be introduced directly into the molten metal either by injecting the liquid polymer directly into the melt, or by injecting the cross-linked powder of the polymer precursor into the melt. This approach is used with a Mg metal matrix. Excellent wetting of the polymer powder enables having it drawn spontaneously into the melt.

POWDER-METALLURGY ROUTE

Copper-SiCN MMCs^[12, 13] were prepared by cryomilling powders of cross-linked commercial polysilazane (Type B1) to a 0.5 to 30- μm particle size with 60 to 100- μm copper powder. Ceramic yield from the polymer ranged from 80-90 wt%. Two-step milling was used to produce samples with 3.5, 6, 10, and 12 vol% ceramic phase (A3, A6, A10, and A12), respectively, as well as a high

volume fraction composite (B30) containing 30-35 vol% PDC. Figure 1 shows an electron micrograph of the milled powder and of the MMC after hot consolidation. Milling led to significant grain refinement (50-130 nm) in the metal.

Microindentation hardness measurements show a linear relationship between the microhardness (which is

proportional to the yield stress) and $(1/\lambda)$, as predicted by Equation 1 for a given particle size. The main effect of higher volume fraction of a ceramic phase is a reduction in interparticle spacing. Polymer-derived ceramic particles that form are inert and therefore do not coarsen, even at high temperatures. Figure 2b confirms the stability of the ceramic particles, showing that

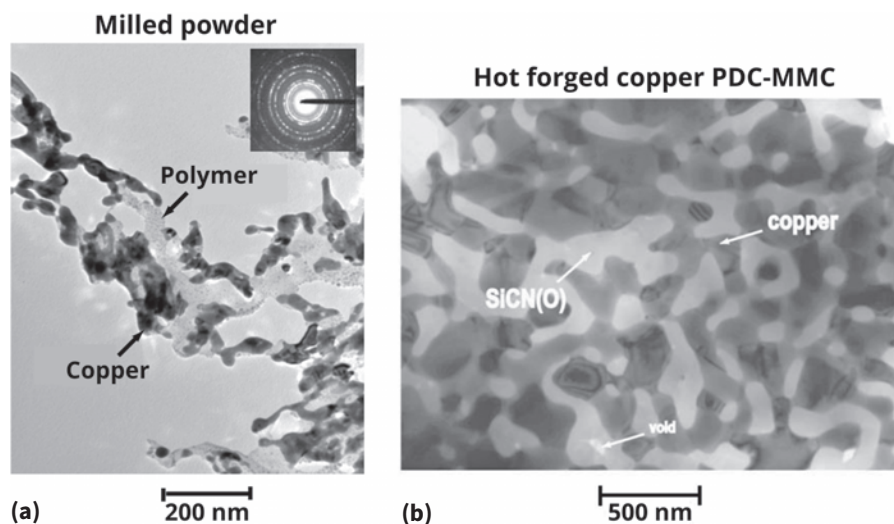


Fig. 1 — Composites made with Cu powder and cross-linked Type B1 precursor, milled and hot consolidated: (a) TEM micrograph of milled powder, and (b) hot-consolidated sample containing 30-35 vol% ceramic phase. The length of the interspersed nanostructure of the metal and ceramic phases is about 100 nm.

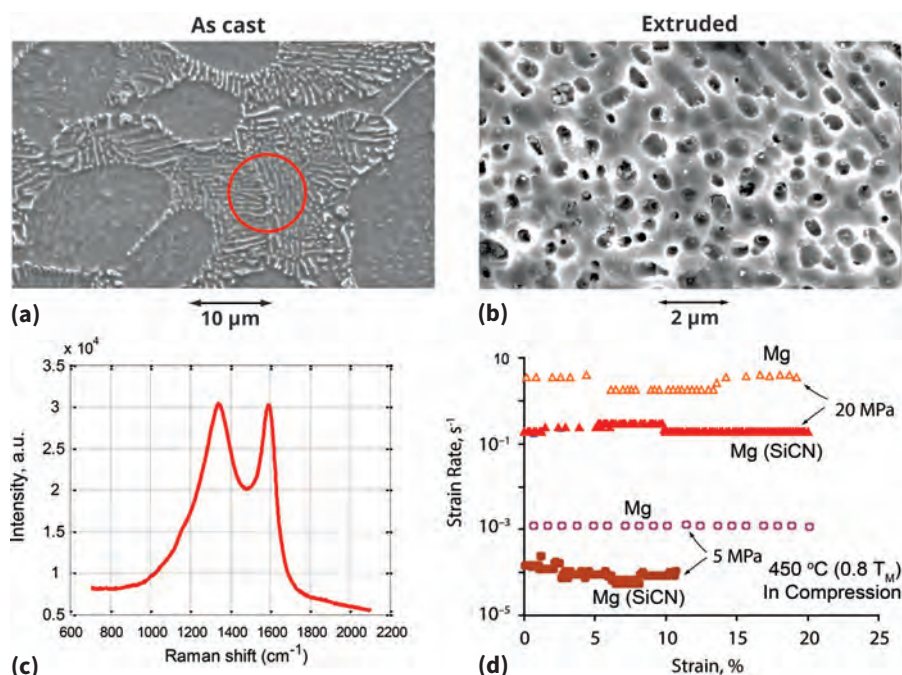


Fig. 2 — Casting made by injecting powder of Type B1 precursor into Mg melt: (a) optical micrograph shows ceramic particles segregate to grain-boundary regions; (b) SEM micrograph after hot extrusion; (c) Raman spectra show D and G peaks of graphene, which confirm full conversion of the precursor into the ceramic phase; and (d) compression creep behavior of pure sample and extruded sample shown in (b).

there is no change in yield stress after annealing at 950°C ($0.9 T_m$ for Cu). The PDC-MMC process enables production of highly creep-resistant metal alloys.

MELT-INJECTION ROUTE

The melting point of magnesium (650°C) is below the temperature where the polymer converts into the ceramic phase, thereby enabling injecting the polymer directly into the melt and having it convert into the ceramic while surrounded by the metal. Two ways to introduce the polymer are by cross-linking it, milling it into a powder (as in the approach with Cu), and then, by injecting it directly as a liquid into the magnesium melt.

The polymer was injected into the magnesium melt by the stir casting method^[14,15]. Highly wetting behavior of the polymer enabled it to be drawn spontaneously into the melt. Type B1 polymer powder (5 wt%) was added into the melt at 730°C and stirred for 15 minutes. The melt was cooled to

675°C, and poured into 15- and 25-mm-diameter cast-iron molds. Cast cylindrical ingots were heat treated at 400°C for one hour and extruded down to a ratio of 9:1. Microstructures of the as-cast and extruded samples are shown in Fig. 2. Raman spectra from the ceramic-particle region in the cast structure are a simple way to determine that the organic precursor has fully converted into the ceramic phase.

The microstructure of the casting (Fig. 2a) shows that the SiCN ceramic particles segregated toward the grain boundary regions, which break down into nanoscale particles (Fig. 2b) after extrusion; interparticle spacing, λ is about 1 μm ^[15], which from Equation 1 is expected to produce only a modest improvement in mechanical properties. Nevertheless, the strain rate (Fig. 2d) measured in compression at 450°C, is reduced by a factor of ~5 by the ceramic particles. Also, creep resistance does not degrade with time, confirming the particles do not coarsen.

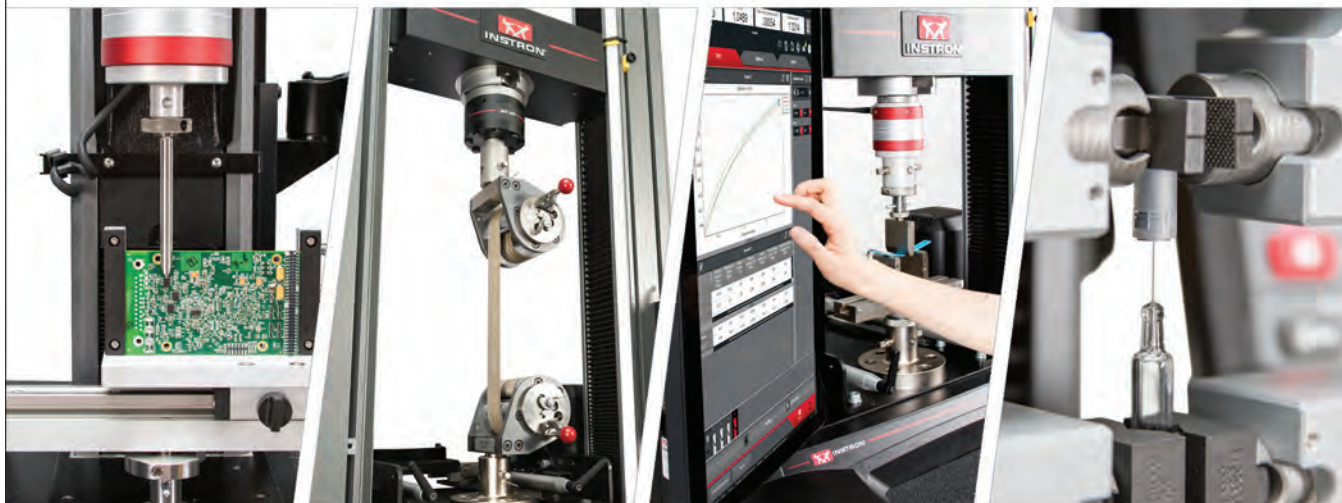
Melt injection experiments were also carried out within a glovebox to prevent oxidation of magnesium. Castings from a 70 × 20 × 90 mm mold^[16] were used directly for mechanical testing without extrusion or further heat treatment. Polymer was inserted in the form of cross-linked powder, but also by injecting the liquid directly into the melt^[16]. The volume fraction of the ceramic phase was 2.5 vol%. Flat dog-bone shaped specimens were machined from the castings for mechanical testing at ambient and high temperatures (350° to 450°C). Creep testing was also performed. Pure Mg castings were also made for comparison.

Results from tensile tests at ambient temperature are shown in Fig. 3. Yield strength increases from 10 MPa for pure Mg to 80 MPa for the castings made with PDCs. Ultimate tensile stress increases from 70 MPa for pure Mg to 130-150 MPa for 2.5% PDC strengthened samples. Tensile ductility is not significantly affected by the addition



LEADING THE WAY IN MATERIALS TESTING

Founded in 1946, Instron® designs and manufactures materials testing systems and accessories to meet a wide range of industry specific applications, helping industry experts extract key performance insights that enable them to make informed decisions at every stage.



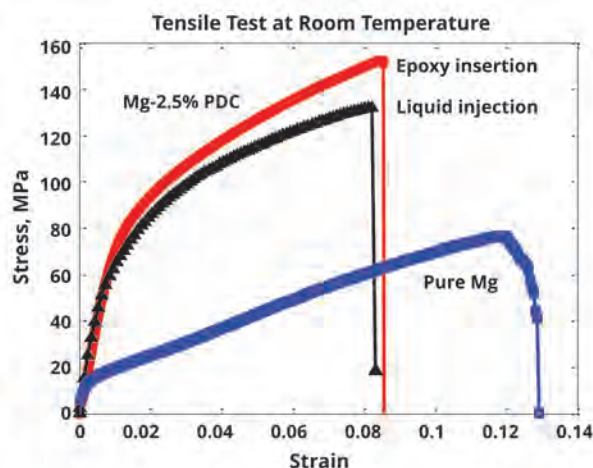


Fig. 3 — Effect of introducing polymer-derived ceramic particles into Mg by in-situ conversion of the organic precursor. The precursor can be injected directly as a liquid or powder of cross-linked polymer into molten magnesium; both give similar results.

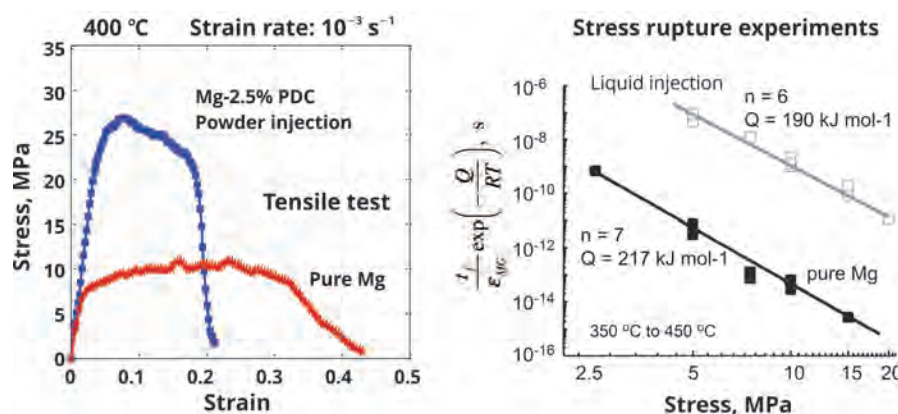


Fig. 4 — Results of creep tests carried out at 350° to 450°C: (left) effect of ceramic dispersion on the flow stress at a strain rate of 10⁻³ s⁻¹; (right) data fitted to the Monkman-Grant relationship.

of the ceramic phase. High ductility is ascribed to strong interfacial bonding between the ceramic particles and the metal matrix. Tensile results at 400°C (Fig. 4) show that flow stress increases from 10 MPa for pure Mg to 25 MPa for the composite. The mode of fracture changed from transgranular to intergranular, which is expected for dispersion-strengthened alloys. The stress rupture behavior of the composites was determined from creep tests at 350° to 450°C (Fig. 4)^[17].

Further work on microstructure characterization and discussion of the strengthening mechanisms is described in the literature^[18-20].

SUMMARY

The developing technology described in this article is poised to enable the design and creation of a new

generation of creep-resistant metal alloys. Aluminum and magnesium are usually precipitation hardened; precipitates are produced by diffusion in the solid state under controlled heat treatment. In high temperature creep, these same diffusion mechanisms lead to coarsening, which degrades creep resistance. PDC-MMCs contain particles that are inert and do not coarsen, thereby enabling a new generation of high-temperature metal alloys.

Melding of polymers and metals to produce high temperature metal alloys is unusual, and a concerted effort is needed to develop the technology. The organic precursors are nonflammable, nontoxic, and environmentally benign, posing little risk in scale-up to manufacturing, although in some instances, shielding with an inert gas may be needed because some of them convert

into the ceramic if exposed to air. Thus, their incorporation into metallurgical processes is feasible. The opportunities may be difficult to fathom today, but they are likely to be revolutionary.

~AM&P

For more information: Rishi Raj is a mechanical engineering professor, University of Colorado Boulder, 596 UCB, Boulder, CO 80309-0596, 303.492.1029, rishi.raj@colorado.edu, www.colorado.edu.

Acknowledgment

The results reported here are from the doctoral theses supervised by M. Surappa, Indian Institute of Science, H. Singh, Indian Institute of Technology, A. Molinari, University of Trento, Italy, and the author. Post-doctoral work (Sudarshan) was supervised by the author^[12,13,20-24]. Doctoral research was carried out partially at University of Colorado Boulder, supported by the Metals and NanoMaterials Program in the NSF Division of Materials Research under Grant No. DMR1105347.

References

1. W.H. Rhodes, Agglomerate and Particle Size Effects on Sintering Yttria-Stabilized Zirconia, *J. Amer. Ceram. Soc.*, 64, (1), p 19-22, 1981.
2. F. Dynys and J.W. Halloran, Influence of Aggregates on Sintering, *J. Amer. Ceram. Soc.*, 67 (9), p 596-601, 1984.
3. D.L. McDanel, Analysis of Stress-Strain, Fracture, and Ductility Behavior of Aluminum Matrix Composites Containing Discontinuous Silicon Carbide Reinforcement, *Metall. and Matls. Trans. A*, 16, (6), p 1105-15, 1985.
4. T.W. Gustafson, et al., Influence of Microstructural Scale on Plastic Flow Behavior of Metal Matrix Composites, *Acta Materialia*, 45, (4), p 1633-43, 1997.
5. B.A. Wilcox and A.H. Clauer, Creep of Thoriated Nickel Above and Below 0.5 TM, *Trans. Met. Soc. AIME*, April, p 236, 1966.
6. J. Hashim, et al., Metal Matrix Composites: Production by the Stir

Casting Method, *J. Matls. Proc. Technol.*, 92, p 1-7, 1999.

7. S.C. Tjong and Z.Y. Ma, Microstructural and Mechanical Characteristics of In Situ Metal Matrix Composites, *Matls. Sci. and Engrg.: R: Reports*, 2000 29, (3), p 49-113, 2000.

8. C.J. Brinker, et al., Symp. Better Ceramics Through Chemistry, North-Holland, 1984.

9. D.C. Bradley, Metal Alkoxides as Precursors for Electronic and Ceramic Materials, *Chem. Rev.*, 89, (6), p 1317-22, 1989.

10. S. Yajima, et al., Development of a Silicon Carbide Fibre with High Tensile Strength, *Nature*, 261, (5562), p 683-5, 1976.

11. P. Colombo, et al., Polymer-Derived Ceramics: 40 Years of Research and Innovation in Advanced Ceramics, *J. Amer. Ceram. Soc.*, 93, (7), p 1805-37, 2010.

12. E. Castellan, G. Ischia, A. Molinari, and R. Raj, A Novel In Situ Method for Producing a Dispersion of a Ceramic Phase Into Copper that Remains Stable

at 0.9 Tm, *Metall. and Matls. Trans. A*, 44, (10), p 4734-42, 2013.

13. E. Castellan, et al., Low-Wear High-Friction Behavior of Copper Matrix Composites Dispersed With an In Situ Polymer Derived Ceramic, *J. of Tribol.*, 137, (2) p 024501, 2015.

14. M.K. Surappa and P.K. Rohatgi, Preparation and Properties of Cast Aluminium-Ceramic Particle Composites, *J. Matls. Sci.*, 16, (4), p 983-93, 1981.

15. Sudarshan, et al., Nanoceramic-Metal Matrix Composites by In-Situ Pyrolysis of Organic Precursors in a Liquid Melt, *Metall. and Matls. Trans. A*, 39, (13), p 3291-7, 2008.

16. Sudarshan, et al., Polymer-Derived In-Situ Metal Matrix Composites Created by Direct Injection of a Liquid Polymer into Molten Magnesium, *Metall. and Matls. Trans. A*, 45, (2), p 551-4, 2014.

17. N.M. Chelliah, et al., Stress-Rupture Measurements of Cast Magnesium Strengthened by In-Situ Production of Ceramic Particles, *J. Magnesium and Alloys*, 2017.

18. N.M. Chelliah, et al., Processing, Microstructural Evolution and Strength Properties of In-Situ Magnesium Matrix Composites Containing Nano-Sized Polymer Derived SiCNO Particles, *Matls. Sci. and Engrg.: A*, 685, p 429-38, 2017.

19. N.M. Chelliah, et al., Microstructural Evolution and Strengthening Behavior in In-Situ Magnesium Matrix Composites Fabricated by Solidification Processing, *Matls. Chem. and Phys.*, 194, p 65-76, 2017.

20. N.M. Chelliah, et al., A Polymer Route to the Design of Thermally Stable Metal Matrix Composites: Materials Selection and In-situ Processing, *Res. and Reports on Metals*, Dec. 4, 2017.

Selected References

1. T. Cross, et al., Mechanical and Tribological Behavior of Polymer-Derived Ceramics Constituted from SiC_xO_yN_z, *J. Amer. Ceram. Soc.*, 89, (12), p 3706-14, 2006.

2. L. Yu and R. Raj, On the Thermodynamically Stable Amorphous Phase of Polymer-Derived Silicon Oxycarbide, *Scientific Reports*, 2015.



Advanced Thermal Processing
Technology Conference & Expo

September 25-28, 2018 | Fiesta Americana | Queretaro, Mexico

Exhibit Space and Sponsorships are Available for Heat Treat Mexico 2018!

This premier event, powered by the strength of the Heat Treating Society and the organizers of Heat Treat North America, showcases heat treating resources and technology for emerging markets in Mexico.

Exhibiting at this show puts you and your company in front of key players, decision makers, and influencers that can help you grow your business!

Exhibitor packages start at \$2,500 USD!

Gain additional exposure with sponsorship and advertising.

For more information or questions contact: exposales@asminternational.org

Organized by:



www.asminternational.org/web/heat-treat-mexico-2018/exhibits

TECHNICAL SPOTLIGHT

ION MILLING MAXIMIZES EBSD SENSITIVITY FOR STUDYING METALLOGRAPHIC SAMPLES

Because electron backscatter diffraction is a surface-sensitive technique, preparing the sample surface so that it is smooth and free of defects is crucial to successful analysis.

Electron backscatter diffraction (EBSD) is a scanning electron microscope (SEM)-based analytical technique that provides a wealth of information regarding the microstructure of the material under study^[1]. New microanalysis instrumentation and software now enables scientists and researchers to conduct experiments using this technique and generate valuable information, quickly and clearly. EBSD involves directing a focused beam of electrons at a sample of interest, which is tilted at a 70° angle in order to maximize backscattered electrons. The atomic planes in the material inelastically scatter these electrons when they satisfy the Bragg equation, diffracting them in such a way as to form a set of paired large angle cones corresponding to the diffracting plane. When projected onto a 2D phosphor screen, pairs of lines of distinct intensity are formed, giving rise to the characteristic Kikuchi bands for the EBSD pattern. An example of the resulting diffraction pattern is shown in Fig. 1.

The Kikuchi bands in the diffraction pattern are characteristic of the crystal structure under study. First, the distance between the bright lines forming each Kikuchi band is inversely proportional to the spacing of the atomic plane from which the electron was diffracted. Next, the intersections of the bands correspond to the zone axes in the crystal. The angle between these intersecting lines provides the information needed to determine crystal orientation. Finally, the intensity of the Kikuchi bands is a function of the

fractional representation of the atomic planes contributing to the backscattered diffraction pattern and the relative mass of the atom, which is important when indexing materials composed of different elements.

An accurate analysis of the material microstructure requires a high degree of confidence in Kikuchi band detection, which in turn requires a high-quality diffraction pattern. Because the technique depends entirely on the top 10–15 nm of the material, optimizing the surface preparation is essential to achieving a high-quality diffraction pattern.

SAMPLE POLISHING METHODS

Polishing samples by hand on a rotating polishing wheel is a low cost, straightforward method to prepare the sample surface for EBSD analysis. Details regarding polishing best practices are thoroughly explained by metallurgical engineer George Vander Voort and are available on his website^[2]. In general, the sample is first rough-polished

with sand paper at successively finer grits—200, 400, and 800—to achieve a generally flat and smooth surface. Next, the sample is fine polished with a series of slurries of successively smaller grinding particulates—9, 3, 1, and 0.25 microns—to create a surface free of scratches and imperfections. The sample can be finished with a gentle polish in a 0.020 micron slurry or vibrated in a colloidal solution to remove any sub-surface strain.

Hand polishing is a highly effective technique for preparing most samples for EBSD analysis when the procedure is carefully followed. A Euler map is a common way to represent the distribution and orientation of the grains within the region of the sample analyzed^[3]. Figure 2 shows the resulting Euler map from a properly polished nickel sample.

When proper technique is not adhered to—or equipment is poorly maintained—results such as those in Fig. 3 can be expected. The electron image of the sample demonstrates that strong,

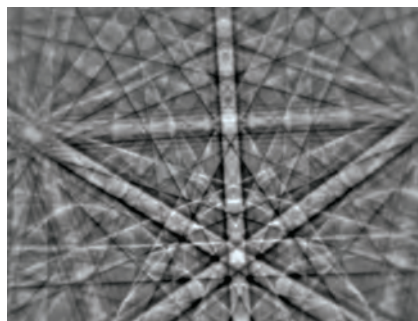


Fig. 1 — Characteristic Kikuchi bands form the typical EBSD diffraction pattern.

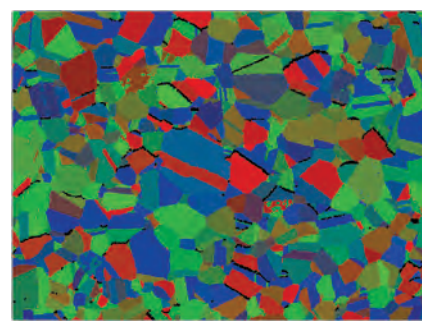
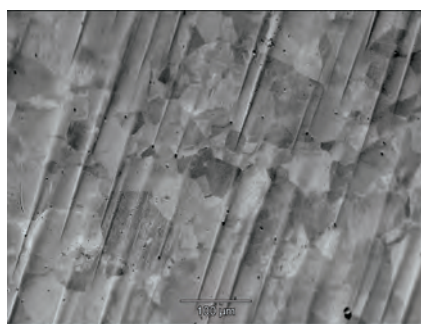


Fig. 2 — Euler map of a properly polished nickel sample.

directional scratches were imparted in the sample surface during polishing (Fig. 3a). As a result, the poor quality Euler map obtained from this sample should be expected (Fig. 3b).

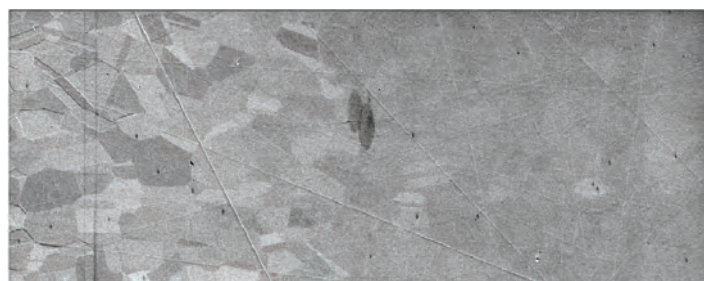


(a)

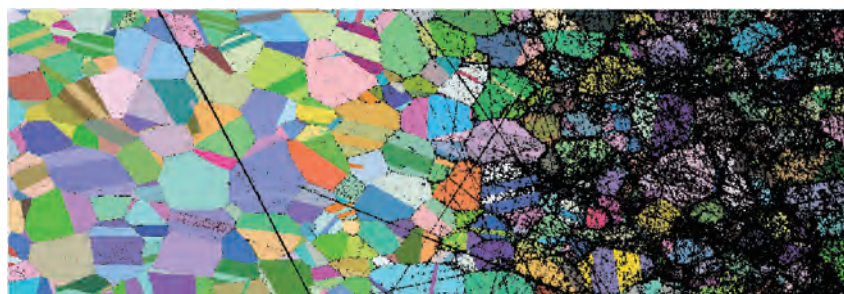


(b)

Fig. 3 — (a) Scratches imparted into sample surface during polishing; (b) poor quality Euler map obtained from sample.



(a)



(b)

Fig. 4 — (a) Left-hand side of image polished by ion milling is clear; grain structure image quality degrades from left to right; (b) corresponding Euler map shows clear grains on left with degrading indexing quality to the right.

ION MILLING

As a final stage in sample preparation, ion milling is an option that eliminates much of the variation inherent to hand polishing and ensures a more consistent and higher quality surface finish. With ion milling, the sample is polished as usual down to a one-micron particulate slurry. It is then bombarded with argon ions at an angle of 20° to 50° at an accelerating voltage of 1–30 kV. The ion bombardment removes material from the surface by sputtering.

Systematically lowering the accelerating voltage reduces both the rate of material removal and the depth of ion penetration into the material, which in turn systematically reduces the damage layer imparted on the surface during the removal process. A final polishing step between 1 and 3 kV results in virtually no surface damage.

The effectiveness of broad ion milling for EBSD sample preparation is demonstrated in Fig. 4. Here, an aluminum sample was prepared as described above with the exception that only the left-hand side of the sample was polished by ion milling. In the electron image, the grain structure is clear on the

left with a general reduction in quality moving to the right with only a few grains visible (Fig. 4a). In the corresponding Euler map, the grains with identified crystal orientation are clear and unambiguous on the left (Fig. 4b). The only exception is a deep scratch angled diagonally through the sample. Moving to the right, the indexing quality degrades so that less than half of the grains are properly identified with EBSD.

This ion milling technique can be applied to a cast iron sample subject to graphitic corrosion within a chlorinated environment. Cast iron lacks the nickel or chrome additives present in stainless steel and is therefore at risk of corrosion. An optical image of a corroded section is shown in Fig. 5a. The sample is mounted in epoxy, polished to one-micron grit, and then ion milled with a monatomic argon beam for 30 minutes and finally at 3 kV for 10 minutes with an Ar⁺ cluster ion source. The electron image demonstrates the grain structure with dark tendrils encroaching throughout the sample (Fig. 5b). Energy dispersive spectroscopy and wavelength dispersive spectroscopy (EDS/WDS) confirm the presence of chlorine and a higher level of carbon in these dark, tendril regions with no detected chlorine and lower levels of carbon throughout the remainder of the sample. An overlay of the Euler maps from EBSD analysis on the electron image confirms the nature of the corrosion (Fig. 5c). The ferritic grain structure expected from uncorroded cast iron is demonstrated, and the dark, tendril regions yield no diffraction patterns, indicating an amorphous structure as expected from this type of corrosion.

SUMMARY

EBSD combined with EDS and electron imaging yields a wealth of rich information regarding the material microstructure. Because EBSD is a surface-sensitive technique, preparing the sample surface so that it is smooth and free of defects is crucial to successful analysis. Traditional hand polishing can achieve high-quality results, although the technique is prone to variation and

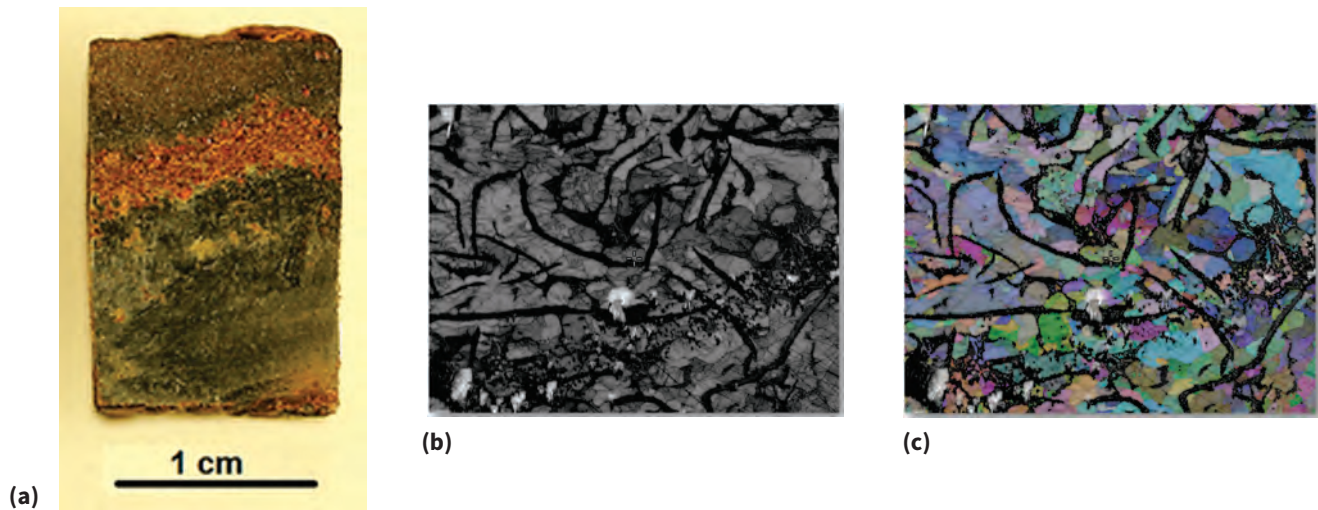


Fig. 5 — (a) Optical image of corroded section of cast iron sample; (b) electron image shows grain structure with dark tendrils encroaching throughout sample; (c) overlay of Euler maps from EBSD analysis on the electron image confirms the nature of the corrosion.

haphazard outcomes. Supplementing hand polishing with ion milling provides a superior surface finish free of operator or technique-related errors, thus enabling a high-confidence EBSD examination of the microstructure of even the most complex materials.
~AM&P

For more information: Keith Thompson is product manager of x-ray microanalysis, Thermo Fisher Scientific Inc., 525 Verona Rd., Madison, WI 53711, 608.276.5603, keith.thompson@thermofisher.com, www.thermofisher.com/pathfinder.

References

1. www.thermofisher.com/microanalysis
2. www.georgevandervoort.com/metallography/list-of-articles.html
3. T.B. Britton, et al., Tutorial: Crystal Orientations and EBSD – or Which Way is Up?, *Mater. Charact.*, Vol 117, p 113-126, July 2016.



Bring Essential Thermal Spray Training to Your Location

Stay relevant and competitive with ASM Customized On-Site Training.

Accredited, location-independent courses provide critical skills and support your team's professional development – while minimizing downtime and travel expenses.

Start today by contacting
Ravi Dodeja at 440.338.5414
or
ravi.dodeja@asminternational.org.

Extensometers

Strain measurement for materials testing

www.epsilontech.com



**34 MODELS
Cover All
Common Tests**

- Measuring ranges from 1% to 2000% strain
- Gage lengths from 0.125 to 10+ inches (3 to 250+ mm)
- Temperature ranges from -265 to 1600°C
- Laser extensometers



Epsilon
technology corp

3975 South Highway 89 Jackson, WY 83001 USA 307 733-8360

SMST 2018 IRELAND

Engaging and Enabling Irish MedTech for Design and Manufacturing with Nitinol



17 May 2018

Clayton Hotel Galway, Old Monivea Rd, Ballybrit

Industry Partner



Corporate Sponsors



FORT WAYNE METALS

Turning knowledge into solutions



Sponsors



One-day education event and forum of academia and industry.

The International Conference on Shape Memory and Superelastic Technologies (SMST) is headed to Ireland on May 17 for a first-time event. This one-day educational opportunity and forum of academia and industry leaders will be held at the Clayton Hotel Galway in Ballybrit. The meeting is intended to enable effective shape memory alloy (SMA) design in Irish biotechnology through open communication in a forum of academia and industry.

Education workshops will be held in the morning, while the afternoon features a special session with leading industrial and academic experts. The day also includes several opportunities to meet with exhibitors and network with attendees during tea socials and an afternoon pub event.

SMST attendees will have the opportunity to learn from leading experts in the SMA field.

Industrial and Academic Experts

Barry O'Brien

Biomedical Engineering NUI Galway

Pat Dooley

Boston Scientific

Shane Mucahy

Fort Wayne Metals

David Bow

Vascutek

Mike Bryant

Leeds University

Fiona Weaver

Cerenovus

Adrian McMahon

Boston Scientific

SMST 2018 SCHEDULE-AT-A-GLANCE

The preliminary schedule included here is subject to change.

DATE/TIME	EVENT
Thursday, May 17	
7:30 – 8:00 a.m.	Breakfast and Registration
8:00 – 10:00 a.m.	Education 1: History, Advances, State of the Art of SMA & NiTi
10:00 – 10:30 a.m.	Tea Social
10:30 a.m. – 12:00 p.m.	Education 2: Applications, When NOT to use SMA, Design for Fatigue
12:00 – 1:00 p.m.	Lunch Social
1:00 – 4:00 p.m.	Industrial and Academic: Short Talks on New Applications, Challenges and Solutions in Design with SMA and NiTi
4:00 – 5:00 p.m.	Open Discussion
Begins at 5:00 p.m.	Pub Social and Networking Event

EXHIBITION HOURS*

10:00 – 10:30 a.m. during tea social

12:00 – 1:00 p.m. during lunch social

2:30 – 3:00 p.m. during tea social

*Exhibition hours are subject to change.

EXHIBITOR LIST*

ADMEDES GmbH

ANV Laser Industry LTD.

Buehler - ITW Test & Measurement GmbH

ECHOBIO

EUROFLEX GmbH

Fort Wayne Metals

Instron

Integer

Luminous Device Technologies

Neolix SAS

Norman Noble

Resonetics

*Exhibitor list current as of March 5.



INVEST IN YOU

Companies are positioned for growth in 2018, and the highest performing organizations will be those who invest in a well trained workforce.

Keep up with new technologies to be a key contributor to your company's growth by enhancing your skills.

Turn to ASM International, the most trusted source for materials information, for the professional development you need.

The dividends to your career, your company, and the advancing industry, will be invaluable.

ASM offers courses covering a wide range of topics to help accelerate your development, including...



Heat Treating



Failure Analysis



Metallurgy



Metallography



Shape Memory



Additive Manufacturing

TO REGISTER FOR THESE OR OTHER COURSES, VISIT:

www.asminternational.org/learning

OR CONTACT:

Ravi Dodeja
ravi.dodeja@asminternational.org
440.338.5414

Andrea Currington
andrea.currington@asminternational.org
440.338.5151 ext. 5463



ASM

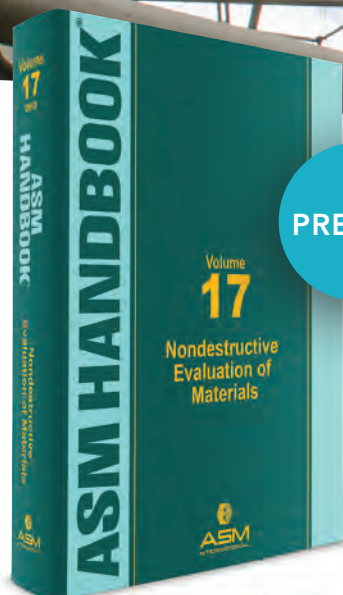
INTERNATIONAL

REFERENCE PUBLICATIONS

.....

SPRING/SUMMER 2018 CATALOG

ASM Handbooks	1-5
Materials Reference.....	6
General Engineering Reference	7
Failure Analysis	7-8
Metallography & Characterization	8-9
Fatigue & Fracture.....	10
Manufacturing & Design	11
Steels	12-13
Nonferrous Metals	13-15
Welding, Brazing & Soldering.....	16
Heat Treating	17-18
Coatings & Surface Engineering	18
Corrosion	19
Plastics, Composites & Ceramics.....	20
Microelectronics	20-21
Metallurgy for the Non-Metallurgist™	21
Alloy Phase Diagrams.....	22



PRE-PUB

ASM Handbook Volume 17: Nondestructive Evaluation of Materials

Prepublication pricing through June 30!

See page 4 for details

Turn the page for the latest releases

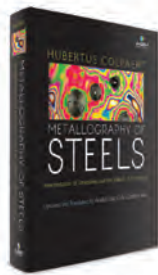


ASM Handbook, Volume 17: Nondestructive Evaluation of Materials

Edited by Aquil Ahmad and Leonard J. Bond
ISBN: 978-1-62708-152-8
Product Code: 05511G

Prepublication pricing through June 30

[See page 4](#)



Metallography of Steels: Interpretation of Structure and the Effects of Processing

By Hubertus Colpaert
Updated and translated by André Luiz V. da Costa e Silva
ISBN: 978-1-62708-148-1
Product Code: 05922G

Prepublication pricing through April 30

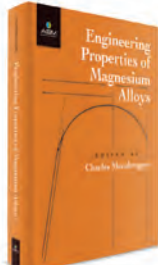
[See page 9](#)



ASM Handbook, Volume 18: Friction, Lubrication, and Wear Technology

Edited by George E. Totten
ISBN: 978-1-62708-141-2
Product Code: 05510G

[See page 4](#)



Engineering Properties of Magnesium Alloys

Edited by Charles Moosbrugger
ISBN: 978-1-62708-143-6
Product Code: 05920G

[See page 14](#)



The History of Metals in America

By Charles R. Simcoe
Edited by Frances Richards
ISBN: 978-1-62708-145-0
Product Code: 05925G

Prepublication pricing through April 30

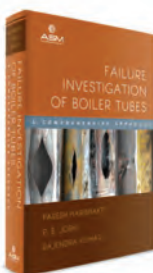
[See page 7](#)



Metallurgy for the Non-Metallurgist™: Mechanical Properties and Their Measurement

New self-guided digital course

[See page 21](#)



Failure Investigation of Boiler Tubes: A Comprehensive Approach

By Paresh Haribhakti, P.B. Joshi, and Rajendra Kumar
ISBN: 978-1-62708-156-6
Product Code: 05243G

Prepublication pricing through August 31

[See page 8](#)



Selected Values of the Crystallographic Properties of the Elements

By John W. Arblaster
ISBN: 978-1-62708-154-2
Product Code: 05244G

[See page 22](#)

The World's Best and Most Comprehensive Materials Reference Guides

All articles are expert-written and peer-reviewed

Each volume of the ASM Handbook® series contains the most up-to-date information in a particular area of interest. Together, the complete set builds on the 95-year tradition of the ASM Handbook as the industry's best-known and most comprehensive source for information on metals and materials technology. Revised volumes and volumes of new topics are being published as warranted by technological advances. Volumes 10, 12, and 16 are now sold as green-covered ASM Handbook volumes, but the red-covered 9th Edition Metals Handbook versions are still current.

ASM Handbook Complete Set, see page 5

Order The Complete ASM Handbook Set – asminternational.org



Volume 1A: Cast Iron Science and Technology

Edited by Doru M. Stefanescu

2017 • Approx. 790 pages

ISBN: 978-1-62708-133-7

Product Code: 05924G

Price: \$297 / ASM Member: \$225

Cast iron development engineers, foundry production and support personnel, product-application engineers, and designers now have an ASM Handbook devoted to

the principles, practices, and application of cast iron science and technology. Content covers all aspects of cast iron fundamentals and metallurgy, primary and secondary processing, effects of processing on properties, process, and product design, and the engineering properties of specific grades, types, and product forms of iron castings.

NEW

Volume 3: Alloy Phase Diagrams

Edited by Hiroaki Okamoto, Mark E. Schlesinger, and Erik M. Mueller

2016 • 778 pages

ISBN: 978-1-62708-070-5

Product Code: 05442G

Price: \$297 / ASM Member: \$225

40% of this volume has been updated and now includes 1083 binary systems, 1095 binary diagrams, 115 ternary systems, and 406 ternary diagrams. New material on solid solutions and phase transformations; thermodynamics; isomorphous, eutectic, peritectic, and monotectic alloy systems; solid-state transformations; and intermediate phases has been added.



Volume 4A: Steel Heat Treating Fundamentals and Processes

Edited by Jon L. Dossett and George E. Totten

2013 • 784 pages

ISBN: 978-1-62708-011-8

Product Code: 05344G

Price: \$297 / ASM Member: \$225



This volume addresses the basics of steel heat treating and thoroughly covers the many steel heat treating

processes. Major topics include: the physical metallurgy of steel heat treatment, fundamentals and practical aspects of steel hardness and hardenability, quenching, annealing, tempering, austempering, and martempering. The volume provides greatly expanded treatment of surface hardening by applied energy, carburizing, carbonitriding, nitriding, and diffusion coatings.

Volume 4B: Steel Heat Treating Technologies

Edited by Jon L. Dossett and George E. Totten

2014 • 582 Pages

ISBN: 978-1-62708-025-5

Product Code: 05434G

Price: \$297 / ASM Member: \$225



Volume 4B expands coverage on equipment, control, troubleshooting, and problems associated with steel heat treating. New articles extensively address distortion and the prevention of cracking – including the modeling and simulation of distortion. General process and procedure factors also are introduced—including temperature uniformity of furnaces, calculation of heat treating costs, and decarburization.

Volume 4C: Induction Heating and Heat Treatment

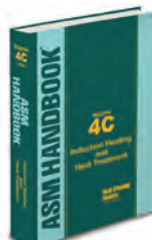
Edited by Valery Rudnev and George E. Totten

2014 • 820 pages

ISBN: 978-1-62708-012-5

Product Code: 05345G

Price: \$297 / ASM Member: \$225



This all new ASM Handbook gives design, manufacturing, and materials engineers an important new reference. Written by internationally recognized experts, Volume 4C provides in-depth and comprehensive coverage on one of the most significant technologies in the metals processing industries. Covering the breadth and significance of induction heating and heat treatment technologies and applications, this new ASM Handbook is a must-have addition to the bookshelf of any materials and manufacturing professional.

SAVE
UP TO
\$87

SET SALE!

Volumes 1 and 2

Product Code: 06062G

Price: \$507 / ASM Member: \$405



Volume 1: Properties and Selections: Irons, Steels, and High-Performance Alloys

1990 • 1063 pages

ISBN: 978-0-87170-377-4

Product Code: 06181G

Price: \$297 / ASM Member: \$225

Extensive data for alloy designations, compositions, and mechanical/physical properties. Covers performance and selection of cast irons, carbon

and low-alloy steels, tool steels, stainless steels, and super alloys. 1,328 photographs, charts and graphs. More than 500 tables.



Volume 2: Properties and Selection: Nonferrous Alloys and Special Purpose Materials

1990 • 1328 pages

ISBN: 978-0-87170-378-1

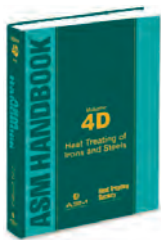
Product Code: 06182G

Price: \$297 / ASM Member: \$225

Your best single-volume source on compositions, properties, selection, and applications of nonferrous metals and alloys. Extensive coverage

on aluminum, titanium, and copper. 1800 illustrations, hundreds of tables and data sheets.

TO ORDER, VISIT WWW.ASMINTERNATIONAL.ORG/REFERENCEPUBS OR CALL 800.336.5152, EXT. 0



Volume 4D: Heat Treating of Irons and Steels

Edited by Jon L. Dossett and George E. Totten
2014 • 730 pages
ISBN: 978-1-62708-066-8
Product Code: 05352G

Price: \$297 / ASM Member: \$225

Packed with information and knowledge for anyone who uses or works with heat treated steels or cast

irons. Written and reviewed by recognized authorities, this new handbook gives you in-depth articles with details on the processing and properties for all significant applications and types of heat treated ferrous alloys. New content includes not only updates on new alloys, but also expanded coverage on the effects of heat treating on the properties for more carbon and low-alloy steels, tool steels, stainless steels, and other high-alloy grades.



Volume 4E: Heat Treating of Nonferrous Alloys

Edited by George E. Totten
2016 • 712 pages
978-1-62708-112-2
Product Code: 05444G

Price: \$297 / ASM Member: \$225

This new volume completes the series of five volumes on the major technological subject of heat treating. This singular work gives engineers,

analysts, and technicians a one-stop source on the wide variety of nonferrous alloys. With expanded coverage on both the industrial practice and the science of heat treating, this new handbook provides more practical information to guide processing requirements and the necessary background information for those without extensive prior knowledge.



Volume 5: Surface Engineering

1994 • 1056 pages
ISBN: 978-0-87170-384-2
Product Code: 06125G

Price: \$297 / ASM Member: \$225

Detailed information on surface cleaning, finishing and coating provided through published articles on testing of coatings and thin films, environmental concerns, and surface engineering of nonmetallic structural materials. Expanded analysis of advanced

processes such as chemical and physical vapor deposition and diffusion coatings. Continuous coatings, electroplating and finishing methods.



Volume 5A: Thermal Spray Technology

Edited by Robert C. Tucker, Jr.
2013 • 412 pages
ISBN: 978-1-61503-996-8
Product Code: 05348G

Price: \$297 / ASM Member: \$225

Co-published by the Thermal Spray Society and ASM International. Replaces the *Handbook of Thermal Spray Technology*, edited by J.R. Davis

(2004). Covers principles, processes, types of coatings, applications, performance, and testing/analysis. An excellent introduction and guidebook for those new to thermal spray.

Expanded selection of applications includes electronics and semiconductors, automotive, energy, and biomedical. Prominent thermal spray markets such as aerospace and industrial gas turbines, and areas of growth such as advanced thermal barrier materials are also reviewed.



THE ASM HANDBOOK VOLUME 4 SERIES Volumes 4A, 4B, 4C, 4D, 4E Heat Treating Set

SAVE
UP TO
\$150

ISBN: 978-1-62708-073-6
Product Code: 05451G

Price: \$1,335 / ASM Member: \$995

Stock your library and save by purchasing the complete 5-volume set.



Volume 5B: Protective Organic Coatings

Edited by Kenneth B. Tator
2015 • 545 pages
ISBN: 978-1-62708-081-1
Product Code: 05437G

Price: \$297 / ASM Member: \$225

This completely new volume addresses a need for comprehensive information on organic coatings, including coating materials, surface preparation,

application processes, industrial uses, and coating evaluation and analysis methods. This volume is essential for industrial coating users, specifiers, and contractors. The content in this volume has been written and reviewed by leading industry experts, making this latest ASM Handbook the definitive resource on this important topic. Plus, Volume 5B is the first volume in the ASM Handbook series to be printed in full color.

Volume 6: Welding, Brazing and Soldering

Edited by D.L. Olson, T.A. Siewert, S. Liu, and G.R. Edwards

1993 • 1299 pages

ISBN: 978-0-87170-382-8
Product Code: 06480G

Price: \$297 / ASM Member: \$225

Practical advice on consumable selection and procedure development, as well as joining fundamentals, processes, assemblies and selection. More than 500 illustrations and 400 tables.



Volume 6A: Welding Fundamentals and Processes

Edited by T. Lienert, T. Siewert, S. Babu, and V. Acoff
2011 • 936 pages
ISBN: 978-1-61503-133-7
Product Code: 05264G

Price: \$297 / ASM Member: \$225

A focused revision of the welding process information in Volume 6: *Welding, Brazing and Soldering* (1993). Updated and expanded articles on the fundamental principles of welding, including heat transfer, solidification, residual stress, and distortion. Workhorse methods of arc and resistance welding, friction stir welding, laser beam welding, explosive welding, and ultrasonic welding.



Brazing Handbook Fifth Edition

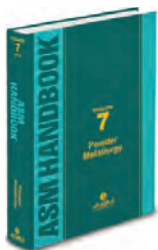
American Welding Society
2007 • 704 pages
ISBN: 0-87171-046-8
Product Code: 05336G

Price: \$144 / ASM Member: \$115

By agreement between the American Welding Society C3 Committee on Brazing and Soldering and the ASM Handbook Committee, the AWS

Brazing Handbook has been formally adopted as part of the ASM Handbook series, and is significantly updated and expanded.

A comprehensive, organized survey of the basics of brazing, processes, and applications. Fundamentals of brazing, brazement design, brazing filler metals and fluxes, safety, and health. New chapters on induction and diamond brazing.



Volume 7: Powder Metallurgy

Edited by Prasan K. Samal and Joseph W. Newkirk
2015 • 907 pages
ISBN: 978-1-62708-089-3
Product Code: 05438G

Price: \$297 / ASM Member: \$225

The updated and revised volume covers all aspects of powder metallurgy – including powder production and characterization, powder compaction, sintering, and compaction methods – and features new coverage of metal injection molding. Extensive coverage is provided of ferrous and nonferrous powder metallurgy materials. The new handbook format simplifies understanding of process and property relationships by treating each metal/alloy family in individual divisions.

Volume 8: Mechanical Testing and Evaluation

Edited by H. Kuhn and D. Medlin
2000 • 998 pages
ISBN: 978-0-87170-389-7
Product Code: 06772G

Price: \$297 / ASM Member: \$225

Mechanical properties and testing of metals, plastics, ceramics, and composites. Comparative mechanical properties and characteristics of materials included throughout. References to ISO, ASTM, DIN, EN, JIS and other standards.



Volume 9: Metallography and Microstructures

Edited by G.F. Vander Voort
2004 • 1184 pages
ISBN: 978-0-87170-706-2
Product Code: 06044G

Price: \$297 / ASM Member: \$225

**BEST
SELLER**

Recommended for anyone who specifies, performs, monitors, evaluates, or uses metallurgical analysis for production QC, research, or educational training. Important updates reflecting the substantial changes in automation, equipment, consumable products and preparation methodology, as well as new metals, alloys and manufacturing technologies that have emerged since 1985.

Volume 10: Materials Characterization

1986 • 761 pages
ISBN: 978-0-87170-016-2
Product Code: 06358G

Price: \$297 / ASM Member: \$225

An easy-to-understand reference on modern analytical techniques. More than 950 illustrations and 95 tables emphasize the practical rather than theoretical. Most common applications and limitations of each method.



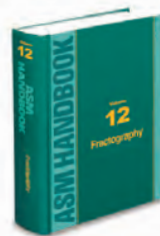
Volume 11: Failure Analysis and Prevention

Edited by R.J. Shipley and W.T. Becker
2002 • 1164 pages
ISBN: 978-0-87170-704-8
Product Code: 06072G

Price: \$297 / ASM Member: \$225

**BEST
SELLER**

General engineering aspects of failure prevention and fundamental root causes, materials selection, and role of design reviews. Features failures related to metals manufacturing operations and the increasingly important role of life assessment methods in failure prevention. Learn the failure analysis process, principles, practices, tools, and techniques used to perform and evaluate failure analysis work and the causes, mechanisms, appearances, and prevention methodology for the four classic types of failure.



Volume 12: Fractography

1987 • 517 pages
ISBN: 978-0-87170-018-6
Product Code: 06365G

Price: \$297 / ASM Member: \$225

Over 1900 illustrations and fractographs, along with 41 tables, provide engineers with enhanced capability for recognizing and interpreting the various features of a fracture. Supplemental illustrations of failed metal-matrix composites, resin-matrix composites, polymers, and electronic materials.

**SAVE
UP TO
\$104**

SET SALE!

Volumes 13A, 13B & 13C
Product Code: 05194G
Price: \$787 / ASM Member: \$595

Three-volume update of the landmark 1987 Metals Handbook volume on corrosion.



Volume 13A: Corrosion: Fundamentals, Testing, and Protection

Edited by Stephen D. Cramer and Bernard S. Covino, Jr.
2003 • 1135 pages
ISBN: 978-0-87170-705-5
Product Code: 06494G

Price: \$297 / ASM Member: \$225

Every article from the 1987 edition has been reviewed, revised, expanded, and updated. Six major sections: Fundamentals of Corrosion, Forms of Corrosion, Corrosion Testing and Evaluation, Methods of Corrosion Protection, Designing for Corrosion Control, and Prevention Tools for the Corrosionist.



Volume 13B: Corrosion: Materials

Edited by Stephen D. Cramer and Bernard S. Covino, Jr.
2005 • 703 pages
ISBN: 978-0-87170-707-9
Product Code: 06508G

Price: \$297 / ASM Member: \$225

48 peer-reviewed articles on how ferrous metals, nonferrous metals, and nonmetals are affected by various elements. Covers: processed materials, including thermal spray coatings, electroplated materials, and clad metals; special products, such as amorphous materials, intermetallics, and metal matrix composites; and nonmetallics, including ceramics, concrete, coatings, composites, and elastomers. Features article on global cost of corrosion and full-color gallery of corrosion damage.



Volume 13C: Corrosion: Environments and Industries

Edited by Stephen D. Cramer and Bernard S. Covino, Jr.
2006 • 1168 pages
ISBN: 978-0-87170-709-3
Product Code: 05145G

Price: \$297 / ASM Member: \$225

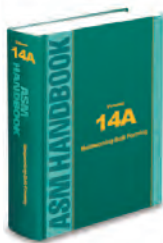
How corrosion impacts segments of the world economy – by environment and by industry sector. Provides answers to corrosion problems affecting your industry and ways to address corrosion issues in the environments that your equipment experiences. Over 250 leading authorities have written or reviewed articles in this volume.

SAVE
UP TO
\$87

SET SALE!

Volumes 14A and 14B
Product Code: 05193G

Price \$507 / ASM Member: \$405



Volume 14A: Metalworking Bulk Forming

Edited by S.L. Semiatin

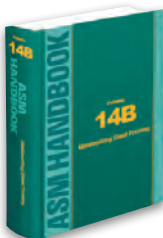
2005 • 888 pages

ISBN: 978-0-87170-708-6

Product Code: 06957G

Price: \$297 / ASM Member: \$225

For manufacturing, materials, and design engineers. Covers the process-design relationships needed to select and control metalworking operations that produce shapes from forging, extrusion, drawing, and rolling methods.



Volume 14B: Metalworking Sheet Forming

Edited by S.L. Semiatin

2006 • 940 pages

ISBN: 978-0-87170-710-9

Product Code: 05120G

Price: \$297 / ASM Member: \$225

For product and production engineers. Methods of sheet metal fabrication technologies, selection of equipment and die materials, specification of forming practices for specific alloys, and new techniques for process design and control.



Volume 15: Casting

S. Viswanathan, Editorial Chair; D. Apelian, R. DasGupta, M. Gwyn, J.L. Jorstad, R.W. Monroe, T.E. Prucha, M. Sahoo, E.S. Szekeres, and D. Twarog

2008 • 1256 pages

ISBN: 978-0-87170-711-6

Product Code: 05115G

Price: \$297 / ASM Member: \$225

Molten metal processing, solidification behavior, modeling, molding, foundry practice, and casting properties. Basic steps and

equipment are described for casting processes, along with their advantages, limitations, and applications.



Volume 16: Machining

1989 • 944 pages

ISBN: 978-0-87170-022-3

Product Code: 06022G

Price: \$297 / ASM Member: \$225

1300 illustrations and 620 tables provide detailed descriptions of various machining and grinding processes. Guidelines for proper selection of cutting tool materials and cutting fluids.



Volume 17: Nondestructive Evaluation of Materials

Edited by Aquil Ahmad and Leonard J. Bond

2018 • Approx. 700 pages

ISBN: 978-1-62708-152-8

Product Code: 05511G

Price: ~~\$297~~ / ASM Member: ~~\$225~~

Prepublication Price: \$267 / ASM Member \$205

Prepublication price good through June 30, 2018!

ASM Handbook, Volume 17 helps readers select, use, and interpret methods used to nondestructively test and analyze engineered products and assemblies. Digital technology is transforming the implementation of NDE and is covered extensively. New case studies and examples illustrate specific NDE techniques and

give new insights which are needed to provide the data needed to solve many real-world NDE problems, to understand and measure early degradation, and to give the required data for remaining safe life or prognostic prediction.



Volume 18: Friction, Lubrication, and Wear Technology

Edited by George E. Totten

2017 • 1108 pages

ISBN: 978-1-62708-141-2

Product Code: 05510G

Price: \$297 / ASM Member: \$225

The 2017 edition of this volume is a comprehensive, up-to-date resource on surface engineering, lubrication, design, and materials selection strategies to improve the reliability and operational life of components. Engineers, researchers, analysts, materials scientists, and students will find in-depth practical insights, development trends, and solutions for improved engineering performance through informed materials selection, lubrication use, design, operation, and employment of surface treatments and coatings.



Volume 19: Fatigue and Fracture

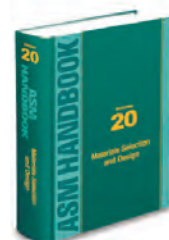
1996 • 1057 pages

ISBN: 978-0-87170-385-9

Product Code: 06197G

Price: \$297 / ASM Member: \$225

Especially valuable in evaluating test data and knowing the key variables that affect results. Gain a better understanding of fracture mechanics to aid in life assessment and life extension of components.



Volume 20: Materials Selection and Design

Edited by G.E. Dieter

1997 • 901 pages

ISBN: 978-0-87170-386-6

Product Code: 06481G

Price: \$297 / ASM Member: \$225

Contributions from more than 100 experts involved with design, materials selection, and manufacturing. Covers metals, ceramics, polymers, and composites and provides case histories and examples.



Volume 21: Composites

Edited by D.B. Miracle and S.L. Donaldson

2001 • 1201 pages

ISBN: 978-0-87170-703-1

Product Code: 06781G

Price: \$297 / ASM Member: \$225

A completely revised and updated version of the Engineered Materials Handbook. Contributions from more than 300 experts representing industry, academia, and research cover the capabilities and applications of all commercially significant types of composite materials.

SAVE
UP TO
\$87

SET SALE!

Volumes 22A & 22B Modeling 2-Volume Set
Product Code: 05320G
Price: \$507 / ASM Member: \$405



Volume 22A: Fundamentals of Modeling for Metals Processing

Edited by David Furrer and Lee Semiatin

2009 • 748 pages

ISBN: 978-0-61503-001-9

Product Code: 05215G

Price: \$297 / ASM Member: \$225

Development of metallic materials and process models that affect nearly every manufacturing industry. A solid foundation of the underlying physics that support many industrial simulation software packages.



Volume 22B: Metals Process Simulation

Edited by David Furrer and Lee Semiatin

2010 • 724 pages

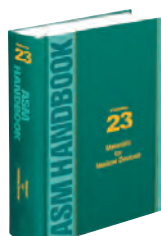
ISBN: 978-0-61503-005-7

Product Code: 05281G

Price: \$297 / ASM Member: \$225

Fundamentals include input data, thermophysical properties and their measurement, phase diagrams, and microstructure. Processes include solidification,

casting, metal forming, machining, joining, and heat treatment. Design topics include design optimization, error propagation and uncertainty, and cost estimating.



Volume 23: Materials for Medical Devices

Edited by Roger Narayan

2012 • 396 pages

ISBN: 978-1-61503-827-5

Product Code: 05285G

Price: \$297 / ASM Member: \$225

Implant materials covered include stainless steels, cobalt-base alloys, titanium, shape memory alloys,

noble metals, ceramics, and polymers. Sections on failure analysis, biotribology and implant wear, corrosion, and biocompatibility.

ASM Handbooks Online™

Gain instant access everywhere, anytime

Access the full content of the ASM Handbooks from your desktop. Find the information you need with a few clicks. Updated quarterly.

Explore the database at:

products.asminternational.org/hbk



ASM Handbook Complete Set

Save up to \$1095!

35 Volumes

ISBN: 978-1-62708-026-2

Product Code: 06951G

Price: \$9300 / ASM Member: \$6975

The ASM Handbook® series contains peer-reviewed, trusted information in every area of materials specialization. The series is the industry's best known and most comprehensive source of information on ferrous and nonferrous metals and materials technology and is packed with over 35,000 pages of articles, illustrations, tables, graphs, specifications and practical examples for today's engineer.

ASM Handbook Complete Print Library

Product Code: 05171G

Price: \$11,500 / ASM Member: \$8600

The easiest and most cost-effective way to build a comprehensive materials library!

Includes:

- ASM Handbook Volumes 1-23
- Engineered Materials Handbook 3-Volume Set
- ASM Desk Editions 2-Volume Set
- ASM Specialty Handbook 9-Volume Set



ASM Handbook Complete Set DVD 2017 Edition

2017 • ASM International

ISBN: 978-1-62708-140-5

Product Code: 05508V

Price: \$6300 / ASM Member: \$5800

Contains peer-reviewed, trusted information in every area of materials specialization. The current

set – 34 volumes, with more than 2,700 in-depth handbook articles, 35,289 pages – available on one disc! Search across the entire series or browse the table of contents for each volume. The content is presented in PDF format, with all of the standard Adobe Reader functions for navigation and finding content within articles. Use with any Windows® platform laptop or desktop PC with a DVD drive. Articles can be printed. Text, tables, and images can be copied and pasted.

Note: Disc files cannot be copied. DVD must be present in the local machine for content access. Purchasers of previous ASM Handbook CD or DVD Complete Sets can receive a special upgrade discount. Contact the ASM Member Service Center for details. Does not include Volume 1A, Volume 17 (2018 edition), or Volume 18 (2017 edition).



Metals Handbook® Desk Edition, 2nd Edition

Edited by J.R. Davis

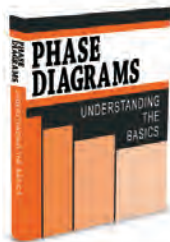
1998 • 1521 pages

ISBN: 978-0-87170-654-6

Product Code: 06542G

Price: \$307 / ASM Member: \$305

The best of the ASM Handbook® series. A convenient source on the properties, selection, processing, testing, and characterization of metals and their alloys.



Phase Diagrams: Understanding the Basics

Edited by F.C. Campbell

2012 • 470 pages

ISBN: 978-1-61503-835-0

Product Code: 05342G

Price: \$187 / ASM Member: \$135

Exceptionally well-written text for non-metallurgists or anyone seeking a quick refresher on an essential tool in modern metallurgy. Ample illustrations for all important liquid and solid reactions. Gas-metal reactions, important in metals processing and in-service corrosion, are also discussed.



Advances in Materials Technology for Fossil Power Plants

Proceedings from the Eighth International Conference

Edited by: J. Parker, J. Shingledecker and J. Siefert

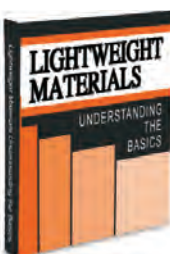
2016 • 1288 pages

ISBN: 978-1-62708-131-3

Product Code: 06839G

Price: \$187 / ASM Member: \$135

The eighth in a series of conferences on the subject of materials for advanced plants, held every three years by EPRI. Boiler, turbine, and balance-of-plant material issues are covered. Co-published by the Electric Power Research Institute (EPRI) and ASM International.



Lightweight Materials: Understanding the Basics

Edited by F.C. Campbell

2012 • 720 pages

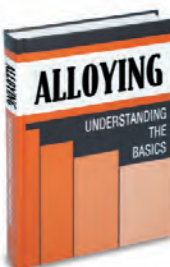
ISBN: 978-1-61503-849-7

Product Code: 05355G

Price: \$187 / ASM Member: \$135

Learn the basics of aluminum, titanium, magnesium, beryllium, engineering plastics, polymer-, metal-, and ceramic-matrix composites, and structural ceramics.

Includes basic metallurgy or materials science aspects of each material, as well as properties, processing, and applications. Guidelines for selecting materials for specific weight-critical applications.



Alloying: Understanding the Basics

Edited by J.R. Davis

2001 • 647 pages

ISBN: 978-0-87170-744-4

Product Code: 06117G

Price: \$187 / ASM Member: \$135

A complete guide to the influence of alloy additions on mechanical properties, physical properties, corrosion and chemical behavior, and processing and manufacturing characteristics.



MS&T 2016 CD

Published by MS&T Partner Societies

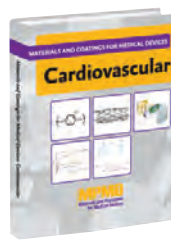
CD-ROM papers in PDF format

ISBN: 978-0-87339-764-3

Product Code: 05508A

Price: \$203 / ASM Member: \$152

Proceedings from the Materials Science and Technology 2016 Conference, Salt Lake City, UT, October 23-27, 2016.



Materials and Coatings for Medical Devices: Cardiovascular

2009 • 452 pages

ISBN: 978-1-61503-000-2

Product Code: 05269G

Price: \$307 / ASM Member: \$231

A unique volume of engineering property data with detailed biological response information, in a consistent data sheet format, for the materials and coatings for cardiovascular medical devices. The emphasis is on materials and coatings used in FDA-approved implantable devices.



SAVE
UP TO
\$67

SET SALE!

Worldwide Guide 2-Volume Set

Product Code: 05192G

Price: \$547 / ASM Member: \$405

Worldwide Guide to Equivalent Irons & Steels, 5th Edition

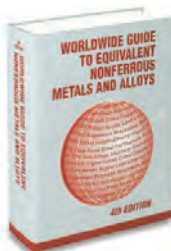
2006 • 1416 pages

ISBN: 978-0-87170-822-9

Product Code: 05121G

Price: \$307 / ASM Member: \$231

Standard worldwide designations for cast irons and steels, wrought carbon and alloy steels, plus stainless, high-strength, and tool steels. Entries for more than 30,000 alloy designations. Well over 5,000 entries have been updated and over 3,000 are new additions. Coverage for specifications and designations from Japan, China, India, and South Korea.



Worldwide Guide to Equivalent Nonferrous Metals and Alloys, 4th Edition

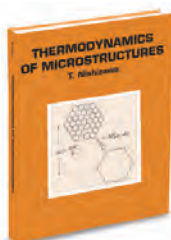
2001 • 1036 pages

ISBN: 978-0-87170-741-3

Product Code: 06735G

Price: \$307 / ASM Member: \$231

Over 20,000 alloy designations, including a complete listing of UNS designations. Includes comprehensive treatment of current European and Japanese standards.



Thermodynamics of Microstructures

By Taiji Nishizawa, translated by Kiyohito Ishida

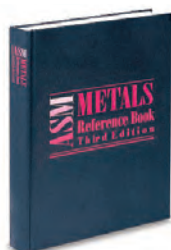
2008 • 308 pages

ISBN: 978-0-87170-716-1

Product Code: 05232G

Price: \$207 / ASM Member: \$155

Fundamental relationships governing the behavior of microstructures.



ASM Metals Reference Book, 3rd Edition

Edited by M.L. Baucio

1993 • 614 pages

ISBN: 978-0-87170-478-8

Product Code: 06118G

Price: \$167 / ASM Member: \$125

Chemical compositions, physical and mechanical properties, manufacturing processes, applications, pertinent specifications and standards, and test methods.



A "MUST-HAVE" READY REFERENCE ON METALLURGY!

Metallurgy for the Non-Metallurgist™ 2nd Edition

Edited by Arthur C. Reardon

2011 • 526 pages

ISBN: 978-1-61503-821-3

Product Code: 05306G

Price: \$177 / ASM Member: \$135

Provides a modern view of the basic principles and current practices of metallurgy. Recommended for anyone who uses, makes, buys or tests metal products. Answer all your basic metallurgy questions by using this updated reference featuring many new illustrations, examples, and descriptions.



Named as an "Outstanding Academic Title." - Choice: Current Reviews for Academic Libraries, January 2013

SEE METALLURGY FOR THE NON-METALLURGIST™ EDUCATION AND TRAINING COURSES ON PAGE 21.



Elements of Metallurgy and Engineering Alloys

Edited by F.C. Campbell

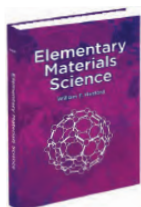
2008 • 672 pages

ISBN: 978-0-87170-867-0

Product Code: 05224G

Price: \$157 / ASM Member: \$115

A thorough presentation of physical and mechanical metallurgical concepts along with a practical survey of all important metals, their alloys, and their engineering properties. Covers basic metallurgy, metallic material selection, and application.



Elementary Materials Science

By William F. Hosford

2013 • 188 pages

ISBN: 978-1-62708-002-6

Product Code: 05373G

Price: \$83 / ASM Member: \$65

An introduction to the subject of materials science with few equations. Intended primarily for students with limited science backgrounds and non-technical professionals in the materials industry.



The History of Metals in America

By Charles R. Simcoe

Edited by Frances Richards

2018 • Approximately 300 pages

ISBN: 978-1-62708-145-0

Product Code: 05925G

Price: \$99 / ASM Member: \$75

Prepublication price: \$89 / ASM Member: \$67

Prepublication price good through April 30, 2018!

This book chronicles the development of metals as both an industrial activity and a science. Progress involving structural metals made possible the air, land, sea, and space travel of today, skyscrapers reaching over 100 stories high, and many other engineering accomplishments that continue to shape modern society. Journey through the evolution of metals and metallurgy from the first iron plant in 1645 to the prevailing metals of the 21st century. Charles R. Simcoe wrote more than 40 articles for ASM International's *Advanced Materials & Processes* magazine, including a monthly series entitled "Metallurgy Lane," which became the basis for this book.



Transformations: Selected Works of G.B. Olson on Materials, Microstructure, and Design

Edited by Carelyn E. Campbell, Michele V. Manuel, and Wei Xiong

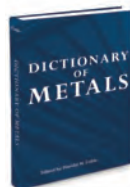
2017 • 547 pages

ISBN: 978-1-62708-137-5

Product Code: 06838G

Price: \$149 / ASM Member: \$129

ASM International and The Minerals, Metals and Materials Society (TMS) have collaborated to present a collection of the selected works of Dr. Greg B. Olson in honor of his 70th birthday in 2017. This collection highlights his influential contributions to the understanding of martensite transformations and the development and application of a systems design approach to materials.



Dictionary of Metals

Edited by Harold M. Cobb

2012 • 374 pages

ISBN: 978-1-61503-978-4

Product Code: 05359G

Price: \$157 / ASM Member: \$115

Includes historical overview beginning with the seven metals of antiquity. Showcases each metallic element, the discoverer and date, naming and its meaning, major applications, significance of the discovery and physical properties.

FAILURE ANALYSIS



How to Organize and Run a Failure Investigation

By Daniel P. Dennies

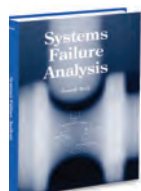
2005 • 223 pages

ISBN: 978-0-87170-811-3

Product Code: 05118G

Price: \$167 / ASM Member: \$125

Outlines a proven, systematic approach to failure investigation. Explains the relationship between various failure sources and the organization and conduct of the investigation.



Systems Failure Analysis

By Joseph Berk

2009 • 214 pages

ISBN: 978-1-61503-012-5

Product Code: 05278G

Price: \$107 / ASM Member: \$75

Learn how to prevent complex systems failures. Written for engineers, quality assurance specialists, and purchasing personnel in organizations that produce or procure complex systems in the aerospace, defense, automotive, biomedical, electronic, and related industries.

**SAVE
UP TO
\$47**

SET SALE!

Handbook of Case Histories in Failure Analysis 2-Volume Set

Product Code: 06391G

Price: \$367 / ASM Member: \$275

Handbook of Case Histories in Failure Analysis Volume 1

Edited by K.A. Esakul

1992 • 504 pages, 115 case histories

ISBN: 978-0-87170-453-5 • Product Code: 06340G

Price: \$207 / ASM Member: \$155

Handbook of Case Histories in Failure Analysis Volume 2

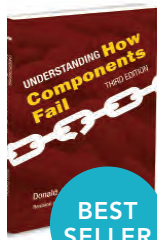
Edited by K.A. Esakul

1993 • 583 pages, 120 case histories

ISBN: 978-0-87170-495-5 • Product Code: 06410G

Price: \$207 / ASM Member: \$155

Learn how others have solved failures in various industries such as automotive, aerospace, utilities, oil and gas, petrochemical, biomedical, ground transportation, off-highway vehicles, and more.



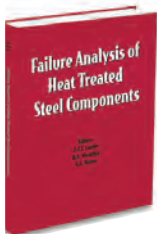
Understanding How Components Fail, 3rd Edition

By Donald J. Wolpi
Edited by Brett Miller

2013 • 310 pages
ISBN: 978-1-62708-014-9
Product Code: 05363G

Price: \$177 / ASM Member: \$135

This new edition of the classic best seller preserves the content from previous editions – focusing on the metallurgical and materials evaluation for failure mode identification. Basic principles and practices are clearly explained. This is one of the first books new engineers and technicians should read.



Failure Analysis of Heat Treated Steel Components

Edited by L.C.F. Canale, R.A. Mesquita
and G.E. Totten

2008 • 652 pages
ISBN: 978-0-87170-868-7
Product Code: 05113G

Price: \$207 / ASM Member \$155

Learn how to identify causes of failures, prevent future occurrences, and improve reliability. Numerous examples helpful to designers, engineers, metallurgists, mechanical and materials engineers, quality control technicians, and heat treaters. Special focus on the demands of tool steels and aerospace materials.

The Failure Analysis Society

This affiliate society is dedicated to advancing the important role failure analysis plays in the materials science industry. FAS provides collaboration, networking, and educational opportunities for materials science professionals.



Become a member today, visit:
www.asminternational.org/web/fas



Failure Investigation of Boiler Tubes: A Comprehensive Approach

By Paresh Haribhakti, P.B. Joshi, and Rajendra Kumar

2018 • Approximately 500 pages
ISBN: 978-1-62708-156-6
Product Code: 05243G

Price: \$220 / ASM Member: \$165

Prepublication price: \$199 / ASM Member: \$149
Prepublication price good through August 31, 2018!

Failures or forced shutdowns in power plants are often due to boilers, and particularly failure of boiler tubes. This book covers properties and selection of materials for boiler tubes, damage mechanisms responsible for failure of boiler tubes, and characterization techniques employed for investigating failures of boiler tubes in thermal power plants and utility boilers of industrial/commercial/institutional (ICI) boilers that lead to forced outages. A large number of case studies based on the actual failures from the field are described, along with photographs and microstructures to allow for easy comprehension of the theory behind the failures. The authors have long standing experience in the field of metallurgy and materials technology, failure investigation, remaining life assessment (RLA) and fitness for service (FFS) for industrial plant and equipment, including power plants.



Life Lessons of a Failure Analyst

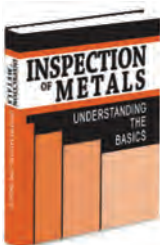
By McIntyre R. Louthan, Jr.

2016 • 202 pages
ISBN: 978-1-62708-110-8
Product Code: 05921G

Price: \$29 / ASM Member: \$22

This compilation of editorials written by popular instructor of the ASM course Metallurgy for the Non-Metallurgist™ and the former editor-in-chief of the *Journal of Failure Analysis and Prevention* is applicable to failure analysts and all others looking to achieve success in almost any career.

METALLOGRAPHY & MATERIALS CHARACTERIZATION



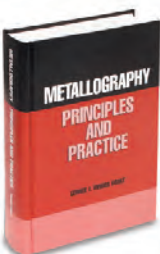
Inspection of Metals: Understanding the Basics

Edited by F.C. Campbell

2013 • 487 pages
ISBN: 978-1-62708-000-2
Product Code: 05372G

Price: \$187 / ASM Member: \$135

Emphasizes final part inspection at the manufacturing facility or on receipt at the user's facility. Provides an intermediate level overview to the different methods used to inspect metals and finished parts and a more detailed review of the specific inspection methods for important metal product forms. The advantages and limitations of each method are discussed, including when other methods may be warranted. Chapters on specific product forms (e.g., castings) compare the different inspection methods and why they are used.



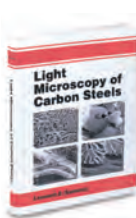
Metallography: Principles and Practice

By G. Vander Voort

1984 • 752 pages
ISBN: 978-0-87170-672-0
Product Code: 06785G

Price: \$177 / ASM Member: \$135

A proven reference work for metallographers, engineers, and technicians as well as students. Thoroughly referenced and well-illustrated with an extensive collection of micrographs and macrographs.



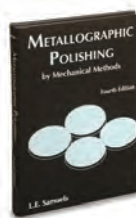
Light Microscopy of Carbon Steels

By L.E. Samuels

1999 • 502 pages
ISBN: 978-0-87170-655-3
Product Code: 06656G

Price: \$237 / ASM Member: \$175

"How to" book gives everyday working examples and discusses the relationship between the constitution, properties, and microstructure of various carbon steel products. Over 1,200 micrographs and 90 other figures.



Metallographic Polishing by Mechanical Methods, 4th Edition

By L.E. Samuels

2003 • 345 pages
ISBN: 978-0-87170-779-6
Product Code: 06964G

Price: \$157 / ASM Member: \$115



ALSO SEE

ASM Handbook, Volume 9: Metallography and Microstructures, page 3



Metallography of Steels: Interpretation of Structure and the Effects of Processing

By Hubertus Colpaert

Updated and translated by André Luiz V. da Costa e Silva

2018 • Approx. 700 pages

ISBN: 978-1-62708-148-1

Product Code: 05922G

Price: \$199 / ASM Member: \$149

Prepublication price: \$179 / ASM Member \$139

Prepublication price good through April 30, 2018!

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



Hardness Testing: Principles and Applications

Edited by Dr. Konrad Herrmann, et al.

2011 • 262 pages

ISBN: 978-1-61503-832-9

Product Code: 05331G

Price: \$157 / ASM Member: \$115

Hardness testing of metals, plastics, rubber and other materials. Technical developments such as the introduction of image processing in the Brinell and

Vickers method, the adaptation of hardness testing machines to process-oriented testing conditions, and the development of highly accurate and efficient calibration methods.



Optical Microscopy of Fiber-Reinforced Composites

By Brian S. Hayes and Luther M. Gammon

2010 • 284 pages

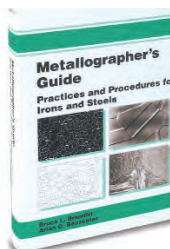
ISBN: 978-1-61503-044-6

Product Code: 05303G

Price: \$177 / ASM Member: \$135

Optical microscopy is one of the most valuable, but under-utilized, tools for analyzing fiber-reinforced polymer matrix composites. Hands-on book covers:

sample preparation, microscopic techniques, and applications. Over 180 full color images illustrate the technology's power to study the microstructure of heterogeneous, anisotropic materials.



Metallographer's Guide: Practices and Procedures for Irons and Steels

By B.L. Bramfitt and A.O. Benscoter

2002 • 354 pages

ISBN: 978-0-87170-748-2

Product Code: 06040G

Price: \$257 / ASM Member: \$185

Important metallurgical concepts related to the microstructures of irons and steels. More than 500 representative microstructures, and how they can be altered by heat treatment and other means.

The International Metallographic Society

Information, relationships, and services that advance the careers of professionals involved in the examination, analysis, characterization, structure, and evaluation of materials. Join ASM and be part of this exclusive affiliate society!

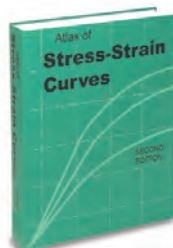


International Metallographic Society
ASM INTERNATIONAL

Become a member today.

Visit

ims.asmiinternational.org



Atlas of Stress-Strain Curves, 2nd Edition

2002 • 816 pages

ISBN: 978-0-87170-739-0

Product Code: 06825G

Price: \$307 / ASM Member: \$231

More than 1400 curves normalized in appearance to aid making comparisons among materials. All diagrams include metric (SI) units, and many also include U.S. customary units captioned with

standard designation, the primary source of the curve, mechanical properties, condition of sample, strain rate, test temperature, and alloy composition.



Tensile Testing, 2nd Edition

Edited by J.R. Davis

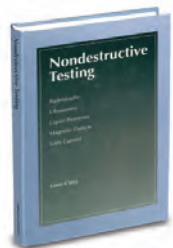
2004 • 283 pages

ISBN: 978-0-87170-806-9

Product Code: 05106G

Price: \$137 / ASM Member: \$105

A complete guide to the uniaxial tensile test, the cornerstone test for determining the mechanical properties of materials. Learn ways to predict material behavior through tensile testing, and how to test metals, alloys, composites, ceramics, and plastics to determine strength, ductility and elastic/plastic deformation.



Nondestructive Testing

By L. Cartz

1995 • 229 pages

ISBN: 978-0-87170-517-4

Product Code: 06390G

Price: \$107 / ASM Member: \$75

Problems and defects of all kinds arise in the development and use of mechanical devices, electrical equipment, hydraulic systems, and transportation mechanisms. However, an extremely

wide range of nondestructive testing (NDT) methods are available to help you examine these different problems and various defects in an assortment of materials under varying circumstances.



Metallographic Etching, 2nd Edition

By G. Petzow

1999 • 240 pages

ISBN: 978-0-87170-633-1

Product Code: 06670G

Price: \$127 / ASM Member: \$95

An outstanding source on etchants of all types and electrolytic polishing solutions used by metallographers to reveal the structure of nearly any material to be prepared and examined.

SAVE
UP TO
\$57

SET SALE!

Fatigue and Durability 2-Volume Set
Product Code: 05282G
Price: \$457 / ASM Member: \$375



Fatigue and Durability of Structural Materials

By S.S. Manson and G.R. Halford

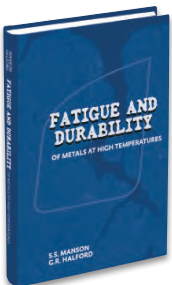
2006 • 456 pages

ISBN: 978-0-87170-825-0

Product Code: 06987G

Price: \$257 / ASM Member: \$185

Focuses on metallic materials but also addresses unique capabilities of important nonmetals.



Fatigue and Durability of Metals at High Temperatures

By S.S. Manson and G.R. Halford

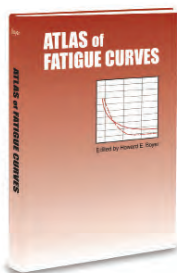
2009 • 268 pages

ISBN: 978-0-87170-718-5

Product Code: 05206G

Price: \$257 / ASM Member: \$185

Written by preeminent experts, this work gives development engineers, students, and component designers an important reference on how to analyze time-dependent metal fatigue at high temperatures.



Atlas of Fatigue Curves

Edited by H.E. Boyer

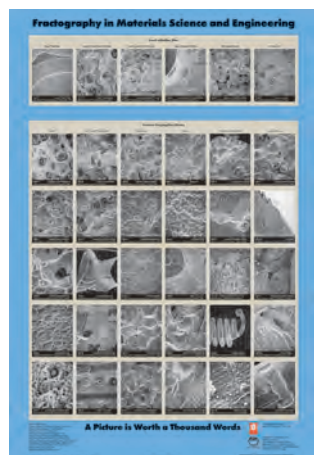
1986 • 518 pages • Illustrated

ISBN: 978-0-87170-214-2

Product Code: 06156G

Price: \$307 / ASM Member: \$231

More than 500 fatigue curves for industrial ferrous and nonferrous alloys. Standard S-N curves, curves showing effect of surface hardening on fatigue strength, crack growth-rate curves, curves comparing the fatigue strengths of various alloys, effect of temperature, humidity, frequency, aging, environment and more.



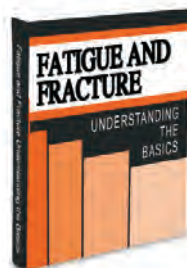
Fractography Poster

By Mohan D. Chaudhari

Product Code: 06568G

Price: \$49 / ASM Member: \$37

The ASM Fractography Poster is a ready reference of important surface-fracture appearances for crack initiation and propagation modes. The poster illustrates 36 common fracture modes with fractographs for several common structural steels, cast irons, superalloys, Ti-6Al-4V, copper alloys, and tungsten filament. It is designed to be a communication aid for engineers, students, and failure analysts when discussing product performance or failure modes. The poster is approximately 60 cm (2 ft) wide and 90 cm (3 ft) tall.



Fatigue and Fracture: Understanding the Basics

Edited by F.C. Campbell

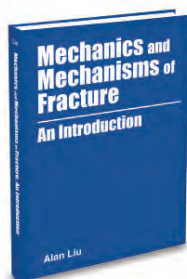
2012 • 698 pages

ISBN: 978-1-61503-976-0

Product Code: 05361G

Price: \$187 / ASM Member: \$135

Covers mechanical properties of materials, differences between ductile and brittle fractures, fracture mechanics, the basics of fatigue, structural joints, high temperature failures, wear, environmentally-induced failures, and steps in the failure analysis process. Chapters devoted to fatigue and fracture of steels, aluminum alloys, titanium and titanium alloys, ceramics, polymers, and continuous fiber polymer matrix composites.



Mechanics and Mechanisms of Fracture: An Introduction

By A.F. Liu

2005 • 458 pages

"Recommended." - *Choice: Current Reviews for Academic Libraries*, June 2006

ISBN: 978-0-87170-802-1

Product Code: 06954G

Price: \$167 / ASM Member: \$125

Fundamental and practical concepts of fracture are described in terms of stress analysis and the mechanical behavior of materials.



Fatigue and Fracture Reference Library DVD 2012 Edition

2012 • ASM International

ISBN: 978-1-61503-981-4

Product Code: 05366V

Price: \$703 / ASM Member: \$601

The most comprehensive collection of fatigue and fracture technical information and data ever assembled on one disc—more than 10,000 pages in all!

A complete guide to the fatigue and fracture behavior of irons, steels, nonferrous alloys, and composites. Fundamentals, fatigue mechanisms, fatigue strength, fracture mechanics, fatigue and fracture control, and much more.

DVD can be used with any Windows platform laptop or desktop computer with a DVD drive. Articles can be printed, and text, tables, and images can be copied and pasted. Note: The files on the disc cannot be copied, so the DVD must be present in the local machine for the content to be accessed.

Become a part of ASM's Shape Memory and Superelastic Technologies

Share ideas, connect with industry leaders, and build a lifelong professional network. All are welcome to join and to help this industry grow.

Become a member today: smst.asminternational.org





Hot Working Guide: A Compendium of Processing Maps, Second Edition

Edited by Y.V.R.K. Prasad, K.P. Rao, and S. Sasidhara

2015 • 628 pages

ISBN: 978-1-62708-091-0

Product Code: 05445G

Price: \$265 / ASM Member: \$199

This is a unique source book with flow stress data for hot working, processing maps with metallurgical interpretation and optimum processing conditions for metals, alloys, intermetallics, and metal matrix composites. In the second edition, significant additions of maps on stainless steels, magnesium alloys, titanium alloys and nickel alloys have been made.

SAVE
UP TO
\$87

SET SALE!

Sheet Metal Forming: 2-Volume Set

Product Code: 05351G

Price: \$327 / ASM Member: \$245



Sheet Metal Forming: Fundamentals

Edited by Taylan Altan and A. Erman Tekkaya

2012 • 314 pages

ISBN: 978-1-61503-842-8

Product Code: 05340G

Price: \$207 / ASM Member \$155

Principal variables of sheet forming – including interactions between variables – are clearly explained, as a basic foundation for the most effective use of computer aided modeling in process and die design.



Sheet Metal Forming: Processes and Applications

Edited by Taylan Altan and A. Erman Tekkaya

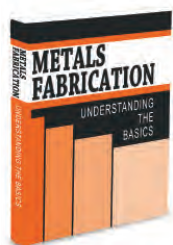
2012 • 382 pages

ISBN: 978-1-61503-844-2

Product Code: 05350G

Price: \$207 / ASM Member: \$155

The latest developments on the design of sheet forming operations, equipment, tooling, and process modeling.



Metals Fabrication: Understanding the Basics

By F.C. Campbell

2013 • 439 pages

ISBN: 978-1-62708-018-7

Product Code: 05374G

Price: \$187 / ASM Member: \$135

This book can be read and understood by anyone with a technical background. It is especially useful to those who deal with metals including designers,

mechanical engineers, civil engineers, structural engineers, material and process engineers, manufacturing engineers, faculty, and materials science students. This volume covers the basics of metal fabrication, delving deep into the technology of metals fabrication.



Extrusion, 2nd Edition

Edited by M. Bauser, G. Sauer, and K. Siegert

2006 • 608 pages

ISBN: 978-0-87170-837-3

Product Code: 06998G

Price: \$257 / ASM Member: \$185

Newest edition. Overview of extrusion processes, equipment, and tooling. Metallurgical fundamentals of extrusion are covered in detail.



Cold and Hot Forging: Fundamentals and Applications

Edited by T. Altan, G. Ngaile and G. Shen

2005 • 341 pages

ISBN: 978-0-87170-805-2

Product Code: 05104G

Price: \$207 / ASM Member: \$155

Fundamentals of forging technology, principal variables of the forging process and their interactions, and computer-aided techniques such as finite-element analysis (FEA) for forging process and tooling design.

ASM Specialty Handbook® Tool Materials

Edited by J.R. Davis

1995 • 501 pages

ISBN: 978-0-87170-545-7

Product Code: 06506G

Price: \$307 / ASM Member: \$231



Casting Design and Performance

2009 • 272 pages

ISBN: 978-0-87170-724-6

Product Code: 05263G

Price: \$197 / ASM Member: \$145

For designers, manufacturing engineers, and purchasing personnel who specify and evaluate metal castings. General design principles with in-depth coverage on important design configurations of cast components, casting design influences in casting solidification and properties. Dynamic properties are described in detail for cast iron, steel, and aluminum.



Gear Materials, Properties, and Manufacture

Edited by J.R. Davis

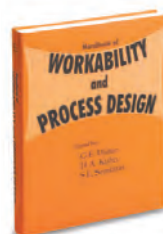
2005 • 339 pages

ISBN: 978-0-87170-815-1

Product Code: 05125G

Price: \$187 / ASM Member: \$135

Overview of gears, lubrication and wear; in-depth treatment of metallic alloys (ferrous and nonferrous) and plastic gear materials; gear manufacturing methods (including metal removal, casting, forming, and forging); heat treatment; and failure analysis, fatigue life prediction and mechanical testing.



Handbook of Workability and Process Design

Edited by G.E. Dieter, H.A. Kuhn, and S.L. Semiatin

2003 • 414 pages

ISBN: 978-0-87170-778-9

Product Code: 06701G

Price: \$247 / ASM Member: \$185



Advanced High-Strength Steels: Science, Technology and Applications

By Mahmoud Y. Demeri

2013 • 312 pages

ISBN: 978-1-62708-005-7

Product Code: 05370G

Price: \$167 / ASM Member: \$125

A comprehensive examination of the types, microstructures, and attributes of AHSS as well as a review of current and future applications, the benefits, trends, and environmental and sustainability issues.



Engineering Properties of Steel

Edited by Philip Harvey

1982 • 509 pages

ISBN: 978-0-87170-144-2

Product Code: 06241G

Price: \$157 / ASM Member: \$115

Extensive data on properties of more than 425 steels are presented in a ready-reference format that makes information easy to find.



Steel Metallurgy for the Non-Metallurgist

By John D. Verhoeven

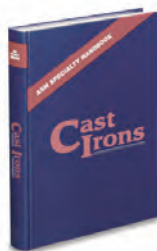
2007 • 225 pages

ISBN: 978-0-87170-858-8

Product Code: 05214G

Price: \$107 / ASM Member: \$75

A practical primer on steel metallurgy for those who select, heat, forge, or machine steel.



ASM Specialty Handbook® Cast Irons

Edited by J.R. Davis

1996 • 494 pages

ISBN: 978-0-87170-564-8

Product Code: 06613G

Price: \$307 / ASM Member: \$231

Basic information on metallurgy, solidification characteristics, and properties, as well as extensive reviews on the low-alloy gray, ductile, compacted graphite, and malleable irons.



Steels: Processing, Structure, and Performance, 2nd Edition

By George Krauss

2015 • 682 pages

ISBN: 978-1-62708-083-5

Product Code: 05441G

Price: \$207 / ASM Member: \$155

This is the essential information resource for anyone who makes, uses, studies, or designs with steel. The expanded and updated Second Edition emphasizes processing, alloying, microstructure, deformation, fracture, and properties of major steel types ranging from low-carbon sheet steels, pearlitic rail and wire steels, to quench and tempered medium- and high-carbon martensitic steels. Microstructural aspects of steelmaking, hardenability, tempering, surface hardening, and embrittlement phenomena have been updated.



Stainless Steels for Design Engineers

By Michael F. McGuire

2008 • 312 pages

ISBN: 978-0-87170-717-8

Product Code: 05231G

Price: \$187 / ASM Member: \$135

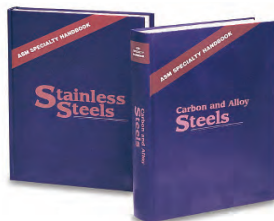
Addresses selection for corrosion resistance, processing, and major applications.

SAVE
UP TO
\$67

SET SALE!

ASM Specialty Handbook® Steels, 2-Volume Set
Product Code: 06491G

Price: \$547 / ASM Member: \$405



ASM Specialty Handbook® Stainless Steels

Edited by J.R. Davis

1994 • 576 pages

ISBN: 978-0-87170-503-7

Product Code: 06398G

Price: \$307 / ASM Member: \$231

Hundreds of figures and tables. Your single resource for stainless information.

ASM Specialty Handbook® Carbon and Alloy Steels

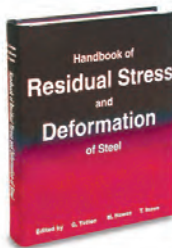
Edited by J.R. Davis

1996 • 731 pages

ISBN: 978-0-87170-557-0

Product Code: 06611G

Price: \$307 / ASM Member: \$231



Handbook of Residual Stress and Deformation of Steel

Edited by G. Totten, M. Howes, and T. Inoue

2002 • 499 pages

ISBN: 978-0-87170-729-1

Product Code: 06700G

Price: \$167 / ASM Member: \$125

Recommended heat treating practices, methods for maintaining temperature uniformity during heating, tips for preventing oxide formation, and techniques for measuring residual stresses.



FOR MORE DETAILS

Visit www.asminternational.org/referencepubs and explore all the offerings available.



Stahlschlüssel (Key To Steel) 2016 Edition

By Verlag Stahlschlüssel Wegst GmbH
2016 • 895 pages
ISBN: 978-3-922599-32-6
Product Code: 05512G
Price: \$249 / ASM Member: \$215

Decipher steel designations and find equivalent materials worldwide. More than 70,000 standard designations and trade names from approximately 300 steelmakers and suppliers. Covers structural steels, tool steels, valve steels, high temperature steels and alloys, stainless and heat-resisting steels, and more. Standards and designations from 25 countries are cross-referenced. Text in English, French, and German.



Stahlschlüssel (Key To Steel) CD-ROM 2016 Edition

By Verlag Stahlschlüssel Wegst GmbH
2016
ISBN: 978-3-922599-33-3
Product Code: 05512C
Price: \$689 / ASM Member: \$605

(Single User Network Installation)

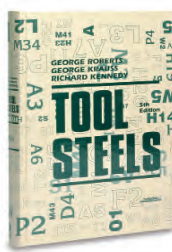
The CD version offers flexible and powerful capabilities, including the ability to search for steels by designation, chemical composition, and mechanical/physical properties.



Steel Castings Handbook, 6th Edition

Co-published by Steel Founders' Society of America and ASM International
1995 • 472 pages
ISBN: 978-0-87170-556-3
Product Code: 06820G
Price: \$233 / ASM Member: \$175

Purchase, design, and manufacture of castings (including casting and molding, heat treatment, and quality assurance), materials selection for mechanical and chemical properties, and materials selection for processing properties.

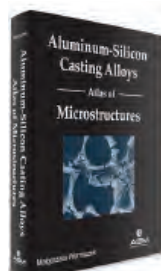


Tool Steels, 5th Edition

By G. Roberts, G. Krauss, and R. Kennedy
1998 • 364 pages
ISBN: 978-0-87170-599-0
Product Code: 06590G
Price: \$207 / ASM Member: \$155

Contains a significant amount of information from the past two decades presented in an easy-to-use outline format, making this a "must have" reference for engineers involved in tool-steel production, as well as in the selection and use of tool steels in metalworking and other materials manufacturing industries.

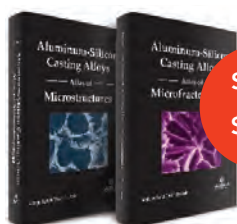
NONFERROUS METALS



Aluminum-Silicon Casting Alloys: Atlas of Microstructures

By Małgorzata Warmuzek
2016 • Approximately 186 pages
ISBN: 978-1-62708-108-5
Product Code: 05919G
Price: \$199 / ASM Member: \$149

This atlas provides engineers and researchers who work with aluminum castings with a practical and substantive tool for the visual analysis of the microscopic images of the microstructure of the aluminum casting alloys, as examined during routine laboratory procedures.



Aluminum-Silicon Casting Alloys: Atlas of Microstructures and Atlas of Microfractographs Set

By Małgorzata Warmuzek
Product Code: 05928G
Set Price: \$278 / ASM Member: \$213

SAVE
UP TO
\$49



Titanium: Physical Metallurgy, Processing, and Applications

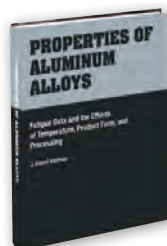
Edited by F.H. Froes
2015 • 404 pages
ISBN: 978-1-62709-079-8
Product Code: 05448G
Price: \$187 / ASM Member: \$135

This book covers all aspects of the history, physical metallurgy, corrosion behavior, cost factors and current and potential uses of titanium. Extensive detail on extraction processes is discussed, as well as the various beta to alpha transformations and details of the powder metallurgy techniques.

SAVE
UP TO
\$57

SET SALE!

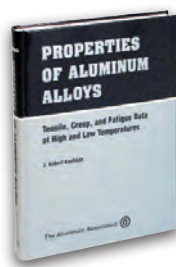
Properties of Aluminum 2-Volume Set
Product Code: 05250G
Price: \$457 / ASM Member: \$335



Properties of Aluminum Alloys: Fatigue Data and the Effects of Temperature, Product Form, and Processing

Edited by J.G. Kaufman
2008 • 574 pages
ISBN: 978-0-87170-839-7
Product code: 05156G
Price: \$257 / ASM Member: \$195

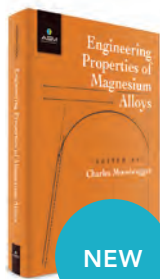
One of the most comprehensive collections of fatigue data yet available for aluminum alloys, temperatures, and products. The data, including over 1000 curves and numerous tables, are presented in a consistent format, conveniently arranged by alloy and temper.



Properties of Aluminum Alloys: Tensile, Creep, and Fatigue Data at High and Low Temperatures

Edited by J.G. Kaufman
1999 • 311 pages
ISBN: 978-0-87170-632-4
Product code: 06813G
Price: \$257 / ASM Member: \$195
Co-published by the Aluminum Association and ASM International.

TO ORDER, VISIT WWW.ASMINTERNATIONAL.ORG/REFERENCEPUBS OR CALL 800.336.5152, EXT. 0



Engineering Properties of Magnesium Alloys

Edited by Charles Moosbrugger

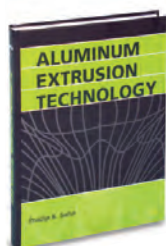
2017 • 184 pages

ISBN: 978-1-62708-143-6

Product Code: 05920G

Price: \$199 / ASM Member: \$149

Written for engineers, scientists, teachers, and students engaged in the design process of material selection and material elimination. While focused on mechanical properties for structural design, the physical properties that are germane to corrosion behavior and electrical applications are represented. Datasheets for individual magnesium alloys provide a handy quick reference to specific properties and performance. Topics such as the alloy designation system and product forms are addressed.



Aluminum Extrusion Technology

By P.K. Saha

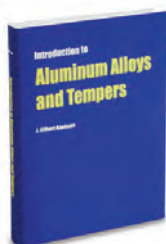
2000 • 259 pages

ISBN: 978-0-87170-644-7

Product Code: 06826G

Price: \$207 / ASM Member: \$165

Practical information and reviews of important theoretical concepts in the different areas of extrusion technology. Intended for technical and engineering personnel, as well as research students in manufacturing.



Introduction to Aluminum Alloys and Tempers

By J.G. Kaufman

2000 • 258 pages

ISBN: 978-0-87170-689-8

Product Code: 06180G

Price: \$43 / ASM Member: \$32

Advantages and limitations of aluminum alloys and temper combinations in terms of the relationship of their composition, process history, and microstructure to service requirements.



Aluminum: Properties and Physical Metallurgy

Edited by John E. Hatch

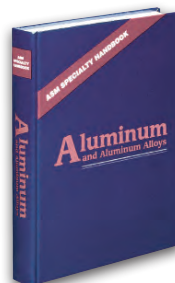
1984 • 424 pages

ISBN: 978-0-87170-176-3

Product Code: 06236G

Price: \$169 / ASM Member: \$125

A collective effort of 53 recognized experts on aluminum and aluminum alloys. This book is a joint venture by world-renowned authorities and the Aluminum Association Inc. and ASM International.



ASM Specialty Handbook® Aluminum and Aluminum Alloys

Edited by J.R. Davis

1993 • 784 pages

ISBN: 978-0-87170-496-2

Product Code: 06610G

Price: \$307 / ASM Member: \$231

Hundreds of illustrations, tables, and graphs. Emerging technologies, including aluminum metal-matrix composites, are combined with all the essential aluminum information from the ASM Handbook® series (with updated statistical information).



ASM Specialty Handbook® Copper and Copper Alloys

Edited by J.R. Davis

2001 • 652 pages

ISBN: 978-0-87170-726-0

Product Code: 06605G

Price: \$307 / ASM Member: \$231

Covers the selection and applications of copper and copper alloys. Includes all of the essential information contained in the ASM Handbook® series.

ASM Specialty Handbook® Heat-Resistant Materials

Edited by J.R. Davis

1997 • 591 pages • ISBN: 978-0-87170-596-9

Product Code: 06612G

Price: \$307 / ASM Member: \$231

ASM Specialty Handbook® Magnesium and Magnesium Alloys

Edited by M. Avedesian and H. Baker

1999 • 314 pages • ISBN: 978-0-87170-657-7

Product Code: 06770G

Price: \$307 / ASM Member: \$231

ASM Specialty Handbook® Nickel, Cobalt, and Their Alloys

Edited by J.R. Davis

2000 • 442 pages • ISBN: 978-0-87170-685-0

Product Code: 06178G

Price: \$307 / ASM Member: \$231



SET SALE!

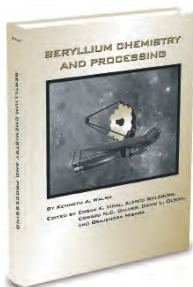
ASM Specialty Handbook 9-Volume Set

Product Code: 06697Z

Price: \$2490 / ASM Member: \$1865

Includes:

- Aluminum and Aluminum Alloys
- Cast Irons
- Carbon and Alloy Steels
- Copper and Copper Alloys
- Heat-Resistant Materials
- Magnesium and Magnesium Alloys
- Nickel, Cobalt, and Their Alloys
- Stainless Steels
- Tool Materials



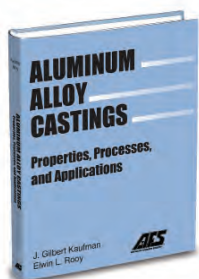
Beryllium Chemistry and Processing

By K.A. Walsh • Edited by E.E. Vidal, A. Goldberg, E. Dalder, D.L. Olson, and B. Mishra

2009 • 680 pages
ISBN: 978-0-87170-721-5
Product Code: 05223G

Price: \$257 / ASM Member: \$191

Beryllium compounds of industrial interest, alloying, casting, powder processing, forming, metal removal, joining, and other manufacturing processes are covered. Environmental degradation of beryllium and its alloys both in aqueous and high temperature condition, plus health and environmental issues.



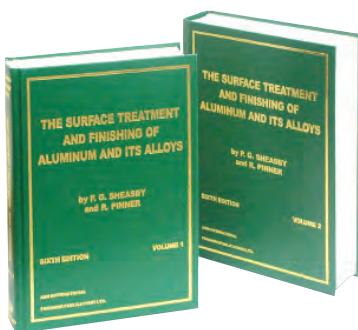
Aluminum Alloy Castings: Properties, Processes, and Applications

By J.G. Kaufman and E.L. Rooy

2004 • 340 pages
Co-published by ASM International and the American Foundry Society.
ISBN: 978-0-87170-803-8
Product Code: 05114G

Price: \$257 / ASM Member: \$185

Extensive collections of property and performance data, including aging response curves, growth curves, and fatigue curves.



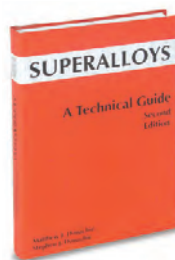
The Surface Treatment and Finishing of Aluminum and Its Alloys, (2 Volume Book + CD)

By P.G. Sheasby and R. Pinner

2001 • 1387 pages
Co-published by Finishing Publications Ltd. and ASM International
Vol. 1 ISBN: 978-0-90447-721-4
Vol. 2 ISBN: 978-0-90447-722-1
CD ISBN: 978-0-90447-723-8
Product Code: 06945G

Price: \$477 / ASM Member: \$405

A comprehensive review and guide to surface engineering – cleaning, finishing, and coating – of aluminum and its alloys. Covers anodizing and coloring treatments. Two-volume set, including CD.



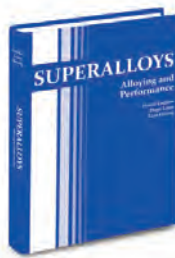
Superalloys: A Technical Guide, 2nd Edition

By M.J. Donachie and S.J. Donachie

2002 • 439 pages
ISBN: 978-0-87170-749-9
Product Code: 06128G

Price: \$207 / ASM Member: \$155

Covers virtually all technical aspects related to the selection, processing, use, and analysis of superalloys.



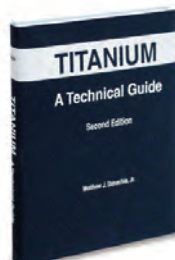
Superalloys: Alloying and Performance

Blaine Geddes, Hugo Leon, and Xiao Huang

2010 • 176 pages
ISBN: 978-1-61503-040-8
Product Code: 05300G

Price: \$107 / ASM Member: \$75

An introduction for understanding the compositional complexity of superalloys and the wide range of alloys developed for specific applications. The basics of alloying, strengthening mechanisms, and structure of superalloys are explained in optimizing particular mechanical properties, oxidation/ corrosion resistance, and manufacturing characteristics such as castability, forgeability, and weldability.



Titanium: A Technical Guide, Second Edition

By M.J. Donachie, Jr.

2000 • 381 pages
ISBN: 978-0-87170-686-7
Product Code: 06112G

Price: \$207 / ASM Member: \$155

Significant features of the metallurgy and application of titanium and its alloys.



Materials Properties Handbook: Titanium Alloys

Edited by R. Boyer, E.W. Collings, and G. Welsch

1994 • 1169 pages
ISBN: 978-0-87170-481-8
Product Code: 06005G

Price: \$357 / ASM Member: \$265

The most comprehensive titanium data package ever assembled. Information on applications, physical properties, corrosion, mechanical properties, fatigue, fracture properties, and elevated temperature properties.



SET SALE!

Principles of Brazing and Principles of Soldering

Product Code: 05124G

Price: \$287 / ASM Member: \$215

Principles of Brazing

By David M. Jacobson and Giles Humpston

2005 • 268 pages

ISBN: 978-0-87170-812-0

Product Code: 05123G

Price: \$167 / ASM Member: \$125

Compares joining methods, explains the fundamental parameters of brazes, and surveys the metallurgy of braze alloy systems.

Principles of Soldering

By Giles Humpston and David M. Jacobson

2004 • 271 pages

ISBN: 978-0-87170-792-5

Product Code: 06244G

Price: \$167 / ASM Member: \$125

The fundamental characteristics of solders, fluxes, and joining environments and the impact these have in the selection and successful use of soldering.



Brazing, 2nd Edition

By M.M. Schwartz

2003 • 421 pages

ISBN: 978-0-87170-784-0

Product Code: 06955G

Price: \$157 / ASM Member: \$115

This popular book answers practical questions that arise in the application and use of brazing technology. A current and comprehensive resource on brazing fundamentals.



Weld Integrity and Performance

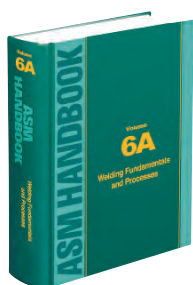
1997 • 417 pages

ISBN: 978-0-87170-600-3

Product Code: 06593G

Price: \$207 / ASM Member: \$155

For welding engineers, welders, metallurgists, and materials science engineers involved with the application, fabrication, and assessment of welded structures. Selected articles are compiled from various ASM International publications that deal with structural welds involving important ferrous and nonferrous engineering metals and alloys.



Volume 6A: Welding Fundamentals and Processes

Edited by T. Lienert, T. Siewert, S. Babu, and V. Acoff

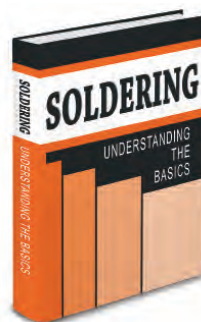
2011 • 936 pages

ISBN: 978-1-61503-133-7

Product Code: 05264G

Price: \$297 / ASM Member: \$225

A focused revision of the welding process information in Volume 6: *Welding, Brazing and Soldering* (1993). Updated and expanded articles on the fundamental principles of welding, including heat transfer, solidification, residual stress, and distortion. Workhorse methods of arc and resistance welding, friction stir welding, laser beam welding, explosive welding, and ultrasonic welding.



Soldering: Understanding the Basics

By M.M. Schwartz

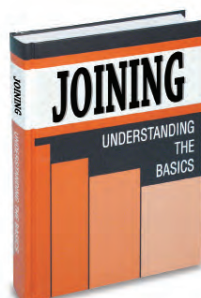
2014 • 184 pages

ISBN: 978-1-62708-058-3

Product Code: 05338G

Price: \$187 / ASM Member: \$135

Covers various soldering methods and techniques as well as the latest on solder alloys, solder films, surface preparation, fluxes and cleaning methods, heating methods, inspection techniques, and quality control and reliability.



Joining: Understanding the Basics

Edited by F.C. Campbell

2011 • 346 pages

ISBN: 978-1-61503-825-1

Product Code: 05329G

Price: \$187 / ASM Member: \$135

Extends ASM's Understanding the Basics series into fabrication technologies. An introduction to welding, brazing, soldering, fastening, and adhesive bonding. Addresses metallurgical issues that must be understood during welding, including joining systems of materials that are the same, similar, or different.



Vacuum Heat Treatment: Applications, Equipment, and Operation

By Daniel H. Herring • Publisher: BNP Media

2016 • 1076 pages
ISBN: 978-0-692-76738-2
Product Code: 75192G

Price: \$154.99 / ASM Member: \$139.49

This book provides a wide range of useful practical and technical information to help readers make better decisions about their equipment, process, and service needs.

Atmosphere Heat Treatment

By Daniel H. Herring • Publisher: BNP Media

Volume 1: Principles, Applications, Equipment

2014 • 700 pages
ISBN: 978-0-692-28393-6
Product Code: 75149G

Price: \$154.99 / ASM Member \$139.49

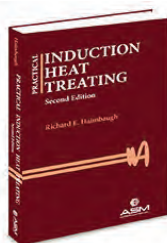
Volume 1 emphasizes fundamental principles, materials, metallurgy, applications, and equipment.

Volume 2: Atmospheres, Quenching, Testing

2015 • 824 pages
ISBN: 978-0-692-51299-9
Product Code: 75169G

Price: \$154.99 / ASM Member \$139.49

Volume 2 focuses on furnace atmospheres, quenching practices, testing, safety, conservation, maintenance, and specification compliance.



Practical Induction Heat Treating, Second Edition

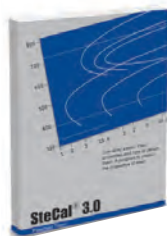
By R.E. Haimbaugh

2015 • 365 pages
ISBN: 978-1-62708-089-7
Product Code: 05505G

Price: \$207 / ASM Member: \$155

A quick reference source for induction heaters and ties in the metallurgy, theory, and practice of

induction heat treating from a hands-on explanation of what floor people need to know. Includes updated information on quenching methods, applications, inspection for quality control and material on power supplies.



SteCal® 3.0 (CD + Booklet)

By P. Tarin and J. Pérez

2004 • Microsoft Windows format
ISBN: 978-0-87170-796-3
Product Code: 07482A

Price: \$447 / ASM Member: \$335

Use for predicting the properties obtained from heat treating low-alloy steels. An excellent tool for heat treaters to use in estimating and refining heat treating

parameters for unfamiliar steels, or comparing the properties of two steels of different composition to arrive at the most appropriate composition for a particular application.



Heat Treatment of Gears: A Practical Guide for Engineers

By A.K. Rakshit

2000 • 209 pages
ISBN: 978-0-87170-694-2
Product Code: 06732G

Price: \$167 / ASM Member: \$125

Heat treat distortion of gears is discussed in detail for the major heat treat processes. A case history of each successful gear heat treat process is included.



SET SALE!

Atlas of Time-Temperature Diagrams, 2-Volume Set
Irons & Steels / Nonferrous Alloys
Product Code: 06191G
Price: \$547 / ASM Member: \$405

Atlas of Time-Temperature Diagrams

These two volumes comprise the most comprehensive collection of time-temperature diagrams. Each volume features commonly used curves as well as out-of-print and difficult-to-find data.

Irons & Steels

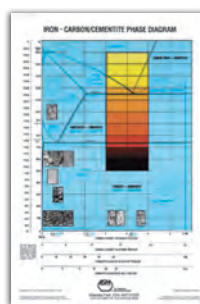
Edited by G. Vander Voort
1991 • 804 pages • 1839 diagrams
ISBN: 978-0-87170-415-3
Product Code: 06150G

Price: \$307 / ASM Member: \$231

Nonferrous Alloys

Edited by G. Vander Voort
1991 • 474 pages • 500 diagrams
ISBN: 978-0-87170-428-3
Product Code: 06190G

Price: \$307 / ASM Member: \$231



Heat Treater's Color Poster

Product Code: 06423G

Price: \$39 / ASM Member \$29

The iron-carbon (Fe-C) phase diagram can be used as a map to chart the proper sequence of operations for heat treating of a given steel. This popular poster shows the iron-carbon/cementite equilibrium phase diagram, with representative microstructures for important phases. The poster is approximately 60 cm (2 ft) wide and 90 cm (3 ft) tall.



SET SALE!

Heat Treater's Guides,
2-Volume Set Product Code: 06489G
Price: \$547 / ASM Member: \$405



BEST SELLER

Heat Treater's Guide: Practices and Procedures for Irons and Steels, 2nd Edition

1995 • 904 pages • ISBN: 978-0-87170-520-4
Product Code: 06400G

Price: \$307 / ASM Member: \$231

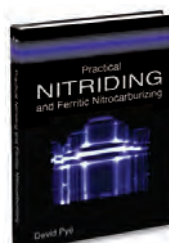
Each data sheet gives the chemical composition of the alloy, a listing of similar U.S. and foreign alloys, its characteristics, and the recommended heat treating procedure. Additional heat treating data is included, such as representative micrographs, isothermal transformation diagrams, cooling transformation diagrams, tempering curves, and data on dimensional change.

Heat Treater's Guide: Practices and Procedures for Nonferrous Alloys

1996 • 669 pages • ISBN: 978-0-87170-565-5
Product Code: 06325G

Price: \$307 / ASM Member: \$231

Quick access to recommended heat treating information for hundreds of nonferrous alloys, plus composition, trade names, common name, specifications (both U.S. and foreign), available product forms, and typical applications. Information is presented by alloy group in the datasheet format established in the companion edition on irons and steels.



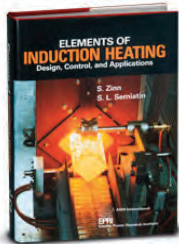
Practical Nitriding and Ferritic Nitrocarburizing

By David Pye

2003 • 256 pages
ISBN: 978-0-87170-791-8
Product Code: 06950G

Price: \$207 / ASM Member: \$155

This book will help you to understand nitriding and nitrocarburizing processes, select the appropriate process and process parameters, control the process, evaluate results, and troubleshoot.



Elements of Induction Heating: Design, Control, & Applications

By S. Zinn, S.L. Semiatin

1988 • 335 pages

ISBN: 978-0-87170-308-8

Product Code: 06522G

Price: \$107 / ASM Member: \$75



Practical Heat Treating, 2nd Edition

By J.L. Dossett and H.E. Boyer

2006 • 296 pages

ISBN: 978-0-87170-829-8

Product Code: 05144G

Price: \$147 / ASM Member: \$105

An excellent introduction and guide for design and manufacturing engineers, technicians, students, and others who need to understand why heat treatment is specified and how different processes are used to obtain desired properties. Clear, concise, and non-theoretical language.

Surface Hardening of Steels: Understanding the Basics

Edited by J.R. Davis

2002 • 364 pages

ISBN: 978-0-87170-764-2

Product Code: 06952G

Price: \$147 / ASM Member: \$105

A practical selection guide to help engineers and technicians choose the most efficient surface hardening techniques that offer consistent and repeatable results. Emphasis is placed on processing temperature, case/coating thickness, bond strength, and hardness level obtained.

ASM Heat Treating Society Welcomes You.

Not a heat treater? Not a problem! All are welcome to join HTS, the world's largest membership society dedicated to the advancement of heat treating as a theoretical and applied discipline. Our members work in several industries, including equipment manufacturing, research, and government. Take advantage of a century of heat treating expertise. Join the ASM Heat Treating Society today, and connect, share, and grow with us.



Join the conversation today!
Visit hts.asminternational.org

COATINGS & SURFACE ENGINEERING



Volume 5B: Protective Organic Coatings

Edited by Kenneth B. Tator

2015 • 545 pages

ISBN: 978-1-62708-081-1

Product Code: 05437G

Price: \$297 / ASM Member: \$225

This completely new volume addresses a need for comprehensive information on organic coatings, including coating materials, surface preparation,

application processes, industrial uses, and coating evaluation and analysis methods. This volume is essential for industrial coating users, specifiers, and contractors. The content in this volume has been written and reviewed by leading industry experts, making this latest ASM Handbook the definitive resource on this important topic. Plus, Volume 5B is the first volume in the ASM Handbook series to be printed in full color.

Thermal Spray Society wants you.

The leading global source for thermal spray information, representing 1500 members around the globe from over 500 leading companies, research institutions and universities. Take advantage of being a part of this global community and join TSS and ASM today!



Join today at:
tss.asminternational.org



Surface Engineering for Corrosion and Wear Resistance

Edited by J.R. Davis

2001 • 279 pages

Co-published by IOM Communications and ASM International

ISBN: 978-0-87170-700-0

Product Code: 06835G

Price: \$107 / ASM Member: \$75

Provides practical information to help engineers select the best possible surface treatment for a specific corrosion or wear application. Covers process comparisons, and dozens of useful tables and figures compare surface treatment thickness and hardness ranges; abrasion and corrosion resistance; processing time, temperature, and pressure; costs; distortion tendencies; and other critical process factors and coating characteristics.



High Pressure Cold Spray: Principles and Applications

Edited by C.M. Kay and J. Karthikeyan

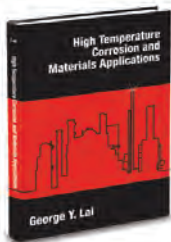
2016 • 324 pages

ISBN: 978-1-62708-096-5

Product Code: 05446G

Price: \$199 / ASM Member: \$179

A highly practical and useful "go-to" resource that presents an in-depth look at the high pressure cold spray process and describes applications in various industries. Applications of cold spray processes including protective coating production, development of performance enhancing layers, repair and refurbishing of parts, and NNS fabrication are elaborated in each industry with illustrative case studies by cold sprayers actively involved in the field.



High-Temperature Corrosion and Materials Applications

By George Y. Lai

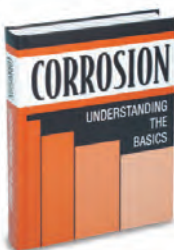
2007 • 480 pages

ISBN: 978-0-87170-853-3

Product Code: 05208G

Price: \$237 / ASM Member: \$175

Covers oxidation, nitridation, carburization and metal dusting, corrosion by halogen and halides, sulfidation, erosion and erosion-corrosion, hot corrosion in gas turbines, boilers and furnaces, stress-assisted corrosion and cracking, molten salt corrosion, liquid metal corrosion and embrittlement, and hydrogen attack.



Corrosion: Understanding the Basics

Edited by J.R. Davis

2000 • 563 pages

ISBN: 978-0-87170-641-6

Product Code: 06691G

Price: \$197 / ASM Member: \$145

A "how to" approach to understanding and solving the problems of corrosion of structural materials. Written for those with limited technical background. Provides more experienced engineers with a useful overview of the principles of corrosion and can be used as a general guide for developing a corrosion-control program.



Handbook of Corrosion Data, 2nd Edition

Edited by B. Craig and D. Anderson

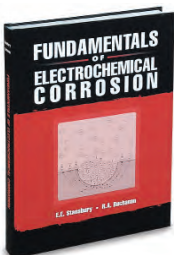
1995 • 998 pages

ISBN: 978-0-87170-518-1

Product Code: 06407G

Price: \$307 / ASM Member: \$231

Includes "Corrosion of Metals and Alloys" and "Corrosion Media." The first part contains summaries on the general corrosion characteristics of major metals and alloys in various corrosion environments. The second part is organized alphabetically by chemical compound and the data for each corrosive agent/compound are in tabular form.



Fundamentals of Electrochemical Corrosion

By E.E. Stansbury and R.A. Buchanan

2000 • 487 pages

ISBN: 978-0-87170-676-8

Product Code: 06594G

Price: \$157 / ASM Member: \$115



Stress-Corrosion Cracking: Materials Performance and Evaluation, Second Edition

Edited by Russell H. Jones

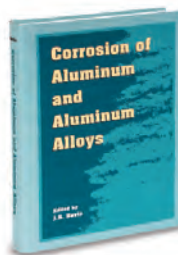
2016 • 473 pages

ISBN: 978-1-62708-118-4

Product Code: 05509G

Price: \$199 / ASM Member: \$149

This new second edition serves as a go-to reference on the complex subject of stress-corrosion cracking (SCC), offering information to help metallurgists, materials scientists, and designers determine whether SCC will be an issue for their design or application; and for the failure analyst to help determine if SCC played a role in a failure under investigation.



Corrosion of Aluminum and Aluminum Alloys

Edited by J.R. Davis

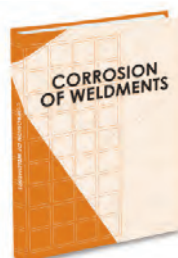
1999 • 313 pages

ISBN: 978-0-87170-629-4

Product Code: 06787G

Price: \$167 / ASM Member: \$125

Presents comprehensive coverage of the corrosion behavior of aluminum and aluminum alloys, with emphasis on practical information about how to select and process these materials in order to prevent corrosion attack.



Corrosion of Weldments

Edited by J.R. Davis

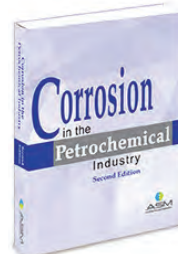
2006 • 236 pages

ISBN: 978-0-87170-841-0

Product Code: 05182G

Price: \$207 / ASM Member: \$155

Details the many forms of weld corrosion and the methods used to minimize weld corrosion.



Corrosion in the Petrochemical Industry, Second Edition

Edited by Victoria Burt

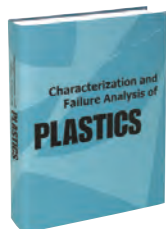
2015 • 426 pages

ISBN: 978-1-62708-094-1

Product Code: 05503G

Price: \$219 / ASM Member: \$165

A comprehensive guide to understanding and preventing corrosion in the petrochemical industry. Written for engineers, production managers and technicians, this book explains how to select the best material for a corrosion-sensitive petrochemical application, and how to choose among various prevention methods. Included in the second edition are new articles on corrosion inhibitors and high-temperature environments.



Characterization and Failure Analysis of Plastics

2003 • 482 pages

ISBN: 978-0-87170-789-5

Product Code: 06978G

Price: \$247 / ASM Member: \$185

Covers the performance of plastics and how it is characterized during design, property testing, and failure analysis. Selected by *Choice* magazine for its excellence in scholarship and presentation, the significance of its contribution to the field, and value as an important treatment of the subject.



Composite Filament Winding

Edited by S.T. Peters

2011 • 174 pages

ISBN: 978-1-61503-722-3

Product Code: 05286G

Price: \$167 / ASM Member: \$125

Topics include capabilities and limitations of filament winding, practical issues such as fiber and resin handling, winding theory, software and numerical control, history of the process, and more.



Optical Microscopy of Fiber-Reinforced Composites

By Brian S. Hayes and Luther M. Gammon

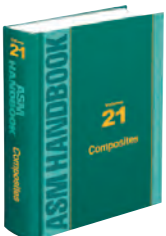
2010 • 284 pages

ISBN: 978-1-61503-044-6

Product Code: 05303G

Price: \$177 / ASM Member: \$135

Optical microscopy is one of the most valuable but under-utilized tools for analyzing fiber-reinforced polymer matrix composites. Covers sample preparation, microscopic techniques, and applications. The power to study the microstructure of heterogeneous, anisotropic materials is illustrated with over 180 full color images.



Volume 21: Composites

Edited by D.B. Miracle and S.L. Donaldson

2001 • 1201 pages

ISBN: 978-0-87170-703-1

Product Code: 06781G

Price: \$297 / ASM Member: \$225

See page 4 for more information.

**SAVE
UP TO
\$164**

SET SALE!

Engineered Materials Handbook® 3-Volume Set

Product Code: 06943G

Price: \$457 / ASM Member: \$405

Engineered Materials Handbook®

The comprehensive and practical coverage you expect from ASM International on the properties, selection, processing, testing, and characterization of nonmetallic engineered materials.



Volume 2: Engineering Plastics

1988 • 883 pages

ISBN: 978-0-87170-280-7

Product Code: 06248G

Price: \$207 / ASM Member: \$155

Volume 3: Adhesives and Sealants

1990 • 893 pages

ISBN: 978-0-87170-281-4

Product Code: 06012G

Price: \$207 / ASM Member: \$155

Volume 4: Ceramics and Glasses

1991 • 1217 pages

ISBN: 978-0-87170-282-1

Product Code: 06912G

Price: \$207 / ASM Member: \$155



Structural Composite Materials

By F.C. Campbell

2010 • 630 pages

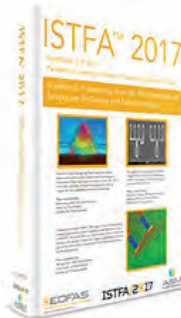
ISBN: 978-1-61503-037-8

Product Code: 05287G

Price: \$167 / ASM Member: \$125

All aspects of continuous and discontinuous fiber-reinforced polymer, metal, and ceramic composites are described in terms of fabrication, properties, design, analysis, and in-service performance.

MICROELECTRONICS



ISTFA™ 2017

Proceedings from the 43rd International Symposium for Testing and Failure Analysis

2017 • 645 pages

ISBN: 978-1-62708-150-4

Product Code: 02219G

Price: \$167 / ASM or EDFAS™ Member: \$125

The theme for the November 2017 conference is Striving for 100% Success Rate. Papers focus on the tools and techniques needed for maximizing the success rate in every aspect of the electronic device failure analysis process.



ISTFA™ 2016

Proceedings from the 42nd International Symposium for Testing and Failure Analysis

2016 • 659 pages

ISBN: 978-1-62708-135-1

Product Code: 02218G

Price: \$167 / ASM or EDFAS™ Member: \$125

This volume features the latest research and practical data from the premier event for the microelectronics failure analysis community. The papers address the symposium's theme, The Next Generation FA Engineer.



Microelectronics Failure Analysis Desk Reference, 6th Edition (Book + CD)

Edited by Richard J. Ross

2011 • 674 pages

ISBN: 978-1-61503-725-4

Product Code: 09110Z

Price: \$207 / ASM or EDFAS™ Member: \$155

This updated reference book, prepared by experts in their fields, contains dozens of articles covering a range of topics.



**FREE
TO EDFAS
MEMBERS**

Electronic Device Failure Analysis™ Magazine

Case Histories • Industry News • Training Opportunities • Useful URLs • Product News
Ask the Experts

Frequency: 4 issues per year
ISSN: 1537-0755
CODEN: EDFAAO
Product Code: EDFA

Print Price: \$135

Contains key information dedicated to meeting the technical and networking needs of electronic device failure analysis technicians, engineers, and managers. Technical articles contributed by experts that cover everything from operations to analysis techniques. Trends of failure analysis in the microelectronics industry. News of the Electronic Device Failure Analysis SocietySM keeps you in the loop. Guest columns provide vital perspective into FA topics.

The Electronic Device Failure Analysis SocietySM

This technical society fosters education and communication in the microelectronics failure analysis community. Get discounts on publications, software, and educational materials, and special pricing for the ISTFA conference by joining EDFAS today.

Visit: edfas.asminternational.org

EDFAS
Electronic Device Failure Analysis Society
ASM INTERNATIONAL

METALLURGY FOR THE NON-METALLURGIST™



Metallurgy for the Non-Metallurgist™

Classroom Courses and Customized On-Site Training

Design, manufacturing, and maintenance engineers are increasingly relying on their knowledge of metallurgy to identify, assess, and solve the challenges they face. Metallurgy and the decisions that impact it are a critical factor in the entire product life cycle of everything from the cars we drive to the bridges we cross to the GPS satellites that guide our commutes. While many improvement pathways are becoming prohibitively steeper due to decades of optimization, metallurgy is ripe with opportunity and reward for those who understand it.

Metallurgy for the Non-Metallurgist™ will equip you with the knowledge you need to leverage the process-structure-property-performance relationships that govern metals and alloys and, in turn, the cost, quality, and lifetime of the engineered components and systems made from them.

Contact us to register for a course or arrange for custom training.
Call 440.338.5151, ext. 0 or professionaldevelopment@asminternational.org



NEW

Metallurgy for the Non-Metallurgist™: Mechanical Properties and Their Measurement Self-Guided Digital Course

The extent to which metals can be pushed, the limits of endurance under static and dynamic force loads, high-energy impacts, twisting, bending, and other applied stresses, is usually established by conducting standard mechanical tests that are described in detail in "Mechanical Properties and Their Measurement." In this self-guided digital course, students will learn – with the help of rich visuals, narrated animations, demonstration videos, and interactive quizzes – how to measure properties such as tensile strength, hardness, and impact resistance and what the tests reveal about material behavior and failure mechanisms, including fracture, creep, and fatigue. The course also includes information on ASTM test procedures and how they avoid measurement-induced errors stemming from metallurgical and microstructural changes.

For more information, visit: www.asminternational.org/learning/courses/online



**BEST
SELLER**

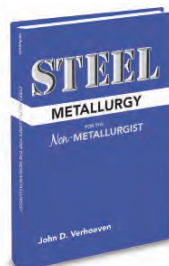
**A "MUST-HAVE" READY REFERENCE
ON METALLURGY!**

Metallurgy for the Non-Metallurgist™ 2nd Edition

Edited by Arthur C. Reardon
2011 • 526 pages
ISBN: 978-1-61503-821-3
Product Code: 05306G

Price: \$177 / ASM Member: \$135

Provides a modern view of the basic principles and current practices of metallurgy. Recommended for anyone who uses, makes, buys or tests metal products. Answer all your basic metallurgy questions by using this updated reference featuring many new illustrations, examples, and descriptions.



Steel Metallurgy for the Non-Metallurgist

By John D. Verhoeven
2007 • 225 pages
ISBN: 978-0-87170-858-8
Product Code: 05214G

Price: \$107 / ASM Member: \$75

A practical primer on steel metallurgy for those who select, heat, forge, or machine steel.



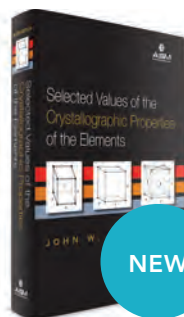
Pearson's Crystal Data: Crystal Structure Database for Inorganic Compounds®*

Edited by Pierre Villars and Karin Cenizal

The Pearson's Crystal Data® DVD is the world's largest database containing critically evaluated crystallographic and derived data for intermetallics, oxides, halides, minerals, and other inorganic materials and compounds. This allows users to check data against crystallographic rules and therefore

interpret the properties of chemical compounds quickly and efficiently. It is an essential tool for scientists and engineers working with inorganic crystalline matter. The 2017-2018 release includes 304,000 structural data sets (including atom coordinates and displacement parameters, when determined) for about 173,000 different phases. The database provides approximately 18,800 experimental diffraction patterns and around 284,000 calculated diagrams (interplanar spacings, intensities, Miller indices). In addition, over 42,500 figure descriptions for cell parameters as a function of temperature, pressure, or concentration are given. To reach these results, scientific editors have critically analyzed and processed over 98,400 original publications. Innovative software developed by Crystal Impact offers a large variety of elaborate features for easy retrieval of desired information.

*For more information on Pearson's Crystal Data Database, contact Sales at sales@asminternational.org or 440.338.5151.



NEW

Selected Values of the Crystallographic Properties of the Elements

By John W. Arblaster

2018 • 684 pages

ISBN: 978-1-62708-154-2

Product Code: 05244G

Price: \$249 / ASM Member: \$189

This reference book presents a unique and comprehensive review of the crystallographic properties of all the elements and will be a valuable resource for metallurgists and crystallographers. The crystallographic properties are evaluated at ambient pressure in order to provide a base line for high pressure studies. Lattice parameters of the elements are presented as a function of temperature and related properties such as thermal expansion coefficients, molar volumes, and densities are provided. Special attention is given to ensure that the selected values correspond to the latest values of atomic weights and the fundamental constants.



Binary Alloy Phase Diagrams, 2nd Edition

Edited by T.B. Massalski, H. Okamoto,
P.R. Subramanian, and L. Kacprzak

1990 • 3589 pages

ISBN: 978-0-87170-403-0 (3-Volume Set)

Product Code: 57718G

Price: \$1643 / ASM Member: \$1546

3-volume set includes 4,700 binary alloy phase diagrams.



Handbook of Ternary Alloy Phase Diagrams 10-Volume Set

Edited by Pierre Villars, Alan Prince, and Hiroaki Okamoto

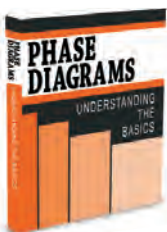
1995

ISBN: 978-0-87170-525-9

Product Code: 57706G

Price: \$8514 / ASM Member: \$8417

More than 18,000 ternary diagrams.



Phase Diagrams: Understanding the Basics

Edited by F.C. Campbell

2012 • 470 pages

ISBN: 978-1-61503-835-0

Product Code: 05342G

Price: \$187 / ASM Member: \$135

Exceptionally well-written text for non-metallurgists or anyone seeking a quick refresher on an essential tool in modern metallurgy. Ample illustrations for all

important liquid and solid reactions. Gas-metal reactions, important in metals processing and in-service corrosion, are also discussed.



Pearson's Desk Edition

Edited by Pierre Villars • 1997

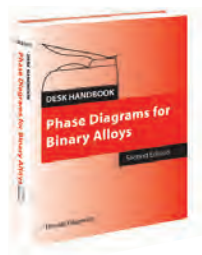
ISBN: 978-0-87170-603-4

(2-Volume Set)

Product Code: 57763G

Price: \$950 / ASM Member: \$850

27,686 entries of the highest quality crystal data, representing 27,686 different compounds.



Desk Handbook: Phase Diagrams for Binary Alloys, 2nd Edition

By Hiroaki Okamoto

2010 • 855 pages

ISBN: 978-1-61503-046-0

Product Code: 57751G

Price: \$358 / ASM Member: \$286

Includes 2421 diagrams of which 450 are new or greatly revised; among these, 87 are not in the First Edition. Approximately 600 crystal structure tables of systems for which phase diagrams are unknown.

ASM Alloy Phase Diagram Database™

A fully-searchable database containing more than 40,300 binary and ternary alloy phase diagrams, from more than 6,200 systems, each with their associated crystal and reaction data. Also includes all inorganic systems.

Use to assist with troubleshooting, manufacturing control, and the development of new materials.



For more information on how to subscribe, contact the Digital Database Manager at **440.338.5409** or via email at sales@asminternational.org.

EARLE TO CHAIR 2018 NOMINATING COMMITTEE

Members of the 2018 Nominating Committee have been selected and **Ms. Jacqueline M. Earle, FASM**, Caterpillar (retired), was elected to serve as chair by the ASM Board of Trustees. Earle has been a member of ASM International since 1983 and served as ASM trustee from 2013-2016. She received her B.S. degree from the University of Pittsburgh and earned an M.S. degree in mechanical engineering from Bradley University. She spent her entire career at Caterpillar, working on materials for diesel engines, managing new product programs for generator sets, and providing technical support for remanufactured product.



Earle

Earle's ASM volunteer career began at Pitt. She then served in various roles with the Peoria Chapter. Peoria has a very strong volunteer base and she is most proud of starting the first student Materials Camp in 2005. Earle has also served ASM members at the national level, on the Membership, U.S. Chapter Council, and Volunteerism Committees. To spread materials education beyond ASM chapters, she led workshops for the "Expanding Your Horizons" programs, to teach materials engineering to middle school girls. Earle also served as guest speaker and project mentor for the "Project Lead The Way" high school programs.

ASM Officers Appoint Members

In accordance with the ASM International Constitution, ASM president **Dr. Frederick E. Schmidt, FASM**, vice president **Dr. David U. Furrer, FASM**, and immediate past

president **Dr. William E. Frazier, FASM**, appointed nine members to the Nominating Committee from among candidates proposed by chapters, committees, councils, and ASM Affiliate Society boards. The committee is responsible for selecting 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 3 of the Constitution states that the office of president shall be filled for a period of one year by succession of the vice president. The 2018 Nominating Committee's nominee for vice president will serve as ASM's president in 2020.

2018 Nominating Committee Members Include:

Michael Connelly, FASM, Casey Products, Chicago (nominated by Chicago Regional Chapter); **Laura Diers**, Honeywell, Long Beach, Calif. (nominated by Los Angeles Chapter); **Jaret Frafjord**, IMR Test Labs, Portland, Ore. (nominated by International Metallographic Society); **John Keough, FASM**, Applied Process Inc., Ann Arbor, Mich. (nominated by Heat Treating Society); **James Saal**, QuesTek Innovations LLC, Evanston, Ill. (nominated by Chicago Regional Chapter); **John Shields, FASM**, Pentamet Associates LLC, Cleveland (nominated by Cleveland Chapter); **Ashok Tiwari**, CHEMI-CHEM, Mumbai, India (nominated by India Council and India Chapter); **Wego Wang, FASM**, Federal Aviation Administration, Burlington, Mass. (nominated by Boston Chapter); **Dehua Yang**, Ebatco, Eden Prairie, Minn. (nominated by the Handbook Committee).

The Nominating Committee will meet on April 12-13 and its recommended slate of officers will be published in the May/June issue of *ASM News*.

In This Issue

59

Earle Chairs
Nominating
Committee

60

CEO
Corner

61

Canada
Council Awards

63

Women in
Engineering

65

Chapters in
the News

» HIGHLIGHTS CEO CORNER

December Issue of *Shape Memory & Superelasticity* Honors Miyazaki

The December issue of *Shape Memory & Superelasticity* contained invited papers written as a tribute to Prof. Shuichi Miyazaki, a pioneer in the technology of shape memory alloys. Miyazaki's study on thermomechanical treatment and fatigue of NiTi paved the way for development of many practical applications and industrial production of NiTi alloys. The special issue was organized by Prof. Yinong Liu, University of Western Australia, and Prof. Hee Young Kim, University of Tsukuba. Additional papers in honor of Miyazaki will also appear in the March 2018 issue of the journal. As a benefit of membership, SMST members receive full text online access to *Shape Memory and Superelasticity*.



Miyazaki

Prof. Miyazaki has co-edited and co-authored seven

books, including *Shape Memory Alloys*, published by Springer Verlag in 1996, *Shape Memory Alloys for Biomedical Applications*, published by Woodhead Publishing in 2009, *Thin Film Shape Memory Alloys*, published by Cambridge University Press in 2009, and *Shape Memory and Superelastic Alloys*, published by Woodhead Publishing in 2011. He has co-authored 26 book chapters and co-edited 12 special issues in international journals. His research has been published in more than 300 scholarly journals and in 78 review papers in materials science and engineering.

Prof. Miyazaki has been the recipient of many national and international awards, including the Thomson Reuters' ISI Highly Cited Researcher in Materials Science Field in 2004 and the Gold Medal Award from the Japan Institute of Metals in 2014. He also has served as a board member of ASM's International Organization of Shape Memory and Superelastic Technologies, and currently serves as associate editor of *Shape Memory and Superelasticity*.

CEO CORNER

Welcome to MemberNation

You may be wondering how ASM's Digital Transformation is progressing. At this writing, we have completed the deployment of all five of our e-commerce backbone systems, including our new MemberNation association management system, which went live on February 19.



Mahoney

Since then, thousands of our members have successfully logged in, updated their profiles, and interacted with the new environment. Through these early stages, we have received valuable feedback from many, many volunteers who have helped wring out the systems. We have also executed thousands of electronic transactions, generating more than \$1 million in orders. Of those transactions, 94% were completed without human intervention.

I would now like to share a few key points regarding some of the new features you may have noticed, which markedly differ from our previous association management system (iMIS):

1. Using your email address to prompt log-in via password, with periodic password renewals, is an industry standard we have adopted. On a rotating basis, members may use their ASM ID as passwords, but not on a fixed basis.

2. Using your profile page as the My ASM landing page is deliberate. We have adopted this process in order to continuously enable members to update their data, thereby avoiding one of the biggest issues with our old system—inaccurate member data.
3. Later this month, the old shared Workspaces within iMIS will become Collaboration areas in the new Salesforce/MemberNation environment. We want to thank the dozens of volunteers at the chapter, affiliate, and committee levels who tested these tools for several weeks after the go-live, before we migrated roughly 380 collaboration pages from the old systems into the new systems. For members, these areas will be accessible via the Collaboration tab at the top of your profile page.

As with all new system go-lives, we are working through a backlog of updates and fixes. Some of those fixes will be released individually over the next few weeks and months. Others will be bundled into a major update release called a "sprint," with the first sprint slated for July.

Finally, we will complete the systems implementations of our Digital Transformation by deploying a publishing system in mid-2018 and a content repository by early 2019. Coupled with content reengineering work over the next two years, this should render ASM content fully discoverable, searchable, accessible, and interoperable via the internet during the remaining two years of the ASM Renewal.

Please share any feedback on these developments with me via email. Thank you.

William T. Mahoney, CEO, ASM International
bill.mahoney@asminternational.org

NOMINATIONS AND CANDIDATES HIGHLIGHTS

ASM and its Affiliate Societies Seek Student Board Members

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

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

Opportunities specific to each Society:

ASM International

- Attend four board meetings (July 26-28, October 14-17 during MS&T18, spring and summer 2019)
- Term begins June 1

ASM Electronic Device Failure Analysis Society

- Attend one board meeting (fall 2019)
- Participate in three teleconferences
- Term begins in October

ASM Thermal Spray Society

- Attend one board meeting (fall 2018)
- Participate in two teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins in October

Application deadline has been extended to April 23.

To view the complete form and rules, visit asminternational.org/students/student-board-member-programs.

Chapter Volunteer Honor Roll

The ASM Volunteerism Committee is seeking nominations for the Chapter Volunteer Honor Roll. This Honor Roll recognizes chapter volunteers whose performance is considered exemplary of the type of volunteer essential to the success of ASM. We invite all chapters to nominate volunteers from your chapter to be featured on the Honor Roll.

It is suggested that the Chapter Executive Committee select a member who is currently serving the chapter as a

volunteer in an ongoing capacity. These names will later appear in an "ASM Volunteer Honor Roll" article in *ASM News*. Submit your nomination by May 18 at research.net/r/NRYSDLZ. This is a unique opportunity to celebrate your most valued volunteers. We look forward to your submissions.



Canada Council Award Nominations due April 30

ASM's Canada Council is seeking nominations for its 2018 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. The 2017 recipient was Dr. R. Winston Revie, FASM, emeritus scientist, Materials Technology Lab, retired, Canmet, Ottawa, Ontario.

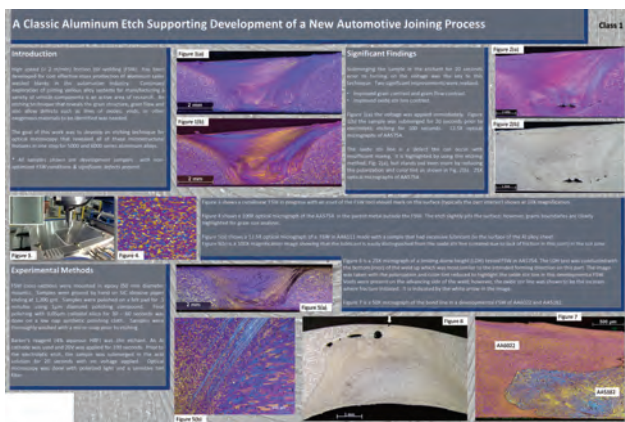
M. Brian Ives Lectureship – This award was established in 1971 by the Canada Council of ASM to identify a distinguished lecturer who will present a technical talk at a regular monthly meeting of each Canadian ASM Chapters that elect to participate. The winner receives a \$1000 honorarium and travels to each ASM Canada Chapter throughout the year to give their presentation with expenses covered by the ASM Canada Council. The 2017 recipient was Dr. Raj Thamburaj, corporate director, Advanced Engineering, Magellan Aerospace Ltd., Mississauga, Ontario.

John Convey Innovation Awards – In 1977, the Canada Council created a new award to recognize sustaining members 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. The 2017 recipient was Mr. Michael J. Anderson, MSc, Peng., associate materials research engineer, Syncrude Canada Ltd., Research and Development Center, Edmonton, Alberta.

View sample forms, rules, and past recipients at asminternational.org/membership/awards/nominate.

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

» HIGHLIGHTS HISTORY OF METALS



IMC 2017 Jacquet-Lucas winning poster by Elvin Beach et al. from Worthington Industries Inc.

International Metallographic Contest at MS&T

Deadline: October 2

The International Metallographic Contest (IMC), an annual contest cosponsored by the International Metallographic Society (IMS) and ASM International to advance the science of microstructural analysis, will again be held at MS&T in Columbus, Ohio, October 14-18. Five different classes of competition cover all fields of optical and electron microscopy:

Class 1: Light Microscopy—All Materials

Class 2: Electron Microscopy—All Materials

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

Class 4: Artistic Microscopy (Color)—All Materials

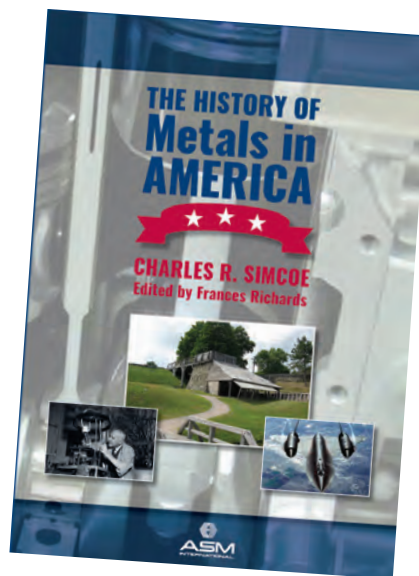
Class 5: Artistic Microscopy (Black & White)—All Materials

Best-In-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of \$3000. For a complete description of the rules, tips for creating a winning entry, and judging guidelines, visit metallography.net.

“Metallurgy Lane” is Basis for New Book

The History of Metals in America by Charles Robert (Bob) Simcoe and edited by Frances Richards will be available this month. This book chronicles the development of metals as both an industrial activity and a science. Progress involving structural metals made possible the air, land, sea, and space travel of today, skyscrapers reaching over 100 stories high, and many other engineering accomplishments that continue to shape modern society.

Readers will embark on a fascinating journey through the evolution of metals and metallurgy from the beginning of iron production in colonial times with the first iron plant in 1645 to the prevailing metals of the 21st century. Simcoe wrote more than 40 articles for *Advanced Materials & Processes* magazine, including the monthly series entitled “Metallurgy Lane,” which became the basis for this book. Special prepublication pricing is available through April 30. Visit asminternational.org/historyofmetals.



ASM Announces Volunteer Opportunities

Are you looking for an opportunity to showcase your talents or exercise a newly gained skill? Volunteering with ASM may be your chance to do just that! ASM offers countless volunteering, mentoring, and teaching opportunities to fulfill your personal goals. Whether it be the desire to give back or helping the next generation of engineers, ASM has a place to put your talents and strengths to work for the betterment of the materials science community.

Volunteers are the heart of ASM. The passion and commitment of our volunteers drive our success at every level, and we invite you to consider joining our volunteer team.

Some of our volunteer opportunities include: technical committees, society committees, affiliate committees, local chapters, and Materials Camp. Learn more about the ways you can get involved. Visit asminternational.org/types-volunteer.

ASM Launches New Digital Course: Mechanical Properties and Their Measurement

Learn materials science in a new way—on your computer, tablet, or smartphone—within a completely digital environment, on your own schedule. ASM just launched a new highly-interactive digital course format that makes it easier to comprehend, retain, and apply new concepts. The first digital course module, “Mechanical Properties and Their Measurement,” is now available. In this self-guided course, students will learn—with the help of rich visuals, narrated animations, demonstration videos, and interactive quizzes—how to measure properties such as tensile strength, hardness, and impact resistance, and what the tests reveal about material behavior and failure mechanisms, including fracture, creep, and fatigue. The course also includes information on ASTM test procedures and how they avoid measurement-induced errors stemming from metallurgical and microstructural changes. For more information on course registration and other details, visit bit.ly/2FLs7N1 or contact John Cerne at john.cerne@asminternational.org.



Screenshots from “Mechanical Properties and Their Measurement” module.

WOMEN IN ENGINEERING

*This profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with **Véronique Vitry**, senior researcher and teaching associate at the Université de Mons (UMONS), in Belgium.*



Vitry

What does your typical workday look like?

Typically, I take my children to school at 8 a.m. and then head to the office, around the corner. My day consists of a mix of classes, meetings, research, teaching prep work, expertise, and administrative work. At 5 p.m. I'm off to pick up the kids and head home. I usually work one hour or so after dinner grading, reviewing, or reading papers and editing the work of Ph.D. students who I supervise. My job is divided between research and teaching. There is also a service component, which includes helping people from industry and taking part in the organization of the university. I sit on several boards, councils, and committees.

What part of your job do you like most?

I enjoy both teaching and research. Teaching allows me to get students interested in materials engineering. I teach various classes to students in years three to five. University degrees in my country are mandatory five year-programs consisting of three years of bachelors and two years of masters. My classes include process metallurgy (my favorite), nanotechnologies, spectroscopic methods in chemical and materials analysis, and process modeling (my least favorite). It's always stimulating to see students discover metallurgy, which is something they're not typically exposed to before my class. The best part is the stars in their eyes after visiting a plant. Research allows me the fun of trying to understand how things work. I'm happiest when I've just made sense of new observations and am able to relate them to other results, or when I read a new paper that explains something I've been curious about.

What attracted you to engineering?

I was always attracted to science and engineering, even as a child. When I was four, I told my mother, “Quand je serai grande je veux être ‘ingéniettte,’” which translates to, “When I'm older, I want to be an engineer-girl.” You can look up the word “ingéniettte” in French, but it does not exist. I made it up because I did not know the feminine form of “ingénieur.”

For a little girl who liked math and wanted to understand how things worked, engineering was the obvious choice. I discovered chemistry when I was 14 and was immediately hooked. Add that to the fact that several engineers were in my family, and my career path was very clear.

» HIGHLIGHTS PROFILE OF A VOLUNTEER

If a young person approached you for career advice about pursuing engineering, what would you tell them?

I would tell them to go for it. It's a wonderful field that opens a lot of doors and the skills you acquire are invaluable. Engineering is a growing field and the opportunities are endless. Nearly everything in today's society is based on engineering, including information technology, entertainment, and even healthcare. Engineers are everywhere, even if they stay out of the limelight.

Hobbies?

Reading and music: I play the cello and direct the university's band.

Last book read?

In French, "Notre-Dame de Paris" by Victor Hugo and in English, "A Column of Fire" by Ken Follett.

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

VOLUNTEERISM COMMITTEE

Profile of a Volunteer



Ben Flocken, Materials Engineer, Honda Research & Development Americas Inc.

As a 2010 graduate of The Ohio State University in materials science and engineering, Ben Flocken was happy to become a "home grown boy" at Honda R&D Americas Inc. in Raymond, Ohio—about 20 minutes from where he grew up. He qualifies materials for production and conducts research for models in development. Introduced to ASM's Material Advantage Chapter in college, Flocken now sees a need to improve efforts to help college students network and enter the professional world.

Flocken's first job with a phosphate and e-coating company came through OSU Career Services. He then took a contract engineer role with Honda and was soon hired fulltime. With personal encouragement from Honda chief engineer Rowdy Joseph (now ASM's Chapter Council Chair), Flocken got involved in the Columbus ASM Chapter and

became chapter chair a few years later. "We're slowly building the chapter back up and seeing a revitalization with 300 members and 10 on our executive committee," says Flocken. "We just hosted a meeting at the Honda Heritage Center, a museum about Honda's history in North America. Attendees were very interested and it's showing promise."

He sees the need to improve communication and add value for individual ASM members and companies like Honda by surveying personal, professional, and corporate needs. He's been pleased to improve his own leadership skills in motivating volunteers to get excited about planning programs. "And it's helped me feel more comfortable speaking in front of large crowds and planning ahead!"

Flocken is working to engage the OSU materials science department in events with students and professionals. "It sounds old-school, but face-to-face meetings are important. You need to personally meet someone to grow a connection—not only getting young people involved but re-engaging past members," he says. "For me, volunteering for ASM is different than volunteer work with the YMCA or a foodbank. I get a real sense of accomplishment helping people along in their careers and being part of a student's life going forward."

Without VOLUNTEERS, there is no ASM.

In Recognition of
National Volunteer Week,
April 15-21,
We Thank You!



ASM
INTERNATIONAL

CHAPTERS IN THE NEWS

President Schmidt on the Move

During his ASM presidential year, Fred Schmidt is making tracks, visiting several chapters in the first half of his term. Here's a montage of his recent trips, including a stop in his very own Chicagoland and another at his alma mater in Philly.

Chicago



President Schmidt receives an ASNT globe from Chuck Johnson, ASNT Chicago Chapter chair, at the joint ASNT/ASM meeting in February. Johnson is vice president of Karden Sales. Schmidt presented a talk on “NDT Methods and Characterization in Failure Analysis: Case History Investigations.”



Jennifer Anaya receives an Alpha Sigma Mu scarf from ASM President Schmidt. Anaya is the ASNT Woman of the Year for Mentoring. She is also vice president of operations at Alloyweld Inspection Co. Inc. in Bensenville, Ill.

Canton-Massillon



Ray Fryan, vice president of technology and quality at Timken Steel, was on hand for Schmidt's ASM Canton-Massillon Chapter visit on March 8. Schmidt spoke to the group about career planning and advised attendees to embrace change and diversify their skills.

Los Angeles



President Schmidt was in Los Angeles on February 20 and recognized chapter leaders and members. From left, Daniel Dennies, FASM (Chapter Awards chair), received an ASM presidential coin. Kamal Manish and Satish Dixit (Chapter Education chair) received membership awards.

Philadelphia



In Philadelphia, Schmidt received the Drexel alumni “Service to the Profession Award” from the university's president John Fry (left) and Fred Kaplan, chair of the Board of Alumni Governors in the AJ Drexel Picture Gallery. The award is an engraved crystal Tiffany bowl. Presented on January 27, Schmidt considers it the first of two Eagle “Super Bowls” for 2018.

» HIGHLIGHTS MEMBERS IN THE NEWS

Rocky Mountain Presents Barrett Awards

On March 1, the ASM Rocky Mountain Chapter (RMC) held their 34th annual Barrett Awards Night, cosponsored by Colorado School of Mines (CSM). Multiple CSM student scholarships were awarded. A special chapter award was presented to Stanley Beitscher, FASM, for decades of service to the chapter. The 2018 Charles S. Barrett Silver Medal was awarded to Tresa Pollock from the University of California, Santa Barbara who presented a talk titled "Rapid Acquisition of 3D Data at the Mesoscale for Structural Materials." This ASM-RMC award was established in 1984 in recognition of Charles Barrett, FASM, a pioneer in the study of the structure of metals and the application of x-ray diffraction techniques. The award is presented to individuals whose contributions to the science of metallurgy most exemplify the efforts and career achievements made by Barrett.



CSM students receiving ASM-RMC scholarships (front row, from left) Alec Saville, Chloe Cook, and Melissa Thrun; (back row, from left) chapter scholarship chair John Speer, chapter chair Nik Hrabe, Stuart Shirley, and executive committee member Kip Findley.



2018 Charles S. Barrett Silver Medal recipient Tresa Pollock, FASM (right), and Nik Hrabe.

Los Angeles Holds AM Metals Meeting



Prabir Chaudhury of Exova was recognized by the ASM Los Angeles Chapter for speaking on testing of additively manufactured metals at their November 2017 meeting.

MEMBERS IN THE NEWS

National Academy of Engineering Honors ASM Members

In February, the National Academy of Engineering (NAE) elected 83 new members and 16 foreign members. Among the inductees are several ASM members and their citations: **John Ågren, FASM**, Royal Institute of Technology KTH, Sweden, for development of integrated thermodynamics and kinetics analysis tools enabling computational materials engineering; **Lallit Anand**, Massachusetts Institute of Technology, for contributions to the development of plasticity for engineering technology: theory, experiment, and computation; **Ke Lu**, Shenyang National Laboratory for Materials Science and Institute of Metal Research, Chinese Academy of Sciences, for discovery of nanotwinned materials and contributions to the advancement of nanostructured materials; **Ajay P. Malshe, FASM**, NanoMech Inc. and University of Arkansas, for innovations in nanomanufacturing with impact in multiple industry sectors; **David N. Seidman, FASM**, Northwestern University, for contributions to understanding of materials at the atomic scale, leading to advanced materials and processes.



Election to NAE is among the highest professional distinctions accorded to an engineer. Academy membership honors those who have made outstanding contributions to engineering research, practice, or education. An induction ceremony will be held on September 30 at NAE's annual meeting in Washington.

IN MEMORIAM HIGHLIGHTS

ASM Members among TMS Award and Scholarship Recipients

The Minerals, Metals & Materials Society (TMS) announced recipients of its awards and scholarships for 2018. Recipients were celebrated during the TMS Annual Meeting & Exhibition in Phoenix. Congratulations to the ASM members among the winners:

TMS Fellows-Class of 2018: Carol Handwerker, FASM, Purdue University; Peter Liaw, FASM, University of Tennessee; and Daniel Miracle, FASM, Air Force Research Laboratory.

Brimacombe Medalists-Class of 2018: Ibrahim Karaman, Texas A&M University; Roger Narayan, FASM, University of North Carolina; and Katsuyo Thorton, University of Michigan.

Bruce Chalmers Award: Jyotirmoy Mazumder, FASM, University of Michigan.

Morris Cohen Award: Tresa Pollock, FASM, University of California.

William Hume-Rothery Award: Zi-Kui Liu, FASM, Pennsylvania State University; Marc A. Meyers, FASM, University of California; and Naresh Thadhani, FASM, Georgia Institute of Technology.

Alexander Scott Distinguished Service Award: Tresa Pollock, FASM, University of California; Terence Langdon, FASM, University of South Hampton; and Cong Wang, Northeastern University.

AIME Honorary Membership: Tresa Pollock, FASM, University of California.

Acta Materialia Gold Medal Award: Subhash Mahajan, FASM, University of California.

Acta Materialia Silver Medal Award: Nikhilesh Chawla, FASM, University of Arizona.

Acta Materialia Materials and Society Award: Julie Christodoulou, FASM, U.S. Office of Naval Research.

TMS Light Metals Division (LMD) Young Leaders Professional Development Award: Victoria Miller, North Carolina State University; and Eric Lass, NIST.

TMS Structural Materials Division (SMD) Young Leaders Professional Development Award: Amber Genau, University of Alabama.

AIME Henry deWitt Smith Scholarship: Samuel Rodrigues, McGill University; and Kao Zoua Yang, University of Wisconsin, Milwaukee.

TMS Light Metals Division (LMD) Scholarship: Nicholas Lipski, Colorado School of Mines.

TMS Materials Processing & Manufacturing Division (MPMD) Scholarship: Madeleine McAllister, Case Western Reserve University.

TMS Structural Materials Division (SMD) Scholarship: Cayla Harvey, University of Nevada, Reno.

International Symposium on Superalloys Scholarship: Emily Bautista, Virginia Polytechnic Institute.



At the March TMS meeting in Phoenix, Julie Christodoulou, FASM, director of naval materials S&T division at the U.S. Office of Naval Research, received the Acta Materialia Materials and Society Award.

IN MEMORIAM



Wilks

Gerald Walter (Jerry) Wilks, ASM Life Member, died on February 14 at age 67. He was born in Chicago and raised in Fox Lake, Ill. After serving in the U.S. Air Force in Turkey, he received three degrees from the Illinois Institute of Technology: a B.S. in metallurgical engineering and M.S. degrees in both materials engineering and chemical engineering. Most recently, he worked as senior metallurgical engineer at Citgo Petroleum Corp.'s Lemont refinery. Wilks also worked at the Amoco/BP refinery in Whiting, Ind., Amoco Corp. Materials Research Division, Naperville, Ill., and LaSalle Steel Co. in Hammond, Ind. He was an active member of ASM, AIChE, NACE, and AWS and served as past chairman of AIChE Chicago. Wilks was also actively involved with IIT's South Suburb Alumni Organization and IIT's Triangle Fraternity. Wilks was an engineer's engineer—infinately curious—and recognized by his peers as an industry technical leader. He was awarded three patents, published 14 papers on metallurgical engineering and chemical engineering topics, and presented at national and international conferences. His technical and community service work was recognized in 2012 when he received the CITGO Presidential Award.

Are you maximizing your ASM membership?

GROW YOUR PERSONAL AND PROFESSIONAL NETWORK THROUGH ASM INTERNATIONAL

- Local Chapters
- Online Communities
- ASM Membership Directory
- Volunteer Opportunities

LEARN MORE ABOUT YOUR
MEMBERSHIP BENEFITS

www.asminternational.org/membership

STRESS RELIEF

3D PRINTER TURNS PLASTIC TRASH INTO PERFECT PIPES

Over the past year, Deakin University scientists, Australia, in partnership with Plan International Australia, developed an innovative technology capable of 3D printing plumbing and sanitation supplies using discarded plastics. The team returned from the Solomon Islands in March, where the printers were setup in the field and powered with solar energy, despite a week of heavy rain.

After a scavenging trip to collect waste such as discarded keyboards and ink cartridges, researchers converted the hard and soft plastics into filament that was fed into a solar-powered 3D printer. Then, working with volunteers from local villages to identify leaks in rural water supply systems, the team measured the pipes, designed replacement components, and 3D printed the parts in hard plastics. The team also used soft plastics to print seals for leaking taps.

"It was amazing to get outside the lab environment and test our equipment in the middle of the jungle," says Mazher Mohammed, senior research fellow. "In parts of the Solomon Islands, there is a significant need for customized sanitation products. We saw mismatched pipes everywhere, bandaged up with car inner tubes, bamboo, and cloth. Some taps were leaking the equivalent of a bucket of water every few minutes." The Deakin team made numerous repairs using the repurposed plastic and proved their concept in the field. Further projects are in the works. www.deakin.edu.au.



Solar-powered 3D printers designed to reuse plastic waste were successfully tested in the Solomon Islands. Courtesy of Wikimedia Commons/HugoTagholm.

CLASSIFIED

Heat Treat Machinery Maintenance Leader

LEAD A MAINTENANCE TEAM IN OUR HEAT TREAT DIVISION! Are you a confident, responsible, independent decision maker with a sense of urgency in getting tasks completed? **Come lead our team!**

GENERAL: Responsible for all machinery maintenance duties as assigned in heat treat, mechanical, electrical, hydraulic and pneumatic systems in complex equipment.

MINIMUM QUALIFICATIONS: High school diploma or equivalent; extensive formal technical education and training; and demonstrated proficient performance of all Class B and C Heat Treat Machine Maintenance essential duties.

ESSENTIAL DUTIES:

- Maintain heat treat machinery and furnaces, and keep in good operating condition.
- Assist in all phases of new equipment installation.
- Troubleshoot heat treat machinery and furnace performance problems, plan repair methods, and order parts.
- Schedule heat treat servicing and maintain system records.
- Wear personal protective equipment and follow safety instructions.

Apply by visiting www.modernind.com and clicking on Employment, or by mailing to:

Modern Industries Inc.
613 West 11th Street, Erie, PA 16501

CLASSIFIED

Heat Treat Quality Engineer

LOOKING FOR A CAREER OPPORTUNITY? Are you a self-starter who can work efficiently in a fast-paced environment, using your technical abilities to produce carefully thought-out results? **Join our team!**

BENEFITS: A competitive salary, one of the best health care plans (including medical, dental, and vision insurance), long-term disability, life insurance, 401(k) with company match, 11 paid holidays, paid vacation, and tuition reimbursement.

ESSENTIAL DUTIES:

- Lead process development projects and product introduction projects.
- Lead PPAP development and approval process.
- Resolve product quality issues with customers.
- Ensure completeness of furnace system accuracy tests and temperature uniformity surveys.
- Act as divisional Quality Systems assessor and lead auditor in IATF 16949 and Nadcap accredited division.
- Accompany customer and third-party audits, and ensure corrective actions are implemented.

MINIMUM QUALIFICATIONS: Bachelor's degree in a technical discipline, with materials science or engineering strongly preferred. Two years of job-related experience as a quality professional or project manager strongly preferred. Proficient with current computer software.

Apply by visiting www.modernind.com and clicking on Employment, or by mailing to:

Modern Industries Inc.
613 West 11th Street, Erie, PA 16501



NEW

ASM Digital Course Mechanical Properties and Their Measurement

From our most popular course Metallurgy for the
Non-Metallurgist®

Dive into the world of mechanical properties and testing with the self-guided, ASM Digital Course, Mechanical Properties and Their Measurement.

The rich visuals, narrated animations, demonstration videos, and interactive quizzes allow you to gain a deeper understanding of this vital topic.

By completing the digital course, you will learn:

- Tensile Testing
- Hardness Testing
- Creep Testing
- Fatigue Testing
- Impact Toughness

Price:

Members-\$275

Non-members-\$295

1.5
PDH

Learn more and register for the course:
bit.ly/ASMMechanicalProperties



Education

ADVANCED MATERIALS & PROCESSES EDITORIAL PREVIEW

MAY/JUNE 2018

Automotive Materials

Highlighting:

- Overcoming Barriers of Magnesium Rolling
- Evolution of Aluminum Automotive Sheet
- Trends & Outlook for Materials Science

Special Supplement:

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

Bonus Distribution:

- Thermal Processing in Motion (with IFHTSE)
June 5-7, Spartanburg, S.C.

Advertising closes April 5

JULY/AUGUST 2018

Materials in Sports & Recreation

Highlighting:

- Specialized Materials for Sporting Goods
- Ethical Considerations for Sports Materials
- ASM Annual Event Show Preview

Special Supplement:

- *International Thermal Spray and Surface Engineering* newsletter covering coatings for energy and power generation applications.

Advertising closes June 6

Subscriptions/Customer Service:

800.336.5152 ext. 0

MemberServiceCenter@asminternational.org

Sales Staff:

AM&P/iTSSe/HTPro/ASM Web Media

Erik Klingerman, National Sales Manager

440.338.5151 ext. 5574

erik.klingerman@asminternational.org

Affiliate Sponsorships:

Kelly Thomas, CEM.CMP, National Account Manager

440.338.1733

kelly.thomas@asminternational.org

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 U.S.A.; tel: 724-537-3131; fax: 724-537-3151
Email: admin@wmtr.com; Web: www.wmtr.com.

WMT&R LTD. Westmoreland Building, 5 Beaumont Road, Beaumont Road Industrial Estate Banbury, Oxon, OX16 1RH 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

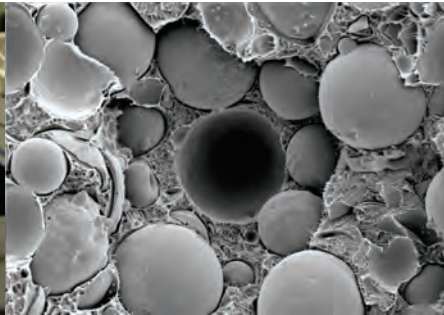
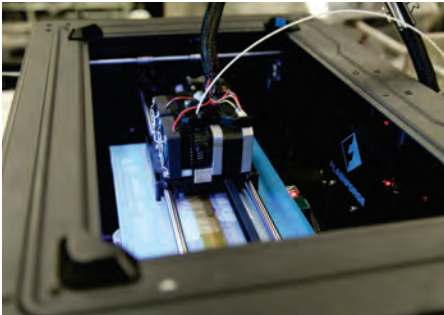
journals-ny@springer.com

AD INDEX

Advertiser	Page
Allied High Tech Products Inc.	BC
Applied Testing Systems	9
Epsilon Technology Corp.	32
Instron	27
LECO Corp.	11
Mager Scientific Inc.	5
Nanovea Inc.	IFC
NSL Analytical Services Inc.	23
Thermo-Calc Software AB	IBC
Tinius Olsen Inc.	24
Westmoreland Mechanical Testing & Research Inc.	71

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



Left, a commercial 3D printer operates with syntactic foam filament developed at the NYU Tandon School of Engineering. Right, syntactic foam composite under high magnification reveals uniformly distributed hollow spheres in a high-density polyethylene matrix.

NYU TEAM CREATES PRINT-READY SYNTACTIC FOAM

Materials scientists at the NYU Tandon School of Engineering are working to bring syntactic foam technology to 3D printing. Syntactic foams are among a special class of composites that incorporate hollow or low-density microspheres in a metal, ceramic, or polymer matrix. They find wide use in aerospace and undersea applications due to their extraordinary buoyancy and strength. One of the motivations for NYU's work is that today's syntactic-foam structures leave significant room for improvement through the elimination of joints and seams and the risks and constraints they impose.

Before NYU researchers could begin assessing the potential of printed foam parts, they had to develop a suitable filament that would work on ordinary fused-filament printers. The team investigated several formulations, ultimately settling on a high-density polyethylene matrix filled with microspheres extracted from recycled fly ash.

Getting the proportions right proved to be a challenge because the microspheres are easily crushed during the mixing process and have a tendency to clog printer nozzles. Through trial and error, the team found that a blend of approximately 40 wt% fly-ash

particles provides the best combination of material properties and printer performance.

As may be expected, part quality is sensitive to process variables such as printer speed, layer thickness, nozzle temperature, and cooling conditions. However, the team proved that once a machine is dialed in, it can print syntactic foam components that compare favorably to their injection molded counterparts in terms of tensile strength, elastic modulus, and other properties. engineering.nyu.edu.

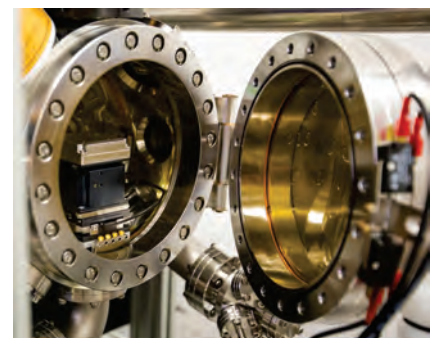
X-RAY SHEDS NEW LIGHT ON AM PROCESS

Researchers at the Department of Energy's SLAC National Accelerator Laboratory are using one of the most powerful instruments in the world to better understand how metal powders respond to the intense heating and cooling cycles associated with additive manufacturing. Working in collaboration with scientists from Lawrence Livermore and Ames labs, the SLAC team is investigating the selective laser melting (SLM) process, using x-ray microscopy to capture melt, flow, and resolidification dynamics and whatever insights they provide on how to control microstructure and prevent formation of pits and other flaws.

Prior attempts to correlate SLM dynamics with part quality have been

limited by an inability to see below the surface of the powder, making it impossible to precisely determine melt depth as each new layer is added. Thermal imaging once offered hope, but it does not capture enough information to identify how and why flaws originate. In contrast, the high flux, penetrating beam from SLAC's hard x-ray, synchrotron light source illuminates the entire depth of the metal powder, giving scientists a detailed, real-time view of melt dynamics.

SLAC researchers are leveraging this x-ray power in two ways—to generate high-resolution images showing what happens as build layers accumulate, and to analyze changes in the atomic structure of the metal during melting and cooling intervals. Following their initial studies on SLM, researchers plan to investigate directed energy deposition (DED) processes, in which metal powder or wire is melted as it is being laid down. DED printers excel at producing complex geometries and are especially useful for making repairs. slac.stanford.edu.



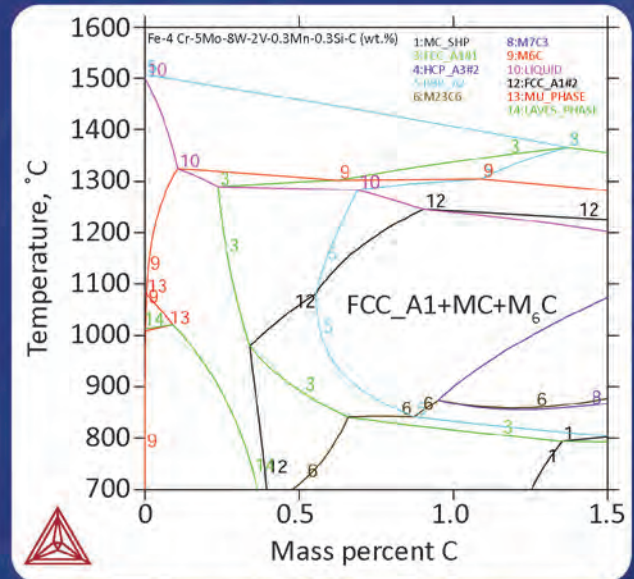
X-ray characterization chamber contains a build platform where SLAC researchers conduct selective laser melting experiments on metal powder while capturing detailed images using x-ray light.

Thermo-Calc Software

Powerful Software for Thermodynamic and Diffusion Calculations

Software:

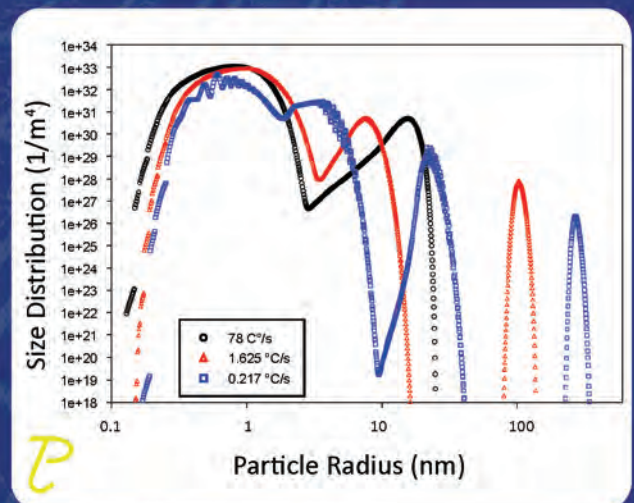
- ✓ **Thermo-Calc** for thermodynamics and phase equilibria in multicomponent systems
- ✓ **DICTRA** for modelling diffusion controlled transformations
- ✓ **TC-PRISMA** for modelling precipitation kinetics
- ✓ **Software development kits** for linking Thermo-Calc to your own software codes
- ✓ **Over 30 Databases** for thermodynamic and mobility applications



Calculation of an isopleth

Benefits:

- ✓ **Predict** what phases form as a function of composition, temperature
- ✓ **Reduce** costly, time-consuming experiments
- ✓ **Base decisions** on scientifically supported predictions and data
- ✓ **Shorten** development time and accelerate materials development while reducing risk
- ✓ **Improve** the quality and consistency of your products through deeper understanding of your materials and processes



Prediction of size distribution for Udimet 720Li at different cooling rates

Thermo-Calc 2018a now available:

Visit our website to learn about the new features and databases in the latest release
www.thermocalc.com/release

Email: info@thermocalc.com

www.thermocalc.com

Celebrating **35 Years** of Providing
Quality Metallographic Sample Preparation
Equipment & Consumables!



2376 E. Pacifica Place
Rancho Dominguez, CA 90220

310.635.2466 Worldwide
800.675.1118 Canada / US

info@alliedhightech.com