JANUARY 2016 | VOL 174 | NO 1

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

ASM INTERNATIONAL

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ADVANCED MANUFACTURING
3D PRINTING BLASTS OFF

ASM INTERNATIONAL


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20X/0.45
∞/0 WD 1.06
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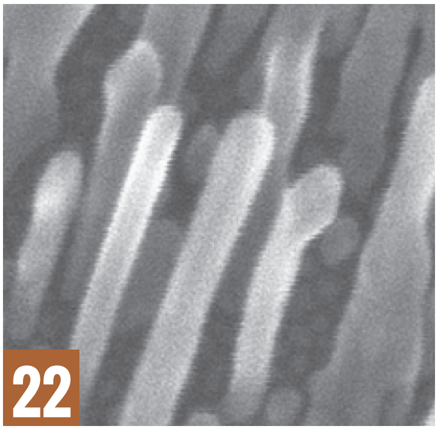
On The Cover:

Orion's Exploration Flight Test 1 launched on a Delta IV Heavy rocket on December 5, 2014. Courtesy of NASA.



ADVANCED MATERIALS & PROCESSES

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FEATURES

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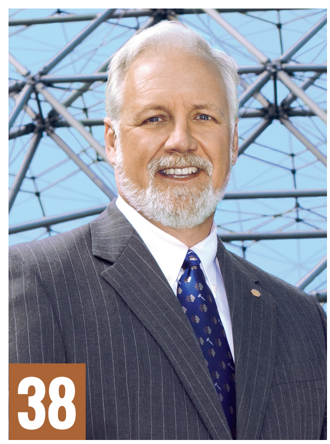

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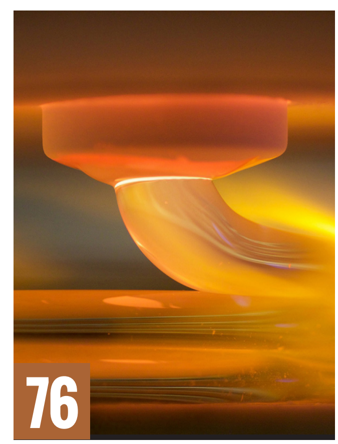

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TRENDS

INDUSTRY NEWS

DEPARTMENTS

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ADVANCED MATERIALS & PROCESSES

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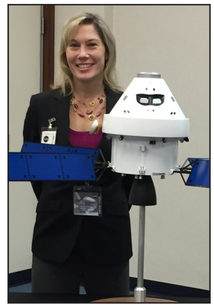
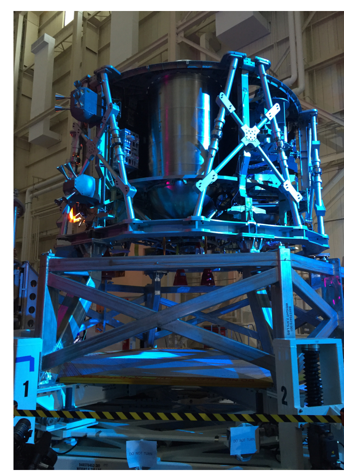
2016: FROM ISM TO ION



Welcome to 2016! We hope you have all enjoyed a restful holiday season and that your new year is off to a good start. As a word watcher, one of my favorite things is to see what the dictionary companies announce as their “Word of the Year.” For 2015, Merriam-Webster declared the suffix “ism” as its 2015 pick. Words such as socialism, fascism, racism, and terrorism received the highest traffic spikes on the company’s website in correlation with the year’s biggest news stories. It was a heavy year indeed. Looking ahead, it would be nice if we could go from “-ism” to “-ion,” as in words like education, imagination, innovation, inspiration, and another recent favorite—Orion.

Speaking of Orion, I had the privilege of attending a media event at NASA Glenn Research Center’s Plum Brook Station in Sandusky, Ohio, in late November. Over the next few months, the facility will run experiments on the newly arrived, full-size test version of Orion’s service module, provided by the European Space Agency (ESA). The module will provide in-space propulsion, as well as power, air, and water for astronauts. Test engineers will use a large vibration table and acoustic chamber to replicate the shaking and noise the module will experience as it enters space. A solar array deployment test and pyrotechnics will also be used to simulate shock loads the module will face during separation from the Space Launch System rocket.

After listening to NASA, ESA, Airbus, and Lockheed Martin dignitaries speak and touring the Plum Brook facility, my colleague and I had the same takeaway. With all of the darkness and destruction taking place around the globe due to various “isms,” it was truly inspiring to learn about international teams of people from different companies and countries working together to build something in the name of science and humanity.



Test version of Orion’s service module at NASA’s Plum Brook Station.

You’ll notice that, coincidentally, Orion’s Exploration Flight Test I is this month’s cover image. One of the interesting aspects of Orion is its use of several noncritical 3D-printed components. Our story covers additively manufactured (AM) spacecraft vents, courtesy of Lockheed Martin. At the Plum Brook event, I had the chance to speak with Mike Hawes, Lockheed’s program manager for Orion. He emphasized the need to develop non-flight-critical AM parts for space applications to help pave the way for more complex, flight-certified part development.

In other AM news, be sure to check out our latest department page—3D PrintShop. With so much happening these days, and covering the topic in nearly every issue, we decided to dedicate our final magazine page to highlighting a few of the most newsworthy AM developments. If you’re working on anything interesting, we’d love to hear about it. We wish all of you a happy and productive 2016!

F. Richards

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These *what ifs* are the motivating drivers pushing predictive maintenance technology to the forefront of product development and maintenance strategies for industries across the globe. And, in the near future, customers are going to expect all heat treatment furnaces to be capable of leveraging the Internet of Things to perform such analysis.

Currently in the thermal processing industry, when a heat treatment furnace breaks, the result is clear: production comes to a grinding halt and the personnel necessary to resolve the issue might not be readily on hand. As a result, companies are faced with unplanned downtime until the problem is resolved, potential overtime wages for the necessary personnel, the cost of rushing critical part shipments and more.

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MARKET SPOTLIGHT

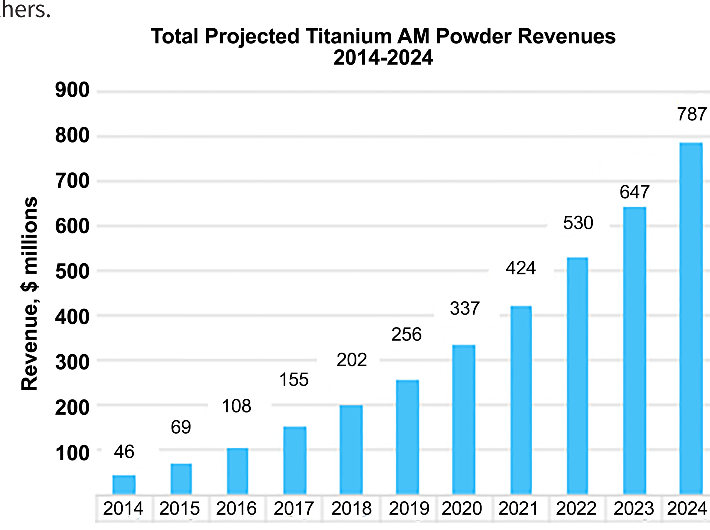
TITANIUM USE IN ADDITIVE MANUFACTURING TO REACH $330 MILLION BY 2020

Titanium Opportunities in Additive Manufacturing, a new report from SmarTech Markets Publishing, Charlottesville, Va., explores opportunities for titanium and its alloys in this growing industry. Titanium is becoming one of three premier metal groups used for additive manufacturing (AM) systems, sought after for its high strength to weight ratio, biological inertness, and other desirable properties when combined with additive processes. Analysts project revenues for titanium powders used in AM to reach more than $330 million by 2020, corresponding to 730,500 kg (1,610,477 lb).

The report provides 10-year forecasts for titanium—in both $ millions and kg—used in aerospace, automotive, jewelry, dental, medical, service bureaus, and other industries. Additional applications discussed include heavy equipment, marine, energy, and consumer products. Projections provide breakouts by Ti-6Al-4V and other alloys. The report also profiles leading companies within the industry, including 3D Systems, Arcam, Concept Laser, EOS, GE, GKN Hoeganaes, Honeywell, Optomec, Praxair, Puris, SLM Solutions, and others.

AM titanium will continue to be used where premium performance is required, say analysts. In the short term, the supply chain for AM titanium powder will continue to be controlled by smaller specialty providers, although larger global metal firms are beginning to enter the market. The vast majority of Ti powder used in current AM systems falls into two types—Ti-6Al-4V and commercially pure titanium.

Titanium is being explored for smaller structures in aircraft engines such as brackets and housings, but may expand into larger structural components to drive demand. By 2020, aerospace is forecast to consume almost 155,000 kg (341,717 lb) of titanium. In addition, titanium has good prospects in medical markets due to bio-inertness and as-manufactured bone ingrowth performance. Current production of titanium implants using AM is growing rapidly, with new products in spine, hip, knee, and other orthopedic areas. Medical applications of AM titanium will account for roughly 274,000 kg (604,067 lb) in 2020 due to this growth. *For more information, visit smartechpublishing.com.*



Source: SmarTech Publishing LLC

FEEDBACK

SILICON CARBIDE GETS DISSED

I just reviewed the article on beryllium space telescope optics in the September issue and immediately wondered why there is no mention of silicon carbide—for example, reaction-bonded Si/SiC composites. Table 1 mentions ULE, aluminum alloy, and magnesium, but not SiC. There is no mention in the text either, unless I missed it. The article is incomplete without such a mention.

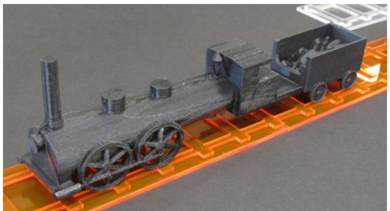
Joe Greene

[Our article traces the development of Be as an optical material that proved to be the best and final choice for the James Webb Space Telescope (JWST) mirrors. We compare it to ULE, the primary mirror material of the Hubble telescope, for which JWST is the successor. The article is not meant to compare optomechanical materials in general. While SiC is an optomechanical material with successful applications of space-based mirrors and structures, it was not seriously considered for JWST mirrors. The reasoning was that SiC could not be fabricated into mirror panels of the required size and weight. The density of SiC is 47% greater than that of beryllium, with obvious ramifications for overall weight. In addition, most types of SiC are a composite of SiC and Si and, as several studies have shown, exhibit dimensional instability when cooled to cryo temperatures.

—Don Hashiguchi, James M. Marder, and Roger Paquin]

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS



Because Zola only described the train engine as having two wheels, the CEID team left the back wheels off of their model as well.

ALL ABOARD THE LITERARY TRAIN

Yale University, New Haven, Conn., assistant French professor Morgane Cadieu and her students created a 3D-printed train based on descriptions from Emile Zola's 1890 novel "La Bête Humaine" ("The Beast Within"). To accomplish her project, Cadieu turned to Yale's Center for Engineering Innovation & Design (CEID). She found that creating a literary train would require both tools and translation. A blueprint of the model could be efficiently drawn up using the CEID's computer-aided design software, at which point it could be rapidly produced on the CEID's 3D printers.

The final product turned out more realistic than Cadieu anticipated. "What we didn't expect is that if you look closely at trains from the end of the 19th century, they really look similar—the chimneys are this high," she says. "And yet Zola's intense focus on small parts of the train—the fog, the sound, the light—could easily be interpreted another way, producing a lot of different trains. For that reason, we decided to connect this 3D train body only through the 2D 'fog' of literary descriptions in between the cars and also above it." In that sense, the model train took on one more symbolic meaning—as the connecting force between literature and science. *For more information: Morgane Cadieu, 203.436.2596, morgane.cadieu@yale.edu, www.yale.edu.*

Top view of the monument via the total station surveying tool, captured by placing a smartphone camera near the eyepiece. Courtesy of NOAA.

WASHINGTON MONUMENT RECEIVES NEW HEIGHT VALUE

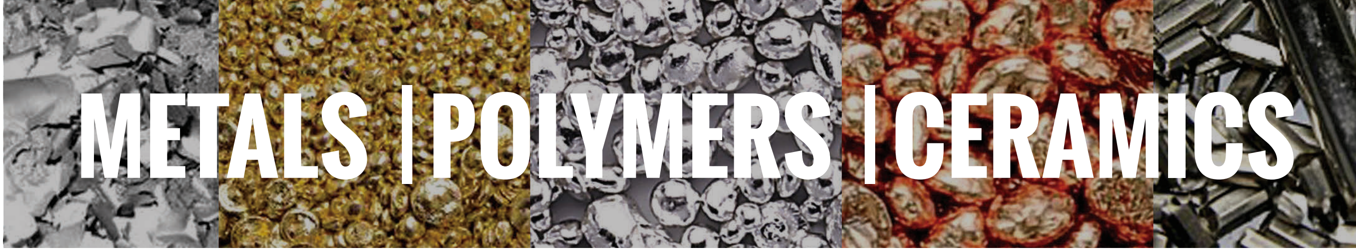
Using new international measurement standards and technology not available in the past, the National Oceanic and Atmospheric Administration's National Geodetic Survey (NGS) has calculated the official architectural height of the Washington Monument to be 554 ft, 7.344 in.—a highly precise measurement that makes it eligible for inclusion in official registers of the world's tallest structures. The measurement was made using certification standards of the Council on Tall Buildings and Urban Habitats and was finalized in December 2014. Although the newly established architectural height differs from the historical height of 555 ft, 5.125 in., neither the starting point nor the so-called "standard deviation" used for the original 1884 measurement is known, making comparison of the two measurements difficult. The new value provides a baseline to determine if the height of the monument is changing in any way. *noaa.gov.*

SCI's Advancing Mortuary Science Education grant program illustrates how 3D technology can be used in mortuary science education to meet community needs.

RESTORING CORPSES WITH 3D PRINTING

The Mortuary Science Program at Wayne State University, Detroit, received a $10,000 grant to support its 3D technology project from Service Corp. International (SCI). Titled "3D Printing in Restorative Art," the initiative seeks to develop an interactive learning module for mortuary science students. The goal is to create anatomical models for laboratory learning and prosthetics for body and feature restoration on deceased individuals. The project illustrates how 3D technology can be used in mortuary science education to meet community needs. Specific objectives include developing a set of core competencies students need to successfully reconstruct body parts, providing a model for other schools. *For more information: 313.577.1202, evely@wayne.edu, www.wayne.edu.*

Are you working with or have you discovered a material or its properties that exhibit OMG - Outrageous Materials Goodness?
Send your submissions to Julie Lucko at julie.lucko@asminternational.org.



METALS | POLYMERS | CERAMICS

Meteoroid image. Courtesy of NASA, ESA, M.A. Garlick (space-art.co.uk), University of Warwick, and University of Cambridge.

METEORITE MAGNET IS RARE-EARTH FREE

Researchers from Tohoku University, Japan, have succeeded in producing a completely rare-earth free, high-quality FeNi magnet. Since the 1960s, it has been widely known that small amounts of FeNi magnets are included in natural meteorites (in an extreme equilibrium state) formed during a cooling period of billions of years. Until recently, it was impossible to produce the magnets artificially in a short time due to the extremely slow diffusion rate of elements around the formation temperature. Now, the team reports producing the magnet by using high atomic diffusivity at low temperatures, when crystallizing from the amorphous state. The effect is like travelling in a time machine—the time scale for magnet formation is reduced from billions of years to just a couple of days. *www.tohoku.ac.jp/en.*

LIGHTWEIGHT PLASTIC HELMET PROTECTS SOLDIERS

DSM Dyneema, the Netherlands, recently collaborated with Morgan Advanced Materials, UK, to develop a major application for Dyneema Force Multiplier Technology in combat helmets. LASA helmets reportedly feature superior ballistic performance in addition to flame retardancy, dynamic deflection, and structural requirements in a lightweight package.

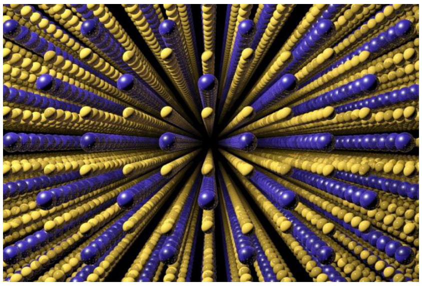
The LASA helmet series includes two styles—the full-cut AC914 helmet for combat operations and the high-cut AC915 assault helmet for special operations, which allows greater situational awareness. The material, which provides ballistic protection, is one component of the ultra-lightweight hybrid composite that allowed Morgan's developers to reduce areal density of the helmet shell by 30%. As a result, the full-cut design weighs only 1.2 kg, while the high-cut model weighs just over 1 kg. This lightweight design offsets the burden of attachments such as night vision goggles and increases comfort and freedom of movement. *morgan-advancedmaterials.com, dsm.com.*

Morgan's LASA AC914 helmet with Dyneema Force Multiplier Technology. Courtesy of Morgan Advanced Materials.

BRIEFS

ELIX Polymers, Spain, created a natural fiber reinforced acrylonitrile butadiene styrene (ABS)—ELIX ECO ABS-NF thermoplastic. Company sources say it is well suited for injection molding applications and specific extrusion processes, delivering an aesthetic value to final parts. The material can be processed without having to modify machines and offers a number of key benefits including high stiffness, heat resistance, low molding shrinkage ratios, low emissions, and weight reduction compared to glass fiber reinforced ABS. *elix-polymers.com*

A new study by researchers at **Texas A&M University,** College Station, and **Los Alamos National Laboratory,** N.M., has led to a new principle to control the macroscopic thermal expansion response of bulk materials, including obtaining zero thermal expansion metals. The key to obtaining a tailored thermal expansion coefficient is the alignment of the alloy's atoms to harness the natural thermal expansion and contraction at the atomic level. *tamu.edu, lanl.gov.*



Using high-performance computing, ORNL researchers are modelling the atomic structure of new alloys to select the best candidates for physical experimentation.

SUPERCOMPUTER AND ICME DRIVE ALLOY DESIGN

A research team from Oak Ridge National Laboratory, Tenn., FCA US LLC, Auburn Hills, Mich., and Nemak, Mexico, is working together to create lightweight powertrain materials that will help the automotive industry meet its 54.5 mpg target by 2025. The ORNL-led project is part of an initiative from DOE's Vehicle Technologies Office.

The team is using integrated computational materials engineering (ICME) to speed development of new high-temperature aluminum alloys for automotive cylinder heads. ICME enables researchers to tailor new alloys at the atomic level to achieve desired properties such as strength and ease of manufacturability. ORNL is breaking new ground by scaling ICME to run on DOE's Titan supercomputer, the second fastest computer in the world. Using Titan's speed and parallel processing power, researchers can predictively model new alloys and select only the best candidates for further experimentation. This predictive capability dramatically reduces the time, energy, and resources devoted to casting trial alloys.

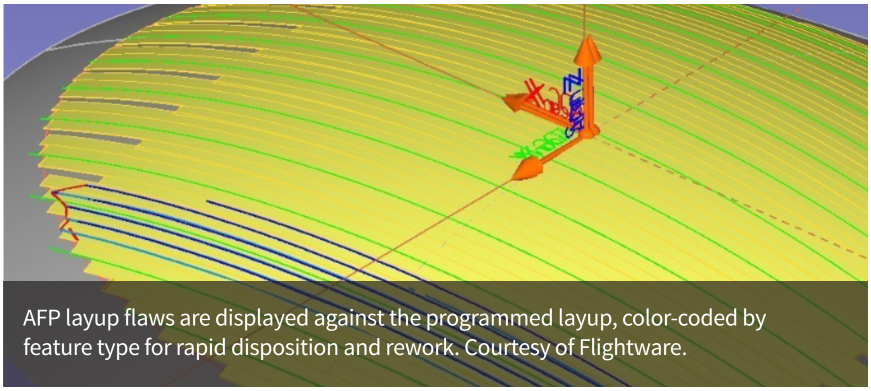
The team is also verifying the computational models through atomic scale imaging and analytical chemistry measurements. ORNL's scanning transmission electron microscopy and atom probe tomography allow researchers to identify and examine the location and chemistry of each atom in the alloy matrix, precipitates, and the interfaces between them. In addition, ORNL and collaborators are creating a database to capture their aluminum alloy discoveries. *ornl.gov, fcanorthamerica.com, nemak.com.*

METAL POWDERS COULD REPLACE FOSSIL FUELS

Metal powders produced using clean primary energy sources could provide a more viable long-term replacement for fossil fuels than other widely discussed alternatives, such as hydrogen, biofuels, or batteries, say researchers at McGill University, Canada. The novel concept uses tiny metal particles—similar in size to fine flour—to power external combustion engines. The idea takes advantage of an important property of metal powders: When burned, they react with air to form stable, nontoxic solid-oxide products that can be collected relatively easily for recycling.

Iron could be the primary candidate as millions of tons of iron powders are already produced annually for various industries. Iron is also readily recyclable with well-established technologies, and some novel techniques can avoid the CO_2 associated with traditional iron production from coal. *www.mcgill.ca.*

TESTING | CHARACTERIZATION



AFP layup flaws are displayed against the programmed layup, color-coded by feature type for rapid disposition and rework. Courtesy of Flightware.

REAL-TIME, AUTOMATED LAYUP INSPECTION TAKES OFF

The Defense Logistics Agency (DLA) awarded a contract to Flightware Inc., Guilford, Conn., to develop a real-time, automated inspection system for use with Automated Fiber Placement (AFP) equipment that makes large composite parts. The capability allows these machines to operate significantly faster, enabling cost savings and increased production. Most large and high-rate composite aircraft structures are built using AFP machines. While these machines quickly place material into a mold, the operation is stopped after every ply to allow human inspectors to validate the machine layup. This is repeated dozens to hundreds of times for a single part. In many cases, the time to inspect the layup by teams of workers with flashlights is longer than the machine layup time. As a result, machines are only productive less than 30% of the time.

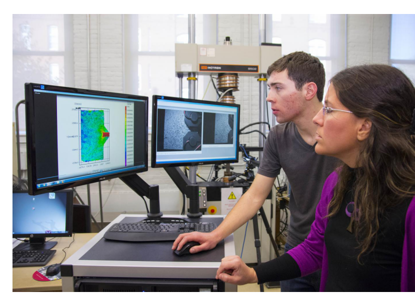
Flightware's Real Time Automated Ply Inspection (RTAPI) program builds on work previously performed under a development contract with NASA. Using commercial sensors and custom software, AFP layups are scanned and compared with programmed instructions created from the part model. Deviations in excess of allowed tolerances are automatically detected and presented to operators for repair.

The first generation Automated Ply Inspection (API) system consists of hardware and software designed to operate in a secondary inspection step after layup, mimicking today's human inspection process. Under the DLA program, API is being modified to work in real time, in parallel with layup being produced by the AFP machine in real time. The new system eliminates the serial inspection step, enabling cost savings on a wide variety of military and civilian aircraft parts. *dla.mil.*

WPI INVESTIGATES AIRCRAFT CRACK FORMATION

A research team at Worcester Polytechnic Institute (WPI), Mass., is studying how stress and fatigue cause microscopic damage to form in metal components. That knowledge will then be translated into new tools to detect and monitor crack formation in aircraft components. Funding comes from the U.S. Army Research Office through the Defense University Research Instrumentation Program (DURIP).

The team will conduct testing and characterization studies to understand and monitor how tiny cracks are initiated and then grow in metal components as they are subjected to cyclic strains and stresses similar to those that wings, fuselages, and other aircraft components experience in service. Using a new imaging system, researchers are able to view the initiation and propagation of cracks at the nanometer scale while metal samples are stressed in a servo-hydraulic testing machine. As a result of this research, the team aims to develop new lightweight metal alloys that are more resistant to cracking. *wpi.edu.*



Professor Diana Lados (right) and Ph.D. candidate Anthony Spangenberger analyze deformation results from a fatigue damage evaluation test performed on an aircraft aluminum alloy.

BRIEF

LECO Corp., St. Joseph, Mich., recently opened its European Application and Technology Center in Berlin. The facility is equipped with the latest LECO analytical technology, with nearly 25 instruments available for customer demonstrations and application work. The facility also features lecture rooms for training employees and customers. *leco.com.*

CORPORATE SPOTLIGHT

MASTER BOND

COMPANY DESCRIPTION

Master Bond is celebrating our 40th anniversary by continuing our mission to develop cutting edge adhesives, sealants, coatings and potting/encapsulation systems utilizing advanced technology for challenging applications. We make customer support a priority in the adhesive selection process. Our technical specialists have decades of experience and will work with you, one-on-one, from the design, prototyping and manufacturing stages to help you meet your requirements. Master Bond will custom formulate products with specific performance properties to meet unique application requirements. This may include the redesign of an existing product or the development of a new composition. We also offer replacements for competitors' discontinued products.

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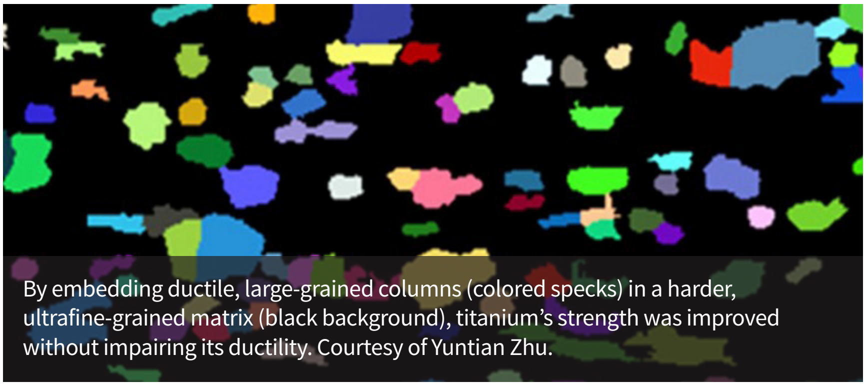
PROCESS TECHNOLOGY



By embedding ductile, large-grained columns (colored specks) in a harder, ultrafine-grained matrix (black background), titanium's strength was improved without impairing its ductility. Courtesy of Yuntian Zhu.

MAKING METALS BOTH STRONG AND DUCTILE

Researchers at North Carolina State University, Raleigh, and the Chinese Academy of Sciences, Beijing, developed a technique to make titanium stronger without sacrificing ductility. The new technique manipulates the grain size to give the metal the strength of ultrafine-grained titanium with the ductility of coarse-grained titanium. Asymmetric rolling was used to process a 2-mm-thick sheet of titanium. The sheet passes between two rollers that apply pressure to each side of the sheet, but one of the rollers rotates more quickly than the other. This not only presses the sheet thinner, but also creates a sheer strain due to the different roller speeds. The crystal structure within the titanium moves forward faster on the side of the fast roller than the other, effectively distorting and breaking down the crystalline structure, creating small grains.

Researchers repeated the process until the metal was 0.3 mm thick, then exposed the sheet to 475°C for five minutes. This allowed some of the small grains to consume each other and form large grains. This second process creates a patchwork quilt of small and large grains. The resulting material is as strong as the small-grained titanium because the surrounding layer of small grains makes it difficult for the large grains to deform. The material also retains the ductility of the large grains, because once enough strain is applied the small and large grains want to deform at different rates. *For more information: Yuntian Zhu, 919.513.0559, ytzhu@ncsu.edu, www.ncsu.edu.*

LINCOLN ELECTRIC TO BUILD NEW WELDING CENTER

The Lincoln Electric Co., Cleveland, will invest $30 million in a new Welding Technology Center on its Euclid, Ohio, campus. The center will focus on training welding educators and industry leaders to address the rising demand for welding education and career pathways in welding and advanced manufacturing. Lincoln Electric will also dedicate resources to support welding training for veterans at this facility.

Construction will begin early this year with an opening anticipated in 2017, marking the centennial anniversary of Lincoln's legacy welding school, the longest-running welding school in the U.S. The new 130,000-sq-ft center will double Lincoln's welding education capacity to 180 welding booths and will include high-tech classroom and seminar spaces. It will also showcase the company's latest technologies and solutions into a comprehensive welding curriculum. *lincolnelectric.com.*

BRIEFS

New Star Metals, Burr Ridge, Ill., changed its name to **Material Sciences Corp.** (MSC). Founded in 2010, New Star added the original MSC to its list of acquisitions in March 2014. MSC joined several other business units as a global supplier of metal products and processing, engineering services, and supply chain management to the automotive, construction, and consumer products industries. *materialsciencescorp.com.*

MSC Material Sciences Corporation

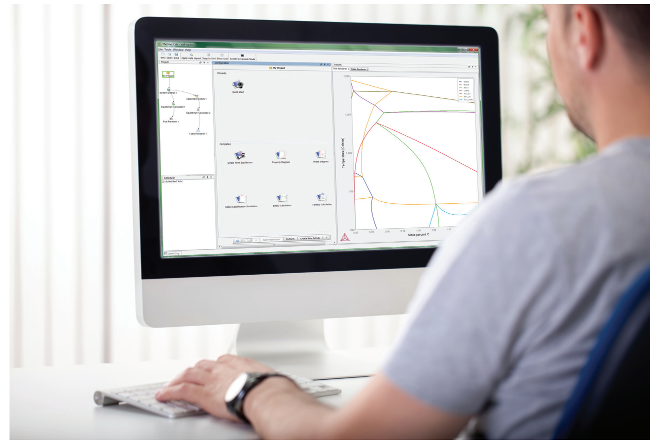
Private equity firm **MidOcean Partners,** New York, completed the sale of **Noranco Inc.,** Toronto, to **Precision Castparts Corp.,** Portland, Ore., on October 30, 2015. Noranco is a supplier of complex machined components and assemblies for mission-critical landing gear, aerostructures, and aero engine applications. *noranco.com, precast.com.*

CORPORATE SPOTLIGHT

THERMO-CALC SOFTWARE

The use of modelling and simulation tools in materials R&D is growing rapidly as highlighted by the publication from the National Academies on Integrated Computational Materials Engineering (ICME) in 2008, and the announcement of the Materials Genome Initiative (MGI) in 2011.

As a leading developer of software and databases for calculations involving computational thermodynamics and diffusion controlled simulations, Thermo-Calc Software is a foundational component of any ICME/MGI framework. For more than 30 years, Thermo-Calc has been used within industry, government research labs and academia to gain insight into problems related to materials science and engineering and is now licensed by more than 1,000 of the world's top companies, research labs and universities in over 70 countries.



SOFTWARE

In addition to our primary software package, Thermo-Calc users can select add-on packages that extend the functionality of the software.

Thermo-Calc: a powerful tool for performing thermodynamic and phase equilibria calculations for multicomponent systems.

DICTRA: an add-on program used for accurate simulations of diffusion in multicomponent alloys.

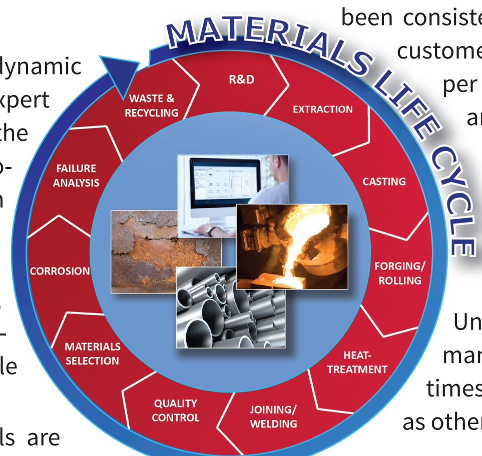
TC-PRISMA: an add-on program for the prediction of precipitation kinetics.

Software developments kits: enable Thermo-Calc to be called directly from the user's own software or from MATLAB.

More information on these products can be found on our website, www.thermocalc.com.

DATABASES

Calculations are based on thermodynamic and mobility databases produced by expert evaluation of experimental data using the CALPHAD approach. More than 30 thermodynamic databases are available which cover a broad range of materials and systems including Fe-based alloys, Ni-, Al-, Mg-, Ti- alloys, solders, oxides and slags, aqueous systems and more. Detailed information on these databases is available on our website, www.thermocalc.com.



Our modelling and simulation tools are used for many different purposes within the lifecycle of a material, from R&D efforts in designing new materials to identifying optimal processing windows, all the way through addressing waste and re-cycling issues. Typical benefits expressed by our customers include:

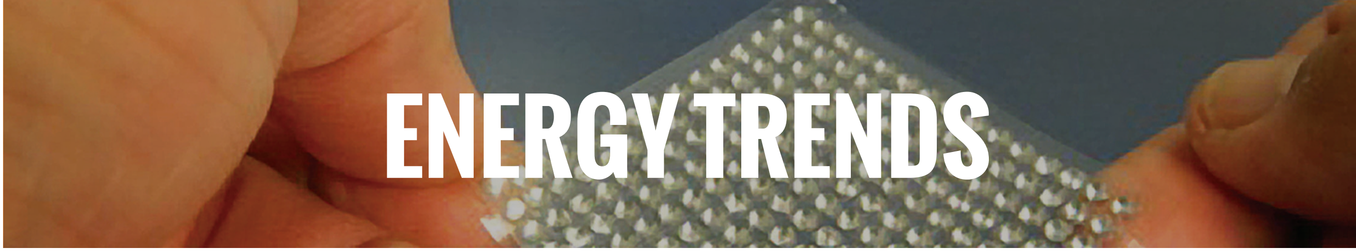
- Reducing the number of costly, time-consuming experiments and testing by making better use of pre-screening/pre-test calculations
- Increasing the value of experiments through deeper understanding of the results
- Defining safe and optimal processing windows in terms of composition tolerances and temperatures
- Basing decisions on scientifically supported models, tools and data
- Shortening development times and bringing products to market faster
- Making predictions that are difficult or even impossible with an experimental approach

REGULAR UPDATES AND SUPPORT

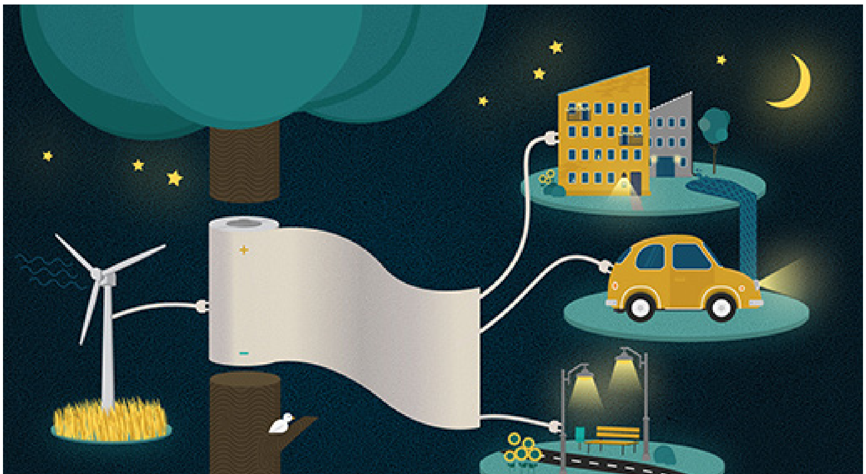
Originally developed in the early 1980s, Thermo-Calc has been consistently updated to satisfy the needs of our customers. Our software are now on a two times per year release cycle, and our main databases are also updated regularly.

Our products are backed by a dedicated technical support team that helps our users get the most from our tools. With representatives in 9 countries around the world and a subsidiary in the United States, local support is available in many regions. Training courses are held two times per year in Sweden and the USA as well as other locations in conjunction with our agents.

Thermo-Calc Software
email: paul@thermocalc.com • web: www.thermocalc.com



ENERGY TRENDS



New material stores energy and can be recharged hundreds of times.

POWER PAPER

Researchers at Linköping University, Sweden, developed a new material consisting of nanocellulose and a conductive polymer that has an outstanding ability to store energy. One sheet of power paper, 15 cm in diameter and a few tenths of a millimeter thick, can store as much as 1 Farad—similar to today's supercapacitors. The material can be recharged in seconds, hundreds of times.

The new material set a world record in simultaneous conductivity for ions and electrons and opens the door to continued development toward even higher capacity. Unlike traditional batteries and condensers, power paper is produced from simple materials, is lightweight, requires no dangerous chemicals or heavy metals, and is waterproof. *For more information: Xavier Crispin, +46 (0)11 36 34 85, xavcr@itn.liu.se, www.liu.se/?l=en.*

VIBRANT BUILDINGS TURN LIGHT INTO ENERGY

Researchers in China developed a new solar-light-absorbing surface that can have almost any design, pattern, and color—useful for turning building facades and roofs into energy-capturing exteriors without sacrificing aesthetics. Because they also use similar materials as existing solar absorbers, this new kind of absorber could lead to wider use of solar thermal technology and greater energy efficiency, says Shao-Wei Wang, Shanghai Institute of Technical Physics.

At the heart of this technology are layered surfaces called solar selective absorbers. The absorbers are covered with multiple layers of transparent dielectric materials, which can reflect light of a particular color. By changing the thickness of these layers, researchers can tune the absorber to reflect light of almost any shade required. Some parts of the absorbing layer can be covered with a thicker transparent dielectric layer than others, allowing researchers to create a single absorber with a rainbow of hues. *http://english.sitp.cas.cn.*

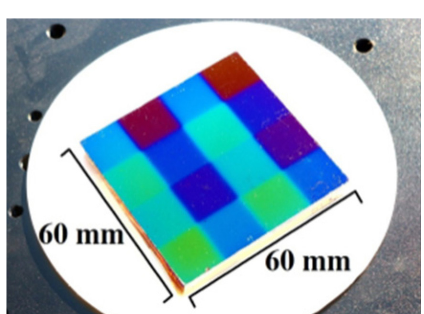


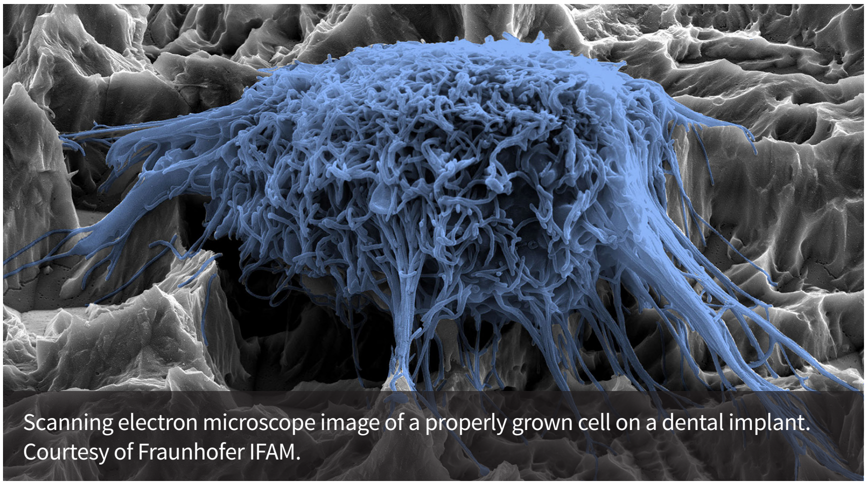
Photo of solar selective absorber array on a glass substrate, taken in direct sunlight.

NANOFASTENERS ENABLE NEXT-GENERATION FUEL CELLS

Professor Hee-Tak Kim at the Korea Advanced Institute of Science and Technology (KAIST) and his team developed a new fastening system that bonds hydrogen and oxygen mechanically rather than chemically, opening the way to development of fuel cell membranes that are less expensive, easier to manufacture, stronger, and more efficient. A pattern of tiny cylindrical pillars was molded on the face of the hydrocarbon membrane. The pillars protrude into a softened skin of the electrode with heat. Next, the mechanical bond sets and strengthens as the material cools and absorbs water. The hydrocarbon membrane is cast using silicone molds.

"This physically fastened bond is almost five times stronger and harder to separate than current bonds between the same layers," says Kim. The new method also appears to offer a way to bond many types of hydrocarbon membranes that, until now, have been rejected because they could not be fastened robustly. This would make these membranes practical for a number of applications beyond fuel cells such as rechargeable "redox flow" batteries. *kaist.edu.*

SURFACE ENGINEERING



Scanning electron microscope image of a properly grown cell on a dental implant. Courtesy of Fraunhofer IFAM.

PLASMA IMPLANT COATING PREVENTS INFECTIONS

To lower the risk of infection and improve the long-term effectiveness of dental implants, researchers at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Germany, developed a new type of implant coating in cooperation with industry partners. The DentaPlas coating helps prevent bacteria growth, allowing the implant to take hold and form a faster and more permanent bond with the jawbone. The new approach combines surface materials that feature both physical and chemical properties. "We have given the DentaPlas coating a rough texture, which promotes cellular growth, in addition to combining it with a hydrophilic plasma polymer coating, which attracts moisture," says Ingo Grunwald at IFAM. Researchers integrated silver nanoparticles into the thin plasma polymer coating, which is no more than 100 nm thick. The silver nanoparticles dissolve over a period of several weeks and during that time they continuously release small quantities of antimicrobial silver ions. *www.ifam.fraunhofer.de/en.html.*

PENGUIN FEATHERS INSPIRE ANTI-ICING COATING

Antarctic penguins live in the bitter cold, where air temperature can drop to -40°C and winds reach speeds of 40 m/s. Although these birds routinely hop in and out of the water in subfreezing temperatures, they manage to keep ice from coating their feathers.

To discover the penguins' anti-icing secret, researchers at University of California, Los Angeles studied penguin feathers, donated by SeaWorld San Diego. Scanning electron microscopy shows that the feathers feature tiny pores that trap air and make the surface hydrophobic. In addition, penguins apply an oil to their feathers, which is

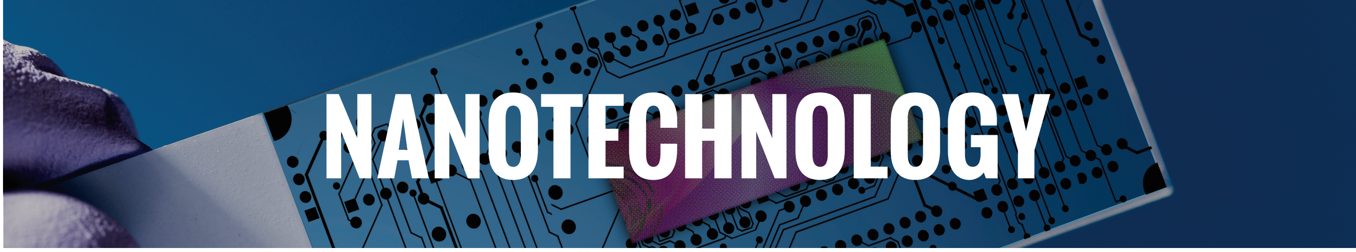
Pirouz Kavehpour poses with a penguin studied by his team to learn about anti-icing tricks.

produced by a gland near the base of their tails. The combination of the nanosized pits and the preen oil makes the feathers superhydrophobic.

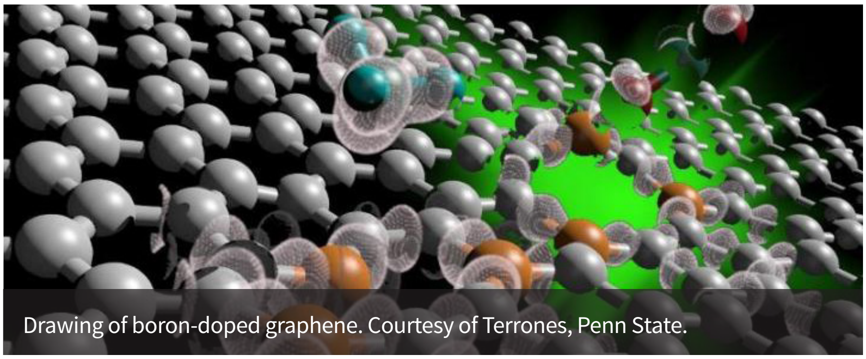
This avian technique could help humans solve some problems with ice. For example, ice on an airplane's wings, flaps, and rudder can alter the aerodynamic properties of the plane and even cause accidents, leading to the need for chemical de-icers. Superhydrophobic surfaces inspired by penguins could be cheaper, longer-lasting, and more environmentally friendly. "It's ironic that a bird that doesn't fly could one day help airplanes fly more safely," says Pirouz Kavehpour, a professor at UCLA. *For more information: Pirouz Kavehpour, 310.825.6494, pirouz@seas.ucla.edu, mae.ucla.edu.*

BRIEF

ASTM International, West Conshohocken, Pa., released a new standard titled *Standard Specification for Electrolytic Plasma Treatment Processing of Conductive Materials.* The specification covers the requirements for cleaning, coating, or surface modification, or combinations thereof, of conductive materials, primarily metals. It covers any conductive material treated or processed by the electrolytic plasma process including products designated as long products, including wire and fine wire; flat-rolled materials; fasteners; connectors; bolts; assemblies; structural materials; hardware items; and medical items. *astm.org.*



NANOTECHNOLOGY



Drawing of boron-doped graphene. Courtesy of Terrones, Penn State.

GRAPHENE BOOSTS DESALINATION EFFICIENCY

The laboratory of Jeffrey Grossman, a professor at Massachusetts Institute of Technology, Cambridge, has demonstrated strong results showing that new filters made from graphene could greatly improve the energy efficiency of desalination plants while potentially reducing other costs as well. At only an atom thick, there is far less friction loss when you push seawater through a perforated graphene filter compared with the polyamide plastic filters that have been used for the last 50 years, says Grossman.

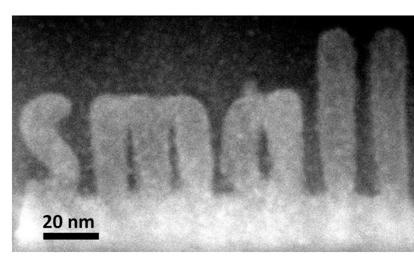
"The process of pumping seawater through filters represents about half the operating costs of a desalination plant. With graphene, we could use 15% less energy for seawater and up to 50% less energy for brackish water," he explains. Another advantage is that graphene filters do not become fouled with biogrowth at nearly the rate that occurs with polyamide filters. In addition, the chlorine used to clean the filters reduces the polyamide's structural integrity, requiring frequent replacement. By comparison, graphene is resistant to the damaging effects of chlorine. *For more information: Jeffrey Grossman, 617.324.3566, jcg@mit.edu, mit.edu.*

BORON-DOPED GRAPHENE ENABLES SUPER SENSITIVE SENSORS

Graphene is known for its remarkable strength and ability to transport electrons at high speed, but it is also a highly sensitive gas sensor. In a study conducted by an international research team, graphene sensors with the addition of boron atoms detected noxious gas molecules at extremely low concentrations, parts per billion in the case of nitrogen oxides and parts per million for ammonia. This translates to 27× greater sensitivity to nitrogen oxides and 10,000× greater sensitivity to ammonia compared to pristine graphene. Researchers from Pennsylvania State University, State College, and colleagues believe these results will enable development of high-performance sensors that can detect trace amounts of many other molecules. These sensors can be used for labs and industries that use ammonia or need to detect nitrogen oxides. *psu.edu.*

USING ELECTRON MICROSCOPES TO BUILD 3D STRUCTURES

Researchers at the Department of Energy's Oak Ridge National Laboratory, Tenn., have developed a unique way to build 3D structures with finely controlled shapes as small as one to two billionths of a meter. The study demonstrates how scanning transmission electron microscopes, normally used as imaging tools, are also capable of precision sculpting of nanometer-sized 3D features in complex oxide materials. By offering single atomic plane precision, the technique could find use in fabricating structures for functional nanoscale devices such as microchips. The structures grow in perfect crystalline alignment, which ensures that the same electrical and mechanical properties extend throughout the whole material. *ornl.gov.*



Researchers use a new SEM technique to sculpt 3D nanoscale features in a complex oxide material. Courtesy of ORNL.

BRIEF

A 4000-sq-ft nanomaterials research laboratory is opening at **Cornell University,** Ithaca, N.Y. The **Center for Nanomaterials Engineering and Technology (CNET)** includes equipment for materials synthesis, physical characterization, and scale-up. The tools can be used to develop and analyze materials for applications including carbon capture and conversion, electrochemical energy storage in batteries, and hydrogels for biomedicine and drug delivery. *cnet.research.engineering.cornell.edu.*

NASA'S ORION CREW VEHICLE SPORTS 3D-PRINTED VENTS

Orion's Exploration Flight Test 1 vehicle used four additively manufactured vent assemblies to equalize pressure between unpressurized portions of the spacecraft and the external environment.

Andrew Clifton* and Roger Taylor III
Lockheed Martin Corp.
Sunnyvale, Calif.

**Member of ASM International*

The Orion Multipurpose Crew Vehicle is NASA's vehicle for human exploration of deep space. Its maiden voyage—Exploration Flight Test 1—was an unmanned flight designed to test the vehicle's main systems, which launched from Kennedy Space Center on December 5, 2014. The trip included two earth orbits followed by reentry at approximately 20,000 mph, subjecting the heat shield to 4000°F. Landing and recovery took place in the Pacific Ocean. Among the technology advancements included on Orion were additively manufactured (AM) vents used as air passages for the unpressurized portions of the spacecraft.

Exploration Flight Test 1 used four vent assemblies to equalize pressure between the unpressurized portions of the spacecraft and the external environment. The assemblies contained the AM housings and integral screens as well as two additional screens that were welded on. Each assembly was then bolted into the vehicle using three mounting flanges. Complete assemblies were roughly the size of a 1-liter water bottle.

Initial design called for a wire mesh to be welded into the housing. Multiple screens were needed for redundancy, and a cylindrical shape was desired due to space limitations inside the vehicle. Because this initial design proved difficult to produce, additive manufacturing was proposed.

PARTS MANUFACTURING

Parts were additively manufactured from a nickel alloy (Inconel 718) using the vendor's recommended procedure. (Note that this was before industry specification ASTM F3055 was available for use.) Each build cycle contained one part and corresponding test coupons. Parts were additively manufactured, stress relieved, hot isostatically pressed (HIP'd), solution treated, and aged. This corresponds with ASTM F3055, Class D, although the processing parameters were not identical. Machining was performed on some surfaces to remove the support structure or to provide a smooth surface for fastener installation. Welding was performed using industry specification AWS D17.1.

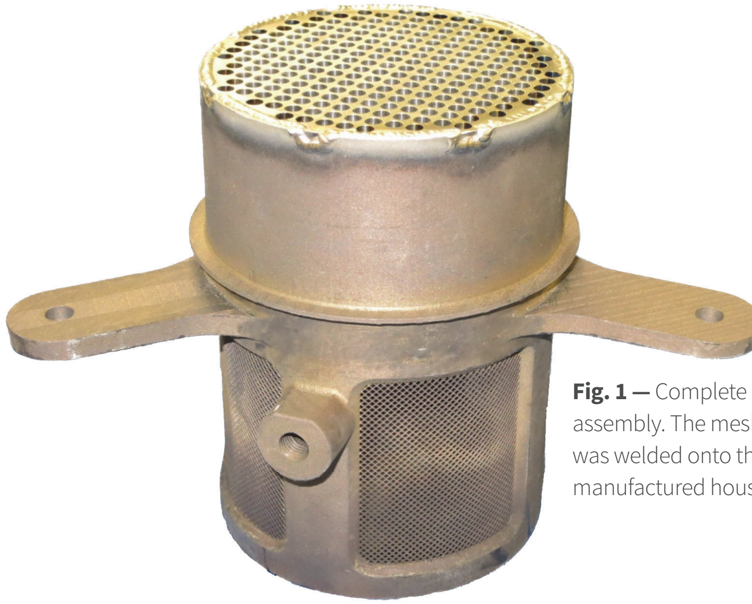


Fig. 1 — Complete passive vent assembly. The mesh on the top was welded onto the additively manufactured housing.

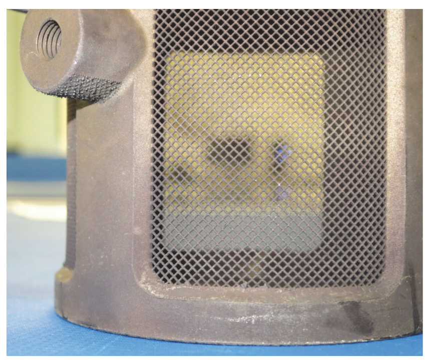


Fig. 2 — Close-up of passive vent, showing AM screen details.

Development welds were performed and examined to determine sufficiency of the weld schedules.

DEVELOPMENT TESTING

Three witness coupons were printed with each part, comprising tensile specimens in the *x, y,* and *z* orientations (where *x* and *y* are on the build plane and *z* is in the build direction). Specimens were manufactured as cylinders, machined to a 0.25-in. test diameter, and tested per ASTM E8 at room temperature. All specimens met ASTM F3055 Class D requirements and were within 15% of specification values. Figure 3 shows typical specimens.

Three tensile specimens were intentionally not HIP'd for comparison. These non-HIP'd specimens exhibited approximately the same strength as the HIP'd specimens, suggesting that the HIP process may not provide a significant strength benefit.

Fig. 3 — Representative tensile specimens after testing.

Microstructural evaluations were also performed. Overall, specimens exhibited very little porosity. Grains were finer near the edges than in the center of the coupons. Specimens were free of Laves phase, an undesirable interglobular phase[1,2]. A typical microstructure is shown in Fig. 4 (50× magnification).

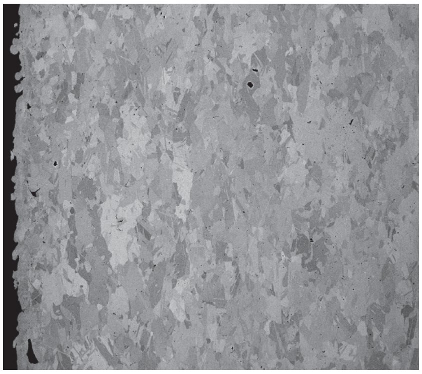


Fig. 4 — Typical microstructure of a HIP'd specimen. Courtesy of NASA.

Microhardness testing was performed on one fully processed specimen. The specimen ranged from 432 to 466 HV_{200} (44-47 HRC). Weld development showed no defects at 20× magnification.

DEVELOPMENT CHALLENGES

A few challenges occurred during development. Initial parts had dimensional errors while the AM process was being refined. For example, defects in the integral mesh are shown in Fig. 5.

One part was scrapped due to unconsolidated material in one of the mounting flanges. This was evident after minor machining of the area near the bolt hole revealed a crosshatch pattern with visible voids.

Also, there was a pause in the build cycle of one of the production parts, which was caused by a power bump. The machine was off for a few hours before the process was restarted. Visual inspection of the as-printed part reveals a dark horizontal line (Fig. 6).

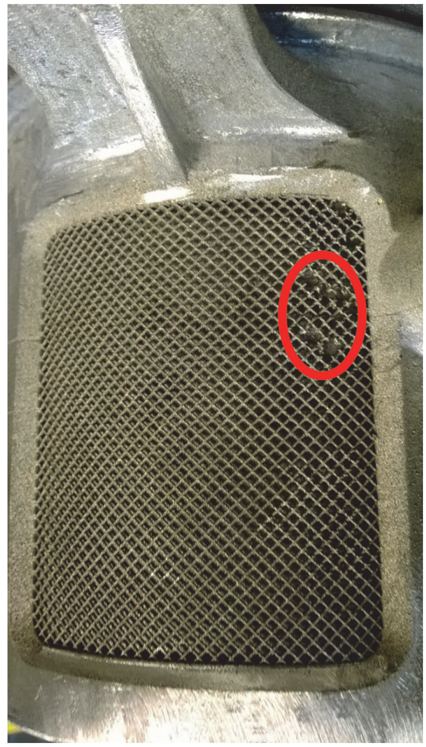


Fig. 5 — Defects in the integral mesh of a development part.

The build pause feature was also present near the end of the *z* orientation (vertical) tensile specimen (Fig. 7). Ideally, this feature would have been in the test region of the tensile specimen, but was not. So the tensile specimen was cross-sectioned and metallurgically evaluated. There was no evidence of a microstructural anomaly or a crack or crack-like defect. The dark feature is a defect at the surface level only. It is possible that the feature is a relative offset between different layers of the parts.

Additionally, all production parts were accidentally stress relieved in air, which was evident when the parts came out with a brown color. The concern was that the integral mesh would embrittle due to oxidation. The *z* orientation tensile specimen cross-sectioned for the build pause feature was also examined for oxidation. Less than 0.001-in. oxidation was observed. Following manufacturing, all parts were subjected to an acceptance vibration test to mimic flight conditions. All parts passed and no integral meshes were damaged.

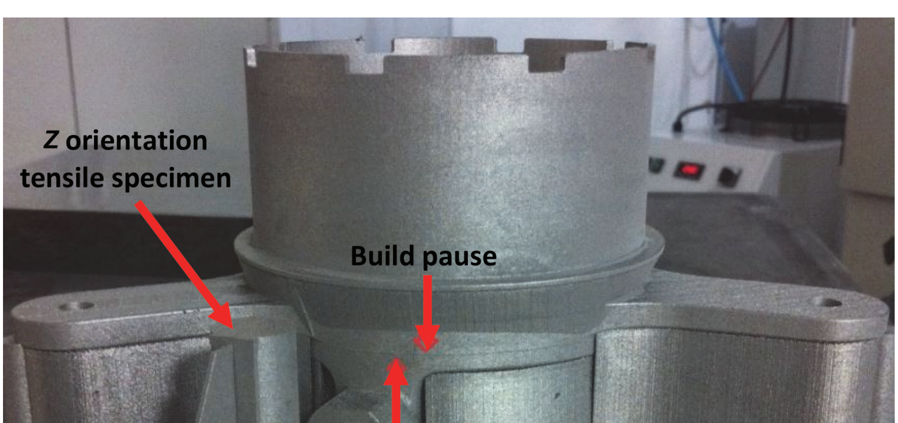


Fig. 6 — As-manufactured part with build pause visible.

POST-MISSION EVALUATION

Orion's Exploration Flight Test 1 was successful and the passive vents performed their function without incident. After landing and recovery, vents were removed from the vehicle and examined. Visual inspection revealed no defects.

CONCLUSIONS

Additive manufacturing was an ideal process for making these vent assemblies because it reduced individual part count and eliminated mesh welding. It also improved the material "buy-to-fly" ratio because the previous design included machining the thin housing from a large piece of bar. Further, developing the manufacturing process on lightly loaded parts such as these vents allows innovation with low technical risk.

Several improvements and additional steps should be considered in the future. First, the tensile specimens did not reflect the exact part geometry. It is possible that specimen size (and subsequent microstructure, heating, and cooling rates) affects material properties. No work was done to correlate the effect of specimen size or geometry. Vents were nonstructural parts made from a high-strength alloy, so the effects of specimen sizes and geometry were not a major concern. However,

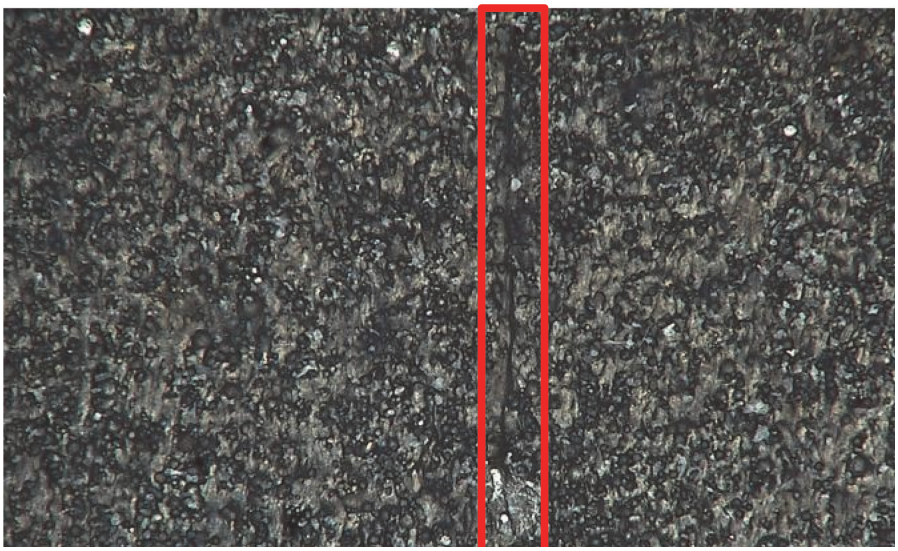


Fig. 7 — Build pause on vertical tensile specimen. Build direction is left to right.

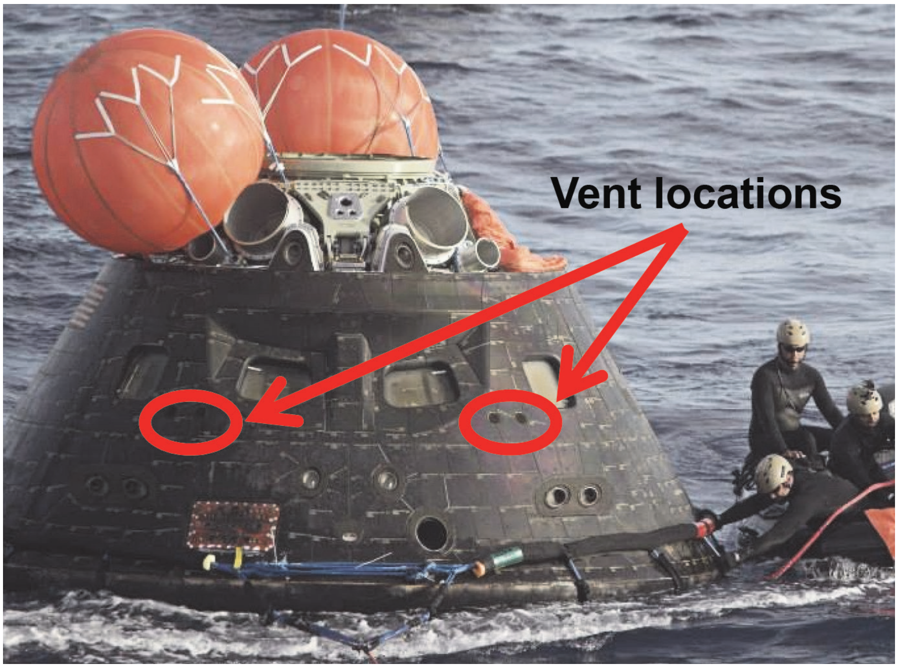


Fig. 8 — Orion Exploration Flight Test 1 vehicle in the Pacific Ocean after landing. Courtesy of NASA.

it may be beneficial to perform these comparisons before making additively manufactured structural parts.

In addition, tensile specimens could have been manufactured to near-net size to reduce specimen preparation time and cost. The *z* orientation (vertical) specimens could have been manufactured to net size, allowing for a comparison between as-manufactured surfaces and smooth machined surfaces. This comparison may be important for parts with significant fatigue loading.

Fatigue curves were not generated. Instead, parts were subjected to a vibration acceptance test, which showed that the parts would be sufficient for the specific mission, but did not lead to a standard stress-versus-cycles (S-N) curve that could be used for other parts and applications. Vibration acceptance and/or fatigue curve generation should be considered if fatigue loading is a concern in other applications.

Testing of three non-HIP'd tensile specimens suggests that HIPing may not be necessary to achieve desired strength levels. ASTM F3055 requires the same mechanical properties for Class D (stress relieved, HIP'd, solution treated, and aged) and Class F (same as Class D, except no HIPing) parts. Results described here support this, but there were not enough specimens to make a complete comparison on the effect of HIPing.

Finally, now that industry standard ASTM F3055 is available for use, it may be easier to standardize manufacturing processes from different vendors. All of the parts in this application were made consecutively by one vendor, but this may not be possible in a large production environment. **~AM&P**

For more information: Andrew Clifton is an associate manager in Structural Materials and Processes, Lockheed Martin Space Systems Co., 1111 Lockheed Martin Way, Sunnyvale, CA 94089, 408.742.1502, andrew.c.clifton@lmco.com, www.lockheedmartin.com.

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2. G.F. Vander Voort, G.M. Lucas, and E.P. Manilova, Metallography and Microstructures of Heat-Resistant Alloys, in *ASM Handbook,* Volume 9: *Metallography and Microstructures,* p 837, ISBN 0-87170-706-3.

METALLIC GLUE FOR AMBIENT ENVIRONMENTS MAKING STRIDES

Advancements in nanoscience are making it possible to metallically glue two solids together at room temperature, in air, and under a small amount of mechanical pressure.

Stephen Stagon and Alex Knapp, University of North Florida, Jacksonville
Paul Elliott and Hanchen Huang, Northeastern University, Boston*

Metallic glues can serve as excellent conductors for heat dissipation and electrical current in electronic devices and also as leak-resistant seals for vacuum environments. The potential market for these applications is extensive and growing rapidly.

TECHNOLOGICAL RELEVANCE

It is common practice to join two solids together using a third substance for gluing or soldering. *Gluing* usually refers to the joining process that is made in ambient conditions—at room temperature, in air, and without pressure, or with a small amount of mechanical pressure[1]. Sealing an envelope with polymer glue is a good example. Despite this process being easy and inexpensive, it often produces properties that make it unsuitable for use in high-tech environments. For example, polymer glue—unlike metallic solder—is permeable to air and moisture, degrades fast in ambient temperature or environment, has low mechanical strength, does not effectively conduct electricity or heat, and does not retain its function at high temperatures[2,3].

In contrast, *soldering* usually refers to the joining process that uses added molten metal at increased temperatures, generally much higher than room temperature[1]. Similarly, *welding* and *brazing* also involve high-temperature melting, where brazing refers to joining through added molten metal at even higher temperatures than soldering, and welding involves melting or fusing the members to be joined, often under an inert environment[1]. The joining from such high temperature processes, as compared to polymer glue, is mechanically strong, effectively conducts electricity and heat, and degrades slowly (if at all) in ambient environments. Further, its leak resistance to air and moisture goes from good to better with time due to oxidation[1].

Metallic gluing refers to the process of joining two solids with metal as the connecting party, which operates at room temperature, in air, and under low pressure. Metallic glues feature the combined advantages of the ambient condition of gluing and the superior properties of the joint from high-temperature soldering (or welding and brazing), making them beneficial to many advanced technologies.

As an example, consider desktop and laptop computers. The core of computing is the central processing unit (CPU), and connecting the CPU to external components for heat dissipation or electrical conduction is necessary. The process of making the connection, if it requires high temperature, can damage the CPU by exceeding the thermal budget[4]. For heat dissipation[5], an ideal connection conducts heat efficiently, which makes metals with high thermal conductivity desirable. However, if solder is used, the temperatures necessary to create a good bond can damage the CPU. Also, solder bonds can be relatively thick, resulting in reduced heat transfer. Further, the thermal conductivity of most solders is low, conducting roughly 5%-20% as effectively as a pure metal such as copper[6,7].

Thermal grease is often used as an interface material, filling the space between the heat sink and CPU. However, the thermal conductivity of this grease is only a fraction that of copper—a mere 1%-2%[7,8]. This low conductivity limits the amount of heat that can be dissipated from the CPU and is a significant barrier to further miniaturization and reliability of devices such as tablets and computers. Thermal greases also suffer from problems such as pump out, where grease is forced out of the interface during thermal cycling, and dry out[5]. Figure 1a shows the configuration of a CPU with a heat sink in a laptop computer, for simplicity. Desktop computers often contain an additional protective and heat transferring plate between the CPU and heat sink with two separate interfaces requiring

*Member of ASM International

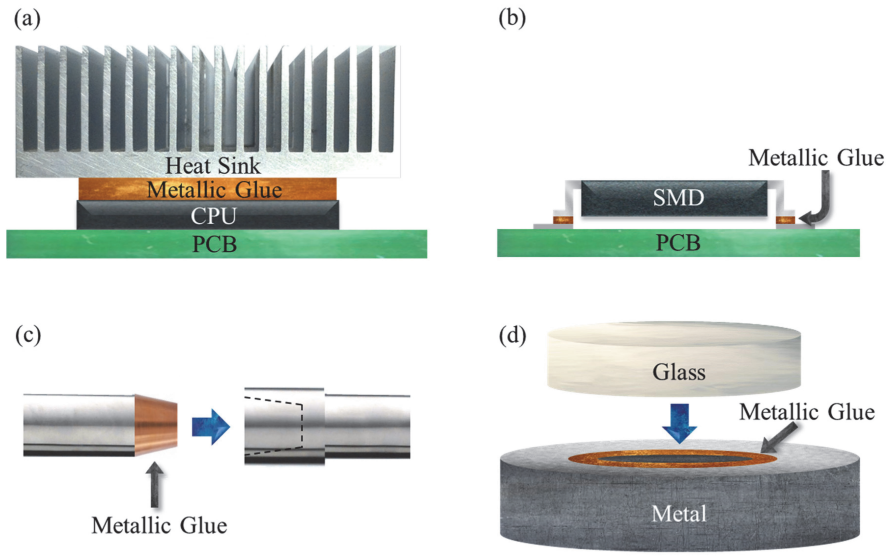

Fig. 1 — Various applications of metallic glue: (a) A central processing unit (CPU) on a printed circuit board (PCB) connected to a heat sink, (b) a surface mount device attached to a PCB, (c) a press-fit pipe fitting for environments where welding is dangerous or impossible, and (d) a glass plate attached to metal with a different coefficient of thermal expansion to cover a cavity with a hermetic seal.

thermal grease, effectively doubling the thermal barrier problem.

In CPUs, and also in many through-hole and surface-mount devices, it is necessary to connect the electrical component to other components, generally through a printed circuit board (PCB). The components experience heating when they are soldered to a PCB or require very precise wire bonding or flip chip equipment, which often demands a thermosonic bonding method. In some cases, temporary heat sinks must be attached to the component during soldering to prevent damage[9]. Also, as component size decreases, soldering or wire bonding becomes more challenging and voids can lead to joint failure[10]. A metallic glue bond eliminates the possibility of heat damage during attachment and simplifies the soldering process to merely pressing parts together to attach (Fig. 1b).

A third example involves connecting pipes or construction parts together, which highlights the benefits of the metal bond's strength (Fig. 1c). With metallic glue, no gases, electricity, or heat is required. This facilitates a process that poses zero risk of asphyxiation, electric shock, or burns, and occurs in safe environments where welding may not be safe or possible, such as hot work in confined spaces. In addition, no welding skill is required.

As a fourth example, the hermetic sealing of materials with much different coefficients of thermal expansion (CTE) benefits greatly from a room temperature bonding method. Generally, when sealing metal to ceramic or glass, materials must be carefully selected to have a similar CTE. If the CTE difference is too large, parts may separate due to geometric mismatch when cooled. When selection of similar CTE materials is not possible, part geometry must be carefully designed so that thermally induced stresses do not become too large to cause warping or material failure. Application examples include compact fluorescent bulbs, glass encapsulated diodes, and windows for inspection and diagnostics in industrial processes and vacuum chambers (Fig. 1d).

NANOSCIENCE-ENABLED TECHNOLOGY

Combining the ambient conditions of gluing with the desirable properties of soldering would be possible if one could use metal as solder at room temperature. Until recently, this remained wishful thinking based on conventional technologies. Now, advancements in both science and technology have made this sought-after ability a reality[11]. Figure 2 outlines a new process that uses nanostructures and eutectic alloys to produce a room temperature metallic glue with the desirable properties of solder. In Fig. 2a, two surfaces to be bonded together are shown facing one another. Each surface is covered with core-shell nanorods. When the mating surfaces are brought together, the large spacing of the nanorods allows them to slide between those on the opposing surface and to interpenetrate (Fig. 2b). When the shell materials from opposing sides come into contact, which together form an alloy with a eutectic temperature at or below room temperature, a liquid alloy is quickly formed (Fig. 2c). Interdiffusion between the liquid alloy and the nanorod cores leads to solidification as the composition deviates from that of eutectic alloys of low melting temperature (Fig. 2d).

Development of this emerging technology is based on efforts to understand how and why nanostructures grow at a fundamental level. One important subject of investigation in nanoscience has been nanorod growth using glancing angle physical vapor deposition[12]. A recent breakthrough in this field involves the development of a theory for both the diameter and separation of nanorods[13,14]. Guided by this theory, the smallest, well separated metallic nanorods came to light (Fig. 3).

Developing the ability to produce well separated nanorods is an important step in realizing this technology, due to the necessity of interpenetration of the nanorods. If they are not sufficiently well separated, the rods will contact one another head-on and act like a porous film. Consequently, bonding will not be successful at low temperatures[15]. At this small scale, if the separation is sufficient, a small shear stress will align the nanorods for inter-digitation, even if they are not well aligned upon initial contact. Further, at the small diameter, a new mechanism of surface diffusion becomes active,

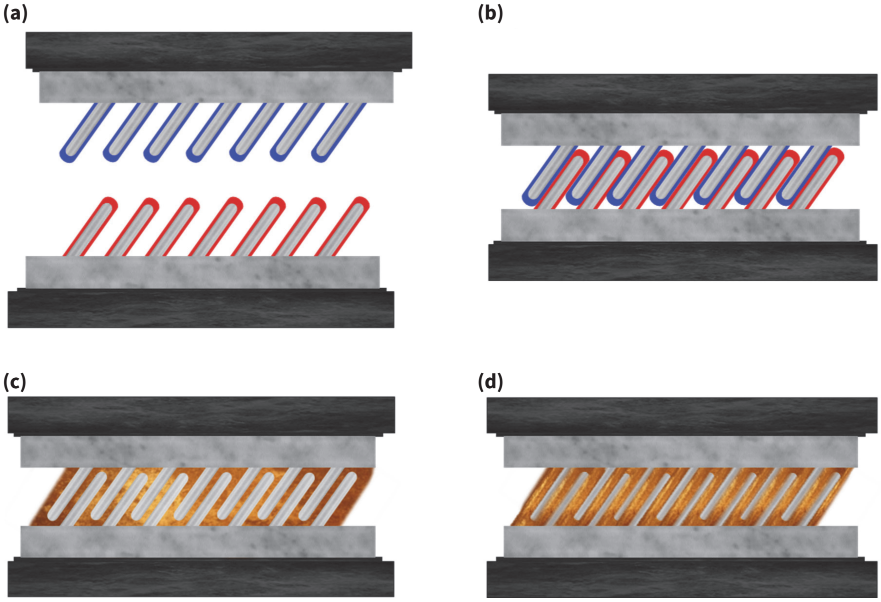

Fig. 2 — Low-temperature metallic gluing enabled by well separated metallic nanorods: (a) Two sets of well separated nanorods, which have metallic cores and shell elements that form a eutectic alloy, are brought together, (b) they interpenetrate under fingertip pressure, (c) shell elements meet and form a eutectic alloy, which is liquid at room temperature, and (d) mixing of eutectic liquid with a metallic core leads to formation of three-component alloys that are solid at room temperature.

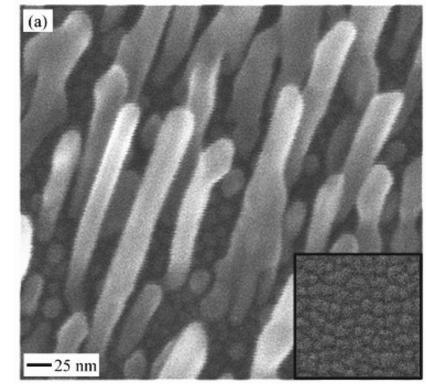

Fig. 3 — Scanning electron microscope image of well separated Cu nanorods. Courtesy of X. Niu, et al., *Phys. Rev. Lett.,* Vol 110, 136102, 2013.

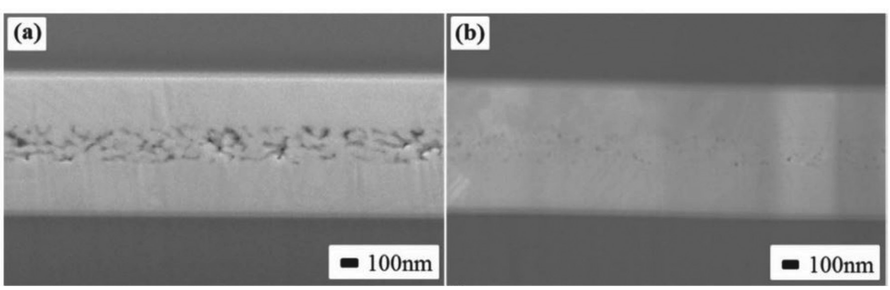

Fig. 4 — Metallic glue formed in air and under a small pressure of 9 MPa (a) at room temperature, and (b) at 100°C. Reprinted with permission from *Scientific Reports*[15].

so diffusion on the nanorod surface is much faster than on flat surfaces[16]. Contact of the sides of the nanorods through interpenetration provides high surface area contact, maximizing the effects of the fast surface diffusion.

While the use of eutectic materials as shells shows preliminary results of a room temperature bond at very low pressure, it is possible to use simpler, single element nanorods in place of the core-shell structure required in the eutectic. Silver was successfully used to create such a bond, but requires higher pressure for sealing[15].

TECHNOLOGICAL IMPACTS

The impact on technology is clear, even using only well separated silver metallic nanorods without a shell. Following the processes in Figs. 2a and 2b, the fast surface diffusion of nanorods without the liquid formation of eutectic alloys, gluing also occurs, although with some voids (Fig. 4a)[15]. To reduce void concentration, a higher processing temperature is needed. As shown in Fig. 4b, performing the gluing process at 100°C largely eliminates voids. Using core-shell nanorods, and therefore the assistance of liquid from the eutectic alloy, it is expected that the room temperature gluing process will produce a bond that is void free, as seen in Fig. 4b.

Even with voids, the metallic glue shown in Fig. 4a has superior thermal conductivity and leak resistance. In tests running a simulated CPU at moderate load with forced air cooling, the metallic glue reduces the CPU temperature by 8°C ±3°C compared to the widely used thermal grease, Arctic Silver 5, operating at 61°C. This is significant, as keeping the CPU 10°-15°C cooler can double its lifespan[5]. The leak rate of the metallic glue shown in Fig. 4a is three orders of magnitude lower than that of polymeric glue. This leak resistance meets the standard for organic solar cell and organic light emitting diode technologies[15], allowing them to survive long-term, which may lead to a new generation of inexpensive solar and lighting technology. Further, as demonstrated in Fig. 1d, metallic glues are also useful as a vacuum seal. Capitalizing on the superior leak resistance of the metallic glue, MPF Manufacturing is investigating using the technology and licensing the patent[17].

Looking forward, the core-shell nanorod glue is expected to perform even better. First, the use of eutectic alloys through the core-shell nanorods will reduce or completely eliminate the voids. As a result, leak resistance will further increase, and heat conduction will become even more effective. Second, the presence of liquid alloys instead of solids will likely reduce the processing pressure from a few megapascals to a fraction of one megapascal, equivalent to fingertip pressure. **~AM&P**

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LINEAR FRICTION WELDING UPDATE: LOWER COSTS, BROADER APPLICATIONS

From joining railroad rails to producing strong aluminum-to-steel joints, recent advancements in linear friction welding are reducing equipment costs and expanding potential uses.

Michael Eff, Jerry Gould, and Tim Stotler
EWI, Columbus, Ohio

Linear friction welding (LFW) is a solid-state process that uses friction and plastic deformation to generate heat. A metallurgical bond between two pieces of material is achieved via relative motion (i.e., friction) of materials under applied force. Solid-state welding processes join without melting materials and are in high demand due to their superior weld quality, ability to join non-fusion-weldable materials, and overall lower peak temperatures than fusion welding processes.

LFW is closely related to rotary friction welding, which uses relative angular motion under force to generate heat. However, LFW uses *translational* motion rather than *rotational* motion and is thus able to join noncircular cross-sections as well. Despite its advantages, industrial applications of LFW have been limited to high value-added components such as jet engine components due to prohibitive equipment costs.

Recently, new advancements in oscillator technology have reduced equipment costs and expanded LFW's commercial viability into applications ranging from producing aluminum-to-steel joints to the joining of railroad rails.

OSCILLATOR TECHNOLOGY ADVANCEMENTS

LFW achieves friction heating and plastic deformation at the interface between the two components to be joined. As the material is heating, it is extruded away from the joint and a new surface, called a *nascent surface,* is formed. By stopping oscillation and forging once the nascent surface is formed, a weld is made between the two pieces. A schematic of this process is shown in Fig. 1.

Key variables for LFW include the axial load along with oscillation frequency, amplitude, and duration. LFW machines must achieve the desired relative velocities between two parts, apply axial loads, and precisely stop oscillation to align parts after welding. In order to maintain high relative velocities under an axial load, shear loads during welding can become large. Therefore, designing an oscillator that can withstand the shear loads opposing oscillation is one of the most critical—and costly—factors of an LFW machine.

Current LFW systems are mostly hydraulic actuation systems, which store energy under high fluid pressure that is first directed to one side of a drive cylinder and then to the other side to generate oscillation. High speed valves with large flow rates, many parallel circuits, and hydraulic accumulators are required for hydraulic control and must change flow direction in 1/60th of a second to achieve a 60-Hz oscillation. Hydraulic servo valves operating at speeds up to four times faster than typical industrial servo valves provide amplitude control[1].

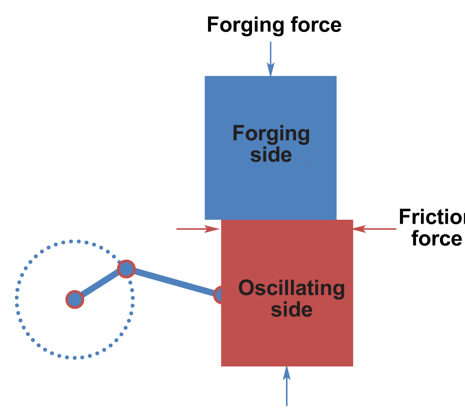

Fig. 1 — Mechanical LFW schematic.

These machines require a significant investment in both capital and floor space and are also complex to operate and maintain. Due to their size and complexity, hydraulic LFW machines have been relegated to producing only the highest value parts for the most demanding applications. A primary application for these systems is welding blades to disks for jet engines[2].

One specialized equipment builder, APCI LLC, South Bend, Ind., recently developed a unique mechanically based oscillator for LFW. Instead of the complex hydraulic systems used to oscillate a part, a motor drive with a continuously variable stroke crank[3] performs this task. Motor rotation drives the crank, which translates rotary motion into linear

Fig. 2 — 100-ton mechanical LFW system. Courtesy of APCI.

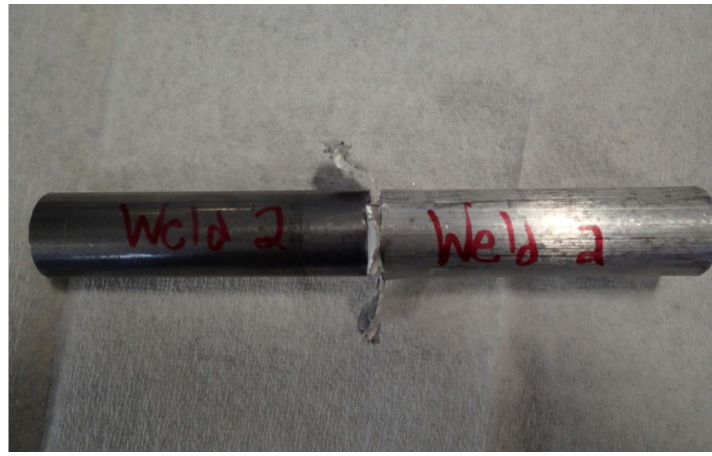

Fig. 3 — As-welded aluminum-to-steel joint.

oscillation—much like a crankshaft and piston/rod assembly. A schematic of the oscillator function is shown in Fig. 1, in which the circle represents the variable stroke crank.

Variable frequency is obtained simply by changing the motor speed that drives the crank. The phase change of a second rotating cam that changes the reference location of the driving crank provides the variable amplitude. Schematically, this increases or decreases the size of the circle in Fig. 1. The oscillation method easily aligns parts at the end of the welding cycle by changing the variable amplitude at the end of the cycle to zero. Application of normal force and fixturing is similar to other linear friction machine designs, applying load perpendicular to the oscillating interface. A 100-ton mechanical LFW system is shown in Fig. 2.

This mechanical oscillation design greatly reduces machine cost and footprint to approximately one-third or less than the size of a comparable hydraulic LFW system. The new system also allows complexity to be added to the weld process, including multiple phases, extending low pressure frictional pre-heats of the surface, and changing the frequency and/or amplitude in the middle of oscillation. Additionally, the mechanical system allows for amplitudes exceeding 6 mm and 70 Hz of oscillation, thus expanding the available parameters.

CASE STUDY

The automotive and aerospace industries are both seeking weight reductions via new materials with high strength-to-weight ratios and multi-material designs, commonly known as lightweighting initiatives. Recent advancements in LFW technology enable it to join aluminum alloys with over 90% efficiency[4]. As an extension of this work, EWI has examined joining aluminum to steel with a mechanical LFW system.

Using this system, EWI joined 6061-T6 aluminum to 1018 steel with joint strengths matching that of the 6061-T6 base material. Joined pieces were 12.7 × 12.7-mm square faces with a 161-mm^2 cross-sectional area. Processing frequency and amplitudes used to join the pieces surpass traditional LFW capability, resulting in joints exceeding 280 MPa ultimate tensile strength. A photo of the as-welded joint is shown in Fig. 3 and a cross-section is shown in Fig. 4.

Joining dissimilar metals, including this combination, typically results in the formation of brittle intermetallic compounds with low strength,

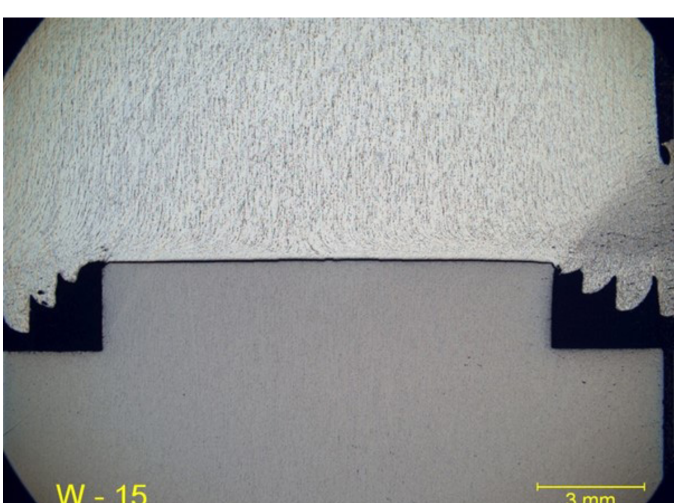

Fig. 4 — Cross-section of aluminum-to-steel joint.

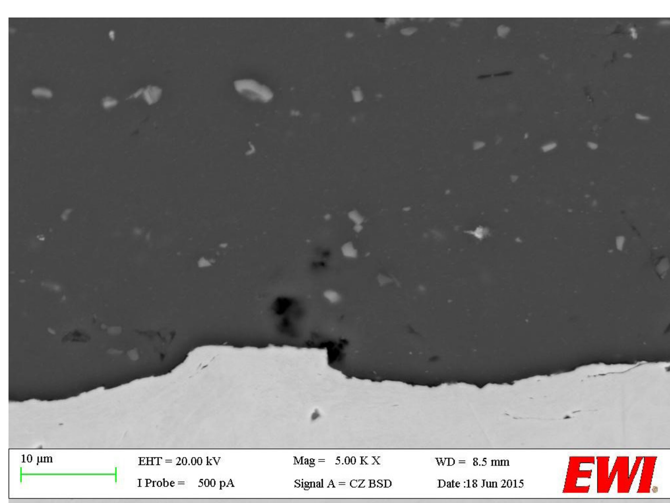

Fig. 5 — Aluminum-to-steel interface under high magnification using SEM.

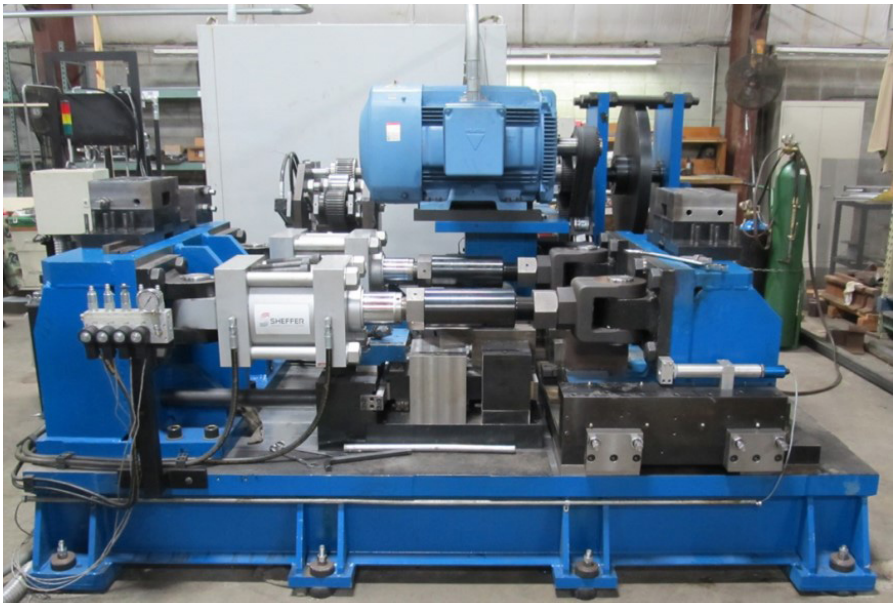

Fig. 6 — 150-ton mechanical LFW system.

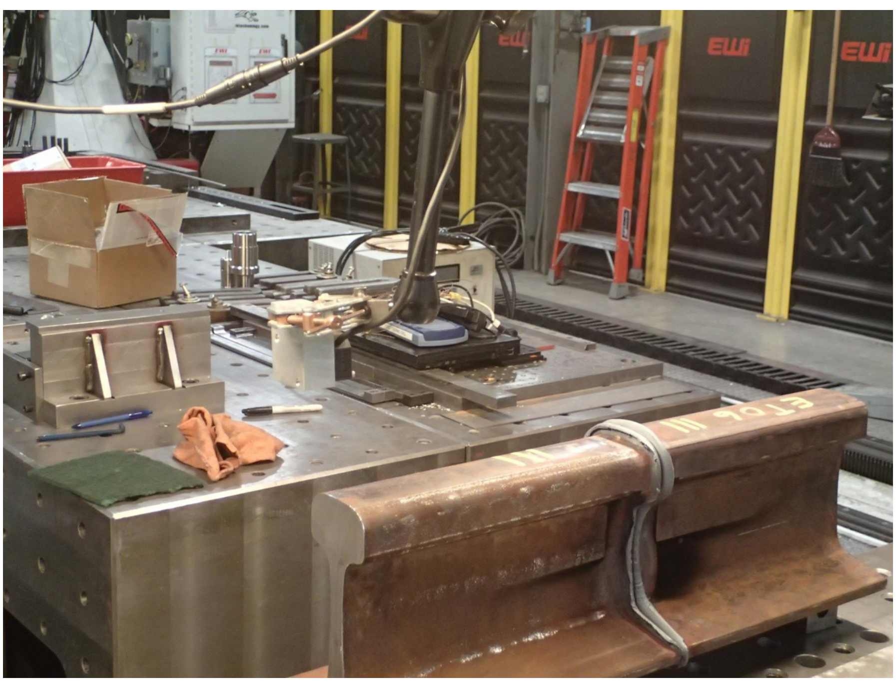

Fig. 7 — Full-section rail joined by LFW.

toughness, and overall poor joint quality. Both optical and scanning electron microscopy identified any intermetallic compound present at the joint interface as shown in Fig. 5.

Working with the Federal Railroad Administration, EWI and APCI co-developed a 150-ton mechanical LFW machine (Fig. 6) capable of joining full section railroad rail (8400 mm^2)[5]. This machine can apply up to 1335 kN of axial load and maintain part oscillation under this load. Currently, rail is joined using thermite or flash butt welding, which results in excessive rail shortening. LFW reduces rail length loss from welding while maintaining current joint performance. This length loss reduction decreases the tension placed on the rail due to elongation. By reducing the stress placed on the joint, rail service life is greatly increased. A photo of a welded rail is shown in Fig. 7.

SUMMARY

LFW is a solid-state process capable of joining noncircular parts by oscillating one part under load to create frictional heating. Advancements in LFW machine design have led to a new mechanical oscillation system, enabling new applications due to a decrease in equipment cost, reduction of the machine footprint, and an increase in the technology's processing capabilities. Potential applications vary from existing aerospace components and dissimilar materials joining to heavy duty applications such as rail joining.

The LFW process is able to make aluminum-to-steel joints with a matching strength of aluminum alloy and also produce full-section rail steel welds. LFW is an emerging technology with uses that are still being defined. **~AM&P**

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NEW PROCESS JOINS NITINOL TO STAINLESS STEEL

A new solid-state joining process for medical guidewire applications increases joint strength, provides superior bending properties, and does not require tertiary metals or ferrules.

Pankaj Gupta, Arne Rimmereide, and Roger Dickenson, Lake Region Medical, Chaska, Minn.*

A guidewire is a medical device used in various minimally invasive vascular applications. Its foundation is a metal core wire, typically constructed of stainless steel or Nitinol. A metal coil, polymer jacket, or combination of the two covers the core wire on the distal end in order to make the tip atraumatic, kink resistant, and flexible.

Designing a guidewire is an intricate exercise in balancing strength and flexibility. For example, a guidewire with a spring-tempered stainless steel core has good pushability and torque transmission due to its high yield strength and Young's modulus. These properties are important in order to navigate to the desired treatment sites and deliver the desired clinical therapy. However, exceeding the yield strength of the material in a bending mode results in permanent bends and kinks, which severely reduces guidewire performance. Nitinol is a superelastic material providing great kink resistance, but it lacks pushability due to an inherently lower Young's modulus, which results in less support in delivering therapies or devices. Ideally, a guidewire core combines the excellent mechanical properties of stainless steel in the main body, with the kink resistance of Nitinol at the distal tip.

A bimetal medical guidewire with a stainless steel proximal section and Nitinol distal section enhances performance compared to guidewires made of either alloy alone. However, standard fusion welding of Nitinol (NiTi) to stainless steel (SS) is challenging because it causes brittle intermetallic Fe-Ti to form, leading to unpredictable brittle joints. To avoid this, current joining methods use either a transition section made of a tertiary metal or a ferrule joining process.

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JOINING OPTIONS

Metallurgically, joining Nitinol to stainless steel via fusion welding is problematic due to the formation of brittle Fe-Ti intermetallics[1,2], as previously mentioned. One method of avoiding brittle intermetallics is to use a tertiary metal, such as Nickel, when joining the stainless steel to Nitinol[3], but this adds cost and complexity to the design and can degrade performance.

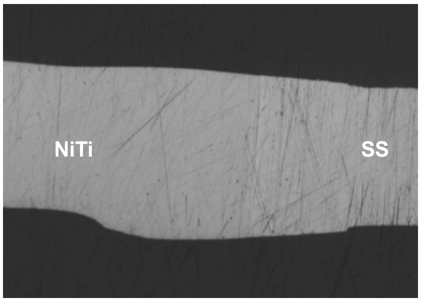
Solid-state processes such as friction welding[4], explosive welding[5], and ultrasonic welding[6] can also be used to join dissimilar metals while avoiding the formation of brittle intermetallics in the joint. Another method used in guidewire applications is to insert the ends of the stainless steel and Nitinol into a ferrule (a section of hypotube) and then secure both ends using adhesive or solder. This method requires preprocessing to reduce the diameter at the ends of each core in order to fit the parts together, which adds cost and complexity. Further, this decrease in core diameter, along with the stiffer section of hypotube, and the addition of joint material, creates a kink point and reduces clinical performance.

An alternative proprietary solid-state butt joining process for Nitinol and stainless steel wires ranging in diameter from 0.013 to 0.020 in. that does not require tertiary metals or ferrules was developed by researchers at Lake Region Medical (LRM). The resulting joint strength is approximately 80% of the tensile strength of the raw Nitinol wire with excellent bending properties. Complete 0.014-in. outer diameter guidewires were built using solid-state weld technology, tested, and compared to a competitor's product with a hypotube joint design. The solid-state weld joint's metallurgical characteristics as well as data from guidewire functional tests are presented here.

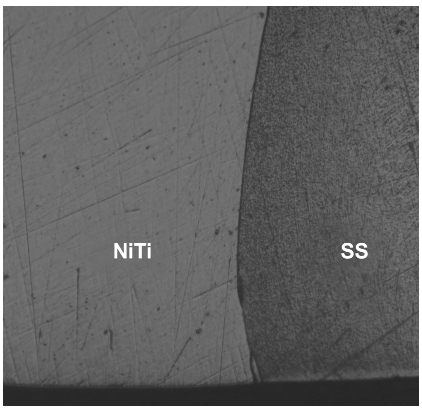
EXPERIMENTAL PROCEDURES

Solid-state weld joints were created using pre-straightened superelastic binary Nitinol (54.5%-57.0% Ni) and 304v spring-tempered stainless steel wires with subsequent evaluation of joint strength, durability, and microstructure. Parts went through preconditioning by cycling the joint 10 times through a U-bend fixture with a 0.10-in. radius, prior to obtaining tensile strength data by pulling the joint to failure using an MTS testing system. Joint microstructures were examined using standard metallographic methods of polishing and etching the longitudinal joint sections. In addition, optical microscopy and scanning electron microscopy (SEM) confirmed overall joint quality. Energy dispersive spectroscopy (EDS) analysis on the cross-section determined the weld zone length with intermixed Nitinol and stainless steel.

A grinding study was conducted on the solid-state welded bimetal joints using 0.018-in. stainless steel to 0.020-in. Nitinol wires. This allowed



(a)



(b)

Fig. 1 — Post polishing SEM image of joint shows its seamless nature (a); SEM image of joint after etching shows presence of small grains in HAZ (b).

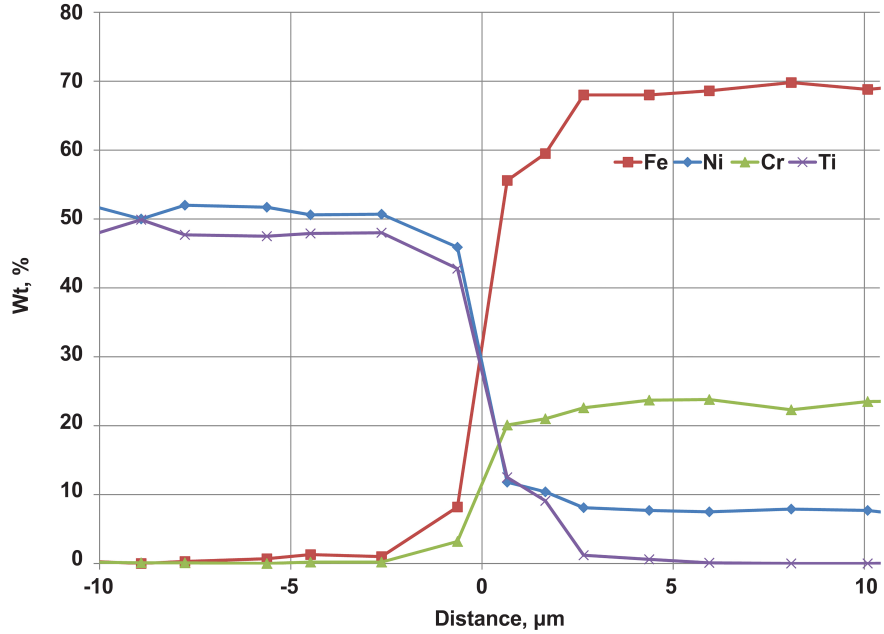


Fig. 2 — EDS composition profile at the interface for LRM solid-state weld joint.

strength and joint quality evaluations closer to the core central axis. The wire, including the joint area, was ground to diameters of 0.014, 0.010, and 0.008 in., then tensile tested to evaluate change in joint strength throughout the cross-sectional area. After initial joint strength and quality assessments, full guidewires were assembled using cores joined with the LRM solid-state weld process from 0.014-in. stainless steel and 0.014-in. Nitinol. The core wire distal grind profile for this study mimicked the stiffness profile of a commercially available bimetal guidewire, enabling performance comparisons between the two designs. The competing design wire consisted of Nitinol and stainless steel joined via a Nitinol hypotube and adhesive. The two designs were tested side-by-side comparing lateral stiffness, tensile strength, and simulated clinical performance in a 2D plate model emulating a tortuous vessel. After tensile testing, the fracture surface was analyzed using a tabletop SEM (Hitachi TM 300).

EXPERIMENTAL RESULTS

Results show that the new solid-state welding process produces a clean and defined transition between the stainless steel and Nitinol and that the interface is free of defects and/or porosity. Figure 1 shows SEM images of a joint cross-section between 0.018-in. stainless steel and 0.020-in. Nitinol. Figure 1(a) shows the interface after polishing while Fig. 1(b) shows the interface after etching the stainless steel side. The heat-affected zone (HAZ) is approximately 0.012-in. (~300 µm) long, and is distinguished from the drawn wire elongated grain structure by the presence of a fine, uniform grain structure. A fine grain size is an inherent solid-state processing advantage compared to fusion welding, which is characterized by the presence of a cast dendritic structure and large grains in the HAZ[2,7]. Figure 2 shows the EDS analysis at the interface of the solid-state weld joint, collected within 10 µm on either side of the joint. The data shows that chemical intermixing of Nitinol and stainless steel extends approximately 1 µm on either side of the joint interface.

LRM engineers ground welded 0.018-in. stainless steel and 0.020-in. Nitinol wires to different diameters, post joining in order to determine joint grindability, thus providing design options and an assessment of joint strength uniformity toward the wire central axis. All tested samples passed the U-bend preconditioning test, which indicates excellent joint bending properties. Tensile tests yielded an average joint strength of approximately 80% of the tensile strength of Nitinol wire. All tensile samples failed at the stainless steel to Nitinol interface, leading to the hypothesis that a relatively small HAZ and presence of fine grain structure contribute to the high strength of the joint. With small sample sizes, 95% of the confidence interval indicates no loss of stiffness as the core diameter is reduced via grinding as seen in Fig. 3.

Full guidewires were built using the proprietary solid-state welded joints located approximately 40 cm from the distal tip. The grind profile and joint location aligned with leading competitive guidewires and enabled comparative bench testing. Figure 4 shows the lateral stiffness results, and the inset of Fig. 4 shows the LRM solid-state weld joint in comparison to the hypotube joint design. It is evident that the LRM joint is significantly shorter than the 3-cm long hypotube joint. The solid-state weld also shows a smooth and even bending transition from stainless steel to Nitinol, while the

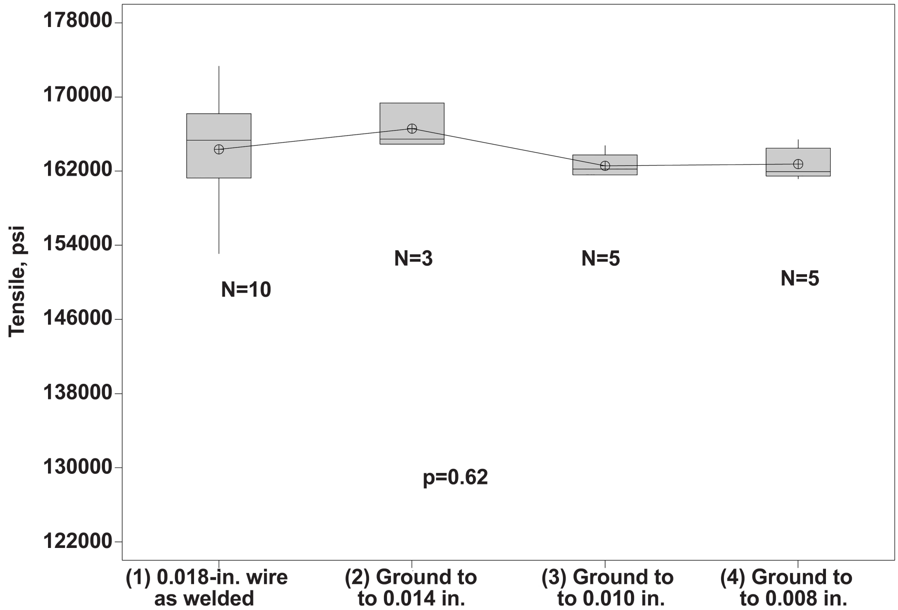


Fig. 3 — No statistically significant difference, at a 95% confidence level, in joint tensile strength with reduction in cross-sectional area. This shows joint consistency.

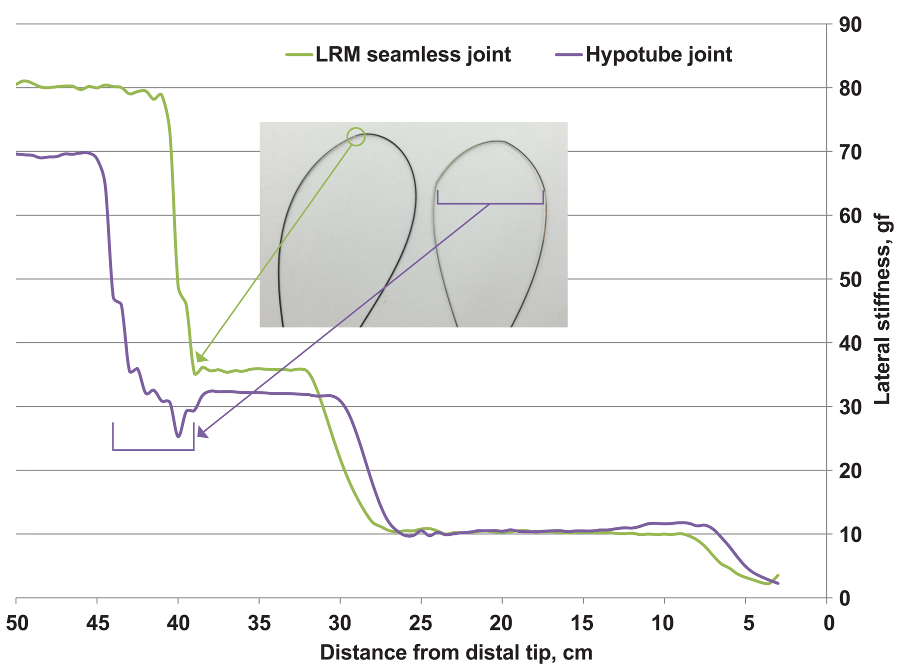


Fig. 4 — Lateral stiffness testing on 0.014-in. diameter guidewire with LRM solid-state joint, compared to competitive guidewire with hypotube joint.

hypotube joint design exhibits sharp transitions that could cause kinks and performance degradation.

The lateral stiffness graph shows the seamless nature of the LRM guidewire at around 40 cm from the distal tip. A direct change in stiffness occurs at the solid-state weld joint. Conversely, the graph shows that the sample guidewire with the 3-cm long hypotube joint has a less desirable stiffness load profile.

Table 1 summarizes the tensile data for 0.014-in. diameter LRM solid-state welded guidewires. The LRM joint exhibits high tensile strength compared to the hypotube adhesive joint. Figures 5(a) and 5(c) show that the failure mode for the hypotube joint design was adhesive failure, with subsequent core pullout from the hypotube. Therefore, the Nitinol wire end exhibits a smooth shear cut surface, Fig. 5(c). The LRM

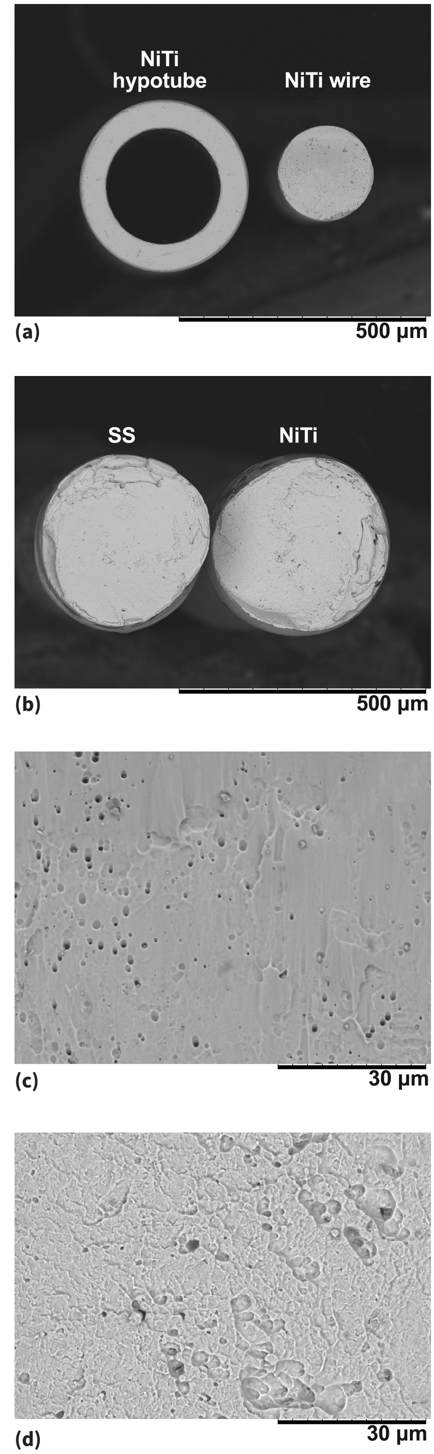


Fig. 5 — SEM image of fracture surface, post tensile testing. Low magnification (200×) of hypotube joint and LRM solid-state joint, respectively (a) and (b); high magnification image (2000×) of NiTi wire side of hypotube joint and LRM solid-state joint, respectively (c) and (d).

solid-state weld joint failed at or near the joint interface, Fig. 5(b). The fracture surface of the LRM solid-state weld exhibits micro-roughness and dimples

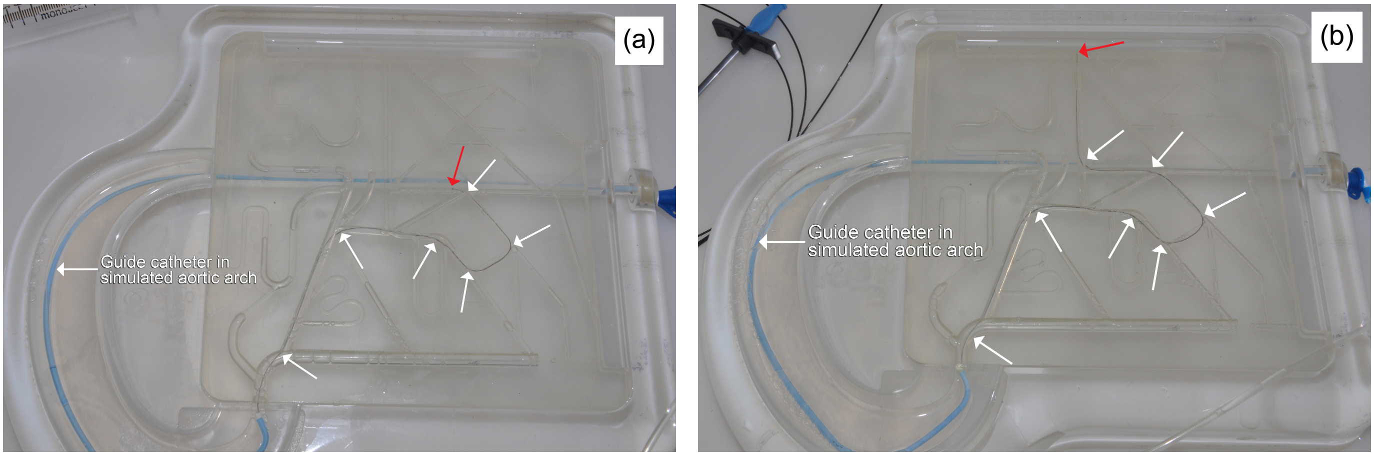


Fig. 6 — Testing of LRM full guidewire 0.014-in. diameter in 2D plate model. Hypotube joint (a) and LRM solid-state weld joint (b).

TABLE 1–TENSILE DATA SUMMARY FOR 0.014-IN. DIAMETER SOLID-STATE WELDED GUIDEWIRES

Sample ID	Sample quantity	Break load (Std. dev.), lb	% of NiTi break load*	Failure location
LRM seamless joint	5	28.6 (0.72)	89	Joint interface
Hypotube joint	5	5.1 (0.35)	16	NiTi wire attached to NiTi hypotube

*NiTi wire tensile strength for 0.014-in. NiTi wire was roughly 32 lb.

on the Nitinol wire, typical of a ductile fracture mode, Fig. 5(d).

Figure 6 shows the two wires in simulated performance testing using a 2D plate model, which features several channels simulating tortuous vessels. The wire is inserted through a guide catheter (Vistabrite tip JL4 Fr manufactured by Cordis) into a predetermined pathway to assess wire tracking and torque response. The guidewire with the LRM solid-state weld tracked much further into the pathway than the guidewire hypotube joint. Red arrows indicate the distal-most position that each wire navigated.

CONCLUSIONS

Nitinol wire was joined to stainless steel wire via a proprietary solid-state process without the use of filler material. This process proves to be a superior method to create joints between dissimilar metals such as stainless steel and Nitinol. It offers significant performance enhancements for guidewire applications by merging a high-stiffness stainless steel body for pushability with a softer, more kink resistant Nitinol for the distal section. The solid-state weld process yields a fine-grained HAZ and defect-free interface, resulting in excellent bend and tensile properties at the joint.

Initial performance testing using a 2D plate model simulating vasculature indicates that the LRM solid-state weld offers superior performance in clinical application compared to one of the leading bimetal guidewires on the market. **~AM&P**

For more information: Arne Rimmereide is manager of R&D, Lake Region Medical, 340 Lake Hazeltine Dr., Chaska, MN 55318, 952.641.8383, arne.rimmereide@lakeregionmedical.com, www.lakeregionmedical.com.

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COURSE	DATE	LOCATION
JANUARY		
Metallurgy for the Non-Metallurgist™	1/25-28	ASM World Headquarters
FEBRUARY		
Heat Treating for the Non-Heat Treater	2/1-3	North Charleston, SC
Introduction to Metallurgical Lab Practices	2/9-11	ASM World Headquarters
How to Organize and Run a Failure Investigation	2/22-23	Foothill Ranch, CA
Basics of Heat Treating (formerly known as Introduction to Heat Treating)	2/22-24	ASM World Headquarters
Principles of Failure Analysis (3 day)	2/24-26	Foothill Ranch, CA
Introduction to Materials Science	2/22-24	ASM World Headquarters
Heat Treating Furnaces and Equipment (formerly known as Advanced Heat Treating)	2/25-26	ASM World Headquarters
MARCH		
Metallurgy for the Non-Metallurgist™ – Blended	3/1-2	ASM World Headquarters
Practical Interpretation of Microstructures	3/7-10	Allied High Tech, CA
Metallographic Techniques	3/14-17	ASM World Headquarters
Introduction to Thermal Spray	3/21-22	ASM World Headquarters
Titanium and Its Alloys	3/21-24	ASM World Headquarters
APRIL		
Superalloys	4/4-6	North Charleston, SC
Practical Heat Treating	4/4-7	ASM World Headquarters
Component Failure Analysis	4/4-7	ASM World Headquarters
Principles of Failure Analysis	4/11-14	ASM World Headquarters
Metallographic Interpretation	4/18-21	Struers, Westlake, OH
Practical Fracture Mechanics	4/18-19	IMR Test Labs, NY
Aluminum and Its Alloys	4/19-21	ASM World Headquarters
Practical Fractography	4/20-21	IMR Test Labs, NY
Corrosion	4/25-28	ASM World Headquarters
Mechanical Testing of Metals	4/25-28	ASM World Headquarters
MAY		
Metallography for Failure Analysis	5/2-5	ASM World Headquarters
Metallurgy of Welding and Joining	5/9-12	ASM World Headquarters
Advanced Metallographic Techniques	5/9-12	ASM World Headquarters
Design for Additive Manufacturing – Materials, Processes, and Geometries	5/16-17	America Makes
Metallurgy of Steel for the Non-Metallurgist	5/16-18	ASM World Headquarters
Practical Induction Heat Treating	5/16-18	ASM World Headquarters
Vacuum Heat Treating	5/19-20	ASM World Headquarters
Metallographic Techniques – Blended (Lab Session)	5/23-24	ASM World Headquarters

EDUCATION COURSES KEY

CHAIR ICON In-classroom course with on-site instructor

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METALLURGY LANE

Metallurgy Lane, authored by ASM life member Charles R. Simcoe, is a continuing series dedicated to the early history of the U.S. metals and materials industries along with key milestones and developments.

PIONEERS IN METALS RESEARCH–PART IV

EDGAR BAIN PIONEERED THE STUDY OF THE REACTION OF AUSTENITE TO LOWER TEMPERATURE PHASES DURING ISOTHERMAL TRANSFORMATION, RESULTING IN A NEW PHASE NAMED IN HIS HONOR—BAINITE.

After finishing high school in Marion, Ohio, Edgar C. Bain enrolled at The Ohio State University in chemical engineering in 1908. His initial interest in metallography began in a class where he saw photomicrographs of ferrite, pearlite, and martensite. Bain would follow this field of science throughout his career. His first job after graduation was with the National Bureau of Standards in Washington. After a few years, he returned to Ohio State to work on an advanced degree, where he took the only course offered in metallography and metallurgy. Before he earned his master's degree, his department head recommended him as an instructor at the University of Wisconsin teaching metallography and pyrometry. Due to his limited knowledge, he first took a summer course in these subjects. He selected the laboratory course at Columbia University taught by William Campbell and Henry Marion Howe.

American metallurgist Edgar C. Bain, of bainite fame. Courtesy of Library of Congress.

He taught at Wisconsin for one year, then accepted a research position at the B.F. Goodrich Co. When the U.S. entered WWI, Bain joined the army where he worked in chemical warfare research. After his discharge, he joined General Electric's National Lamp Works where he worked under Zay Jeffries.

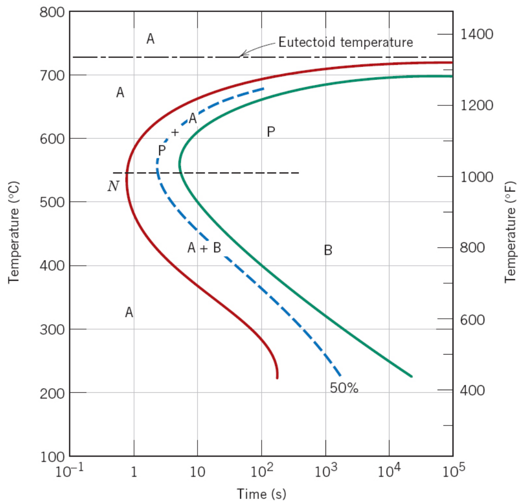
His first assignment was to investigate the problem of failed dies of high-speed steel during the wire drawing of tungsten. He studied the mechanism of secondary hardening, which was still a mystery after 20 years of use. Bain and Jeffries published their results in a famous paper on the "Red Hardness of High-Speed Steel" in *Iron Age* magazine in 1923. They combined the principles of precipitation hardening by Paul Dyer Merica with a mechanism of slip for rows of atoms to slide past one another for plastic deformation. The secondary hardening they proposed was that the formation of tungsten carbide at 1100°F keyed the slip to increase the hardness.

From left to right, Marcus Grossmann and Edgar Bain of Atlas Steel Corp., Dunkirk, N.Y., circa 1923. Courtesy of ASM.

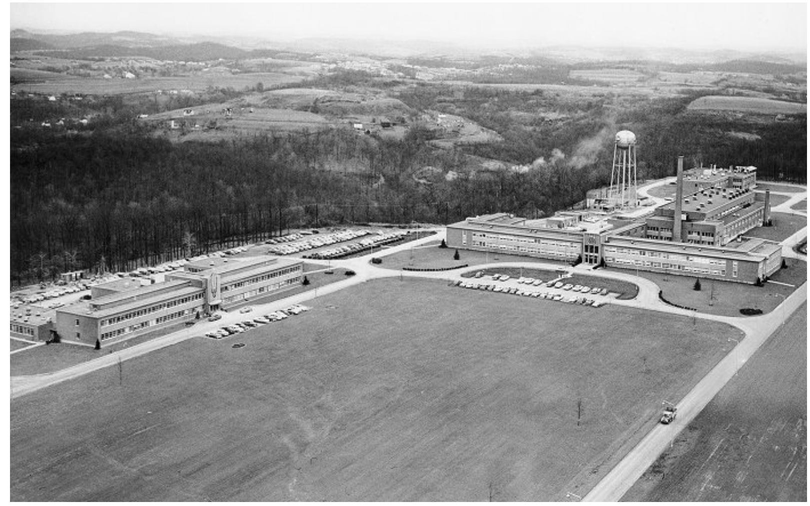
Bain also studied the crystal structure of metal solid solutions using x-ray diffraction, a new tool. Previous theory taught by Howe at Columbia and Albert Sauveur at Harvard stated there were patches of crystal structure of the solvent and other patches with the solute. Bain's results for copper and zinc (brass) showed for the first time that the solute atoms of a different crystal structure simply replaced solvent atoms at random without changing the crystal structure.

After four years of working with Jeffries at GE, Bain joined Atlas Steel in Dunkirk, N.Y., where he worked on high-speed and other alloy tool steels with Marcus Grossmann. This was an especially productive time for Bain as he was now pursuing a career studying transformation during steel heat treatment and the effect of alloy additions. Alloy steels were becoming ever more important with the expanded production of automobiles and farm machinery, but understanding heat treatment and alloying elements had made little progress.

In July 1924, Bain joined the Union Carbide and Carbon Corp., a producer of ferroalloys including ferrochromium. During the summer of 1927, he took a leave from his work and visited steel plants, laboratories, and universities in Europe with Grossmann. They met with some early researchers who had done the first studies on tool steels, alloy steels, and the transformation of austenite.



Isothermal transformation diagram for an iron-carbon alloy of eutectoid composition (0.80% C), including austenite to pearlite and austenite to bainite transformations. Courtesy of ASM.



Aerial view of U.S. Steel's Research Center showing the Edgar C. Bain Laboratory for Fundamental Research on the left. Courtesy of Historic Pittsburgh, images.library.pitt.edu/pittsburgh.

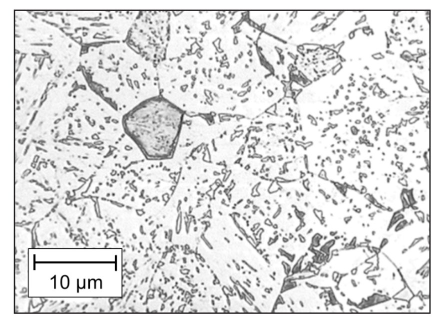
PHASE TRANSFORMATIONS

Bain joined the newly formed Research Laboratory of U.S. Steel in 1928. His first assignment was to design and equip a laboratory in a vacant building in Kearney, N.J. Here he undertook research on the transformation of austenite to pearlite in 0.80% carbon steel. This steel had the carbon content that formed only pearlite, called the eutectoid composition. He hired a young metallurgist, E.S. Davenport, to help with his research.

The experiment was unique in that they studied the formation of pearlite over time at a constant temperature. This was the first time anyone had studied a metal reaction as a function of time. It had been assumed that only temperature was important in transformation. They heated very thin samples to the austenitic phase, and quenched them in a bath heated to the transformation temperature. At various time intervals, a sample was removed and quenched in a room temperature water bath to form martensite in the untransformed austenite. The microstructure was then examined to measure the amount of pearlite that had formed at the constant higher temperature.

Plotting the percent transformation against time on a logarithmic scale for transformation to start, to progress, and to end provided the rate of transformation. The resulting curves started slowly, progressed rapidly, and ended slowly. Plotting the beginning and ending times for many different temperatures resulted in a curve with a c-shape. At the highest temperatures, the start and end of transformation was delayed in time. As temperature decreased, the reaction was faster until about 1100°F. At even lower temperatures, the reaction rate decreased again and a new microstructure formed that was not pearlite. This new phase was named bainite in his honor.

The paper published by Davenport and Bain in 1929 received worldwide attention, and with his previous research on tool steels, alloy steels, and his pioneering work in x-ray diffraction, he was recognized as America's leading metals scientist. During his active research career at U.S. Steel, Bain and his coauthors published 20 technical papers between 1929 and 1939. He also coauthored a book on tool steels with Marcus Grossmann in 1931 and published his book *Functions of the Alloying Elements in Steel* in 1939. He was promoted to vice president of research and technology of the Carnegie-Illinois Steel Corp. in 1943 and moved to Pittsburgh where he later became vice president of research and technology for the entire U.S. Steel Corp. The corporation built a research campus in 1956 in Monroeville, Pa., which included the Edgar C. Bain Laboratory for Fundamental Research.



Granular bainite. Courtesy of EWI.

AWARDS AND HONORS

Bain was active in many technical societies, served as president of ASM in 1937, was elected into the National Academy of Sciences in 1954, and received many other honors. He also earned several awards for his career in metals research. These include the Robert W. Hunt Medal in 1929, Henry Marion Howe Medal in 1931, Albert Sauveur Achievement Award in 1946, ASM Gold Medal in 1949, and the Franklin Institute's John Price Wetherill Medal in 1949. Edgar Bain suffered a stroke in 1959 that left him partially paralyzed. He continued to consult from his home and wrote his autobiography, *Pioneering in Steel Research: A Personal Record,* published by ASM in 1975 after his death in 1971.

For more information: Charles R. Simcoe can be reached at crsimcoe1@gmail.com.

2015–2016 PRESIDENT OF ASM INTERNATIONAL

JON D. TIRPAK

Angie Tirpak, Mount Pleasant, S.C.

We love campfires and enjoy them regularly in our backyard in Mount Pleasant, South Carolina. Using our usual Friday night setting, let me share some tales told by my husband and your president. Often these tales are in response to questions posed by our children or neighbors, especially since we are "from off," which means we are transplants, in South Carolina jargon.

THE FORMATIVE YEARS

Jon's Slovak father, Leslie, and second-generation Italian mother, Maria, raised Jon and his two older brothers to be hardworking and self-sufficient. In Basking Ridge, N.J., where the boys grew up, they studied hard, played sports, explored the nearby woods, joined Scouts, worked around the house, got after-school jobs, and led the National Honor Society. They also learned a lot from family members including their grandfather Carl, a German sailor who came to America in 1922, their uncle Dominic, a patternmaker for Liberty Ship engine castings, and their aunt Angie, a guidance counselor's secretary who had an early insight that typing would be required for college papers. Jon met other inspirations along the way as well, including his high school English teacher, Frances Buys, who suggested he write from a different perspective, and Al Taylor, his chemistry teacher, who taught him to ensure that calculated values are associated with units. While in high school, Jon was first exposed to the metals industry while working on a junk metal truck hauling barrels of scrap and also while working for a jeweler fashioning gold, silver, and platinum rings. During these early years, Jon unknowingly became hooked on metals.

Other influences came from Scout Troop 56 in Millington, N.J., with whom Jon spent Monday nights and countless weekends. In particular, Scoutmaster David Taylor and assistant Scoutmaster Gerry Harris were two who mentored and inspired him. Jon still corresponds with David, who influenced his early ideas about engineering, civic duty, and leadership. It was Gerry who pointed Jon to the Appalachian Trail (AT). In 1974, while visiting the trail in Pennsylvania, Jon put thru-hiking the AT on his bucket list before *bucket list* was even a thing.

THE COLLEGE YEARS

Jon and his brothers were given the option of going to work or college and knew this from an early age. Their parents also made it clear that they would be responsible for half of their tuition if they chose college. Jon was fortunate enough to earn a four-year Air Force ROTC scholarship. While at Lafayette College, he met two new inspirations: Bennie Ward and Professor Chet Van Tyne. Working as a river guide in Northern Maine between his freshman and sophomore years, Jon met Bennie, a metallurgist from Reynolds Aluminum. Sometime during a week of hiking, fishing, and camping, the topic of Jon's future was sparked around the campfire. Bennie suggested that Jon consider metallurgical engineering as a career. Toward the end of his sophomore year—with Bennie's comments ringing in his ears like a blacksmith's hammer working iron on an anvil—Jon chose metallurgical engineering over mechanical. In his junior year, he plunged into metallurgy with Professors Van Tyne, McGeady, Gill, and Jones. The next two years flew by, including a summer internship in a copper refinery. Upon graduation and commissioning as a Second Lieutenant, Jon launched for his first assignment at the Air Force Materials Research Laboratory in Dayton, Ohio.

The Tirpaks enjoy a backyard campfire in Mount Pleasant, S.C.

EMERGING PROFESSIONAL PART I

While in the Birthplace of Aviation, Jon worked on premium aluminum castings, durability and damage tolerance, design allowables, composites, carbon-carbon, and emerging materials property databases. He was welcomed into the Dayton Chapter of the American Society for Metals by David Lewis, Chapter Chair. This launched Jon into the Society's volunteer ranks at the Chapter level. In 1985, he served as an executive officer within an Air Force sponsored think tank called Project Forecast II. This was an eye-opening experience, which explored far reaching technologies and systems aimed at maintaining U.S. dominance of air and space. Jon also completed his master's degree in materials engineering during this time.

Springboarding to Norton AFB and the Ballistic Missile Office (BMO) was eye opening as well. The military was surfing on the Reagan Buildup, the Soviet Union had to go, and the U.S. was upping the ante through a massive weapons systems initiative. Jon's primary assignment was to integrate all Air Force nuclear testing requirements, which he did. Sometime during that brief period, split between the BMO in San Bernardino, Calif., and the Nevada Test Site near Las Vegas, Jon realized he needed to switch paths, separate from the Air Force, and pursue his dream of thru-hiking the Appalachian Trail.

METALLURGIST GONE WILD

Hiking the Trail is one of the most significant events in Jon's life. In 1988, he completed the 2137-mile journey atop the Appalachians from Georgia to Maine. Since first meeting Jon after his thru-hike, the frequency and intensity—and perhaps accuracy—of his trail hiking tales has diminished, although each year given any day between April and October, Jon can recollect within 20 miles or two days where he was on the trail. The kids and I like to tease him about his adventures, which are often prefaced by the phrase, "Back in '88 when…" Nonetheless, Jon's AT experience was a significant event further framing his perspectives on life.

EMERGING PROFESSIONAL PART II

Upon returning from his "sabbatical," Jon resumed participation in the Dayton Chapter while working at Universal Technology Corp. (UTC). Chapter Chair David Lewis from Armco Steel welcomed him back to ASM. Soon thereafter, Greg Barthold recruited Jon for the Federal Affairs Committee and he was thrust into the realm of ASM International on the national level. It was during this second tour in Dayton when Jon and I met at a National Cash Register (NCR) party.

SEASONED PROFESSIONAL

While at UTC, a small business in Dayton, Ohio, Jon evolved into a seasoned professional working on Air Force contracts. Many of these involved advanced aerospace materials and manufacturing technology. When the Cold War ended and the business changed, Jon accepted a position in Ann Arbor, Mich., to lead Aeroquip Corp.'s near-net shape manufacturing and business development. During that move, I left NCR and joined Chelsea Milling Co., ultimately marrying Jon and starting our family.

For the past 19 years, most of his efforts have been directed at building teams and consortia to develop solutions for vexing technical and enterprise problems through a mix of industrial, academic, and government research. Most of his research focuses on metalworking with links to database development and IT tools such as the National Forging Tooling Database (with the University of Toledo), Simulation of Lean Practices through Job Shop Lean Modeling (with The Ohio State University), and Deformation Modeling (with Scientific Forming Technologies Corp.).

SOUTH CAROLINA

Since relocating to the Palmetto State in 1996, our family has grown and we are proud of our children. Nicola is a sophomore at Mercer University, Natasha is a junior at the Academic Magnet High School of Charleston, and Nathan is a freshmen at Wando High School. Charleston is a terrific city and we feel fortunate to live in a place where others vacation. For that, we thank SCRA and appreciate Jon's hard work as a metallurgical engineer and committed member of ASM International, which has been with us over the decades. Thank you for allowing me to share some tales of my husband and your president. Should you visit the Lowcountry, we hope you stop by for a campfire. You know Jon's story, and now we would like to hear yours. **~AM&P**

Jon thru-hiked the 2137-mile Appalachian Trail in 1988.

The Tirpaks enjoy many outdoor activities including ziplining.

ASMNEWS

PRESIDENT TIRPAK APPOINTS COMMITTEE COUNCIL CHAIRS

ASM International President Jon D. Tirpak, FASM, appointed a chair to each of the Society's general committees and councils. All appointments were unanimously approved by the Board of Trustees. Terms began September 1, 2015. Congratulations to all of our ASM International leaders!

Committee/Council chairs include:

Mr. Burak Akyuz, team lead, metallurgy and failure analysis, Applied Technical Service Inc., was appointed chair of the Failure Analysis Committee.

Ms. Beth Armstrong, staff scientist, Oak Ridge National Laboratory, was appointed chair of the Volunteerism Committee.

Dr. Aziz I. Asphahani, FASM, chief executive officer, QuesTek Innovations LLC, continues as chair of the Investment & ASM Materials Education Foundation Investment Committee.

Mr. Premkumar Aurora, partner, Aurora Engineering Co., continues as chair of the India Council.

Prof. Laura Bartolo, senior research associate, Northwestern University, was appointed chair of the Content Committee.

Dr. Corbett Battaile, principal member of technical staff, Sandia National Laboratories, was appointed chair of the Materials Property Database Committee.

Dr. Amber Black, applications engineer, Precision Technologies Inc., was appointed chair of the Emerging Technologies Awareness Committee.

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

Mr. Craig Clauser, president, Craig Clauser Engineering, continues as treasurer and chair of the Finance Committee.

Dr. Zayna Connor, senior engineer specialist, Caterpillar Inc., was appointed chair of the Technical Books Committee.


Akyuz


Armstrong


Asphahani


Aurora

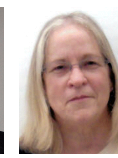

Bartolo


Battaile


Black


Chawla


Clauser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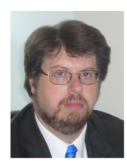
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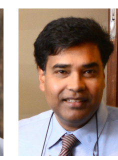
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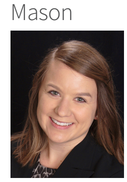
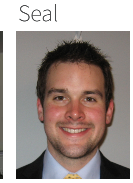

Spangler


Stockdale


Taylor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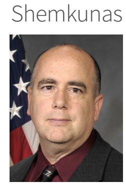

Tiley


Ulvan


Vander Voort

Ms. Diana Essock, FASM, president, Metamark Inc., continues as chair of the Women in Materials Engineering Committee.

In This Issue

Dr. Robert L. Freed, FASM, principal consultant, DuPont Co., continues as chair of the Education Committee.

Dr. Deidre Hirschfeld, manager, Sandia National Laboratories, continues as chair of the College and University Committee.

Dr. Elizabeth Hoffman, senior engineer, Savannah River National Laboratories, continues as chair of the New Products and Services Committee.

Dr. Padma Kodali, Caterpillar Inc., continues as chair of the Action in Education Committee.

Dr. Hua-Tay Lin, FASM, distinguished professor, Guangdong University of Technology, continues as chair of the Journal of Materials Engineering and Performance Committee.

Mr. Paul Mason, president, Thermo-Calc Software, continues as chair of the Alloy Phase Diagram Committee.

Prof. John E. Morral, FASM, professor emeritus, The Ohio State University, was appointed chair of the ASM & TMS Joint Commission on Metallurgical and Materials Transactions Committee.

Dr. Judy Schneider, FASM, professor, University of Alabama at Huntsville, was appointed chair of the ASM and MS&T Programming Committee.

Prof. Sudipta Seal, FASM, university distinguished and Pegasus Professor, University of Central Florida, was appointed chair of the Awards Policy Committee.

Dr. Michael P. Shemkunas, project engineer, The Boeing Co., was appointed chair of the AeroMat Organizing Committee.

Ms. Madison Spangler, process safety management specialist, DCP Midstream, was appointed co-chair of the Emerging Professionals Committee.

Ms. Anne Stockdale, materials engineer, General Atomics Aeronautical Systems Inc., was appointed chair of the Chapter Council.

Dr. Douglas J. Taylor, consultant, DTX, continues as chair of the Membership Committee.

Mr. Andrew J. Thome, project metallurgist, Carpenter Technology Corp., continues as co-chair of the Emerging Professionals Committee.

Dr. Jaimie Tiley, FASM, materials engineer, US Air Force Research Lab, was appointed chair of the AM&P Editorial Committee.

Dr. Erhan Ulvan, technical manager, Acuren Group, continues as chair of the Canada Council.

Mr. George Vander Voort, FASM, consultant, Vander Voort Consulting LLC, continues as chair of the Handbook Committee.

ASM Seeks Vice President and Board of Trustees Nominations

ASM is seeking nominations for the position of vice president as well as three trustees. The Society's 2017 vice president and trustee elects will serve as a voice for the membership and will shape ASM's future through implementation of the ASM Strategic Plan.

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

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

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

Deadline for nominations is **March 15.** For more information, visit asminternational.org/vp-board-nominations or contact Leslie Taylor, 440.338.5151 ext. 5500, or leslie.taylor@asminternational.org.

Annual ASM Award Nominations due February 1

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

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

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

2016 Bradley Stoughton Award for Young Teachers

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

Do you know a colleague who:

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

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

Ursula Kattner, FASM, Receives 2016 J. Willard Gibbs Phase Equilibria Award

ASM is pleased to announce that Dr. Ursula R. Kattner, FASM, physical scientist, National Institute of Standards and Technology, is the 2016 J. Willard Gibbs Phase Equilibria Award recipient. She is cited "for contributions to the thermodynamic assessment of metallic alloys and application to metallurgical processing."

The Gibbs Award was established in 2007 to recognize outstanding contributions to the field of phase equilibria. The award honors J. Willard Gibbs, one of America's greatest theoretical scientists. The award is endowed by QuesTek Innovations LLC.

Gibbs laid the thermodynamics foundations of phase equilibria with his brilliant essay, "On the Equilibrium of Heterogeneous Substances," published in 1876 and in 1878 in the *Transactions of the Connecticut Academy*.

Kattner will receive her award at MS&T16 in October in Salt Lake City.

Scranton Iron Furnaces Receive ASM Historical Landmark Award

On October 11, 2015, the Scranton Iron Furnaces were awarded the 2015 ASM Historical Landmark Award. ASM Trustee Jacqueline Earle, a Scranton area native, attended the celebration that was held at the Anthracite Heritage Museum in Scranton, Pa. The furnaces were one of the largest iron production capabilities in the U.S. by 1865 and ranked as the second largest iron producer in the U.S. by the 1880s. The first furnace was built there in 1841, but is no longer standing. The plaque reads, "The Scranton Iron Furnaces spurred the nation's industrial revolution in iron and coal through the use of anthracite. Locally produced rails contributed to the growth of America's 19th century railroads."

The furnaces shown here were constructed between 1848 and 1857.

JTST Announces Editorial Transition

After 12 years of serving as editor-in-chief of the *Journal of Thermal Spray Technology* (JTST), Christian Moreau, FASM, TS HoF, has transferred his responsibilities to Armelle Vardelle, FASM. The transition was announced by Robert Tucker, Jr., FASM, TS HoF, chair of the Journal of Thermal

McDonald

Moreau

Vardelle

Spray Technology Committee. Moreau became JTST editor in 2004 and led the journal through an extraordinary period of growth, in which the journal increased from a quarterly to six issues per year in 2007, then to eight annual issues in 2013.

Vardelle has been lead editor of JTST since 2013 and prior to that was an associate editor from 2006 through 2012. She will be succeeded as lead editor by André McDonald. Vardelle is a professor and co-chair of the department of materials at the engineering school of the University of Limoges, France. McDonald, associate professor, University of Alberta, is chair of the ASM Thermal Spray Society Training Committee, lead editor of the 2015 International Thermal Spray Conference Proceedings, and has served as a guest co-editor of the journal.

ASM, HTS, IMS and TSS Seek Student Board Members

We're looking for Material Advantage student members to provide insights and ideas to the ASM, HTS, IMS, and TSS 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

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

Opportunities specific to each Society:

ASM International
- Attend four Board meetings (June 20-22, October 23-26 during MS&T16, March and June 2017)
- Term begins June 1

ASM Heat Treating Society
- Attend two Board meetings (October 2016 during Furnaces North America and spring 2017)
- Participate in two teleconferences
- Term begins in September

ASM International Metallographic Society
- Attend one Board meeting (July 2017)
- Participate in monthly teleconferences
- Term begins in August

ASM Thermal Spray Society
- Attend one U.S. Board meeting in the second half of 2016
- Participate in two teleconferences
- Receive a one-year complimentary membership in Material Advantage
- Term begins in October

Heat Treating Society Seeks Board Nominations

The ASM HTS Awards and Nominations Committee is seeking nominations for three directors, a student board member, and a young professional board member. Candidates must be an HTS member in good standing. Nominations should be made on the formal nomination form and can be submitted by a chapter, council, committee, HTS member, or an affiliate society. The HTS Nominating Committee may consider any HTS member, even those who have previously served on the HTS Board. Nominations for Board members are due **February 1.**

For more information and the nomination form, visit the HTS website at hts.asminternational.org and click on Membership and Networking, and then Board Nominations; or contact Joanne Miller at 440.338.5151 ext. 5513, joanne.miller@asminternational.org.

HTS Seeks Young Professional for Board Position

The ASM Heat Treating Society Board is seeking a qualified individual to fill the Young Professional Board Member position. HTS values the input and participation of young people at all levels of activity and wants to hear more of what the next generation has to say.

Young professionals must be within 10 years of graduation, have an interest in the field of heat treating, and be a member of ASM or ASM-HTS. This nonrenewable, one-year term as a voting member of the HTS Board begins in September. The new member must attend two HTS Board meetings (to be financially supported by their company) and participate in four teleconferences. Application deadline is **February 1.**

For more information and details on how to apply, visit hts.asminternational.org and click on Membership and Networking, and then Board Nominations.

HTS AWARD DEADLINES

Nominations Sought for George H. Bodeen Heat Treating Achievement Award

ASM's Heat Treating Society (HTS) is currently seeking nominations for the George H. Bodeen Heat Treating Achievement Award, which recognizes distinguished and significant contributions to the field of heat treating through leadership, management, or engineering development of substantial commercial impact. Deadline for nominations is **February 1, 2017.**

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

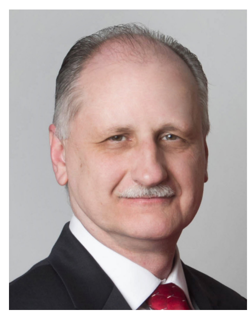
The ASM Heat Treating Society established the Best Paper in Heat Treating Award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advantage in managing the business of heat treating. The award, endowed by Bodycote Thermal Process-North America, is open to all full-time or part-time students enrolled at universities (or their equivalent) or colleges. The winner will receive a plaque and a check for $2500. Deadline is **March 1, 2016.**

For nomination rules and forms for these two awards, visit the Heat Treating Society website at hts.asminternational.org and click on Membership and Networking, and then Society Awards. For additional information or to submit a nomination, contact Joanne Miller at 440.338.5151, ext. 5513, joanne.miller@asminternational.org.

Canadian Teachers Enjoy ASM Materials Camp

During 2015, the ASM Materials Education Foundation and local ASM chapters in Canada collaborated with the NACE Foundation of Canada, local NACE sections, and the NACE Northern Area in presenting five-day ASM Materials Camps in Calgary and Ottawa for teachers. This was the 10th such camp to be hosted in Calgary and the seventh in Ottawa. Camps were held at the University of Calgary and at Ashbury College in Ottawa. A total of 48 teachers attended the camps. Each teacher received a "C-kit," courtesy of Carboline, including materials and documentation for carrying out corrosion-based experiments and a corrosion video.

VOLUNTEERISM COMMITTEE



Profile of a Volunteer

Rich Polenick, Technical Manager, Ellwood Specialty Steel Co.

Rich Polenick is a metallurgist with a passion for the steel industry. "We're in an area considered the Rust Belt. People think of it as old and outdated," he reflects. "But show them how steel is made, forged, and shaped—and they're fascinated!" A longtime ASM volunteer, Polenick enjoys seeing students inspired by teachers returning from ASM Teachers Camps at Youngstown State University in Ohio.

Ottawa teachers enjoy a five-day ASM Materials Camp.

He works as a technical manager for Ellwood Specialty Steel, a Pennsylvania company making tool steel products used in plastic and die casting molds. He began as an hourly steel mill laborer before deciding to enter Youngstown State University and study metallurgical engineering at age 23. A college professor introduced him to ASM, and he's been an active member of the Warren Chapter since 1990.

Hired by GM (which became Delphi), Polenick worked with the company for 25 years before joining Ellwood. And for 25 years he's been serving as his Chapter's secretary. "It's not unusual in our Chapter to stay in a role for a long time, but I never felt I had to. I had the tools to do it so I just kept doing it!" He arranges meetings, dinners, plant tours, and speakers, and also keeps track of membership.

Polenick acknowledges the ASM value of networking and information exchange, but sees great change driven by online information. "ASM was built on its handbooks, the Bible of materials engineering. It's still a good resource, but now we have a generation with knowledge at their fingertips."

He finds himself impressed by opportunities to evolve both the industry and the Chapter. "I presented a webinar on metals and heat treatment and 300 people signed up to listen to me talk for an hour," Polenick marvels. "It really is a very efficient way to communicate." After attending ASM's Leadership Days last summer, he says he is inspired by the younger people creating the future of ASM with new ideas and a different approach.

CHAPTER NEWS

Northwest PA Chapter Hosts Student Night

From left to right, William Bennett, chair of the Northwest Pennsylvania Chapter, with Davide Piovesan, assistant professor of mechanical engineering at Gannon University. In November 2015, the Chapter hosted a student night with record attendance where Piovesan gave a talk titled, "Antibiotic Impregnation of Metal Rod for Treatment of Compound Fractures."

Ontario Chapter Explores Failure Analysis

From left to right, Paul Okrutny, chair of the Ontario Chapter, with Doug Perovic, a professor at the University of Toronto. Perovic gave a presentation to nearly 60 attendees on "Forensic Engineering and Failure Analysis" at the Chapter's November meeting.

MEMBERS IN THE NEWS

Saenz Leads Team to Support Nigerian STEM Efforts

Theresa Saenz, a materials engineering student at Purdue University, is leading a team of 15 undergraduates providing technical support for the Inwelle Center in Nigeria while they install a 20 kW solar system. The center provides STEM training for women and children and currently runs on generators. The project is being documented by Raw Science TV and will be used as an example at other schools in developing areas. The Purdue team is seeking corporate sponsors and donations for solar panels, inverters, and batteries for the new system. For more information, email saenzt@purdue.edu.

McGeehan Elected President of MPIF

Patrick McGeehan, vice president and general manager of the specialty metal products division of Ametek Inc., Eighty Four, Pa., was elected the 28th president of the Metal Powder Industries Federation (MPIF). His two-year term took effect at the conclusion of MPIF's annual meeting recently held in Austin, Texas, in November 2015. McGeehan earned his BS and MS degrees in materials science and engineering from Drexel University. He has been with Ametek Inc. for seven years and worked at Hoeganaes Corp. for 25 years before that.

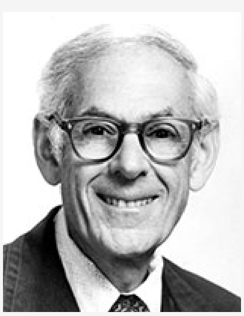
Paranthaman Named AAAS Fellow

The American Association for the Advancement of Science (AAAS) recently named **Mariappan Parans Paranthaman, FASM,** of Oak Ridge National Laboratory (ORNL), as a new fellow. Paranthaman is a distinguished research staff member and leader of the materials chemistry group of ORNL's Chemical Sciences Division, and also serves on the faculty for the University of Tennessee's Bredesen Center for Interdisciplinary Research and Graduate Education. He is cited by the AAAS "for distinguished contributions to the field of chemistry, including materials for superconductors, solar cells, lithium ion batteries, and processing of magnetic materials." Paranthaman will be honored at the AAAS annual meeting in February.

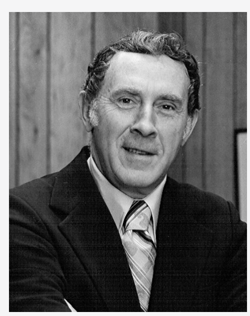
Mr. Rare Earth Aims to Retire

Karl A. Gschneidner Jr., FASM, will formally retire effective January 5 after a distinguished career that led him to become internationally recognized as "Mr. Rare Earth." Gschneidner, who turned 85 in November, has dedicated his career to the study of rare earth metals. He is a distinguished professor of materials science and engineering at Iowa State University, a senior metallurgist at the Ames Laboratory, and chief scientist of the Critical Materials Institute. Although Gschneidner will officially retire, he will keep the same office he has had since 1963 and will stay involved in research. "The biggest difference in being retired will be that I don't have to be here for meetings! I can just concentrate on the research," he says.

IN MEMORIAM



Morris E. Fine, FASM, the Walter P. Murphy Professor Emeritus of Materials Science and Engineering and the Technological Institute Professor Emeritus of Materials Science and Engineering at Northwestern University, passed away on September 30, 2015, at age 97. He received his Ph.D. in metallurgy from the University of Minnesota in 1943 and was a member of Northwestern's faculty since 1954. Along with colleague Don Whitmore, Fine co-created the University's department of metallurgy in 1955 and became its first chair. In 1958, the world's first department of materials science was born. Fine came to Northwestern with a range of experiences that included work with the Manhattan Project in Chicago and Los Alamos and later with Bell Labs in New Jersey. Although he retired from Northwestern in 1988, he continued to be an active member of the community until his final days. Fine enjoyed an extensive list of honors throughout his career, including the ASM Gold Medal in 1986.

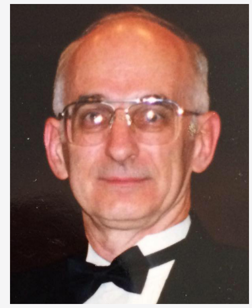


Kempton H. Roll, FASM, founding executive director of the Metal Powder Industries Federation (MPIF), died on November 4, 2015, at age 92. He attended Carnegie Institute of Technology and graduated from Yale University in 1945 with a degree in metallurgical engineering and served in the Pacific during WWII as a bomb disposal officer with the U.S. Navy. He earned a master's degree from Brooklyn Polytechnic Institute in 1953. Well known in the national and international metalworking communities, Roll retired in 1988 after a 40-year career. He joined the Lead Industries Association in 1948 as technical director with responsibilities for the former Metal Powder Association (MPA), forerunner of MPIF. He was named executive director of MPA in 1956 and helped found MPIF in 1957 as the umbrella organization representing different sectors of the metal powder producing and consuming industries. Roll was a member of ASM since 1946.

IN MEMORIAM

Frederick Rollins Specht, Jr., 61, passed away on November 11, 2015. He was nationally known as a heat induction expert for more than 40 years. He taught seminars across the country, including for ASM, and was a consultant for Inter-power Induction Inc. As a member of ASM International since 1985, Specht served on many committees including several in the area of heat treating. He served two terms as a Heat Treating Society (HTS) board member, was a member of the HTS Web Committee, and also served as the conference and expo co-chair for two Heat Treat events, in addition to other committees. Specht also spoke at seminars and meetings on the topic of induction heat treating at many ASM conferences. Most recently, he taught Practical Induction Heat Treating for ASM's education department.

George D. Pfaffmann, FASM, passed away on November 22, 2015, at age 87. He was an active and longtime member of the Heat Treating Society's Research & Development and Technical Programming Committees, and a member of ASM since 1953. He also served on the HTS Board from 1999-2001 and on the HTS Awards & Nominations Committee from 2004-2009. Retired from Ajax Tocco after more than 50 years, Pfaffmann authored several ASM books and tutorials on induction heating and received the ASM Instructor of Merit Award in 2002.

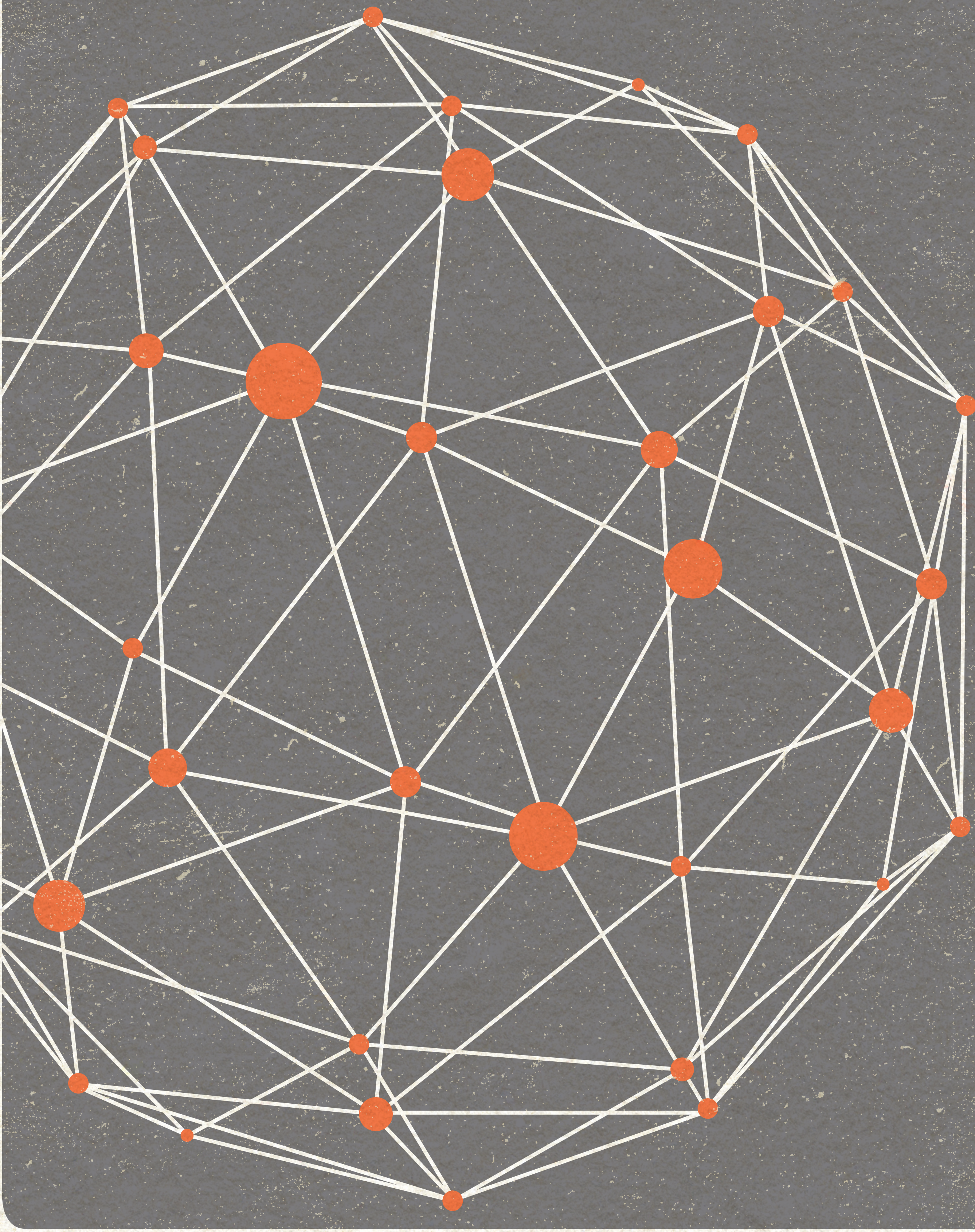


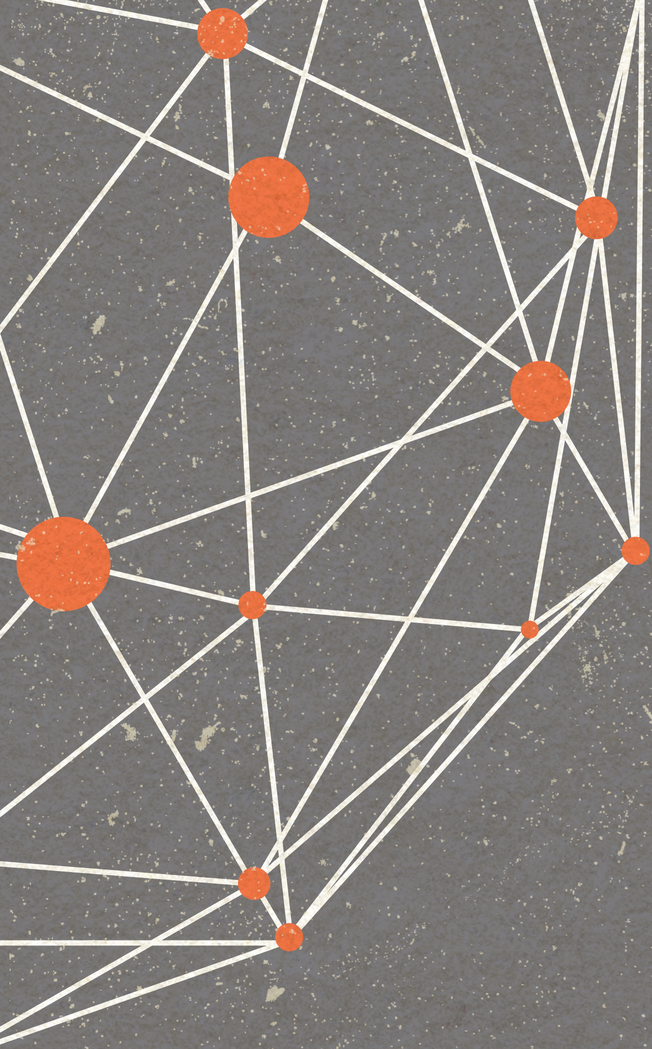
Bruce P. Bardes, FASM, passed away on October 18, 2015, at age 76. Bardes was a Captain in the U.S. Army and a graduate of Massachusetts Institute of Technology where he earned his bachelor's, master's, and Sc.D. degrees. Bardes served as editor-in-chief of ASM's *Metals Handbook* during the late 1970s. He then held several positions at GE Aircraft Engines and served as a professor at University of Illinois, Miami University, and University of Cincinnati. In later years, Bardes was vice president and principal metallurgist at Cincinnati Metallurgical Consultants and president of Materials Technology Solutions Co. A member of ASM since 1963, he received many professional awards and honors, including the Eisenman Memorial Award from ASM's Cincinnati Chapter.

ASM INTERNATIONAL

REFERENCE PUBLICATIONS CATALOG

INFORM. EDUCATE. CONNECT. | 2016





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ASM Handbook Complete Set, see page 5

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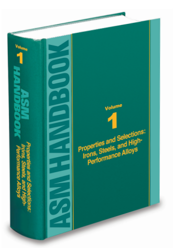
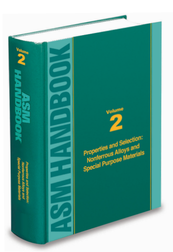


Volume 1: Properties and Selections: Irons, Steels, and High-Performance Alloys

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
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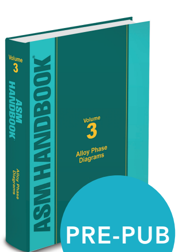
Your best single-volume source on compositions, properties, selection, and applications of nonferrous metals and alloys. Extensive coverage on aluminum, titanium, and copper. 1800 illustrations, hundreds of tables and data sheets.

Volume 3: Alloy Phase Diagrams



2016 • Approx. 800 pages
ISBN: 978-1-62708-070-5
Product Code: 05442G

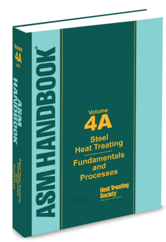
40% of the volume has been updated and now includes approximately 1,100 binary and 400 ternary diagrams. Diagrams cover most commercial alloy systems. New introductory information has been added, including chapters about solid solutions and phase transformations, thermodynamics, and isomorphous, eutectic, peritectic, and monotectic alloy systems.

Price: ~~$297~~ / ASM Member: ~~$225~~
Prepublication Price: $267 / ASM Member: $205
Prepublication price good through March 31, 2016!

Volume 4: Heat Treating

1991 • 1012 pages
ISBN: 978-0-87170-379-8
Product Code: 06184G
Price: $297 / ASM Member: $225

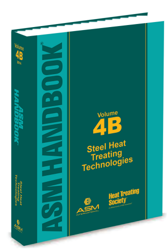
World's best reference guide to heat treating and surface hardening of steel, heat treating equipment, process and QC considerations, plus heat treating of cast irons, stainless steels, heat-resistant alloys, tool steels and nonferrous alloys.



Volume 4A: Steel Heat Treating Fundamentals and Processes

Edited by Jon L. Dossett and George E. Totten
2013 • 784 pages
IBSN: 978-1-62708-011-8
Product Code: 05344G
Price: $297 / ASM Member: $225

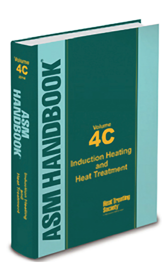
This volume addresses the basics of steel heat treating and thoroughly covers the many steel heat treating processes. Major topics include: the physical metallurgy of steel heat treatment, fundamentals and practical aspects of steel hardness and hardenability, quenching, annealing, tempering, austempering, 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

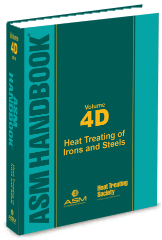
Volume 4B expands coverage on equipment, control, troubleshooting, and problems associated with steel heat treating. New articles extensively address distortion and the prevention of cracking – including the modeling and simulation of distortion. General process and procedure factors also are introduced—including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



Volume 4C: Induction Heating and Heat Treatment

Edited by Valery Rudnev and George E. Totten
2014 • 820 pages
IBSN: 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.



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.

Volumes 4A, 4B, 4C, 4D: Heat Treating Set

2014

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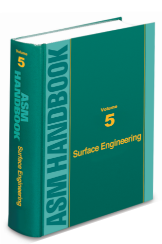


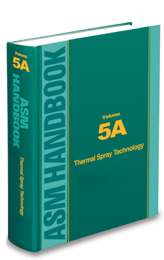
Volume 5: Surface Engineering

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.

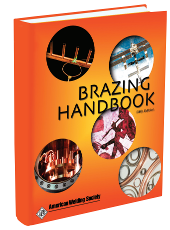
2013 • 412 pages

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.



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 5B: Protective Organic Coatings

Edited by Kenneth B. Tator

2015 • 545 pages

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Volume 6: Welding, Brazing and Soldering

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

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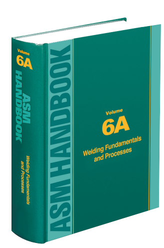

Volume 6A: Welding Fundamentals and Processes

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.

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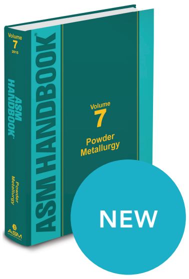


Volume 7: Powder Metallurgy

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

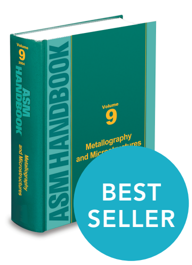
Edited by H. Kuhn and D. Medlin

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

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

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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.

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Edited by R.J. Shipley and W.T. Becker

2002 • 1164 pages

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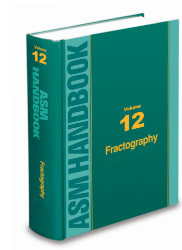
Price: $297 / ASM Member: $225

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

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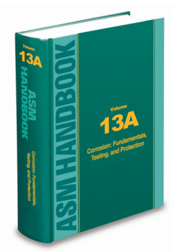


Volume 13A: Corrosion: Fundamentals, Testing, and Protection

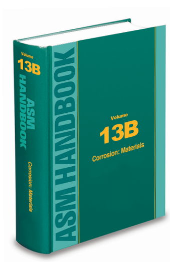
Edited by Stephen D. Cramer and Bernard S. Covino, Jr.

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

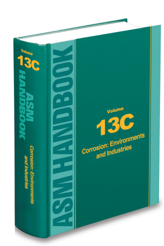
Edited by Stephen D. Cramer and Bernard S. Covino, Jr.

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.

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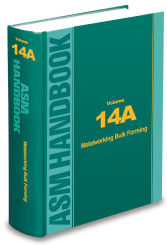

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Edited by S.L. Semiatin

2005 • 888 pages

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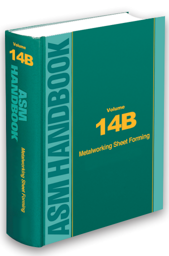

Volume 14B: Metalworking Sheet Forming

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2006 • 940 pages

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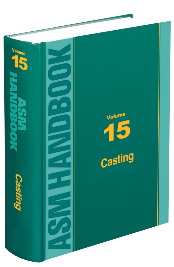
For product and production engineers. Methods of sheet metal fabrication technologies, selection of equipment and die materials, specification of forming practices for specific alloys, and new techniques for process design and control.



Volume 15: Casting

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

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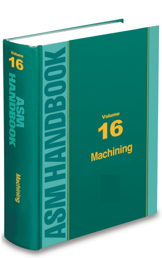
Molten metal processing, solidification behavior, modeling, molding, foundry practice, and casting properties. Basic steps and equipment are described for casting processes, along with their advantages, limitations, and applications.



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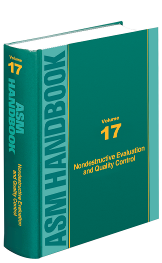

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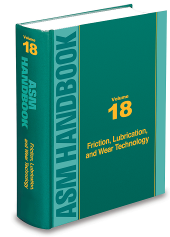

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Edited by P.J. Blau

1992 • 942 pages

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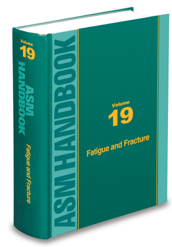
A guide to the basic concepts, methods of lab testing and analysis, materials selection, and field diagnosis of friction, lubrication, and wear problems. Provides the tools needed to understand the tribological behavior of materials and solve problems on the job.



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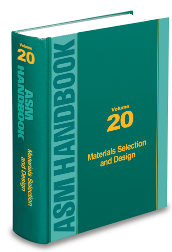

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1997 • 901 pages

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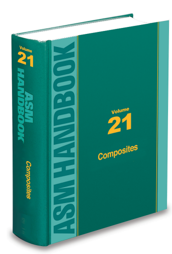
Contributions from more than 100 experts involved with design, materials selection, and manufacturing. Covers metals, ceramics, polymers, and composites and provides case histories and examples.



Volume 21: Composites

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

2001 • 1201 pages

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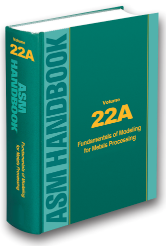

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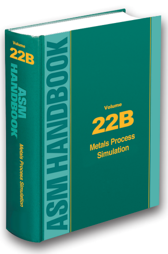
Development of metallic materials and process models that affect nearly every manufacturing industry. A solid foundation of the underlying physics that support many industrial simulation software packages.



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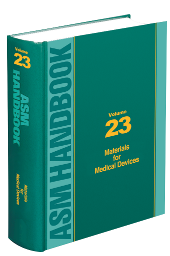

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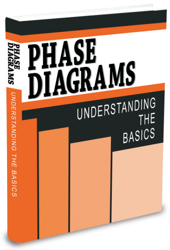

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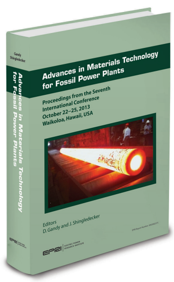
Exceptionally well-written text for non-metallurgists or anyone seeking a quick refresher on an essential tool in modern metallurgy. Ample illustrations for all important liquid and solid reactions. Gas-metal reactions, important in metals processing and in-service corrosion, are also discussed.



Advances in Materials Technology for Fossil Power Plants

Proceedings from the Seventh International Conference, 2013, EPRI

Edited by: D. Gandy and J. Shingledecker

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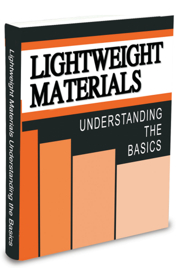
The conference brought together representatives from all of the national advanced ultrasupercritical projects including the U.S., Europe, Japan, China, and India. Proceedings are organized into nine topical areas: technology overviews, nickel-base alloys for advanced ultrasupercritical power plants, materials for turbines, alloys T23/24, Grades 91/92, oxidation and corrosion, welding and weld performance, new alloys concepts, and creep and general topics.

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

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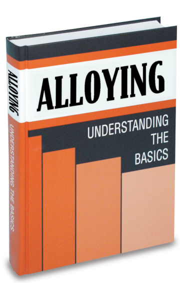
Learn the basics of aluminum, titanium, magnesium, beryllium, engineering plastics, polymer-, metal-, and ceramic-matrix composites, and structural ceramics. Includes basic metallurgy or materials science aspects of each material, as well as properties, processing, and applications. Guidelines for selecting materials for specific weight-critical applications.



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Edited by J.R. Davis

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

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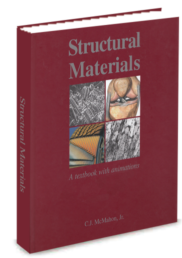

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By C.J. McMahon, Jr.

2004 • 470 pages

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A comprehensive introduction to structural materials and the underlying principles that affect their selection, properties, and performance. The book focuses on familiar applications (for example, materials selection for bicycle components) to tell a coherent story that conveys important concepts in a memorable fashion. Purchase of the book includes online access to dozens of animations and tutorials to visually demonstrate key concepts and processes.

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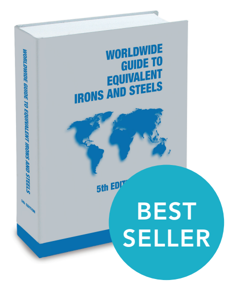

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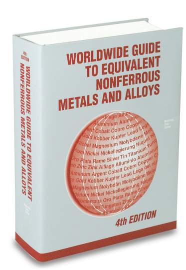

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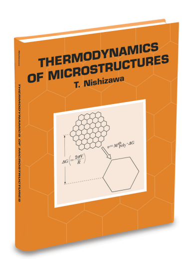

Thermodynamics of Microstructures

By Taiji Nishizawa, translated by Kiyohito Ishida

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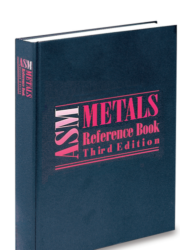
Price: $207 / ASM Member: $155

Fundamental relationships governing the behavior of microstructures.



ASM Metals Reference Book, 3rd Edition

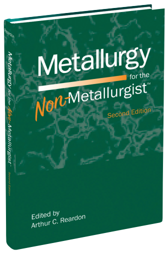
Edited by M.L. Bauccio

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.



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ISBN: 978-1-61503-821-3
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This completely revised edition provides an all new modern view of the basic principles and current practices of metallurgy. Recommended for anyone who uses, makes, buys or tests metal products.

Why are cast irons so suitable for casting? Do some nonferrous alloys respond to heat treatment like steels? Why is corrosion so pernicious? Answer all your basic metallurgy questions in this updated reference featuring many new illustrations, examples, and descriptions.

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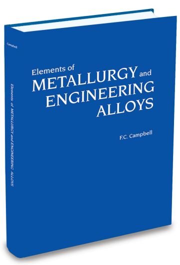


Elements of Metallurgy and Engineering Alloys

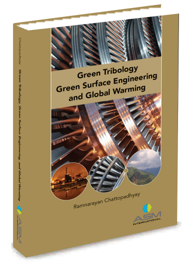
Edited by F.C. Campbell

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 both basic metallurgy and the practical engineering aspects of metallic material selection and application.



Green Tribology, Green Surface Engineering, and Global Warming

By Ramnarayan Chattopadhyay

2014 • 336 pages

ISBN: 978-1-62708-064-4
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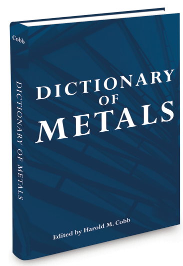
Price: $187 / ASM Member: $135

This book describes green engineering concepts to improve energy efficiency by reducing energy losses due to friction and wear in metalworking operations and by extending component life.



Dictionary of Metals

Edited by Harold M. Cobb

2012 • 374 pages

ISBN: 978-1-61503-978-4
Product Code: 05359G

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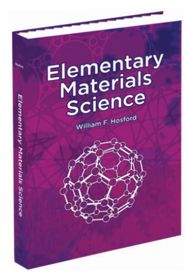
Includes historical overview beginning with the seven metals of antiquity. Showcases each metallic element, the discoverer and date, naming and its meaning, major applications, significance of the discovery and physical properties.



Elementary Materials Science

By William F. Hosford

2013 • 188 pages

ISBN: 978-1-62708-002-6
Product Code: 05373G

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Very few equations! Intended for students with limited science backgrounds. Useful for nontechnical professionals in the materials industry. The basics of bonding, crystal structures, and amorphous materials. Chapters devoted to phase relations, mechanical behavior, electrical behavior, magnetic behavior, and corrosion. Addresses nonferrous metals, iron and steel, ceramics, polymers, composites, and wood. More on forming and shaping, and recycling.

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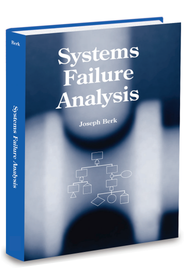

Systems Failure Analysis

By Joseph Berk

2009 • 214 pages

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Price: $107 / ASM Member: $75

Complex systems failures can have hundreds of potential causes. Learn how to analyze and prevent them. Written for development engineers, quality assurance specialists, manufacturing engineers, purchasing personnel, and field service engineers. Great for organizations that produce or procure complex systems in the aerospace, defense, automotive, biomedical, electronic, and related industries.

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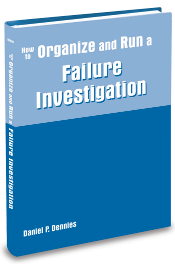
By Donald J. Wulpi
Edited by Brett Miller

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.



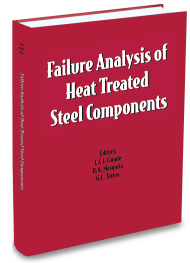
How to Organize and Run a Failure Investigation

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.



Failure Analysis of Heat Treated Steel Components

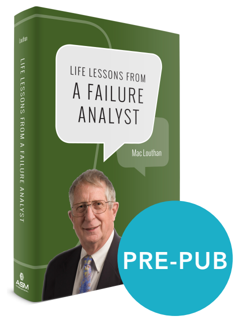
Edited by L.C.F. Canale, R.A. Mesquita and G.E. Totten

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.



Life Lessons from a Failure Analyst

By McIntyre R. Louthan, Jr.

2016 • Approximately 120 pages

ISBN: 978-1-62708-110-8
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Comprised of a compilation of 38 editorials written by the former editor-in-chief of the *Journal of Failure Analysis and Prevention,* these editorials are applicable to failure analysts and all others looking to achieve success in almost any career. Presented through entertaining personal stories, the editorials focus on learning good communication skills, leadership, and strength in character from a seasoned failure analysis professional.

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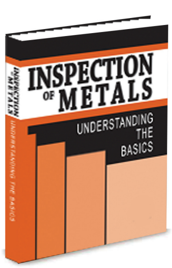
METALLOGRAPHY & MATERIALS CHARACTERIZATION



Inspection of Metals: Understanding the Basics

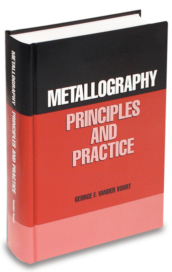
Edited by F.C. Campbell

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

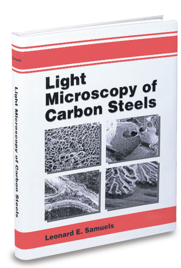
By G. Vander Voort

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

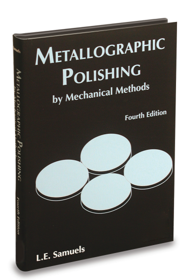
By L.E. Samuels

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.



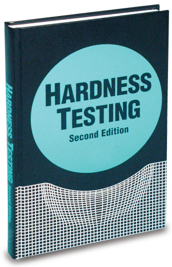
Metallographic Polishing by Mechanical Methods, 4th Edition

By L.E. Samuels

2003 • 345 pages

ISBN: 978-0-87170-779-6
Product Code: 06964G

Price: $157 / ASM Member: $115



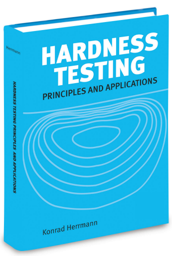
Hardness Testing, 2nd Edition

Edited by H. Chandler

1999 • 192 pages

ISBN: 978-0-87170-640-9
Product Code: 06671G

Price: $77 / ASM Member: $55



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

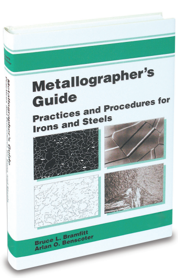
By Brian S. Hayes and Luther M. Gammon

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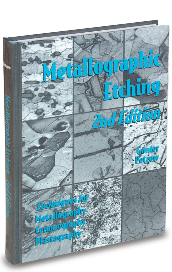
Important metallurgical concepts related to the microstructures of irons and steels. More than 500 representative microstructures, and how they can be altered by heat treatment and other means.



Metallographic Etching, 2nd Edition

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1999 • 240 pages

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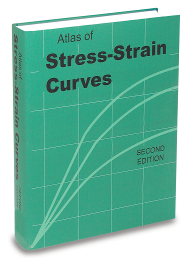

Atlas of Stress-Strain Curves, 2nd Edition

2002 • 816 pages

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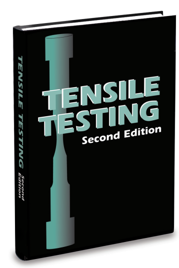
Product Code: 06825G

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

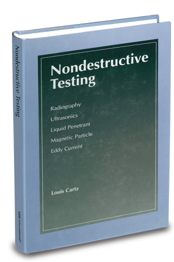
Edited by J.R. Davis

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

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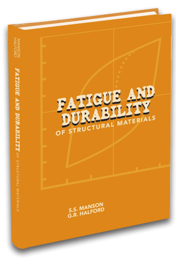

Fatigue and Durability of Structural Materials

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

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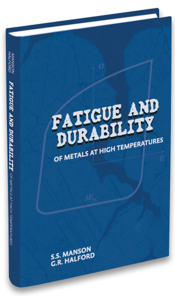
Focuses on metallic materials but also addresses unique capabilities of important nonmetals.



Fatigue and Durability of Metals at High Temperatures

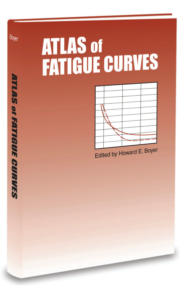
By S.S. Manson and G.R. Halford

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

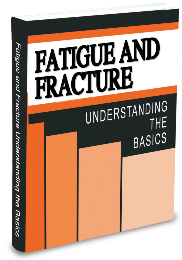
Edited by H.E. Boyer

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.



Fatigue and Fracture: Understanding the Basics

Edited by F.C. Campbell

2012 • 698 pages

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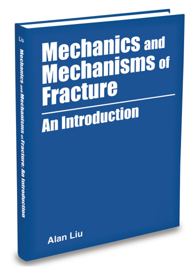
Covers mechanical properties of materials, differences between ductile and brittle fractures, fracture mechanics, the basics of fatigue, structural joints, high temperature failures, wear, environmentally-induced failures, and steps in the failure analysis process. Chapters devoted to fatigue and fracture 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
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Price: $167 / ASM Member: $125

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

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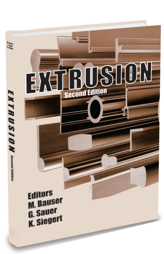

Extrusion, 2nd Edition

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

2006 • 608 pages

ISBN: 978-0-87170-837-3
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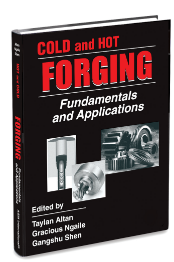
Newest edition. Overview of extrusion processes, equipment, and tooling. Metallurgical fundamentals of extrusion are covered in detail.



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

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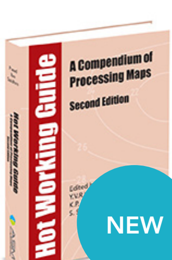
Fundamentals of forging technology, principal variables of the forging process and their interactions, and computer-aided techniques such as finite-element analysis (FEA) for forging process and tooling design.



NEW

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

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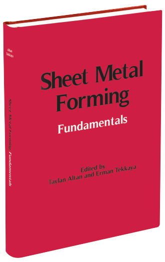


Sheet Metal Forming: Fundamentals

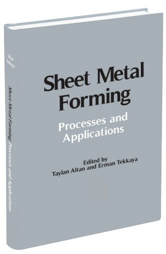
Edited by Taylan Altan and A. Erman Tekkaya

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

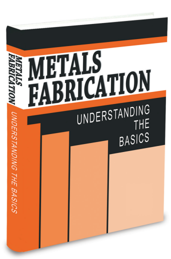
Edited by Taylan Altan and A. Erman Tekkaya

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

IBSN: 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.

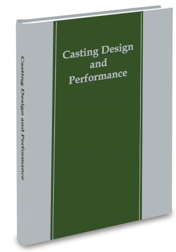
ASM Specialty Handbook® Tool Materials

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

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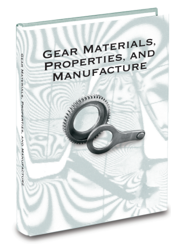
Product Code: 05263G

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

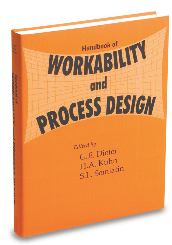
Edited by J.R. Davis

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

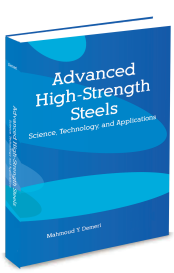
Edited by G.E. Dieter, H.A. Kuhn, and S.L. Semiatin

2003 • 414 pages

ISBN: 978-0-87170-778-9
Product Code: 06701G

Price: $247 / ASM Member: $185

STEELS



Advanced High-Strength Steels: Science, Technology and Applications

By Mahmoud Y. Demeri

2013 • 312 pages

IBSN: 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.

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Over 11,000 pages in PDF format.
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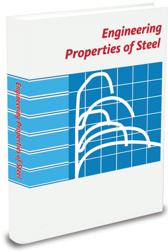
DVD can be used with any Windows platform laptop or desktop computer with a DVD drive. Articles can be printed, and text, tables, and images can be copied and pasted. Note: The files on the disc cannot be copied, so the DVD must be present in the local machine for the content to be accessed.



Engineering Properties of Steel

Edited by Philip Harvey

1982 • 509 pages

ISBN: 978-0-87170-144-2
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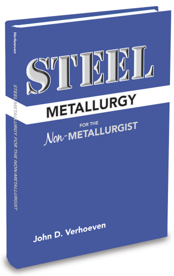
Price: $157 / ASM Member: $115

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

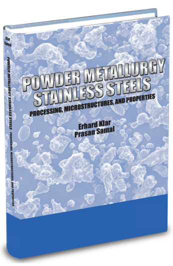
By John D. Verhoeven

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.



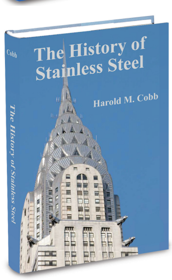
Powder Metallurgy Stainless Steels: Processing, Microstructures, and Properties

By E. Klar and P. Samal

2007 • 256 pages

ISBN: 978-0-87170-848-9
Product Code: 05200G

Price: $107 / ASM Member: $75



The History of Stainless Steel

By Harold M. Cobb

2010 • 384 pages • Illustrated

Soft Cover ISBN: 978-1-61503-010-1
Product Code: 05276G

Price: $43 / ASM Member: $32

Hard Cover ISBN: 978-1-61503-011-8
Product Code: 05279G

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Will light the imagination of those curious about how technology can advance and benefit society. Architects, historians, and railroad enthusiasts will enjoy this book as well. Includes a "Stainless Steel Timeline" that lists over 450 interesting and important facts and events on stainless steels technology and applications.

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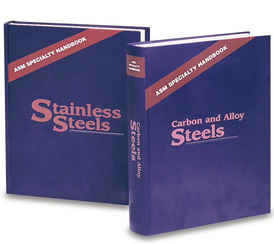

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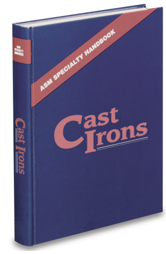

ASM Specialty Handbook® Cast Irons

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Product Code: 06613G

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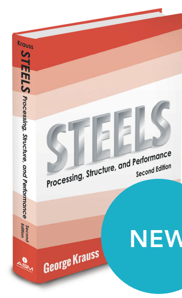
Basic information on metallurgy, solidification characteristics, and properties, as well as extensive reviews on the low-alloy gray, ductile, compacted graphite, and malleable irons.



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

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2015 • 682 pages

ISBN: 978-1-62708-083-5
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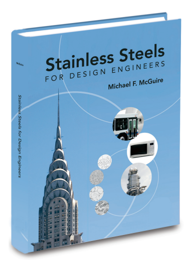


Stainless Steels for Design Engineers

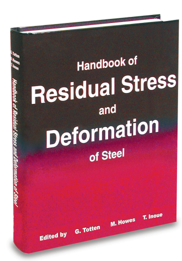
By Michael F. McGuire

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.



Handbook of Residual Stress and Deformation of Steel

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

2002 • 499 pages

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

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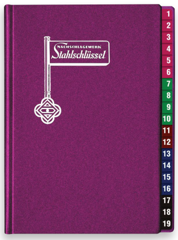

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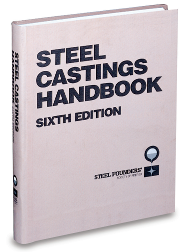


Steel Castings Handbook, 6th Edition

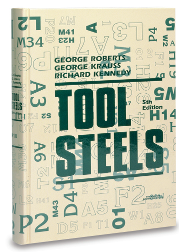
Co-published by Steel Founders' Society of America and ASM International

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.

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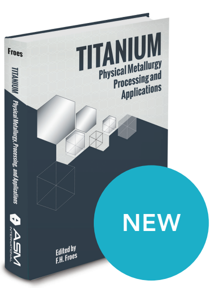

Titanium: Physical Metallurgy, Processing, and Applications

Edited by F.H. Froes

2015 • 404 pages

ISBN: 978-1-62709-079-8
Product Code: 05448G

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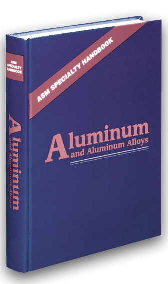
This book covers all aspects of the history, physical metallurgy, corrosion behavior, cost factors and current and potential uses of titanium. Extensive detail on extraction processes is discussed, as well as the various beta to alpha transformations and details of the powder metallurgy techniques.



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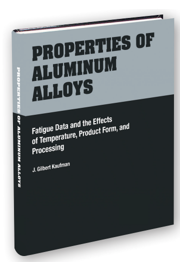

Properties of Aluminum Alloys: Fatigue Data and the Effects of Temperature, Product Form, and Processing

Edited by J.G. Kaufman

2008 • 574 pages

ISBN: 978-0-87170-839-7
Product code: 05156G

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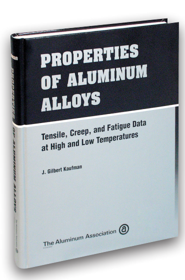
One of the most comprehensive collections of fatigue data yet available for aluminum alloys, temperatures, and products. The data, including over 1000 curves and numerous tables, are presented in a consistent format, conveniently arranged by alloy and temper.



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

Edited by J.G. Kaufman

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ISBN: 978-0-87170-632-4
Product code: 06813G

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Co-published by the Aluminum Association and ASM International.

ASM Specialty Handbook® Copper and Copper Alloys

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2001 • 652 pages
ISBN: 978-0-87170-726-0
Product Code: 06605G

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

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ISBN: 978-0-87170-596-9
Product Code: 06612G

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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

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ASM Specialty Handbook® Nickel, Cobalt, and Their Alloys

Edited by J.R. Davis
2000 • 442 pages
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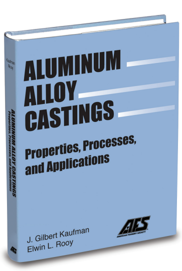
Product Code: 06178G

Price: $307 / ASM Member: $231

The compositions, properties, processing, performance, and applications of nickel, cobalt, and their alloys.

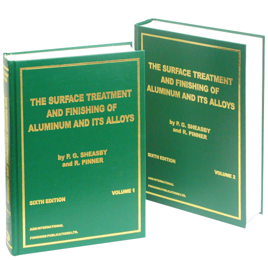


Aluminum Alloy Castings: Properties, Processes, and Applications

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
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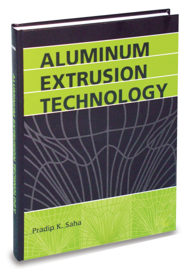

Aluminum Extrusion Technology

By P.K. Saha
2000 • 259 pages
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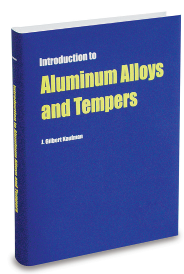
Practical information and reviews of important theoretical concepts in the different areas of extrusion technology. Intended for technical and engineering personnel, as well as research students in manufacturing.



Introduction to Aluminum Alloys and Tempers

By J.G. Kaufman
2000 • 258 pages
ISBN: 978-0-87170-689-8
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Price: $43 / ASM Member: $32

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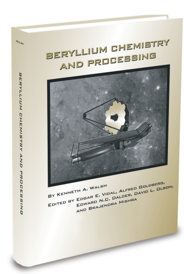

Beryllium Chemistry and Processing

By K.A. Walsh • Edited by E.E. Vidal, A. Goldberg, E. Dalder, D.L. Olson, and B. Mishra
2009 • 680 pages
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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.

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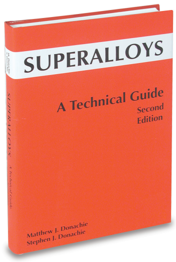


Superalloys: A Technical Guide, 2nd Edition

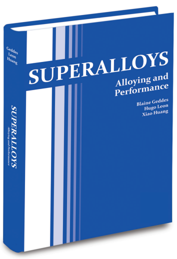
By M.J. Donachie and S.J. Donachie

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

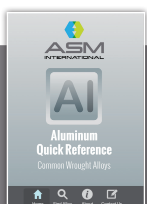
Blaine Geddes, Hugo Leon, and Xiao Huang

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.



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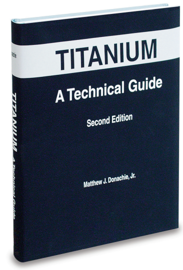
Find reference data on more than 200 common wrought aluminum alloy designation-tempers. Content includes typical mechanical and physical properties and chemical composition limits.



Titanium: A Technical Guide, 2nd Edition

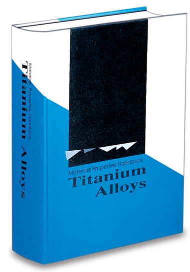
By M.J. Donachie, Jr.

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.

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Product Code: 05318V

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The 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.

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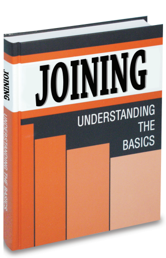

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Product Code: 05123G

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

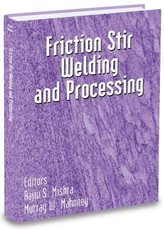
By Giles Humpston and David M. Jacobson

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.



Friction Stir Welding and Processing

Edited by R.S. Mishra and M.W. Mahoney

2007 • 368 pages

ISBN: 978-0-87170-840-3
Product Code: 05112G

Price: $157 / ASM Member: $115

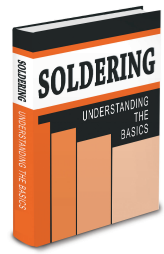
Weld Integrity and Performance

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.



Soldering: Understanding the Basics

By M.M. Schwartz

2014 • 184 pages

IBSN: 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.

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.

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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. A wide variety of additional heat treating data is included, such as representative micrographs, isothermal transformation diagrams, cooling transformation diagrams, tempering curves, and data on dimensional change.

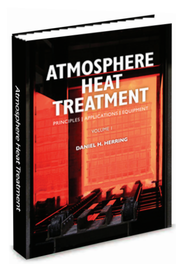
Heat Treater's Guide: Practices and Procedures for Nonferrous Alloys

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.



Atmosphere Heat Treatment: Principles, Applications, Equipment, Volume 1

By Daniel H. Herring • Publisher: BNP Media

2014 • 700 pages

ISBN: 978-0-692-28393-6
Product Code: 75149G

Price: $154.99 / ASM Member $139.49

This comprehensive resource emphasizes fundamental principles, materials, metallurgy, applications, and equipment. The focus is on the needs of heat treating and engineering practitioners working in the field. It provides practical advice, a diverse set of application examples, and a wide range of technical and engineering information necessary to make informed decisions about how to heat treat and what equipment and features are necessary to do the job.

NEW

Atmosphere Heat Treatment: Atmosphere, Quenching, Testing, Volume 2

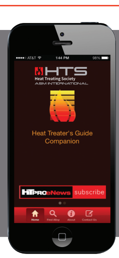
By Daniel H. Herring • Publisher: BNP Media

2015/TBD • 824

ISBN: 978-0-692-51299-9
Product Code: 75169G

Price: $154.99 / ASM Member $139.49

This second volume provides a comprehensive resource on the subject of atmosphere heat treatment and gives a wide range of useful information, both from a practical and a technical standpoint. Readers of this book will be able to make better and more informed decisions about their equipment, process, and service needs. Written specifically for the heat treater, engineer, and metallurgist by one of their own.



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Quick reference data on more than 430 steel, aluminum, and magnesium alloys. Use by itself or as a companion to the Heat Treater's Guide print and online database products. Published by ASM and the Heat Treating Society.

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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

NEW

Practical Induction Heat Treating, Second Edition

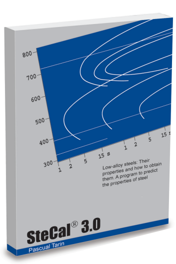
By R.E. Haimbaugh
2015 • 365 pages
ISBN: 978-1-62708-089-7
Product Code: 05505G
Price: $207 / ASM Member: $155

This book is 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. New material has been added including updated information on quenching methods, applications, inspection for quality control, and updated material on power supplies.

Heat Treatment of Gears: A Practical Guide for Engineers

By A.K. Rakhit
2000 • 209 pages
ISBN: 978-0-87170-694-2
Product Code: 06732G
Price: $167 / ASM Member: $125

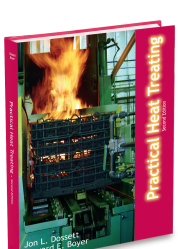
Heat treat distortion of gears is discussed in detail for the major heat treat processes. A case history of each successful gear heat treat process is included.



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.



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

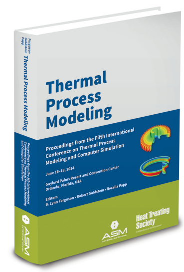
An excellent introduction and guide for design and manufacturing engineers, technicians, students, and others who need to understand why heat treatment is specified and how different processes are used to obtain desired properties. Clear, concise, and non-theoretical language.

Heat Treating Reference Library DVD, 2012 Edition

2012 • ASM International
ISBN: 978-1-61503-840-4
Product Code: 05347V
Price: $703 / ASM Member: $601

A complete guide to the heat treating of steels and nonferrous alloys. More than 3000 articles, data sheets, and diagrams from the ASM Handbook and other authoritative sources—more than 15,000 pages of content.

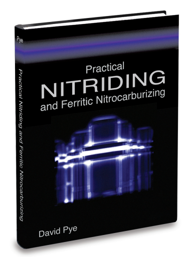
The DVD can be used with any Windows platform laptop or desktop computer with a DVD drive. Articles can be printed, and text, tables, and images can be copied and pasted. Note: The files on the disc cannot be copied, so the DVD must be present in the local machine for the content to be accessed.



Thermal Process Modeling: Proceedings of the 5th International Conference on Thermal Process Modeling and Computer Simulation

Edited by B.L. Ferguson, R. Goldstein, and R. Papp
2014 • 329 pages
ISBN: 978-1-62708-068-2
Product Code: 05447G
Price: $168 / ASM Member: $139

This collection of papers represents the heart of the 5th International Conference on Thermal Process Modeling and Computer Simulation. Thermal processes are key manufacturing steps in producing durable and useful products, with solidification, welding, heat treating, and surface engineering being primary steps.



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

Nitriding and ferritic nitrocarburizing offer unique advantages over other surface hardening heat treatments. This book will help you to understand these processes, select the appropriate process and process parameters, control the process, evaluate results, and troubleshoot.

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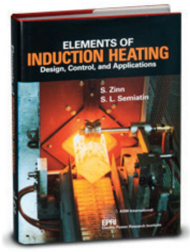


Elements of Induction Heating: Design, Control, & Applications

By S. Zinn, S.L. Semiatin

1988 • 335 pages

ISBN: 978-0-87170-308-8
Product Code: 06522G

Price: $107 / ASM Member: $75

Surface Hardening of Steels: Understanding the Basics

Edited by J.R. Davis

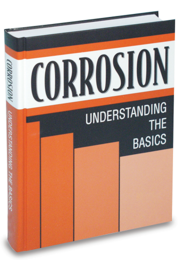
2002 • 364 pages

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.

CORROSION



Corrosion: Understanding the Basics

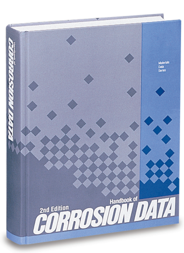
Edited by J.R. Davis

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

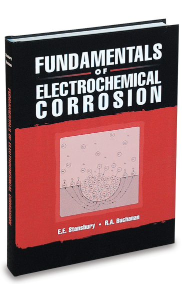
Edited by B. Craig and D. Anderson

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.



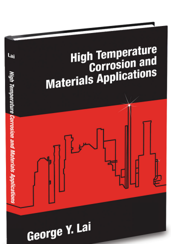
Fundamentals of Electrochemical Corrosion

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



High-Temperature Corrosion and Materials Applications

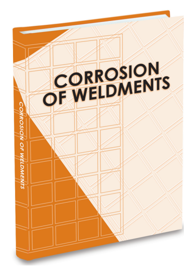
By George Y. Lai

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 of Weldments

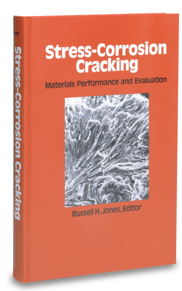
Edited by J.R. Davis

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.



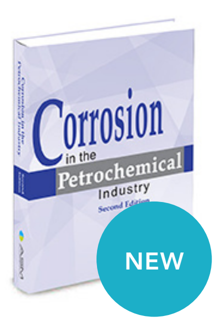
Stress-Corrosion Cracking: Materials Performance and Evaluation

Edited by R.H. Jones

1992 • 448 pages

ISBN: 978-0-87170-441-2
Product Code: 06355G

Price: $207 / ASM Member: $155



Corrosion in the Petrochemical Industry, Second Edition

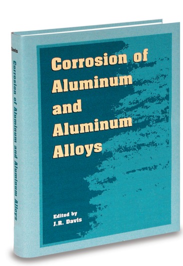
Edited by Victoria Burt

2015 • 426 pages

ISBN: 978-1-62708-094-1
Product Code: 05503G

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.

Price: $219 / ASM Member: $165



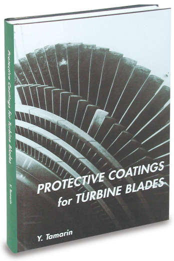
Corrosion of Aluminum and Aluminum Alloys

Edited by J.R. Davis

1999 • 313 pages

ISBN: 978-0-87170-629-4
Product Code: 06787G

Price: $167 / ASM Member: $125



Protective Coatings for Turbine Blades

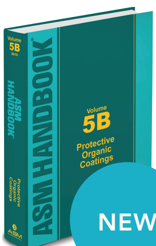
By Y. Tamarin

2002 • 244 pages

ISBN: 978-0-87170-759-8
Product Code: 06738G

Price: $53 / ASM Member: $42

Addresses the problem of surface protection for aircraft engine turbine blades. Based on the author's 30+ years of work on the development and application of coatings to protect against oxidation and hot corrosion. Describes and details a methodology for optimizing turbine blade surface protection.



NEW

Volume 5B: Protective Organic Coatings

Edited by Kenneth B. Tator

2015 • Approx. 590 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.

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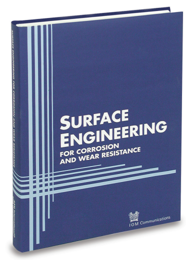


Surface Engineering for Corrosion and Wear Resistance

Edited by J.R. Davis

2001 • 279 pages

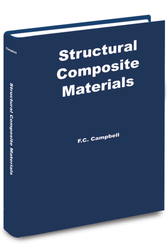
Co-published by IOM Communications and ASM International

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.

PLASTICS, COMPOSITES & CERAMICS



Structural Composite Materials

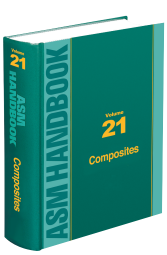
By F.C. Campbell

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.



Volume 21: Composites

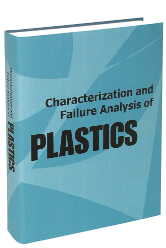
Edited by D.B. Miracle and S.L. Donaldson

2001 • 1201 pages

ISBN: 978-0-87170-703-1
Product Code: 06781G

Price: $297 / ASM Member: $225

See page 4 for more information.



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.

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Price: $457 / ASM Member: $405

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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

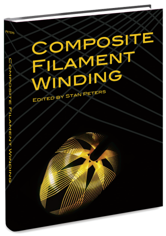
Price: $207 / ASM Member: $155

Volume 4: Ceramics and Glasses

1991 • 1217 pages

ISBN: 978-0-87170-282-1
Product Code: 06912G

Price: $207 / ASM Member: $155



Composite Filament Winding

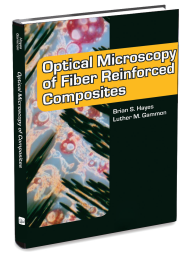
Edited by S.T. Peters

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

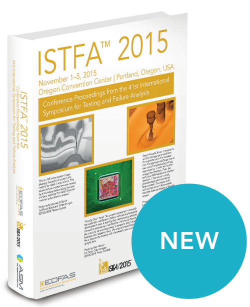
2010 • 284 pages

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.

MICROELECTRONICS



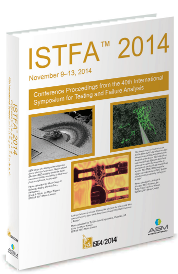
ISTFA™ 2015
Proceedings from the 41st International Symposium for Testing and Failure Analysis

2015 • Approx. 500 pages

ISBN: 978-1-62708-102-3
Product Code: 02217G

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, Follow the Data!



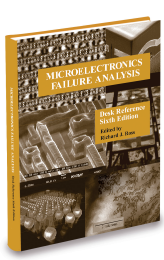
ISTFA™ 2014
Proceedings from the 40th International Symposium for Testing and Failure Analysis

2014 • 560 pages

ISBN: 978-1-62708-074-3
Product Code: 02216G

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, Exploring the Many Facets of Failure Analysis.



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.

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: $122

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 Society℠ keeps you in the loop. Guest columns provide vital perspective into FA topics.

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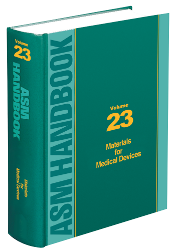

Volume 23: Materials for Medical Devices

Edited by Roger Narayan
2012 • 396 pages
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Product Code: 05285G
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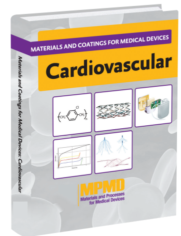
State-of-the-art reference for implant materials including stainless steels, cobalt-base alloys, titanium, shape memory alloys, noble metals, ceramics, and polymers. Examples of materials- and mechanical-based failures of medical devices. Covers biotribology, implant wear, clinical wear, and biological aspects. Corrosion effects, corrosion products, mechanically assisted corrosion, and corrosion fatigue. Biocompatibility of ceramics and polymers.

Volume 23 is a replacement for the *Handbook of Materials for Medical Devices* edited by J.R. Davis (ASM, 2003). It features new content that greatly expands the scope and depth of coverage, including a more in-depth discussion of materials and focus on applications.



Materials and Coatings for Medical Devices: Cardiovascular

2009 • 452 pages
ISBN: 978-1-61503-000-2
Product Code: 05269G
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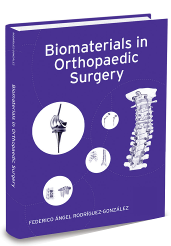
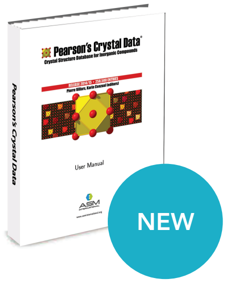
A unique volume of engineering property data with detailed biological response information, in a consistent data sheet format, for the materials and coatings for cardiovascular medical devices. The emphasis is on materials and coatings used in FDA-approved implantable devices.



Biomaterials in Orthopaedic Surgery

By Federico Ángel Rodríguez-González
2009 • 236 pages
ISBN: 978-1-61503-009-5
Product Code: 05233G
Price: $137 / ASM Member: $105

Biomaterials (metallic, nonmetallic, and bone allografts) used for orthopaedic applications and the engineering and clinical aspects of their use and performance. Case studies and specific applications include internal and external bone fracture fixation, hip and knee joint replacements, spine implants and disc prostheses, and the application of structural bone allografts for patients with bone tumors.



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2015/16

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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. The new 2015-2016 release includes more than 274,000 structural data sets for about 157,500 different chemical formula, roughly 17,900 experimental powder diffraction patterns, and about 255,000 calculated diagrams (interplanar spacings, intensities, Miller indices). In addition more than 45,200 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 89,000 original publications. Innovative software developed by Crystal Impact offers new features for easy retrieval of desired information.

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*For more information on Pearson's Crystal Data Database, contact Denise Sirochman at 888.605.6153 or denise.sirochman@asminternational.org.

Handbook of Ternary Alloy Phase Diagrams
10-Volume Set

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1995

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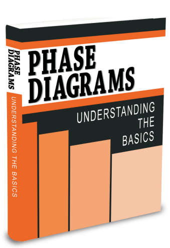


Phase Diagrams: Understanding the Basics

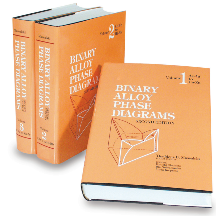
Edited by F.C. Campbell

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.



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

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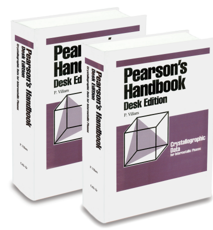
3-volume set includes 4,700 binary alloy phase diagrams.



Pearson's Desk Edition

Edited by Pierre Villars • 1997

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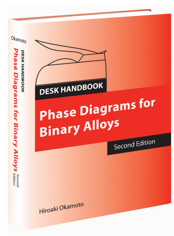
27,686 entries of the highest quality crystal data, representing 27,686 different compounds.



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.

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STRESS RELIEF

TEAM BUILDING WITH HUMANS AND ROBOTS

Construction workers on some sites are getting new, non-union help. SAM—short for semi-automated mason—is a robotic bricklayer being used to increase productivity as it works with humans. In this scenario, the robot is responsible for tasks such as picking up bricks, applying mortar, and brick placement while humans handle more nuanced activities, like setting up the worksite, laying bricks in tricky areas such as corners, and handling aesthetic details, like cleaning up excess mortar. SAM can complete precise and level work while being mounted on a scaffold that sways slightly in the wind. The robot can correct for differences between theoretical building specifications and what is actually on site, says Scott Peters, cofounder of Construction Robotics, Victor, N.Y., which designed SAM as its debut product. Peters says SAM's purpose is to leverage human jobs, not entirely replace them. A human mason can lay 300 to 500 bricks a day, while SAM can lay 800 to 1200. One human plus one SAM equals the productivity of having four or more masons on the job. *construction-robotics.com.*

SAM repetitively lays bricks while human masons handle the finishing touches.

CONCRETE 3D PRINTING GETS SUPERSIZED

Top view of concrete printer. Courtesy of Eindhoven University of Technology/Rien Meulman.

Eindhoven University of Technology, the Netherlands, is using a concrete printer that enables objects up to 11 × 5 × 4 m to be printed. The printer looks a bit like an overhead hoisting crane in a production hall, but instead of a hoisting cable it features a swivel printer head for concrete. Attached to this via a hose is a concrete mixing and pump unit. The Dutch company ROHACO built the printer, the first of its kind. A complete wall can be printed with every required functionality—fiber-reinforced concrete to make it strong, an active insulation layer to retain heat, dirt-repelling exterior concrete to keep it clean, and a layer on the inside to enhance acoustics. *www.tue.nl/en.*

KETCHUP OFFERS INSIGHTS INTO SOFT MATTER

Soft matter consists of a huge class of materials that can behave either as liquids or solids depending on circumstances. Soft matter can be found in everything from laptop screens and advanced batteries to ketchup, mayonnaise, and toothpaste. Cambridge University, UK, researchers developed new mathematical models to describe why these materials behave the way they do, which could help improve them for both domestic and high-tech applications.

Professor Michael Cates discovered that mathematical models can explain how soft materials can suddenly convert from liquid-like to solid-like behavior—through a process resembling an internal traffic jam. Cates discussed the *jamming* behavior of colloids and dense suspensions. Both are types of soft matter with an internal structure something like tiny ping-pong balls dispersed in a liquid. Researchers recently created *active* colloids in which the ping-pong balls are self-propelled, like tiny rockets. When their propulsion is switched on, these particles form tight clusters, despite having no attractive forces between them.

Heinz ketchup. Courtesy of Jeremy Brooks/Flickr.

"The question in this case is what causes the clustering?" wonders Cates. He concluded that each cluster is effectively a sort of traffic jam. When a dense suspension flows in response to stress, particles must push past each other. As long as the stress is low, they easily slide past with little friction between them. But when stress is increased, friction between particles also increases. *www.cam.ac.uk.*

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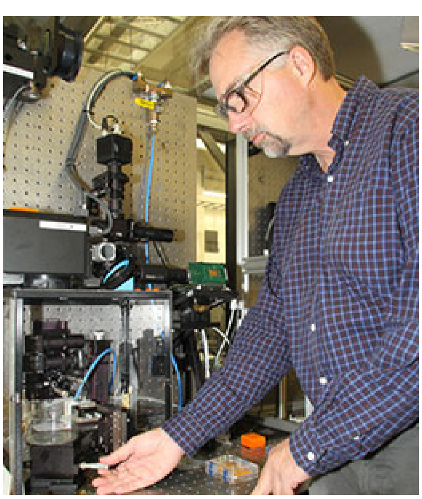
3D PRINTSHOP

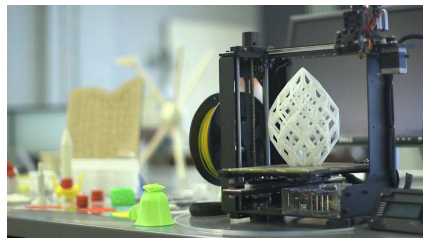
NEW PRINTER OFFERS BEST OF BOTH WORLDS

A 3D-printing device developed by a Lawrence Livermore National Laboratory (LLNL) engineer won a 2015 Federal Laboratory Consortium (FLC) Far West Region Award for outstanding technology development. The award, given for the Large Area Projection Micro Stereolithography (LAPμSL) technology, was presented to Bryan Moran at the recent FLC Far West/Mid-Continent Region meeting in San Diego. The LAPμSL is an image projection micro-stereolithography system that rapidly produces very small features over large areas by using optical techniques to write images in parallel. This approach is a departure from conventional techniques, which either require mechanical stage movements or the rastering of beams to expose pixels in series. LAPμSL combines the advantages of laser-based stereolithography (large area and speed, but poor resolution) and digital light processing stereolithography (fine details and speed, but only over a small area), enabling rapid printing of fine details over large areas.

"The LAPμSL system is conceptually similar to building a mosaic of tiles that then combine to make a much larger picture," says Moran. He adds that many applications could benefit from the ability to create complex shapes and small features, unlike other 3D printers, which sacrifice overall part size for small feature size. For example, parts produced with the new machine can be used as master patterns for injection molding, thermoforming, blow molding, and various metal casting processes. *For more information: Bryan Moran, 925.423.3568, moran5@llnl.gov, www.llnl.gov.*



LLNL optical engineer Bryan Moran makes an adjustment to the Large Area Projection Micro Stereolithography machine. Courtesy of Steve Wampler/LLNL.



UL is coordinating research on 3D printer emissions with Georgia Tech and Emory University.

PARTNERSHIP EXPLORES HEALTH IMPACT OF PRINTER EMISSIONS

UL, a safety science organization based in Northbrook, Ill., recently announced partnerships with Georgia Institute of Technology and Emory University's Rollins School of Public Health to study the impact of 3D printing on indoor air quality. The research is designed to characterize chemical and particle emissions of 3D printing technologies and to evaluate their potential impact on human health. The first research phase, led by Rodney Weber of Georgia Tech, is to define the appropriate analytical measurement and risk evaluation methodologies for characterizing and assessing particle and chemical emissions from 3D printing technologies. The second phase, conducted by The Rollins School of Public Health at Emory, will assess potential health hazards from exposure to the emissions. *ul.com, gatech.edu, emory.edu.*

MIT's glass 3D printing process. Courtesy of Steve Keating.

UNIQUE SYSTEM PRINTS TRANSPARENT GLASS

Researchers at Massachusetts Institute of Technology, Cambridge, have developed the ability to print optically transparent glass objects. A major obstacle to accomplishing this task is the extremely high temperature needed to melt the material. Others have used tiny particles of glass, melded together at a lower temperature via sintering. But such objects are structurally weak and optically cloudy. In contrast, the system developed at MIT produces glass objects that are both strong and fully transparent to light. Molten glass is loaded into a hopper after being gathered from a conventional glassblowing kiln. When complete, the finished piece must be cut away from the moving platform on which it is assembled. In operation, the device's hopper and a nozzle through which the glass is extruded to form an object are maintained at temperatures of roughly 1900°F, far higher than those used for other 3D printing. The new process could allow unprecedented control over the glass shapes that can be produced, including variable thicknesses and complex inner features. Additional work will focus on the use of colors in the glass, which the team has already demonstrated in limited testing. *web.mit.edu.*