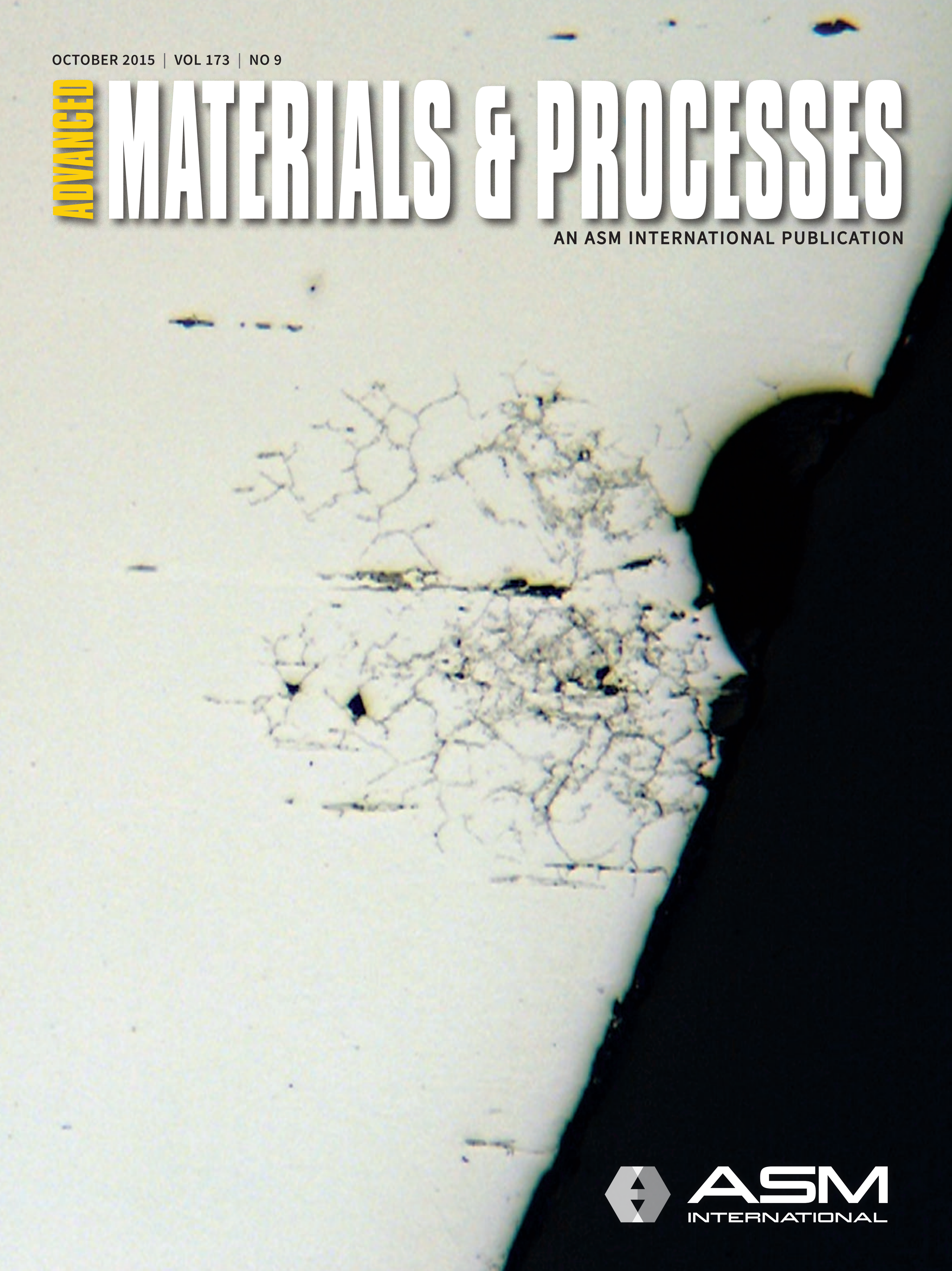
OCTOBER 2015 | VOL 173 | NO 9

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION



ASM INTERNATIONAL

OCTOBER 2015 | VOL 173 | NO 9

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

NDT & FAILURE ANALYSIS

FAIL!

P.32

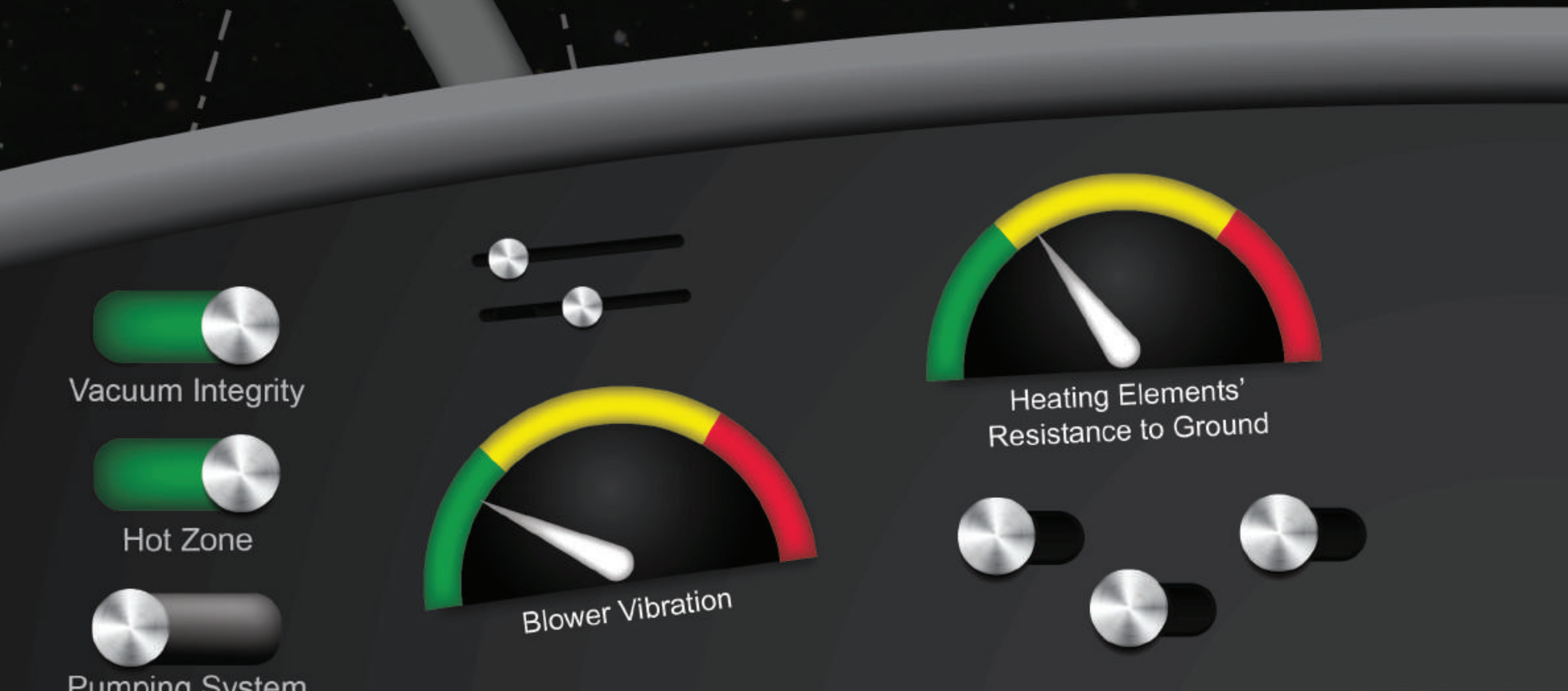
ASM INTERNATIONAL

Mission: Provide customers with state-of-the-art heat treatment equipment integrated with advanced technology

TITAN® 2.0

Target Acquired:

- Vacuum furnace
- Compact design
- Predictive maintenance diagnostics
- Integrated framework
- Touchscreen and scrolling marquee
- Available for immediate delivery



VISIT IPSEN AT ASM HEAT TREAT 2015, BOOTH #701 AND HAVE YOUR PHOTO TAKEN WITH A STAR WARS CHARACTER


ATLAS
Target Acquired:
• Atmosphere furnace
• Easy integration
• Compact footprint
• Ease of maintenance
• Energy-efficient combustion system
• Variable-speed quench agitation
PdMetrics™ Engaged:
• Software platform for predictive maintenance
• Monitors critical system elements
• Stand-alone interface screen
• Smart connectivity
• Predicts and schedules service
• Technical support via Ipsen's Service Cloud
PdMetrics™ is only available with certain furnace models
For more information, visit
www.IpsenUSA.com/ASMHeatTreat2015
Ipsen

Discover what's possible through ASM Education.

Advance your skills, learn from our respected international experts, and earn CEUs. ASM's accredited courses offer a variety of learning options that fit your career goals, schedule, and budget. Stay current in your career or stand out with an ASM certificate program.

Course	Date	Location
Metallurgy of Steel for the Non-Metallurgist	11/2-4	ASM World Headquarters
Aluminum and Its Alloys	11/3-5	ASM World Headquarters
Metallographic Techniques Blended	11/9-10	Buehler Limited, Lake Bluff, IL
Introduction to Heat Treating	11/9-11	ASM World Headquarters
Reverse Engineering: A Material Perspective	11/9-11	ASM World Headquarters
Metallographic Interpretation	11/9-12	ASM World Headquarters
Advanced Heat Treating	11/12-13	ASM World Headquarters
Design for Additive Manufacturing - Materials, Processes, and Geometries	11/16-17	America Makes, Youngstown, OH
Stainless Steel for Design Engineers	11/16-17	ASM World Headquarters
Nitinol for Medical Devices	12/1-3	Foothill Ranch, CA
Practical Heat Treating	12/1-4	ASM World Headquarters
Advanced Metallographic Techniques	12/9-12	ASM World Headquarters
Metallurgy for the Non-Metallurgist	1/25-28	ASM World Headquarters

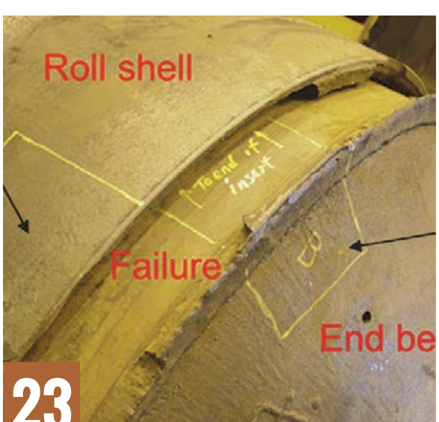
FOR MORE UPCOMING COURSES OR TO REGISTER, VISIT: asminternational.org/learning

ASM INTERNATIONAL

AUTHORIZED IACET PROVIDER

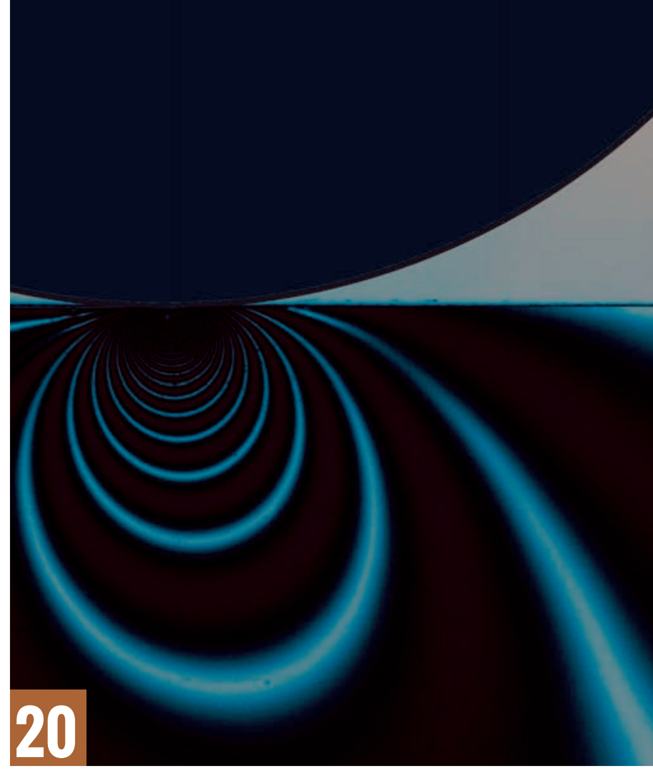
On The Cover:

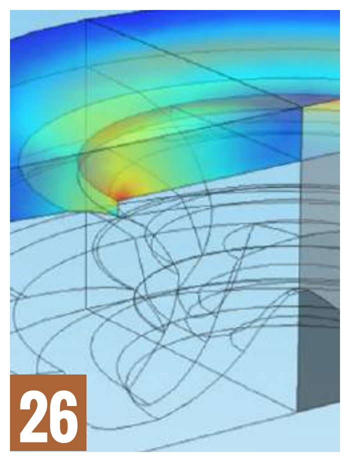
As part of a metallurgical failure analysis, this magnified view of a fractured pin features a pattern of branched cracks adjacent to a corrosion pit. Courtesy of Element Materials Technology, New Berlin, Wis. element.com.



ADVANCED MATERIALS & PROCESSES
OCTOBER 2015 | VOL 173 | NO 9

FEATURES





TRENDS

INDUSTRY NEWS

DEPARTMENTS

Advanced Materials & Processes (ISSN 0882-7958, USPS 762080) is published monthly, except bimonthly July/August and November/December, by ASM International, 9639 Kinsman Road, Materials Park, OH 44073-0002; tel: 440.338.5151; fax: 440.338.4634. Periodicals postage paid at Novelty, Ohio, and additional mailing offices. Vol. 173, No.9, October 2015. Distributed at no charge to ASM members in the United States, Canada, and Mexico. International members can pay a $30 per year surcharge to receive printed issues. Subscriptions: $461. Single copies: $45. POSTMASTER: Send 3579 forms to ASM International, Materials Park, OH 44073-0002.
Change of address: Request for change should include old address of the subscriber. Missing numbers due to "change of address" cannot be replaced. Claims for nondelivery must be made within 60 days of issue. Canada Post Publications Mail Agreement No. 40732105. Return undeliverable Canadian addresses to: 700 Dowd Ave., Elizabeth, NJ 07201. Printed by Publishers Press Inc., Shepherdsville, Ky.

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

ADVANCED MATERIALS & PROCESSES

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

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

Julie Lucko, *Editor*
julie.lucko@asminternational.org

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

Kate Fornadel, *Layout and Design*
kate.fornadel@asminternational.org

Annie Beck, *Production Manager*
annie.beck@asminternational.org

Press Release Editor
magazines@asminternational.org

WELCOMING FAILURE

FAIL! If our October cover didn't grab your attention, we're not sure what will. I suppose you could say that our fall issue celebrates failure. This special edition—with bonus distribution at both the ISTFA and Heat Treat conferences—focuses on nondestructive testing and failure analysis. With that in mind, we present an issue jam-packed with case studies and timely technical advice exploring various industrial failures, electronics challenges, and methods to avoid them.

> **"Success is not final, failure is not fatal. It is the courage to continue that counts."**
> *– Attributed to Winston Churchill*

The idea is that nobody wants to be blamed when things go wrong, but an entire industry is built around the very fact that things often do. From engineered pins to furnace rolls to aerospace electronics, a lot of creativity has been unleashed around avoiding costly mistakes. In fact, our friends at EWI developed an entirely new design and welding process that promises to extend the life of furnace rolls in hot-dip coating lines, which often go bad in less than a year. Now that's real progress, and it's just the type of innovation that stems from a frustrating failure. If things went smoothly all the time, it's pretty clear that improvements would not be mandatory and the status quo could exist indefinitely. It's yet another take on the theme of necessity being the mother of invention.

Perhaps trickiest of all are the electronics failures. Consider this statement from our colleagues at EAG in their excellent article on aerospace electronics: "As advanced semiconductor processes enable more compact devices to be created from smaller structures, even those that appear flawless can still exhibit performance problems arising from as little as one misplaced atom." Seriously?! One misplaced atom? If this daunting thought makes you feel like throwing your hands up, we can assure you that you're not alone. Fortunately, highly sophisticated testing equipment and new analytical methods are being developed to keep pace with today's miniaturized systems.

In addition, attending industry conferences is another way to keep up with technology advancements. Hopefully, many of you reading this column will have the chance to visit ISTFA, the 41st annual International Symposium for Testing and Failure Analysis. This year's program features more than 100 technical presentations on the latest research involving failure analysis of microelectronics. Technical symposia, user groups, tutorials, and a comprehensive equipment exposition offer a great chance to learn about industry developments and network with colleagues. Be sure to check out our show preview included in this issue.

Besides ISTFA, Heat Treat 2015 is also taking place this month, from October 20–22 in Detroit. Every other year, the Heat Treating Society's premier conference and exposition provides an opportunity to learn about some of the latest trends in the industry to stay at the leading edge of heat treating-related technology. We hope to see you there!

In the meantime, we hope you savor and celebrate your successes, but also keep in mind the amazing opportunities and innovations that can arise from failures.

F. Richards

frances.richards@asminternational.org

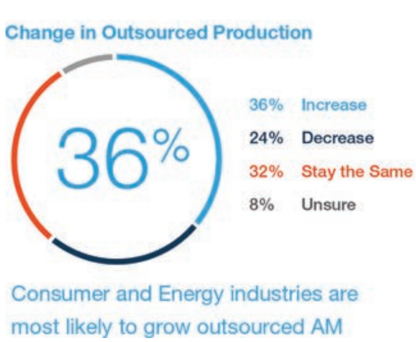
MARKET SPOTLIGHT

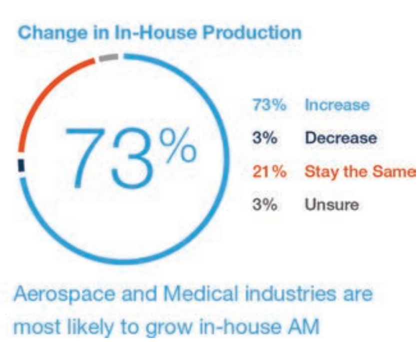
NEW REPORT HIGHLIGHTS 3D PRINTING TRENDS

A new report from Stratasys Direct Manufacturing, Valencia, Calif., *3D Printing's Imminent Impact on Manufacturing,* provides an in-depth look at current and emerging trends in additive manufacturing (AM). The report is based on an independent survey of 700 designers, engineers, and executives—40% of whom are employed by companies with more than $50 million in revenue. The majority of respondents, representing aerospace, automotive, consumer products, and medical devices, say they strongly believe more end-use parts will be designed specifically for AM in the near future. Further, additive metal use is expected to nearly double over the next three years.

Participants were asked what they believe are the greatest benefits of using AM. The most common responses include more complex design capabilities (79%), reduced lead time for parts (76%), and improvements in manufacturing efficiency (42%). Respondents were also asked about their views on in-house production versus outsourcing. With regard to the top benefits of outsourcing, the most popular responses cite access to advanced equipment and materials (73%), less investment risk (60%), ability to produce parts not able to be manufactured internally (53%), and access to AM expertise (47%).

Survey takers were asked to share their views on the top challenges faced by their companies with regard to using AM. Participants cite equipment costs (63%), limited materials (54%), post-processing requirements (39%), and manufacturing costs (38%) as today's top concerns. As far as applications, respondents foresee a 36% increase in tooling by 2018 and 38% growth in end-use parts—with aerospace and automotive expected to see the largest increase. Participants were also polled about which materials they would like to see further developed for AM: Top responses include metals (84%), rubber-like materials (61%), high temperature plastic (60%), and carbon fiber (52%). To access the full report, visit pages.stratasysdirect.com/trend-forecast.





Participants were asked whether they expect their company's in-house 3D printing production to increase, decrease, or stay the same over the next three years, and were asked the same question relative to outsourcing. Courtesy of Stratasys Direct Manufacturing.

FEEDBACK

MINIMILL MISTAKES

The recent article "Steel Minimills—Part 1" (June issue) attributed the supply of the continuous casting machine at the Nucor-Crawfordsville, Indiana, facility to Siemens, which is incorrect. This machine, and all subsequent machines of this design throughout the world, have been furnished by SMS-Siemag AG, now known as SMS Group. Also, the second Nucor facility is located at Hickman, Arkansas, not Iowa.

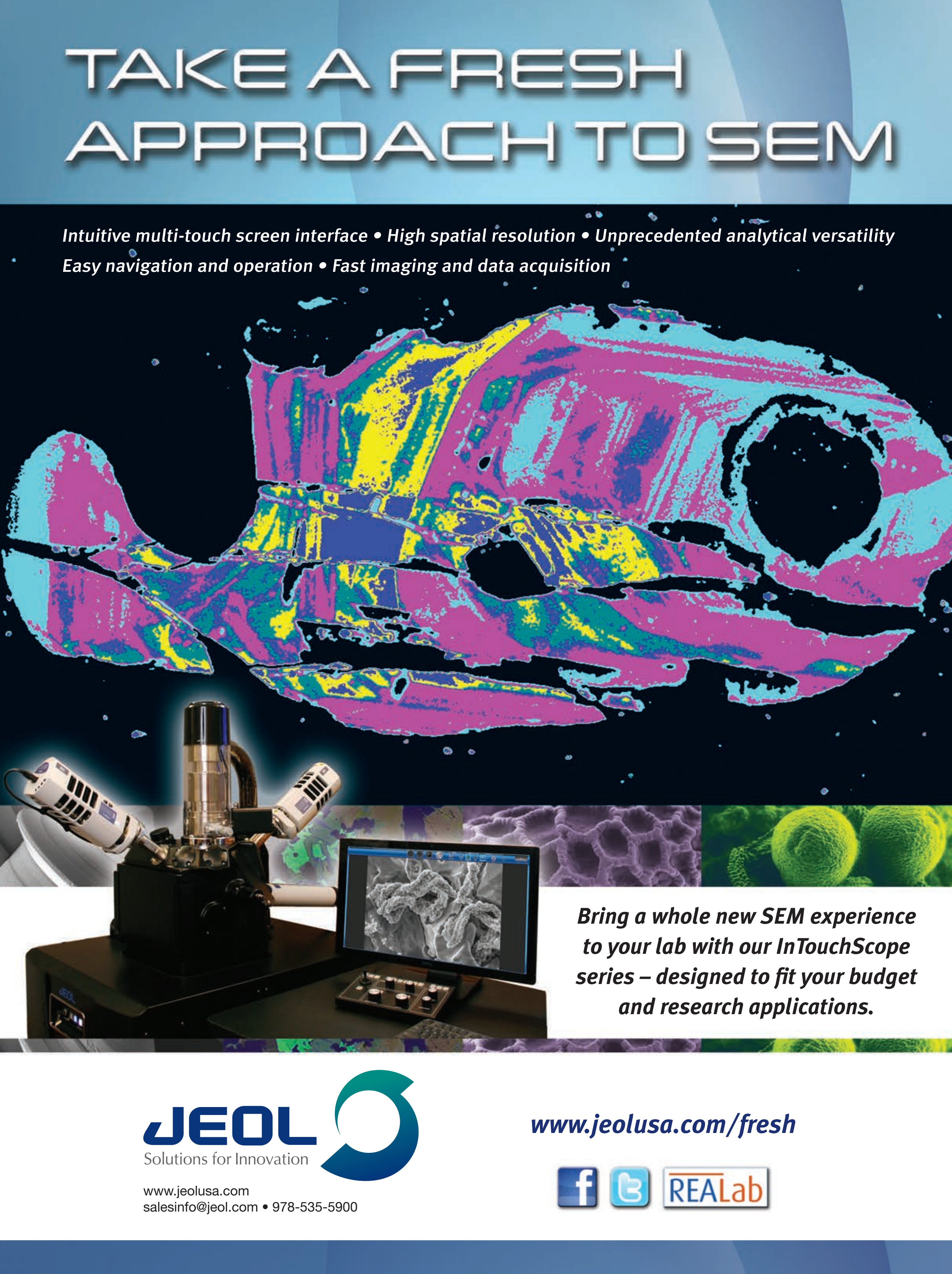
Bob Garness

MINIMILL MEMORIES

I read with great interest the article "Steel Minimills: Part II" (July/August issue). I was a full-time lab technician at North Star Steel from 1972–75, and then part-time from 1975–80 through college. By allowing me to work during school, North Star essentially financed my B.S. degree in metallurgical engineering at the University of Minnesota and I'll always be grateful to them for that. I was there when they built or purchased a plant in Monroe, Michigan, and also when they added a car shredder and an epoxy coating group for their rebar. Every once in a while, I drive by the plant and wonder what happened to North Star and if they are as big as they used to be. Judging from your article, I guess not. Thanks again for the interesting history. It was a pleasure reading about the good ol' days in the steel business.

Steve Nelson

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


TAKE A FRESH APPROACH TO SEM
Intuitive multi-touch screen interface • High spatial resolution • Unprecedented analytical versatility
Easy navigation and operation • Fast imaging and data acquisition
Bring a whole new SEM experience to your lab with our InTouchScope series – designed to fit your budget and research applications.
JEOL
Solutions for Innovation
www.jeolusa.com
salesinfo@jeol.com • 978-535-5900
www.jeolusa.com/fresh
REALab

OMG!
OUTRAGEOUS MATERIALS GOODNESS

The EDAG Light Cocoon features a weatherproof fabric skin stretched over a 3D-printed frame.

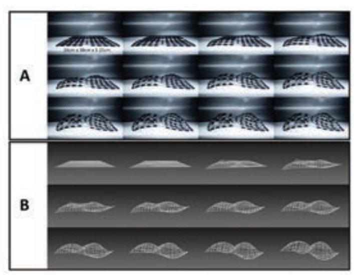
SPORTS CAR BOASTS TEXTILE SKIN

EDAG, Germany, created a sports car with a textile outer skin panel called the Light Cocoon. It features weatherproof fabric skin stretched over a 3D-printed frame. The car also features backlight technology, which illuminates the skeleton-like, organic structure, bringing the car to life, according to company sources. The goal was to make a lightweight and efficient car without any waste. Instead of treating the body as a closed surface, any material not needed for the special load cases was removed. Project partner Jack Wolfskin, an outdoor wear and equipment manufacturer, supplied the stretchy weatherproof fabric to serve as the outer body skin. The sturdy material is four times lighter than standard copier paper. *www.edag.de/en/edag.html.*

4D PRINTING BETTER THAN 3D?

A team of researchers at Massachusetts Institute of Technology, Cambridge, is taking 3D printing to a new level with 4D methods. The goal of the research is to 3D print items that are designed to change shape after they are printed. 3D printing technology uses a wide range of materials to print objects, such as plastic, ceramic, glass, metal, chocolate, and even living cells.

The team used two different materials to print structures, one that was a stiff plastic that did not bend and another created by Stratasys, Edina, Minn., that could absorb water and double in volume when submerged. The 3D-printed square grid measures 15 in. on all sides and could stretch and fold when placed in water. Researchers also printed a shape that resembles the initials MIT and can turn into any shape that resembles the initials SAL. MIT mathematician Dan Raviv says the technique has a variety of potential uses, such as printing home appliances, childcare products, and clothing that could sense the environment to perform better. Using 4D printing for medical implants and cardiac stents is another possibility. *For more information: Dan Raviv, 617.324.0523, darav@mit.edu, www.web.mit.edu.*



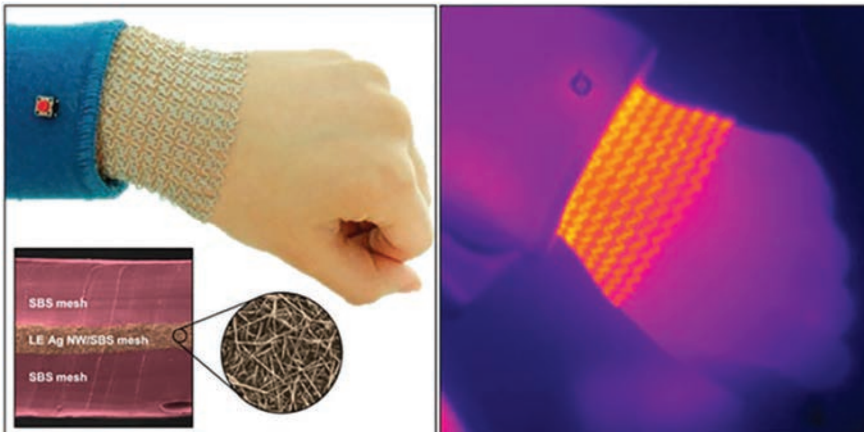
When placed in water, a grid of 3D-printed, water-absorbent material produces a broad range of shapes with complex geometries.

POP-UP PRINTING OUTPERFORMS 3D METHODS

Researchers at Northwestern University, Evanston, Ill., and the University of Illinois at Urbana-Champaign developed a new fabrication technique to create complex 3D micro- and nanostructures. The new method mimics the action of a children's pop-up book—starting as a flat 2D structure and popping up into a more complex 3D assembly. Using a variety of advanced materials including silicon, researchers produced more than 40 different geometric designs, including shapes resembling a peacock, flower, starburst, table, basket, tent, and starfish. "In just one shot you get your structure," says Northwestern's Yonggang Huang. "We first fabricate a 2D structure on a stretched elastic material. Then we release the tension, and a 3D structure pops up." The pop-up assembly technique outperforms 3D printing on many levels and is expected to be useful in building biomedical devices, sensors, and electronics. The technique is fast and inexpensive and can be used to build many different structures at one time. It can also incorporate many different materials, including silicon. The method also enables the incorporation of many materials into one hybrid structure, the building of structures on both micro- and nanolevels (down to a thickness of 100 nm), and the production of a wide range of geometries. *For more information: Yonggang Huang, y-huang@northwestern.edu, www.northwestern.edu.*

Researchers developed a simple fabrication technique that mimics the action of a children's pop-up book. An experimental image of a flowerlike structure is shown here. Courtesy of University of Illinois.

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.



A new heating mechanism made of silver nanowires effectively applies heat to injured muscles.

NOVEL NANOWIRE MESH SOOTHES SORE MUSCLES

A new way of creating therapeutic heat for injuries was developed by Korean scientists from the Center for Nanoparticle Research, Institute for Basic Science. Instead of using materials like carbon nanotubes and gold, the team took a more utilitarian approach to their build material, using thin slivers of silver nanowires. Silver nanowires are miniscule, averaging around 150 nm in diameter and 30 µm in length. The nanowires were blended into a liquid elastic material, which is both soft and stretchy when dry. To be certain the material stays tight on the wound area while heating, a 2D interlocking coil pattern for the mesh structure was created. To fabricate the mesh, a liquid mixture was poured into a shaped mold. The silver-elastic mesh was sandwiched between a top and bottom layer of soft, thin insulation. Material flexibility testing on knee and wrist joints showed the mesh heated while deformed and under stress on knee and wrist joints. It is lightweight, breathable, and generates heat over the entire surface area of the material. *www.ibs.re.kr/eng.do.*

ICY POLYMERS COULD USHER IN NEW ELECTRONICS ERA

Ice could potentially play a role in opening a new era in the electronics industry where conducting polymers are in great demand for practical applications. Chemists at Pohang University of Science and Technology (POSTECH), Korea, discovered an innovative method to form 2D polyaniline (PANI) nanosheets using ice as a hard template. The product, called PANI-ICE, is reported to have distinctly outstanding electrical properties of low resistivity and high conductivity. PANI-ICE nanosheets show electronic current flows twice as high as that of graphene and exhibit over 40 times higher conductivity of PANI materials produced by existing synthetic procedures.

Chemistry professor Moon Jeong Park and his colleagues developed an innovative method that effectively overcomes the disadvantages of existing approaches. PANI nanosheets are fabricated on a smooth surface of deep frozen ice, causing preferential vertical growth and molecular orientation of PANI that significantly enhances its electrical properties. The superior conductivity of PANI-ICE outperforms that of any other existing PANI ever reported. Moreover, the fabricated nanosheets can be easily transferred to various types of substrates as they float on the surface of an ice template. The nanosheets can be patterned into any shape when using prearranged masks. *www.postech.ac.kr.*

BRIEFS

The Ford Motor Co., Dearborn, Mich., and **DowAksa,** Turkey, signed a joint development agreement to advance research on cost-effective, high-volume manufacturing of automotive-grade carbon fiber. The agreement combines DowAksa's feedstock capacity, carbon fiber conversion, and downstream intermediates production capabilities with Ford's expertise in design, engineering, and high-volume manufacturing. *corporate.ford.com, dowaksa.com.*

ThyssenKrupp, Germany, is selling the VDM group to **Lindsay Goldberg,** represented in Europe by **Lindsay Goldberg Vogel,** Düsseldorf. On completion of the transaction, ThyssenKrupp will achieve a positive effect on net financial debt and pension obligations in the mid three-digit million euro range. *thyssenkrupp.com, lindsaygoldbergvogel.com.*

NEW ALLOY SHOWS PROMISE IN HIGH-PRESSURE OXYGEN SYSTEMS

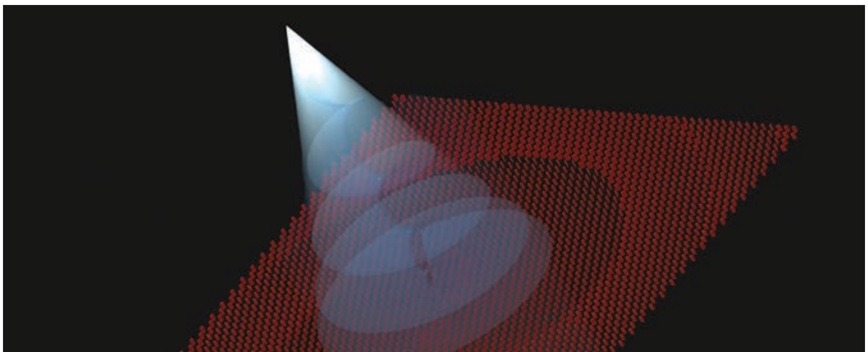
ToughMet, a high-performance copper-nickel-tin alloy, developed by Materion Corp., Mayfield Heights, Ohio, provides many advantages in demanding end-use applications ranging from aerospace sleeve and spherical bearings to oil and gas drilling components to industrial bearings. Now, testing shows that ToughMet may also be suitable for high-pressure oxygen systems where a combination of properties such as high strength, wear, galling, and corrosion resistance along with oxygen flammability resistance are required. Recently, the NASA White Sands Test Facility, Las Cruces, N.M., completed ASTM G124 testing on the ToughMet 3 alloy. Results indicate that ToughMet 3 is burn resistant up to at least 10,000 psig (68.9 MPa) gaseous oxygen, which is typically the highest pressure for such tests. *materion.com.*

METALLIC GLASS RESEARCH MAKES HEADWAY DOWN UNDER

Creating futuristic, next generation materials called *metallic glass* that are ultra-strong and ultra-flexible will become easier and less expensive, say researchers at the University of New South Wales, Australia. While still being metals, these materials become as malleable as chewing gum when heated and can be easily molded or blown like glass. They are also three times stronger and harder than ordinary metals, on average, and are among the toughest materials known.

Most metals are crystalline when solid, with their atoms arranged in a highly organized and regular manner. Metallic glass alloys, however, have a highly disordered structure, with the atoms arranged in a non-regular way. Researches created a unique new model of the atomic structure of metallic glass, which allows scientists to predict the metal combinations that will have glass-forming ability. Their model has been used to successfully predict more than 200 new metallic glass alloys based on magnesium, silver, copper, zinc, and titanium in the past few years. “With our new instruction manual we can start to create many new useful metallic glass-types and begin to understand the atomic fundamentals behind their exceptional properties. We will also be able to engineer these materials on an atomic scale so they have the specific properties we want,” says Kevin Laws from UNSW. *For more information: Kevin Laws, +610.293.855.234, k.laws@unsw.edu.au, www.unsw.edu.au.*

TESTING | CHARACTERIZATION



Schematic shows how a metasurface can generate and focus radially polarized light. Courtesy of Amir Arbabi/Faraon Lab/Caltech.

OPTICAL LENSES MADE OF NANOPILLARS

A team of researchers recently developed flat optical lenses as part of a collaboration between NASA's Jet Propulsion Laboratory and the California Institute of Technology, both in Pasadena. These optical components are capable of manipulating light in ways that are difficult or impossible to achieve with conventional optical devices. The new lenses are not made of glass. Instead, silicon nanopillars are arranged into a honeycomb pattern to create a metasurface that can control the paths and properties of passing light waves. Applications include advanced microscopes, displays, sensors, and cameras that can be mass-produced using the same techniques used to manufacture computer chips.

"Currently, optical systems are made one component at a time, and the components are often manually assembled," says Andrei Faraon, assistant professor of applied physics and materials science at Caltech. "But this new technology is very similar to the one used to print semiconductor chips onto silicon wafers, so you could conceivably manufacture millions of microscopes or cameras at a time."

Seen under a scanning electron microscope, the new metasurfaces resemble a cut forest where only the stumps remain. Each silicon stump, or pillar, has an elliptical cross-section, and by carefully varying the diameters of each pillar and rotating them around their axes, scientists were able to simultaneously manipulate the phase and polarization of passing light. In addition, the new lenses can be used to modify the shape of light beams at will. Semiconductor lasers typically emit into elliptical beams that are difficult to work with, and the new metasurface optical components could replace expensive optical systems used to circularize the beams. The team is currently working with industrial partners to create metasurfaces for use in commercial devices such as miniature cameras and spectrometers, although a limited number are now being used in optical experiments by collaborating scientists in other disciplines. *jpl.nasa.gov.*

ULTRAFAST ELECTRON DIFFRACTION RESEARCH SPEEDS AHEAD

A new instrument at the DOE's SLAC National Accelerator Laboratory, Menlo Park, Calif., uses a method known as ultrafast electron diffraction (UED) to reveal motions of electrons and atomic nuclei within molecules that take place in less than a tenth of a trillionth of a second. The technique complements ultrafast studies with SLAC's x-ray free-electron laser. Similar to x-ray light, highly energetic electrons can take snapshots of the interior of materials as they pass through them. Yet electrons interact differently with materials and "see" different things. Combining both methods enables a

BRIEFS

Modustri, Grand Rapids, Mich., entered into a strategic alliance with **Caterpillar Inc.** (Cat), Peoria, Ill. The companies will work together to enhance the abilities of Cat's customers to measure wear on parts in new ways, potentially saving hundreds of hours and millions of dollars in maintenance expenses. *modustri.com.*

Nordson Corp., Westlake, Ohio, acquired **MatriX Technologies GmbH,** Munich, a manufacturer of automated x-ray inspection equipment used to ensure the quality of electronic printed circuit boards, critical electronic devices, and fully assembled products in consumer, automotive, and other industrial markets. *nordson.com.*

more complete picture that will help researchers better understand and possibly control important ultrafast processes in complex systems ranging from magnetic data storage devices to chemical reactions.

The superior performance of the new UED system is due to a very stable "electron gun" originally developed for SLAC's x-ray laser Linac Coherent Light Source (LCLS). This electron source produces highly energetic electrons, packed into extremely short bunches. It generates 120 of these bunches every second, resulting in a powerful electron beam that is used to probe objects on the inside.

The method works because particles have a second nature: They also behave like waves. Because electron bunches in SLAC's UED instrument are extremely short, they reveal changes that occur in less than 100 femtoseconds. Electrons also provide a path to studies that are very challenging to perform with x-rays. The team's ultimate goal is to turn UED into an ultrafast electron microscope, an instrument that would show details too small to be seen with an optical microscope. Existing electron microscopes can already capture events in 10 billionths of a second, but with SLAC's instrument, researchers hope to push the speed limit to processes that are 1000 times faster. *www.slac.stanford.edu.*

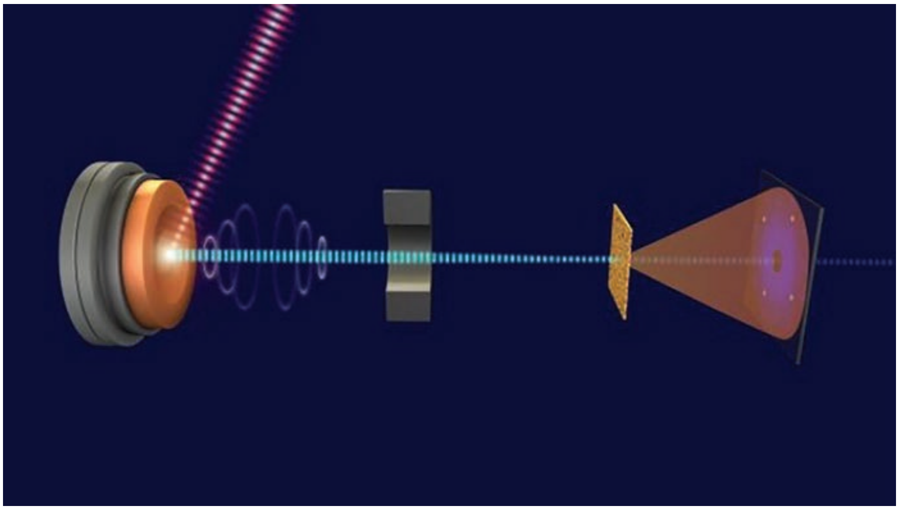


Illustration of SLAC's new apparatus for ultrafast electron diffraction. Courtesy of SLAC.

STATEMENT OF OWNERSHIP, MANAGEMENT, CIRCULATION, ETC.

Required by the Act of 23 October 1962, Section 4369, Title 39, United States Code, showing the ownership, management, and circulation of *Advanced Materials & Processes®*, published monthly, except bimonthly July/August and November/December, at 9639 Kinsman Road, Materials Park, Ohio 44073, USPS # 762-080. Annual subscription rate is $461.

The publisher and editor are Scott D. Henry and Frances Richards, respectively, both of 9639 Kinsman Road, Materials Park, Ohio, 44073. The owner is ASM International®, Materials Park, Ohio, which is a not-for-profit educational institution, the officers being; President and Trustee, Sunniva R. Collins; Vice President and Trustee, Jon D. Tirpak; Secretary and Managing Director, Terry F. Mosier; Treasurer and Trustee, Craig D. Clauser; Immediate Past President and Trustee, C. Ravi Ravindran; Trustees, Iver Anderson, Kathryn Dannemann, Mitchell Dorfman, James C. Foley, Jacqueline M. Earle, John R. Keough, Zi-Kui Liu, Tirumalai S. Sudarshan, and David B. Williams; Student Board Members Aaron Birt, Joseph DeGenova, and Sarah Straub. There are no known bondholders, mortgagees, and other security holders owning or holding 1% or more of the total amount of bonds, mortgages, or other securities.

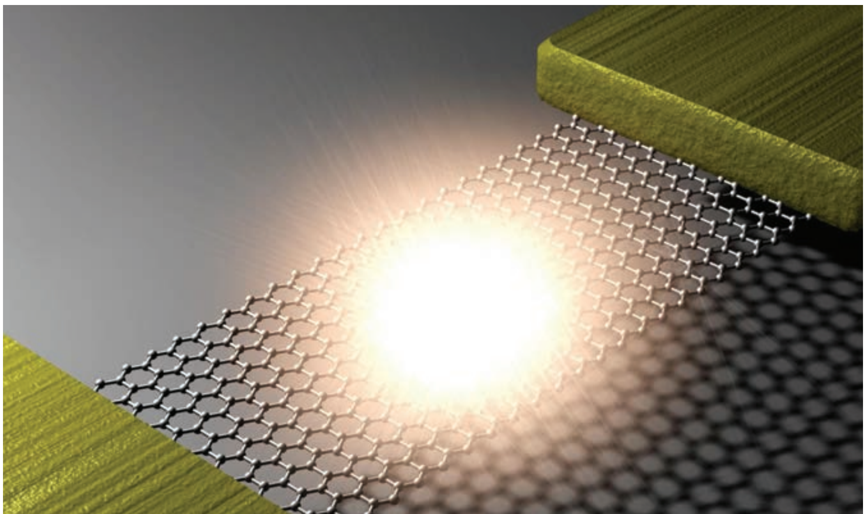
The issue date for circulation data below is September 2015. The average number of copies of each issue during the preceding 12 months is: (a) Total number of copies printed: 13,483; (b) Paid and/or requested circulation: (1) Paid/requested outside-county mail subscriptions: 10,917; (2) Paid in-county subscriptions: 0; (3) Sales through dealers and carriers, street vendors, counter sales, and other non-USPS paid distribution: 1,411; (4) other classes mailed through the USPS: 0; (c) Total paid and/or requested circulation: 12,328; (d.1) Free distribution or nominal outside-county: 525; (d.3) Free distribution by mail: 580; (e) Total free distribution: 1,105; (f) Total distribution: 13,433; (g) Copies not distributed: 515; (h) Total: 13,948; (i) Percent paid: 92. The actual number of copies of single issue published nearest to filing date is: (a) Total number of copies printed: 13,829; (b) Paid and/or requested circulation: (1) Paid/requested outside-county mail subscriptions: 11,250; (2) Paid in-county subscriptions: 0; (3) Sales through dealers and carriers, street vendors, counter sales, and other non-USPS paid distribution: 1,477; (4) other classes mailed through the USPS: 0; (c) Total paid and/or requested circulation: 12,727; (d.1) Free distribution or nominal outside-county: 557; (d.3) Free distribution by mail: 592; (e) Total free distribution: 1,149; (f) Total distribution: 13,876; (g) Copies not distributed: 491; (h) Total: 14,367; (i) Percent paid: 92.

I certify that the statements made by me above are correct and complete.

Scott D. Henry

Publisher

ENERGY TRENDS



Schematic illustration of electrically biased suspended graphene and light emission from the center of the suspended graphene. Courtesy of Young Duck Kim/ Columbia Engineering.

GRAPHENE SHINES BRIGHT IN WORLD'S THINNEST LIGHT BULB

Led by Young Duck Kim, a postdoctoral research scientist in James Hone's group at Columbia University, New York, a team of scientists from Seoul National University and Korea Research Institute of Standards and Science demonstrated—for the first time—an on-chip visible light source using graphene as a filament. They attached small strips of graphene to metal electrodes, suspended the strips above the substrate, and passed a current through the filaments to heat them.

"We've created what is essentially the world's thinnest light bulb," says Hone, a mechanical engineering professor at Columbia. "This new type of 'broadband' light emitter can be integrated into chips and will pave the way towards the realization of atomically thin, flexible, and transparent displays, and graphene-based on-chip optical communications." *For more information: Young Duck Kim, yk2629@columbia.edu, hone.me.columbia.edu.*

HARVESTING SOLAR POWER AT NIGHT

A University of Texas at Arlington materials science and engineering team developed a new energy cell that can store large-scale solar energy even when it's dark. The innovation is an advancement over the most common solar energy systems that rely on using sunlight immediately as a power source.

UT Arlington scientists developed a new solar cell that is more efficient and can store solar energy even at night.

Those systems are hindered by not being able to use that solar energy at night or when it is cloudy.

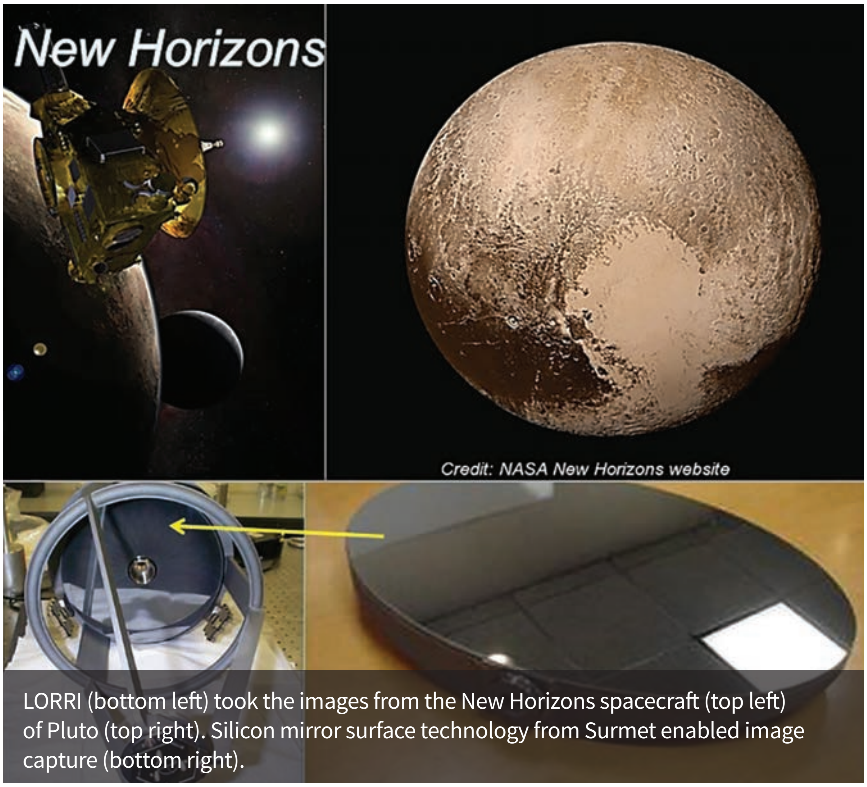
The team developed an all-vanadium photo-electrochemical flow cell that allows for efficient and large-scale solar energy storage at any time. The team is now working on a larger prototype. "This research has a chance to rewrite how we store and use solar power," says Fuqiang Liu, an assistant professor who led the research team. "As renewable energy becomes more prevalent, the ability to store solar energy and use it as a renewable alternative provides a sustainable solution to the problem of energy shortage. It also can effectively harness the inexhaustible energy from the sun."

The work is a product of the 2013 National Science Foundation $400,000 Faculty Early Career Development grant awarded to Liu to improve the way solar energy is captured, stored, and transmitted. *For more information: Fuqiang Liu, 817.272.2704, fuqiang@uta.edu, www.uta.edu/uta.*

BRIEF

A research team from **Carnegie Mellon University,** Pittsburgh, and the **University of California, Berkeley** found that blending together different types of salts in the electrolytes within lithium air batteries can increase their capacity while preserving their ability to be recharged. In addition to lithium air batteries, the new methods are also expected to impact other areas of battery research. *cmu.edu, berkeley.edu.*


Plan
20x/0.45
Plan
Plan



LORRI (bottom left) took the images from the New Horizons spacecraft (top left) of Pluto (top right). Silicon mirror surface technology from Surmet enabled image capture (bottom right).

COATING TECHNOLOGY FINDS NEW HORIZONS

Surmet Corp., Burlington, Mass., contributed the critically enabling silicon mirror-surface technology for the LORRI telescope, part of NASA's New Horizons mission. The unique and proprietary silicon coating technology is strongly adherent, amorphous, and supremely homogeneous at an atomic scale. The coating applied to the mirror substrate of the telescope allows for single point diamond turning and finish polishing, meeting the most stringent wavefront specifications required for capturing ultrahigh resolution images from outer space. The New Horizons mission, launched in 2006, is the first spacecraft to travel to Pluto and the Kuiper Belt. It traveled for nine years to reach its milestone closest approach to Pluto (within approximately 7750 miles) on July 14. *surmet.com.*

DEPOSITION TECHNIQUE CONTROLS NANOWIRE LENGTH

It is now possible to synthesize bimetallic nanowires made of silver and gold whose length can be precisely controlled, thanks to new experiments by European researchers. Because the wires also have roughly the same molecular weight, their "surface plasmon resonances" can be tailored too—in the near- and mid-infrared regions of the electromagnetic spectrum. These nanostructures could be used in a variety of different applications, from metamaterials to solar energy harvesting and biosensing.

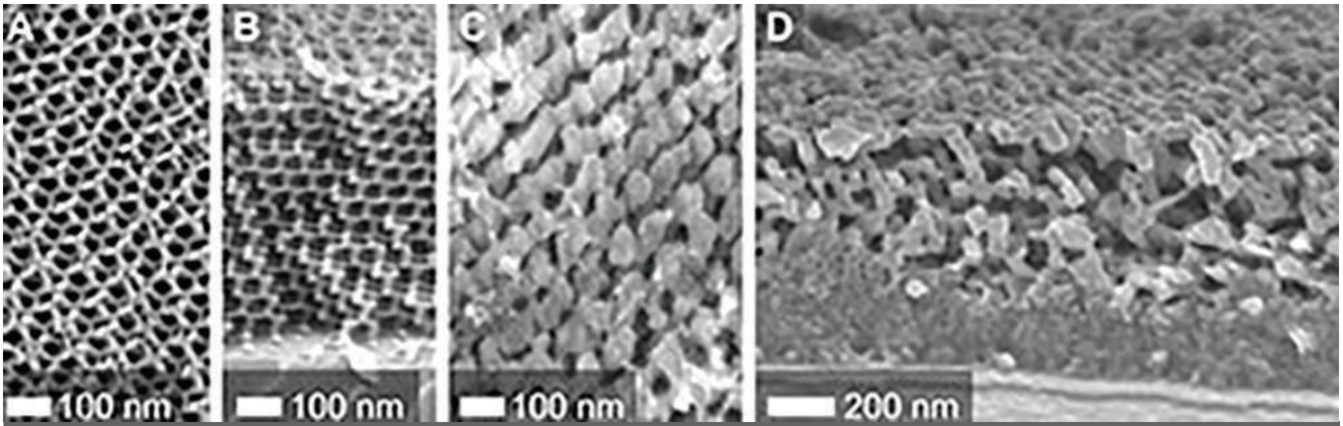
Plasmons are quantized collective oscillations of electrons confined on the surface of a metal that interact strongly with light on the nanoscale. Bimetallic nanostructures such as nanowires, especially those made of silver and gold, are good plasmonic materials. Because plasmonic nanowires collect and focus light at optical to near-infrared wavelengths, they are crucial for developing future nanophotonics devices.

To tailor the surface plasmon resonances of nanowires for specific applications, researchers must accurately control the length of these structures and synthesize them so that they do not differ too much in weight and size. Luis Liz-Marzán of the Centro de Investigación Cooperativa en Biomateriales, San Sebastián, and the Basque Foundation for Science in Bilbao, both in Spain, and others developed a nanowire growth technique based on selectively depositing silver onto specific crystallographic facets of prefabricated gold cores known as pentatwinned gold nanorods. To obtain highly elongated nanostructures just microns in length, researchers avoided secondary nucleation or other side reactions that would compromise the quality of the finished product. *www.cicbiomagune.es.*

BRIEF

Massachusetts Institute of Technology's spinout company **LiquiGlide** licensed its nonstick coating to Norwegian consumer goods producer **Orkla** for use on mayonnaise products sold in Europe. Developed in 2009, the liquid-impregnated coating acts as a slippery barrier between a surface and a viscous liquid. Applied inside a condiment bottle, for example, the coating clings permanently to its sides, while allowing the condiment to glide off completely. *liquiglide.com.*

NANOTECHNOLOGY



Scanning electron microscopy micrographs of a periodically ordered mesoporous gyroidal resin template (A, B) and the resulting laser-induced crystalline silicon nanostructure after template removal (C, D).

FABRICATING SILVER NANOPARTICLES AT ROOM TEMPERATURE

Engineers at Oregon State University, Corvallis, invented a way to fabricate silver for printed electronics at room temperature. "There's a great deal of interest in printed electronics, because they're fast, cheap, can be done in small volumes and changed easily," says engineering professor Chih-hung Chang. "But the heat needed for most applications of silver nanoparticles has limited their use."

Scientists solved that problem by using a microreactor to create silver nanoparticles at room temperatures without any protective coating, and then immediately printing them onto almost any substrate with a continuous flow process. "Because we can now use different substrates such as plastics, glass, or even paper, these electronics could be flexible, very inexpensive, and stable," Chang says. "This could be quite important and allow silver use in many types of electronic applications." *For more information: Chih-hung Chang, 541.737.8548, chih-hung.chang@oregonstate.edu, www.oregonstate.edu.*

POLYMER MOLD PROMISES PERFECT NANOSTRUCTURES

For molds to work, they must be stable while hot liquid materials harden into shapes. In a breakthrough for nanoscience, polymer engineers at Cornell University, Ithaca, N.Y., made such a mold for nanostructures that can shape liquid silicon out of an organic polymer material, paving the way for perfect, 3D, single crystal nanostructures.

The advance comes from the lab of Professor Uli Wiesner, whose prior work involved creating novel materials made of organic polymers. With the right chemistry, organic polymers self-assemble, and researchers used this special ability of polymers to make a mold dotted with precisely shaped and sized nanopores. Normally, melting amorphous silicon, which has a melting temperature of about 2350°F, would destroy the delicate polymer mold, which degrades at about 600°F. The scientists overcame this by using extremely short melt periods induced by a laser. The polymer mold holds up if the silicon is heated by laser pulses just nanoseconds long. At such short time scales, silicon can be heated to a liquid, but the melt duration is so short the polymer doesn't have time to oxidize and decompose. Researchers essentially tricked the polymer mold into retaining its shape at temperatures above its decomposition point. *For more information: Uli Wiesner, 607.255.3487, ubw1@cornell.edu, www.cornell.edu.*

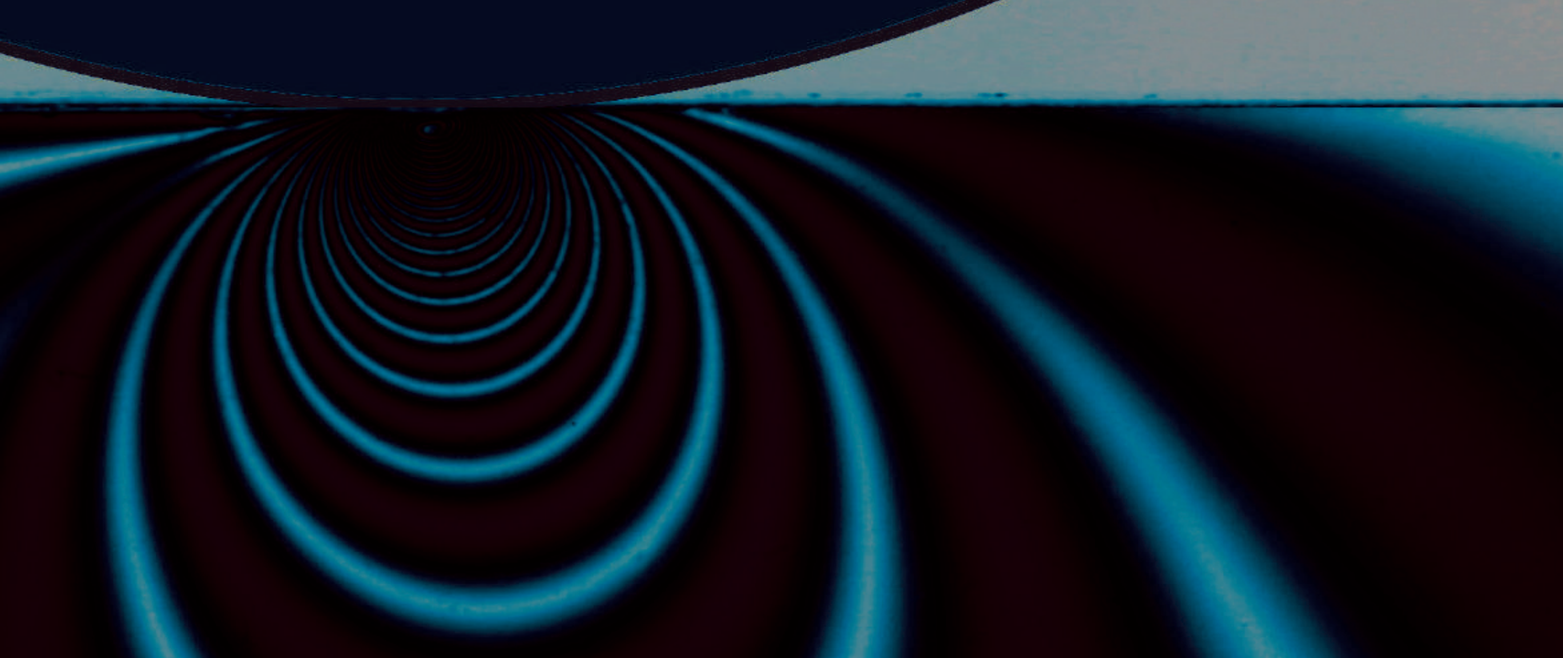
BRIEF

ASTM International, West Conshohocken, Pa., recently published two standards that educate workers about the nanotechnology industry: E2996*, Guide for Workforce Education in Nanotechnology Health and Safety,* and E3001, *Practice for Workforce Education in Nanotechnology Characterization.* E2996 provides an overview of health and safety aspects of nanotechnology, describing the minimum knowledge base needed for an individual involved in nanomanufacturing or nanomaterials research. *astm.org.*

MEASURING RESIDUAL STRESS VIA X-RAY DIFFRACTION HELPS OPTIMIZE ENGINE COMPONENT FABRICATION

Because residual stress has a significant impact on engine component service life, understanding its cause helps optimize fabrication processes to ensure quality. XRD is often the only viable technique to measure residual stresses at certain failure-critical locations.

James Pineault
Proto Manufacturing
Taylor, Mich.



Processing engine components such as crankshafts, gears, shafts, springs, rotors, cylinder heads, and engine blocks poses several difficulties for manufacturers. For example, manufacturing a finished product with the superior material characteristics required for a given application is often challenging. Among the characteristics of interest, residual stress can have a significant impact on the effective service life of engine components. Because residual stresses are introduced in nearly every step in manufacturing, the effect of processing on failure-critical locations must be well understood, controlled, and optimized.

The x-ray diffraction (XRD) technique can be used to characterize residual stresses in crankshafts and is often the only viable method to measure these stresses at certain failure-critical locations, for example, in the rolled fillet radius of a crankshaft. Surface residual stress measurements can be performed nondestructively for inline quality control and for tracking stresses through processing and in-service cycling. Crankshaft subsurface gradients can also be evaluated at various stages of manufacture to benchmark the effects of each manufacturing process.

The service life of engine components often varies greatly as a result of *as manufactured* residual stress levels found in failure-critical locations. With increased demand from consumers for quality, reliability, and seamless performance, manufacturers must meet or exceed specified warranty periods and reduce recalls and warranty repairs. Thus, the stress state of critical components must be accurately characterized so that contributing mechanisms and sources of potentially harmful residual stresses are well understood. Fabrication processes can then be modified and optimized to ensure high-quality components are manufactured at a competitive cost.

CHARACTERIZING RESIDUAL STRESS

When residual stress is thought to be a contributing factor to premature failure, such suspicions may be validated by both experiment and measurement. XRD can also be used to verify the effectiveness of heat treatment processes and the impact of surface treatments such as grinding, turning, rolling, or shot peening.

In order to increase crankshaft life, fillets are commonly burnished or rolled to introduce sufficient compressive residual stresses that inhibit initiation and propagation of fatigue cracks. The effect of the rolling process is often characterized as a function of depth because stress gradients normal to the rolled surface are introduced by the process. Residual stress versus depth profiles are also typically collected at different angles around the circumference of the fillet because manufacturers often vary rolling pressure with angular position around the fillet (Fig. 1). This is particularly important in the case of pin journals, especially when a split pin design is used. In order to segregate rolling induced stresses from those caused by heat treatment and other cold working processes, residual stress as a function of depth must be characterized at various stages. This also includes effects that result from any straightening processes potentially applied as a final manufacturing step.

Stress concentration factors (SCFs) used to estimate applied loads in service are often based on calculation or modeling, or quoted from literature. XRD techniques have been used to experimentally measure the effective SCF for a given undercut radius geometry. As an example, known bending loads were applied to a test crankshaft and stress as a function of applied load was measured in the rolled fillet. The SCF was experimentally derived from this data and the result of 1.83 ± 0.07

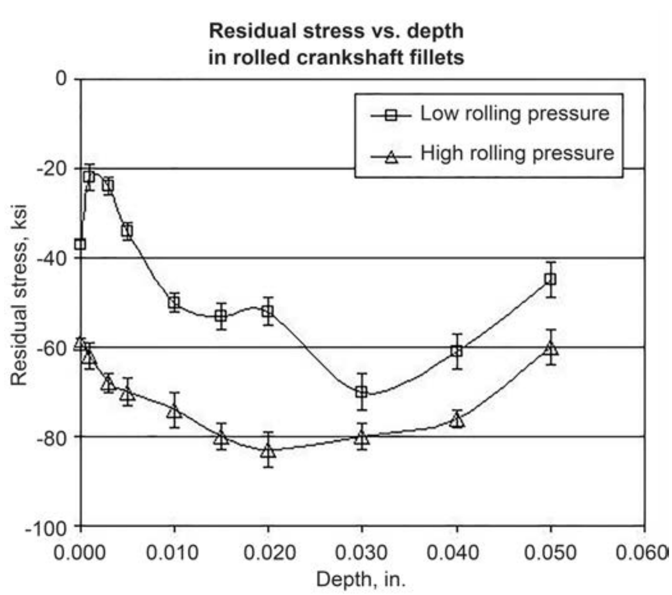


Fig. 1 — Residual stress vs. depth profiles collected on a crankshaft using x-ray diffraction in areas of high pressure and low pressure rolling in a pin journal fillet radius.

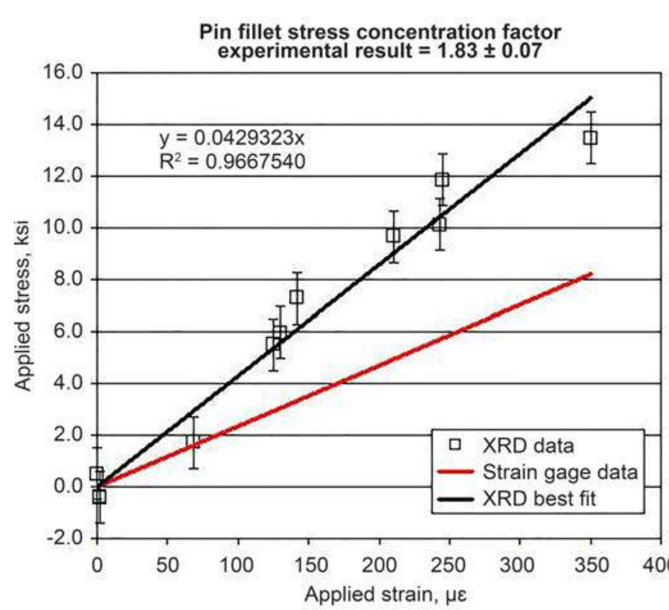


Fig. 2 — Experimental determination of the stress concentration factor (SCF) in a pin journal fillet radius.

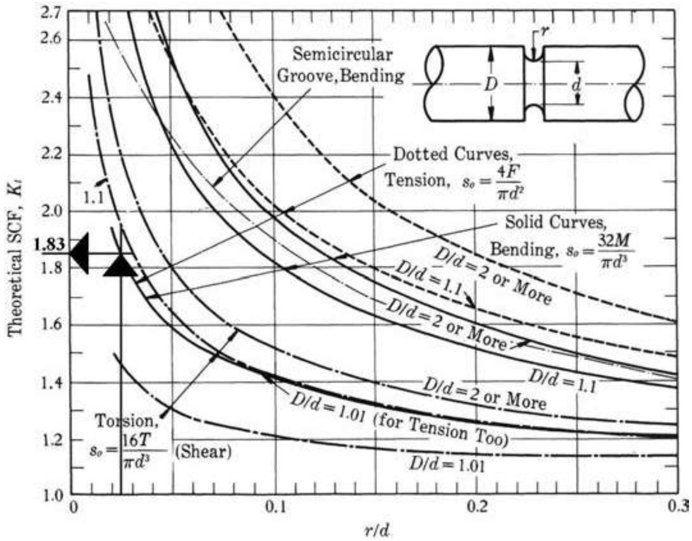


Fig. 3 — Theoretical SCF for geometry similar to a pin journal radius.

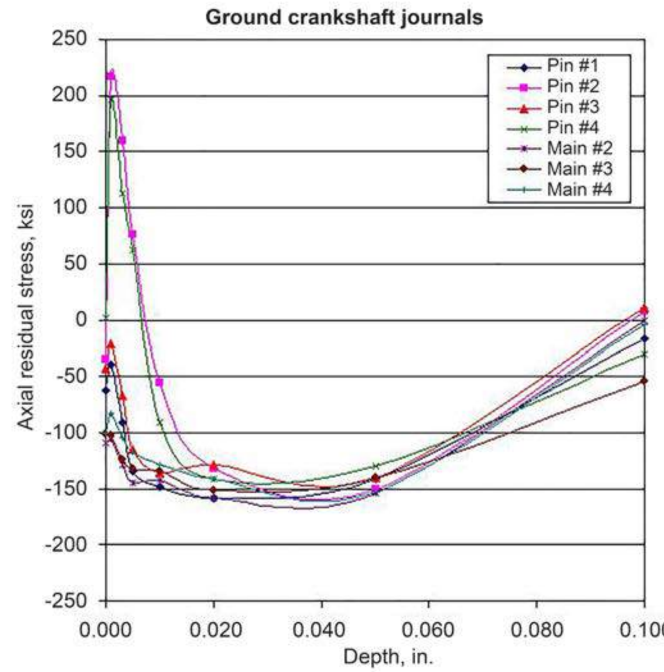


Fig. 4 — Residual stress vs. depth profiles for different grinding parameters.

(Fig. 2) agreed with theoretical calculations within experimental error (Fig. 3).

Main bearing and pin journal surfaces are typically precision ground to obtain the desired dimensional accuracy and surface finish. Tensile residual stresses imparted by grinder burn can have a significant impact on the life of a ground journal. Detection and characterization of grinder burn is therefore extremely important and can be performed using XRD. In general, the maximum tensile stresses due to grinder burn (abusive grinding) are found at shallow depths below the ground surface of a journal suffering from this effect. In order to reliably characterize residual stresses due to grinder burn, it is necessary to collect subsurface residual stress profiles (Fig. 4).

When residual stress measurements are required in the hoop direction of a pin journal in the fillet radius, they can usually be performed without sectioning at locations farthest from the crankshaft axial centerline. However, in cases where measurements are required adjacent to counterweights, or for measurements in the axial direction of the crankshaft, some sectioning may be required. This procedure should be limited to areas where access of the goniometer is hindered by crankshaft geometry or where the incident or diffracted x-ray beam is shadowed (blocked). The effects of sectioning can be characterized by installing a small strain gage near the measurement point in the direction for stress measurement and monitoring it during the process. Subsequent residual stress measurement results can be corrected for relaxation due to sectioning. Current state-of-the-art instrumentation that works in both psi and true-chi modes (rather than modified chi) can minimize the need for sectioning and certain locations can be accessed without sectioning.

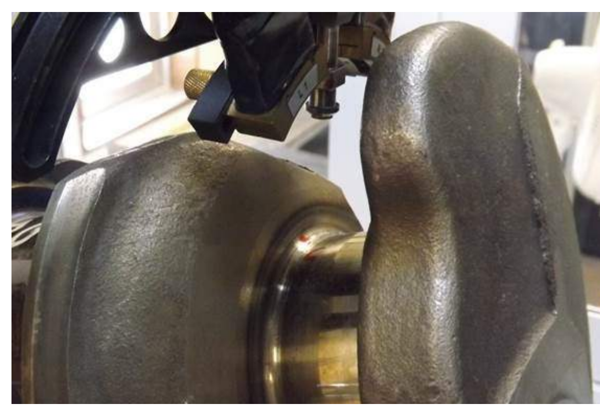


Fig. 5 — State-of-the-art Microarea instrument works in both psi and true chi modes to characterize residual stresses at certain features on a crankshaft without sectioning.

Residual stress measurements should be performed using the multiple exposure technique (MET) in accordance with SAE HS784 and ASTM E2860 recommended procedures, and equipment should be calibrated to national standards including ASTM E915.

Subsurface residual stress gradients can be evaluated for crankshafts taken from various stages of manufacture to benchmark the subsurface effects of each manufacturing process. Once contributing mechanisms and sources of potentially harmful residual stresses are well understood, fabrication processes can then be modified and optimized so that high-quality components can be manufactured at a competitive cost. In many cases, this insight can only be achieved using XRD techniques. **~AM&P**

For more information: James Pineault is laboratory director, Proto Mfg. Inc., 12350 Universal Dr., Taylor, MI 48180, 313.965.2900, xrdlab@protoxrd.com, www.protoxrd.com.

FURNACE ROLL FAILURE ANALYSIS ON HOT-DIP COATING LINE SPURS NEW DESIGN AND WELDING PROCESS

A new design and welding process may extend the life of furnace rolls in hot-dip coating lines, which often fail in less than one year.

Yu-Ping Yang and William Mohr,* EWI, Columbus, Ohio*

Steels are commonly coated for commercial applications by cladding, electrolytic coating, or hot-dip coating methods. The hot-dip process provides a tight metallurgical bond between the steel substrate and protective coating. This method results in a material with the strength of steel, the corrosion protection of a robust coating, and the synergistic heat defense of a coated alloy.

ROLL FAILURE CASE STUDY

A continuous hot-dip coating line is schematically illustrated in Fig. 1[1]. Rolls in the production line transport the steel strip through the line. At the entry point on the left, a steel coil is loaded onto reels. The leading edge of the coil is welded to the tailing edge of the preceding coil. Next, the strip enters the first cleaning stage, an alkaline bath that removes oils, dirt, and residual iron fines from the rolling process, and then goes into the looping tower, which acts as a sheet reservoir. After exiting the looping tower, the strip surface is further cleaned by mechanical brushing and electrolytic alkaline cleaning[2]. Following cleaning, the sheet passes into a preheating furnace where the steel strip is heated by direct fire.

The steel strip then enters a pot containing a bath of molten coating metal where the actual hot-dip coating process takes place. An intermetallic layer is formed between the coating and steel sheet during the hot-dip process, which may consist of either a single phase or more than one phase depending on dipping temperature and time[3]. As the strip exits the pot, a film of molten coating adheres to the surface while forced-air cooling reduces temperature. This prevents coating damage due to contact with the turnaround roll at the top of the upper leg run. The sheet may be subjected to one or more post-treatments before being rewound into coil form or sheared into cut lengths at the end of the line.

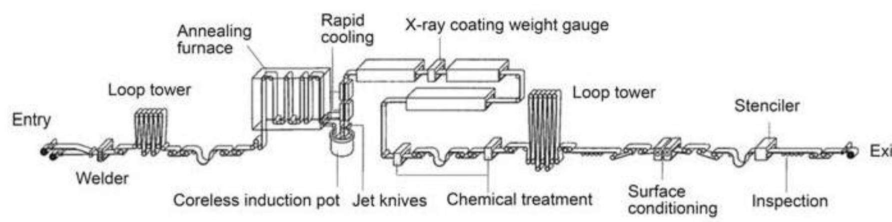


Fig. 1 — Process diagram of a continuous hot-dip coating line[1].

In the case study explored in this article, catastrophic roll failure was observed in the preheating furnace of the continuous hot-dip coating line, as shown in Fig. 2. The failed roll had been in service for approximately seven months. Failure occurred in the weld that joined an end bell to a roll shell, which resulted in the complete 360° separation of the bell from the shell. The roll shell and end bell were made of high-temperature alloy 22-H, while the journal was made of stainless steel 310. Inconel welding electrode 117 was used as weld filler material. The roll shell and end bells were shrink fitted before welding and the specific weld process was flux-cored arc welding. Upon completion of welding, post weld heat treatment was applied for three hours at 1093°C to the entire roll. Historically, this type of roll exhibits a short lifespan—less than one year—which is an ongoing problem.

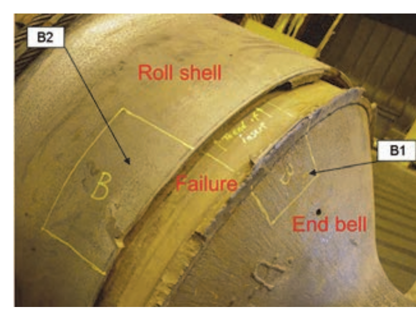


Fig. 2 — Welded joint failure in a furnace roll.

FAILURE ANALYSIS

Service records of the failed roll document its thermal and mechanical loading history. The recorded furnace temperature in the 160 days prior to failure—in a location near the failed roll—shows that the roll was routinely exposed to operating temperatures between 982°–1066°C, with frequent temperature fluctuations of more than 500°C. Occasionally, the furnace temperature dropped to roughly 200°C.

*Member of ASM International

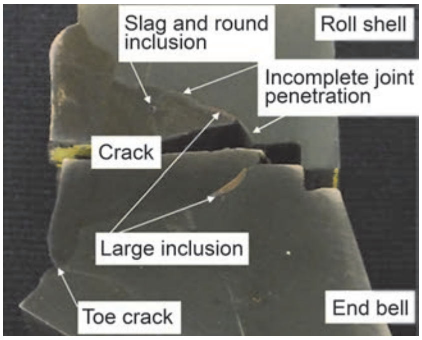


Fig. 3 — Defects and cracks near the welded joint.

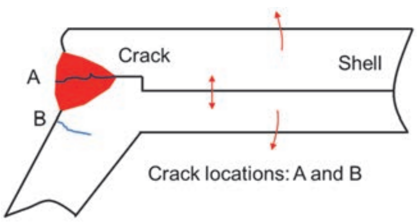


Fig. 4 — Current furnace roll design.

These temperature variations resulted in cyclic thermal loading on the roll. In addition, the mechanical load used to transport the strip was applied on a 90° section of the roll. Because the roll was rotating continuously, it was also subjected to a cyclic mechanical load. Therefore, the furnace roll was working under conditions involving both thermal and mechanical cyclic loading, in addition to high temperature. These conditions could lead to creep-fatigue damage during service.

Macroscopic examination of the welded joint identifies why failure occurred. Figure 3 shows a macrograph of the weld cross-section prepared by cutting the failed roll. Two kinds of cracks (Fig. 4, A, B) were found near the weld. Crack type A initiated from the weld root and propagated to the weld's outer surface, resulting in a separation between the roll shell and end bell. Crack type B appears near the weld toe, which may be the result of stress concentration due to geometric discontinuities during cyclic loading. In addition, defects such as inclusions and incomplete joint penetration were found in the weld. Although the inclusion did not contribute to roll failure, the incomplete joint penetration may have triggered the failure if combined with tensile stress.

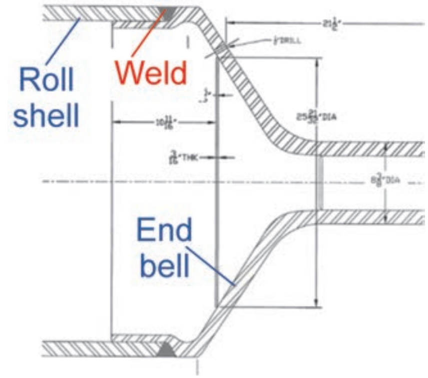


Fig. 5 — New furnace roll design.

FURNACE ROLL REDESIGN

As shown in Fig. 4, the weld root in the furnace roll's current design is a potential crack location due to the mechanical load from transporting the steel strip. To avoid the through-weld crack (crack type A in Fig. 4), the weld that joins the end bell to the roll shell was redesigned, as shown in Fig. 5. In the new design, the weld is rotated 90° and moved slightly away from the end bell to the shell shoulder, which may further reduce weld stress. Further, the material (high-temperature alloy 22-H) used to make the end bell and roll shell is replaced with MO-RE1.

NEW DESIGN EVALUATION

Finite element analysis (FEA) was used to evaluate the new furnace roll design. Due to the symmetry of geometry and loads, a half FEA model was used in the analysis. Symmetric boundary conditions were applied in the symmetric plane, as shown in Fig. 6b. Temperature-dependent material properties were input to the FEA model for base material MO-RE1 and filler material N117.

Steel sheet tension of 31,136 N is transferred to the roll through contact on 25% of the roll circumference over a width of 1270 mm in the center of the roll length and reacted on the journals, as shown in Fig. 6a. In the FEA model, forces were combined and converted into a pressure applied in the 45° direction, as shown in Fig. 6b. Finite element grids show the pressure applied surface, which is a 90° section in the designed roll. Gravitational force is also included in the model. Pressure and

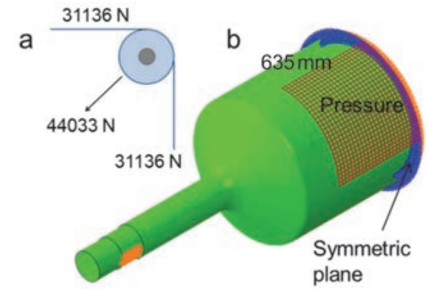


Fig. 6 — Mechanical load applied on the roll.

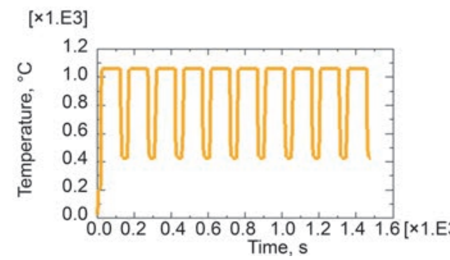


Fig. 7 — Thermal load applied on the roll.

gravity were balanced by supporting the journal from each end of the roll.

Heat transfer analysis was used to predict the temperature history of the welded roll by modeling heat convection from hot air inside the furnace using Abaqus software and a user-developed subroutine. The heat flux (q) was calculated using equation (1) in which the heat convection coefficient (h) was input as a constant number, 20 W/m^2 C. T_s represents furnace temperature, which varies by location and time. Figure 7 is the predicted temperature on the roll for 10 heating cycles.

$$q = h(T - T_S) \qquad (1)$$

Transient, static, stress, and displacement analyses with time-dependent material responses were conducted using the Abaqus commercial finite element code and inputting the predicted temperature history. Isotropic creep and plasticity coupled behavior was modeled by solving a coupled system of constitutive equations. Figure 8 shows the predicted maximum principal stress after the 10th cycle (Fig. 7). Stress magnitudes are low because the roll is at a relatively high temperature of 427°C. High stress is observed in the interface between the weld and base metal, which could be induced by the difference of thermal expansion coefficient between

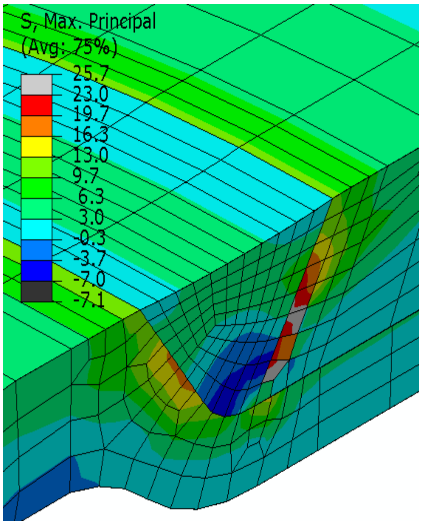


Fig. 8 — Predicted maximum principal stress for welding with flux-cored arc welding.

the weld (N117) and the base metal (MO-RE1). This stress distribution could explain the crack type A observed in the weld macrograph, as shown in Fig. 3.

Electron beam welding (EBW) without filler metal could eliminate the high stress near the weld (Fig. 8). Another FEA was conducted by replacing the material properties in the weld using base material properties and keeping other conditions the same. Figure 9 shows the predicted maximum principal stress with EBW without using filler metal. High stress near the weld disappears, as shown in Fig. 9. Therefore, EBW is an effective method to improve the creep-fatigue life of the furnace roll in the hot-dip coating line. A preliminary welding test shows that EBW could be used to weld the furnace roll.

SUMMARY

A longstanding problem with hot-dip coating lines is that the furnace roll often fails in less than one year. By examining the service history of a failed roll, it was discovered that the furnace roll was working under conditions involving both thermal and mechanical cyclic loading, in addition to high temperatures. Therefore, creep-fatigue damage could occur during roll service. Macroscopic examination of the welded joint found two kinds of cracks—crack A at the weld root and crack B at the weld toe. Crack type A initiated from the weld root and

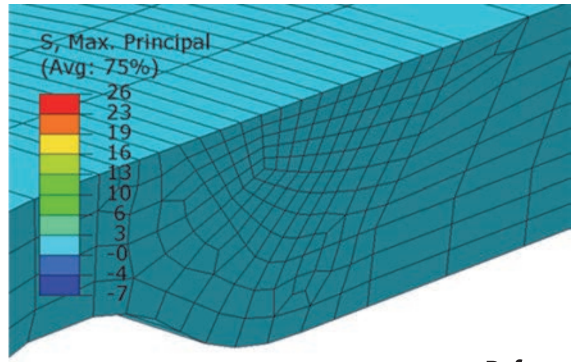


Fig. 9 — Predicted maximum principal stress for welding with electron beam welding.

propagated to the outer surface of the weld, which resulted in separation between the roll shell and end bell. Defects such as inclusions and incomplete joint penetration were also found.

A new furnace roll design was proposed to avoid the through-weld crack in which the weld was rotated by 90°. In addition, the roll material was replaced with MO-RE1. Finite element analysis was used to evaluate the new design. Results show that high stress occurs in the interface between the weld and base metal, which is induced by the difference between the thermal expansion coefficient of the weld and base metal. Electron beam welding without filler metal can eliminate the high stress near the weld. Therefore, the new design, in conjunction with the new welding process, could solve the historical roll failure problem. **~AM&P**

For more information: Yu-Ping Yang is principal engineer, modeling group, EWI, 1250 Arthur E. Adams Dr., Columbus, OH 43221, 614.688.5253, yyang@ewi.org, www.ewi.org.

References

1. G.H. Awan, The Morphology of Coating-Substrate Interface in Hop-Dip-Aluminized Steels, University of Engineering and Technology, Pakistan, Ph.D. dissertation, 2001.

2. C.M. Cotell, J.A. Sprague, and F.A. Smidt, *ASM Handbook,* Volume 5: *Surface Engineering,* p 339-348, 2007.

3. M.B. Isiko, Aluminizing of Plain Carbon Steel—Effect of Temperature on Coating and Alloy Phase Morphology at Constant Holding Time, Norwegian University of Science and Technology, TMT4905 - Materials Technology, Masters thesis, 2012.

TECHNICAL SPOTLIGHT

USING SIMULATION TO DESIGN ANTICORROSIVE AUTOMOTIVE COMPONENTS

Simulation of components and joints made of hybrid materials enables innovative designs for corrosion protection in automotive applications.

Rivets are commonly used to hold different materials together—and can easily be spotted on bridge support beams, airplane doors, and car hoods, for example. Found in metal-bodied vehicles and support structures across the transportation industry, these rivets usually go unnoticed despite their critical role in joining components that must withstand enormous mechanical stress. Some cars contain over 2000 of them. As automotive designs trend toward lightweighting and the use of multiple metals, questions arise regarding the destructive, invisible culprit whose handiwork often goes unnoticed until it is too late: Corrosion.

GALVANIC CORROSION

Galvanic corrosion is a constant problem that costs the automotive industry billions of dollars each year. Caused by chemical reactions between different metals coming into contact with one another, this type of corrosion is often visible as a white powdery growth that forms on the surface of metal parts (Fig. 1, center). Bubbling paint and deteriorating aluminum are also signs that metallic ions are being exchanged and degrading a metal's surface.

Various metal combinations react differently to environmental impacts, and a number of factors such as joining techniques, material properties, and surface roughness affect the chemical reactions on rivets and the sheets they bind together. Therefore, understanding the underlying electrochemistry is essential in order to develop robust corrosion protection.

Engineers at Helmholtz-Zentrum Geesthacht (HZG) and Daimler AG, both in Germany, joined forces to investigate corrosion prevention using multiphysics simulation. The team sought ways to streamline rivet design and development, minimize physical testing, and reduce the need for subsequent steps such as surface treatment.

MODELING OFFERS INSIGHT INTO CORROSION BEHAVIOR

To study galvanic corrosion kinetics, including material loss, surface conditions, and the long-term behavior of interacting metals, Daniel Höche, scientist at HZG, created a simulation of a steel punch rivet joint using Multiphysics software from COMSOL, Burlington, Mass. The rivet was plated with an aluminum-zinc alloy that cathodically protects the steel. Software allows the electrochemical interactions at the surface and edges of the rivet to be analyzed, predicts the decay of joined sheets, and adjusts the geometry to minimize corrosion.

This model consists of the rivet, bonded metal sheets of aluminum and magnesium, a 0.1% NaCl electrolyte layer on the surface representing the outside environment, and a galvanic couple at the interface between the rivet and the sheets (Fig. 2). A corner burr in the rivet geometry was also added to simulate the presence of a sharp edge, which increases gradients in the electrolyte potential. This, in turn, increases current flow and hastens the electrochemical reactions that cause galvanic corrosion.

As the interface between the rivet and sheets experiences corrosion, the magnesium sheet begins to degrade more rapidly than the other metals. The chemical reaction produces magnesium hydroxide, $Mg(OH)_2$, which forms a weak barrier film on the surface. Growth

Fig. 1 — Clean rivet (top). Rivet showing magnesium hydroxide deposit (white growth) due to corrosion (center). Magnification of a rivet in a test sheet (bottom).

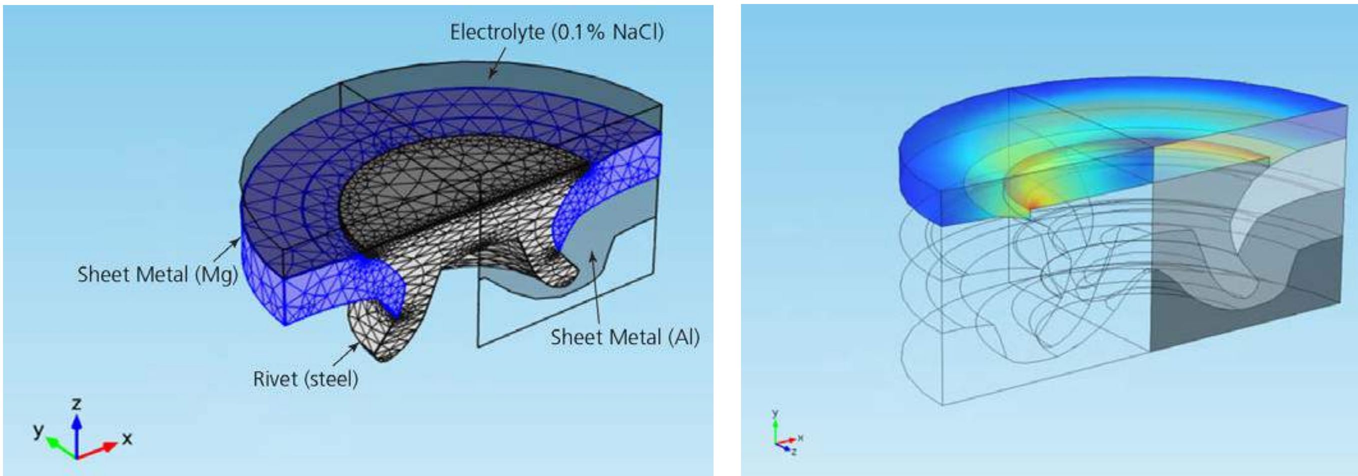


Fig. 2 — Geometry depicting half of a punch rivet joint in COMSOL Multiphysics software (left). Simulation results show current density at the surface of the rivet and sheet metal. The simulation mathematically models current flow at the rivet-sheet interface; the highest current density occurs at the sharp edge (right).

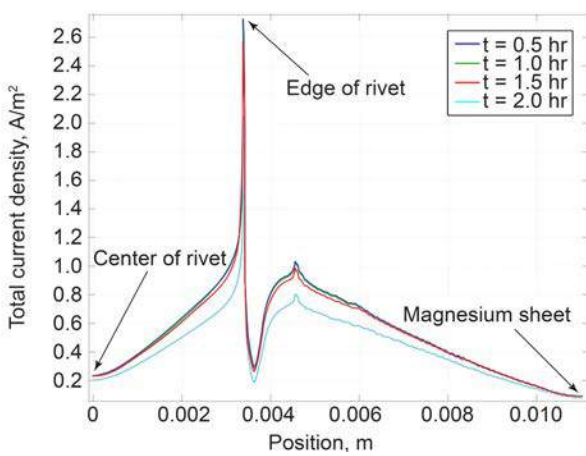


Fig. 3 — Simulation software plot showing localized current density at different positions on the rivet joint's surface.

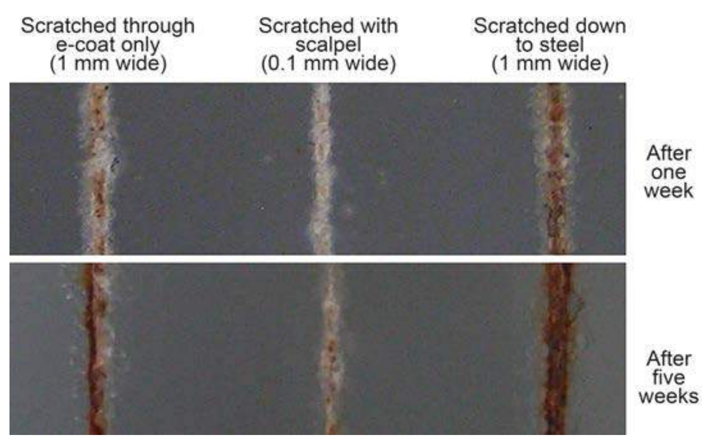


Fig. 4 — Corrosion test on a galvanized steel sheet showing visible corrosion in the scratched layers (view from above). Several initial scratches of varying depths and widths were created in order to analyze the influence of scratch size on the delamination process. Results are shown after one week (top) and five weeks (bottom).

in this deposit layer actually increases resistance to further corrosion, hindering its own progress. However, it cannot be completely stopped due to the porosity of $Mg(OH)_2$ and the growth continues deeper into the metals.

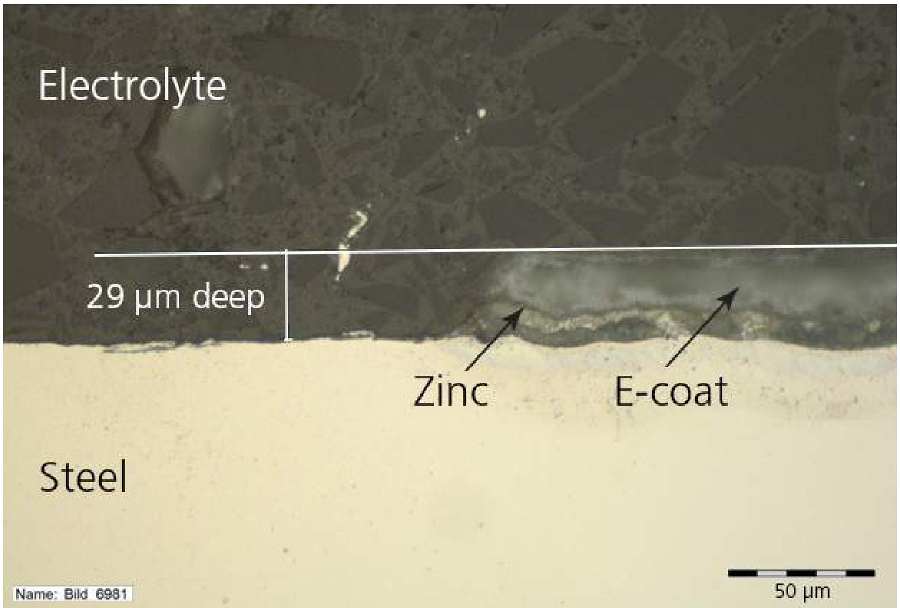
In order to determine electric current distribution and analyze the chemical response, the non-constant growth and influencing material properties must be accounted for. Using the *Chemical Reaction Engineering and Batteries & Fuel Cells* modules in the simulation software, the rivet and sheet metal are treated like a set of electrodes. This allows assessment of the anode/cathode area ratio, electrolyte exposure duration, and changes in electric current due to $Mg(OH)_2$ buildup, which contributes to the magnesium degradation.

Because porosity directly affects barrier properties, the resulting surface topology is influenced by the downward degradation velocity and the opposing growth of the deposit. Basic galvanic current density computations were modified by these layer growth aspects. This led to the study of time-dependent variations in the electrochemical response of the electrodes.

The model includes chemical reaction rates, known electrochemical properties of the metals, and a time-dependent function with an exposure period of 24 hours. Results report the electric potential and current density when the rivet joint is exposed to the electrolyte, and reveal surface coverage (proportion of sheets and rivet surfaces covered by $Mg(OH)_2$) at different times after immersion. Current density varies over distance from the center of the rivet, showing where corrosion will occur most rapidly (Fig. 3).

DELAMINATION RISKS

In addition to galvanic corrosion at the rivet-sheet interface, automotive



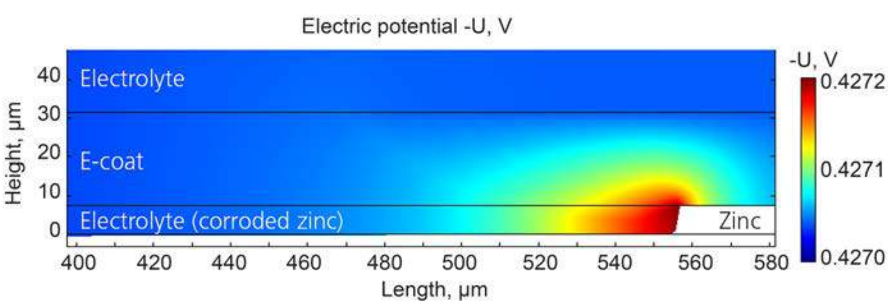


Fig. 5 — Close-up of a cross-section of the test sheet where a scratch destroyed part of the e-coat and zinc layers (top). Simulation software results show the electric potential in the e-coat and electrolyte. The white region shows remaining zinc after much of it was already consumed (bottom).

components are also at risk from exposure to natural elements. Seemingly superficial imperfections, such as a scratch in the coating or paint on a panel, allow moisture and environmental electrolytes access to electrically conductive surfaces. In car paneling, small impairments can create a galvanic couple that causes delamination—the debonding of coatings on metal sheets—which significantly weakens the corrosion protection.

To analyze this additional risk, Höche worked with Nils Bösch of Daimler AG to study delamination on a zinc-plated steel test sheet electrocoated with a layer of cathodic paint called an *e-coat* (Fig. 4). If a scratch extends down to the steel surface, a galvanic couple occurs between the zinc and steel causing the zinc to corrode. This results in a crevice that grows continuously between the e-coat and steel in a horizontal direction, rather than vertically through the layers. This behavior is similar to crevice corrosion, which digs between two surfaces and creates fissures in the metal. Stress fractures at the base of these cracks can eventually cause part failure, even though the obvious damage and overall material loss may appear small.

Höche and Bösch used parametric sweeps in the simulation software to study the electric potential in the electrolyte and e-coat for different e-coat barrier properties. Their model reports the corresponding horizontal growth of the crevice as it consumes the zinc (Fig. 5).

The quest to understand how the size of these surface defects impacts the rate of zinc consumption is ongoing. So far, the model indicates that the width of these defects has a greater influence than the depth—a smaller cathode/anode ratio and more limited diffusion is present in the narrower scratches, which slows the corrosion process compared to a wider impairment. Existing results are being used to further investigate coating flaws for their negative influence on corrosion protection.

LONGER-LASTING STRUCTURAL SUPPORT

Although corrosion cannot be avoided entirely, it can be minimized through expert design and careful analysis. Höche and Bösch reduced the sharp edges in the rivet joint and honed the geometry to minimize the exposed area while maintaining mechanical stability. They also recommended an e-coat for the sheet metal that, based on the parametric study, exhibits the lowest electric current and therefore, the least decay in the paneling. Their computer models offer valuable insight into relevant electrochemical behavior, providing engineers the tools to optimize rivet joints to offer the best corrosion resistance.

Computer-aided analysis can enhance recent progress regarding lightweight, multi-material designs and enable identification of possible corrosion problems early in the development cycle. Despite corrosion being an enemy to the automotive rivet, control of magnesium corrosion through knowledge-based processing and careful geometric design is within reach. **~AM&P**

For more information: Lexi Carver is technical marketing engineer, COMSOL Inc., 1 New England Executive Park, Burlington, MA 01803, 781.273.3322, lexi.carver@comsol.com, www.comsol.com.

TECHNICAL SPOTLIGHT

SOLVING ELECTRONIC SYSTEM FAILURES IN AEROSPACE APPLICATIONS

Determining the root cause of avionics failures requires a disciplined and systematic analytical process supported by sophisticated equipment.

The aerospace industry continues to face difficult challenges with regard to electronic system failures. As advanced semiconductor processes enable more compact devices to be created from smaller structures, even those that appear flawless can still exhibit performance problems arising from as little as one misplaced atom. In addition, avionics and other aerospace systems operate in extremely harsh environments characterized by temperature and power cycling, vibration and shock, and demanding requirements related to high current flows and thermal transfer. Determining the root cause of avionics failures requires a disciplined and systematic analytical process, supported by sophisticated tools that test and visualize the behaviors and characteristics of sample devices.

TYPICAL AVIONICS SYSTEM FAILURES

Aerospace systems fail for a variety of reasons, including quality issues as well as stresses associated with harsh operating environments. The role of quality issues was highlighted in a July 2011 report from the U.S. Government Accountability Office (GAO) entitled "Space and Missile Defense Acquisitions: Periodic Assessment Needed to Correct Parts Quality Problems in Major Programs." The GAO document notes that most parts quality problems are associated with electronic versus mechanical parts or materials, and they result from "…poor workmanship, undocumented and untested manufacturing processes, poor control of those processes and materials and failure to prevent contamination, poor part design, design complexity, and an inattention to manufacturing risks." Even assuming a bulletproof parts quality program, environmental stresses on both military and commercial avionics systems increase the likelihood of field failures. This is especially true with the trend toward smaller surface-mounted and chip-scale packaged devices used to reduce size and weight.

The GAO report lists a number of common device failure types in Department of Defense and NASA aerospace systems including attenuators that exhibit inconsistent performance due to sensitivity to temperature changes; printed circuit boards that fail intermittently due to connection points vulnerable to thermal stresses; and capacitors that develop a phenomenon known as *tin whiskers,* which can cause catastrophic problems to avionics systems. These and other failures can be difficult to diagnose without a comprehensive and disciplined analysis process.

SYSTEMATIC PROCESS HALLMARKS

A thorough process starts with a broad system view and then narrows to the power supply, board, or component level, or even deeper to an integrated circuit (IC) logic block or transistor. The first phase is nondestructive, consisting of visual examination, x-ray, and electrical verification of the failure mode. Prematurely initiating destructive analysis runs the risk of losing valuable information because some failure mechanisms are sensitive to temperature and can change during desoldering or decapsulation.

Once the failure signature is acquired, analysis moves to troubleshooting failures on a printed circuit board (PCB) or component. The goal is to find all failing components and—in the case of electrical overstress—identify the current path. The ultimate goal is to identify both the failure origin and initial failure mechanism. Bypassing full system-level analysis can be a costly mistake. All too often, what initially appears to be electrical overstress might actually involve other failure mechanisms that can be missed without a top-down, system-level approach.

After acquiring electrical data to localize failures to a PCB or component, analysts move to IC and discrete component analysis while looking for the failure mechanisms. A meta-loop process tests each failure hypothesis while evidence either confirms or disproves the hypothesis. If necessary, more information is gathered so a new hypothesis can be proposed. Applying short-loop techniques repeatedly throughout the analysis helps determine the underlying failure mechanism.

DIAGNOSTIC TOOLS

Nondestructive test tools include external visual examination, x-ray and C-mode scanning acoustic microscopy (CSAM), curve trace, and time domain reflectometry (TDR). These tools can be particularly useful for identifying failures related to tin whiskers, a phenomenon that has resurfaced with the move to lead-free processes. The tin whiskers shown in Fig. 1 are conductive metallic structures that grow from the surface of tin finishes. They can cause shorts

Fig. 1 — Scanning electron microscope image of tin whiskers.

across adjacent conductors and, at high altitudes, these shorts can result in conductive plasma generation.

Other nondestructive tests include a superconducting quantum interference device (SQUID) and giant magnetoresistive (GMR) microscopy. Both are magnetic current imaging tools useful for finding shorts and leakages, and mapping their locations on the current path. Thermal imaging can also be used to identify and map hot spots and provide actual temperature measurements. Another common nondestructive electrical test is curve trace. Voltage and current are swept to create an I-V plot, which reveals opens and shorts as well as resistance and leakage, helping to verify and visualize the electrical failure signature.

Nondestructive package tests include particle impact noise detection (PIND) for cavity packages, which is essentially a process of shaking the sample and listening for loose particles inside. Fine and gross leak tests are both used for evaluating hermetic package integrity. In addition, 2D or 3D x-ray imaging is useful for analyzing package integrity and provides a look at PCB internal traces, bond wires, die bumps, de-attached fillets, substrate package traces, and other package elements. Scanning acoustic microscopy (SAM) uses ultrasound pulse echo techniques to look for voids, cracks, and delaminations in ceramic capacitors and plastic packages. Also, TDR can be used here to help determine whether an open/short defect is in the package or at the interface to the die. Other nondestructive optical tests include filtered polarized light inspection, as well as die backside inspection using reflected IR imaging.

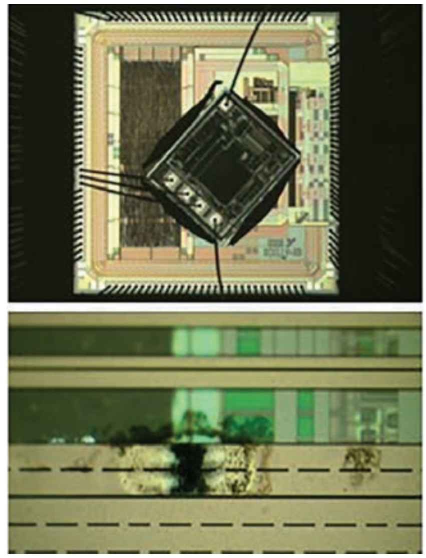


Fig. 2 — Low- and high-magnification microscopes can be used to visualize a package's wires and wire bonds, passivation cracks, electrical overstress, and corrosion.

Based on the electrical failure signature and initial nondestructive testing results, a plan for physical analysis can be formulated. At this point, internal visual inspection using low- and high-magnification optical microscopy is often used to further localize the problem. Optical and scanning electron microscope (SEM) inspection can also help analysts understand morphology and electrostatic discharge (ESD) issues, and can be combined with materials characterization tests to identify foreign materials or corrosive byproducts such as chlorine that would indicate problems related to moisture infiltration.

Rounding out the options for package testing are backside infrared (IR) thermography and other backside laser inspection techniques, and cross-sectioning to look at joint profiles with SEM and other higher-resolution instruments.

LOCALIZING FAILURES TO THE TRANSISTOR LEVEL

Once an electrical failure has been identified through nondestructive testing, the failure mechanism must then be localized to within a few microns of the problem's exact location. Analysts use optical microscopy to look at bond wires, die attach, big cracks in the die, electrical overstress, corrosion, and

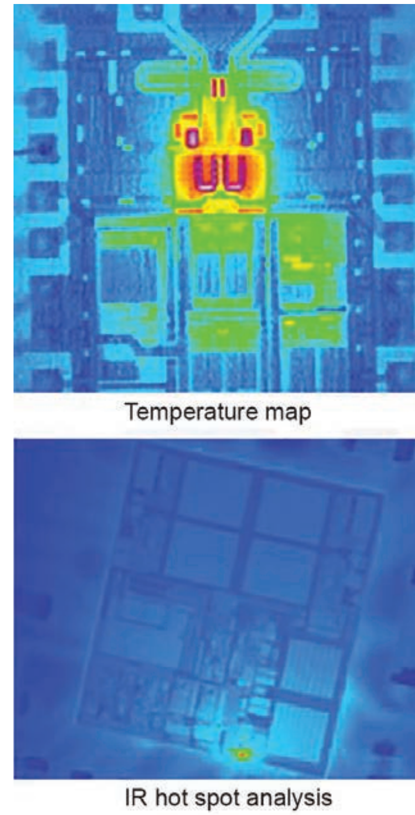


Fig. 3 — Temperature gradient across the die, top, and location of a gate oxide breakdown site, bottom.

other large elements on the die. Wire bonds are a particularly vulnerable design element in avionics systems, which are prone to intermetallic formation due to exposure to elevated temperatures, corrosion due to both high temperature and moisture, and fatigue due to temperature cycling exposure (Fig. 2).

Infrared thermography is another important technique. Avionics packages are frequently exposed to temperatures higher than the maximum allowable for their electronics, reducing component lifetimes and significantly increasing failure probability. Infrared thermography microscopes localize hot spots by measuring true temperature with pixel-by-pixel emissivity correction. Heat is imaged at a 3-micron infrared wavelength to create a color-coded temperature map or hot spot overlay image.

Figure 3 shows two examples where power was dissipated in the sample and creating hot spots. Temperature increase depends on the power dissipated per unit area, so in this case identifying where the device was getting hot is easy. Infrared thermography indicates

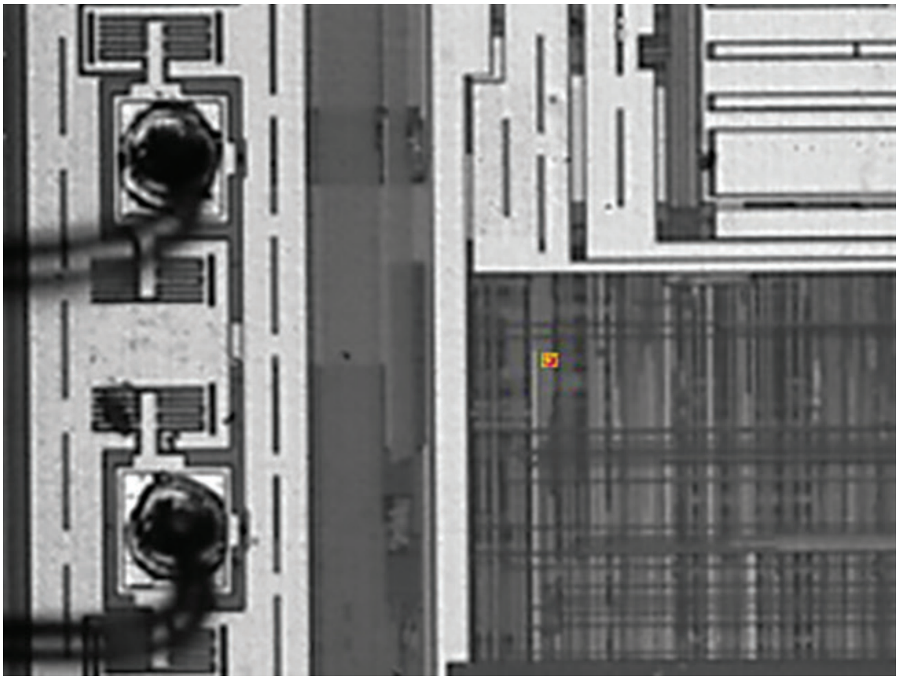


Fig. 4 — Emission microscopy requires little or no sample preparation, other than decapsulation.

how hot the area is and where the power dissipation occurs in the logic block.

Another defect localization technique is light emission microscopy, also known as EMMI. It can be used from either the front or back of the die (often without die thinning) to discover defects or abnormal device operation based on photon emission in the visible and near-infrared (IR) spectrum. These defect-related emissions are often associated with forward or reverse biased p-n junctions. In the example of forward-biased p-n junctions, device emission is generated by placing a large number of electrons and holes in close physical proximity where they recombine and generate light with spectra centered around the silicon bandgap. This light can be captured with a sensitive charge-coupled device (CCD) or indium gallium arsenide (InGaAs) camera in a light-tight box. Two images are captured, one with the microscope light on to acquire the die image, the next with the light off and bias applied to see the emission source (Fig. 4).

Defect-related photon emissions are also generally associated with transistors in saturation, latch-up, and gate oxide breakdown. In avionics applications, these types of failures can be the result of single event effects (SEE), a category of isolated electronic circuitry changes resulting from interactions with high-energy particles and radiation in space. For instance, a single event latch-up (SEL) can cause a transistor element to become fixed in either an on or off state, or a memory bit to become stuck at either a one or zero, latching the affected cell into a permanent state. Latch-ups, in particular, shine very brightly using light emission microscopy. Regardless of device type, any transistor under normal operation will generate a small amount of light. All light emission sites are overlaid on a background die image, enabling failure localization in relation to circuit features.

Laser signal injection microscopy is another important imaging tool, and is used to locate IC defects such as shorts, junction defects, and problems with vias. A laser beam is scanned through a microscope lens over the die while watching for laser-induced shifts in the device current-voltage (I-V) response. Short-wavelength lasers inject photocurrents and can reveal failure sites in transistors and p-n junctions, while longer-wavelength lasers create localized heating that results in temporary resistance changes. In the latter example, leakage paths can be revealed due to the temperature coefficient of resistance.

It is also useful to look at the reflected laser light image and its amplitude using laser timing probe (LTP) techniques. Because the brightness of the reflected laser changes with the voltage on the transistor, an individual transistor's waveform can be measured by running a logic pattern through the sample. It is also possible to see what is not switching, as well as locations that are switching at a certain clock or data frequency, or where a clock stops halfway through, helping to localize the defect.

Localizing failures at the transistor level may also require nanoprobe techniques. Polishing the sample exposes contacts, and a biased probe tip is scanned across its surface to reveal subtle leakage differences between sources, drains, and gates. Another option is to drop up to six probes onto the transistor, make contact at the source, gate, drain, and body, and measure the electrical characteristic of each individual transistor. Electrical characteristics such as threshold voltage, off leakage, and on current can then be measured. Once the problem transistor has been identified, physical analysis can take place.

Transmission electron microscopes (TEMs) are often used after nanoprobe tests. Samples are placed under a focused ion beam and trenches are dug on each side of the target transistor, leaving only a slice the size of the transistor itself. This slice is viewed under the TEM to visualize defects in a way that no other technology can.

Avionics system failures are difficult to identify and solve. The combination of smaller and more complex devices used in demanding environments makes it difficult to find and fix failures. Identifying, localizing, and resolving failures requires a highly disciplined process, supported by numerous sophisticated test and imaging tools. With the right approach, it is possible to isolate a failure's root causes, understand its mechanisms, and resolve it. **~AM&P**

For more information: Winfield Scott is technology director, Evans Analytical Group, 2710 Walsh Ave., Santa Clara, CA 95051, 408.454.4600, wscott@eag.com, www.eag.com/mte.

CASE STUDY

FAILURE ANALYSIS OF A FRACTURED PIN

A pin used to hold the side plates together in a conveyor chain system fractured and failed, prompting a metallurgical failure analysis.

A pin that was used as part of a conveyor chain application failed in service. The company wanted to find out what went wrong, so they submitted the fractured pin to a failure analysis laboratory for metallurgical inspection. Loading applied to the pin was expected to be shear in nature, and perpendicular to the 59-mm-diameter surface at the ends of the pin. Specifically, the owner of the failed pin wanted to determine if inclusions may have caused the failure, if the part had been properly heat treated, and whether or not the steel composition was correct.

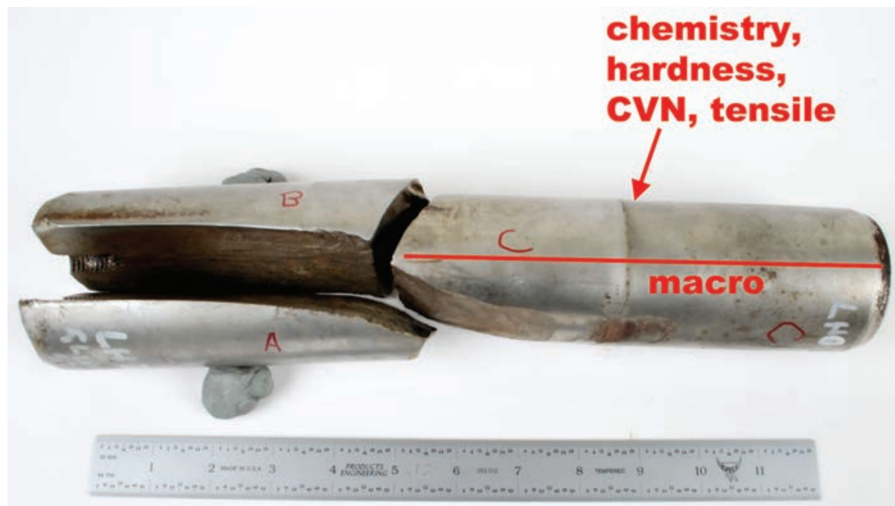


Fig. 1 — Remnants of the failed pin are shown with sections identified as A through C.

VISUAL INSPECTION AND SEM-EDS ANALYSIS

Both visual inspection and scanning electron microscopy/energy dispersive x-ray spectroscopy (SEM-EDS) were initially used to study the failed pin (Fig. 1). Longitudinal fracture surfaces are shown in Fig. 2, with blue arrows indicating the fracture origin region and white arrows indicating the cracking direction. Section MA was selected for metallography and locations 1 through 3 were chosen for closer inspection.

A magnified view of location 1 is shown in Fig. 3, which also exhibits substantial post-fracture rubbing damage. A scanning electron micrograph of location 1 is presented in Fig. 4, although the rubbing damage obscures the original fracture features. Verification of the fracture mode could not be established due to the rubbing damage.

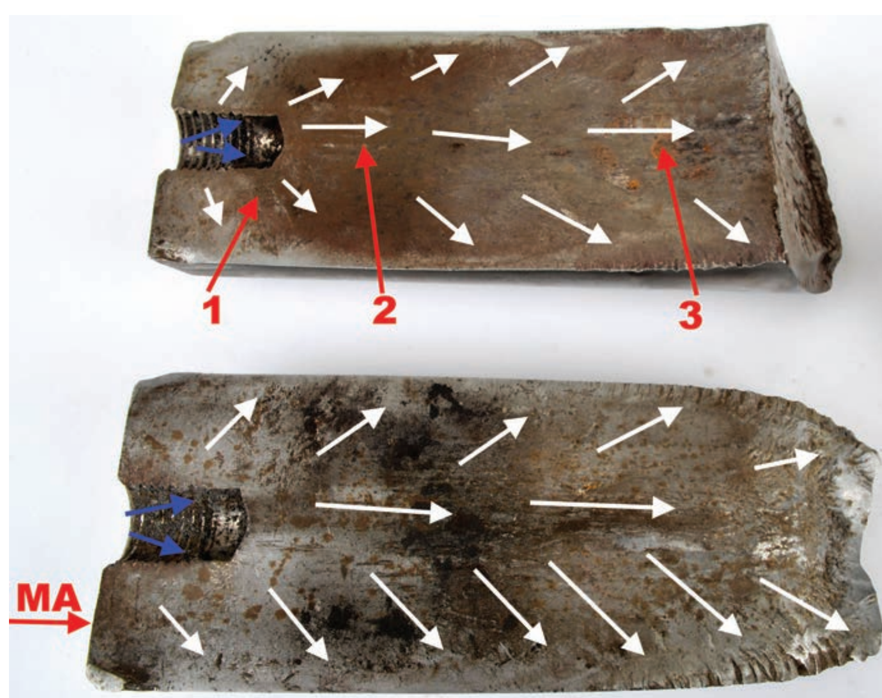


Fig. 2 — Fractures on sections A and B are shown with section MA selected for metallography. Locations 1 through 3 were selected for closer inspection. Blue arrows indicate the fracture origin region while white arrows show the direction of cracking.

A deposit at location 2 was analyzed using EDS, which detected a trace amount of chlorine in addition to a few other foreign elements. Chlorides are known to be corrosive to stainless steel and can contribute to stress-corrosion cracking (SCC). Threads from the hole at the origin region are shown in Fig. 5 and corrosion pits can be seen on the threads.

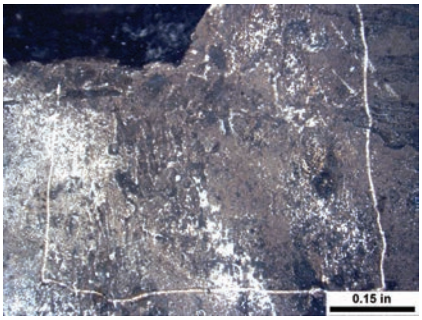


Fig. 3 — Magnified view of location 1, indicated by scribe marks.

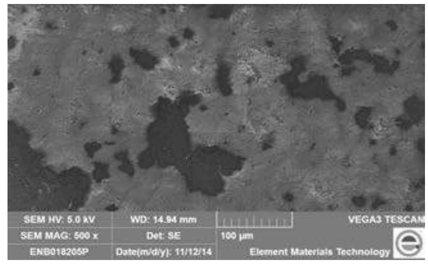


Fig. 4 — Scanning electron micrograph of location 1. Post-fracture mechanical rubbing damage obscures fracture features.

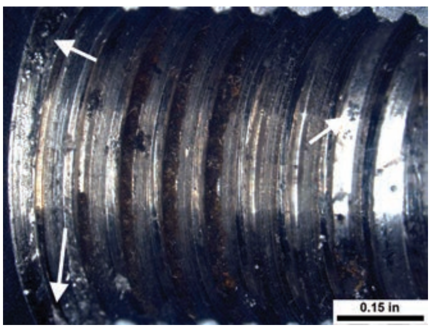


Fig. 5 — Magnified view of pin threads. Arrows indicate corrosion pits.

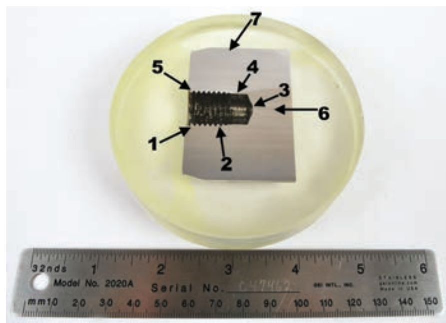


Fig. 6 — Section MA includes locations 1 through 7, which were closely examined.

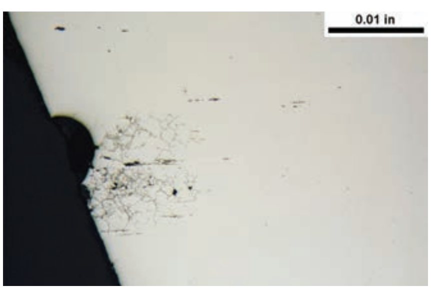


Fig. 7 — Magnified view of location 3. A pattern of branched cracks is present adjacent to a corrosion pit.

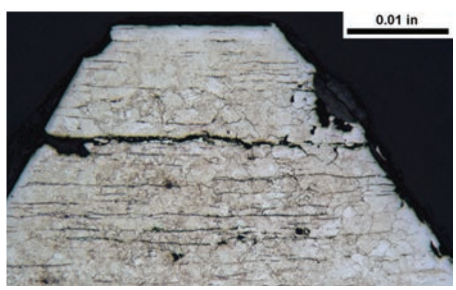


Fig. 8 — Magnified view of a thread crest at location 2. Microstructure consists of martensite and semi-continuous stringers of delta ferrite.

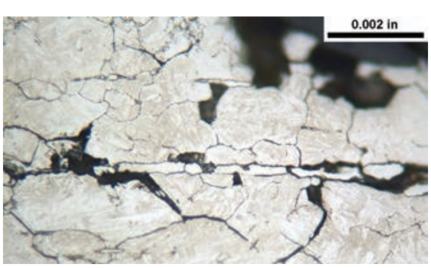


Fig. 9 — Higher magnification view of right center of Fig. 8. Cracking progressed along grain boundaries and delta ferrite stringers.

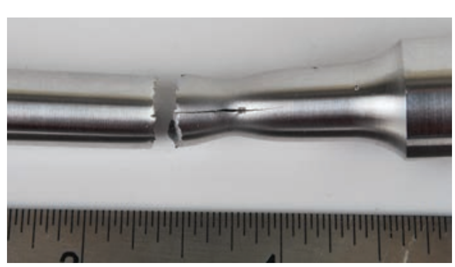


Fig. 10 — Fractured tensile specimen exhibits a longitudinal crack on the bar.

METALLOGRAPHY FEATURES

Section MA is presented in Fig. 6, in which locations 1 through 7 were examined. A magnified view of location 3 is shown in Fig. 7, which exhibits a pattern of branched cracking, indicative of SCC. Magnified views of location 2 are presented in Figs. 8 and 9. The microstructure was found to consist of martensite and semi-continuous stringers of delta ferrite, with much of the cracking through the tooth occurring along the stringers. The presence of these semi-continuous stringers was determined to be a major contributing factor to the pin failure.

TENSILE TEST RESULTS

The ultimate strength of the tensile specimen was 1200 N/mm^2 and exceeded the maximum requirement of 1050 N/mm^2. The fracture on the tensile specimen is shown in Fig. 10, which exhibits a longitudinal crack on one half of the specimen that partially split the piece. Splitting was caused by the semi-continuous delta ferrite stringers, which indicates that the material was brittle in the pin's longitudinal direction.

CHARPY V-NOTCH IMPACT TESTING

Charpy V-notch specimens were excised from the pin with the notches oriented longitudinally. The result for each test was 2 Joules, which did not meet the requirement of 25 Joules. Longitudinal features were present on the fracture surfaces that were associated with delta ferrite stringers. This low impact strength was caused by the semi-continuous delta ferrite stringers.

CONCLUSIONS

Pin cracking initiated at the threaded hole where there was corrosion pitting and evidence of SCC. The cracking is thought to have progressed via corrosion fatigue or brittle overload fracture. The microstructure of the pin consisted of semi-continuous delta ferrite stringers in a matrix of martensite. These stringers were found to be a major factor contributing to the pin failure. The Charpy V-notch impact resistance of the steel was far below the specified requirement. Semi-continuous delta ferrite stringers made the pin's impact resistance very low. Splitting of the tensile specimen was due to the presence of semi-continuous delta ferrite stringers and indicates that the material was susceptible to longitudinal cracking under the application of stress. **~AM&P**

For more information: Craig Schroeder is senior engineer, metallurgy, Element Materials Technology, 3200 South 166th St., New Berlin, WI 53151, 262.901.0534, craig.schroeder@element.com, www.element.com.

41ST INTERNATIONAL SYMPOSIUM FOR TESTING AND FAILURE ANALYSIS

November 1-5 • Oregon Convention Center, Portland

PREMIER SPONSOR:

SPONSORS:

Share experiences and advance the industry at the 41st International Symposium for Testing and Failure Analysis (ISTFA)—the premier event for the microelectronics failure analysis community. This year's theme is *Follow the Data*. The conference will present the latest research, industry advances, and technological achievements within the electronic device failure analysis industry.

EDUCATION SHORT COURSES

SATURDAY, OCTOBER 31

Fault Isolation
8:30 a.m.–4:30 p.m.
Instructor: David Vallett

This course examines both traditional and recent tools and techniques for isolating defects on simple and advanced ICs and microelectronic devices.

Packaging Failure Analysis
8:30 a.m.–4:30 p.m.
Instructor: Becky Holdford

The basics of package failure analysis will be covered including common package construction, the most common fault isolation tools/techniques, common failure modes/mechanisms, die access techniques for plastic and hermetic packages, and some case studies.

Beam-Based Defect Localization
1:00–4:30 p.m.
Instructor: Edward Cole, FASM

This course reviews scanning electron microscopy and scanning optical microscopy techniques for IC failure analysis. The course is suitable for both novice and experienced failure analysts.

MONDAY, NOVEMBER 2

Tools of the Trade Tour
5:00–6:00 p.m.

This tour gives select ISTFA attendees exclusive access to attend and view product demonstrations from top companies prior to the exhibit hall opening. Reception follows.

Social Event
7:00–9:30 p.m.

Enjoy a fun-filled evening at the Punch Bowl Social including food, drinks, and a variety of games. Every full conference attendee receives a ticket as part of their registration.

TUESDAY, NOVEMBER 3

Plenary Session
9:00–10:30 a.m.

Albert Yu-Min Lin, research scientist/engineer from the California Institute for Telecommunications and Information Technology (Calit2), is doing groundbreaking work—without breaking ground—by using noninvasive computer techniques to explore archaeological sites, including that of Genghis Khan.

Expo Welcome Reception
5:00–6:40 p.m.

Attendees are encouraged to mingle on the exhibit floor with exhibitors while enjoying an assortment of appetizers and beverages.

The Oregon Convention Center is located on the east side of the Willamette River in the Lloyd District neighborhood of Portland. It is home to this year's International Symposium for Testing and Failure Analysis, November 1–5.

WEDNESDAY, NOVEMBER 4

EDFAS General Membership Meeting and Luncheon
12:10–1:30 p.m.

SPECIAL CONTESTS

New! Student Poster Competition—Students will present their latest graduate or undergraduate research at ISTFA.

EDFAS Video Contest—Winners will be showcased with their three-minute films about failure analysis results or interesting artifacts.

EDFAS Photo Contest—The best images in optical microscopy, Ray/UV micrographs, photon emissions, and more will be displayed.

EXHIBITION HOURS

Tuesday, November 3
9:00 a.m.–6:00 p.m.

Wednesday, November 4
9:30 a.m.–3:30 p.m.

EXHIBITOR LIST

Company	Booth
Advanced Circuit Engineers	434
Agilent Technologies	212
Allied High Tech Products	127
Angstrom Scientific	317
Applied Beams LLC	306
Attolight AG	518
Balazs Nanoanalysis – Air Liquide	513
Bruker Corp.	303
Bset EQ	420
Carl Zeiss Microscopy	332 and 333
Checkpoint Technologies	135
Control Laser Corp.	216
DCG Systems	233
Digit Concept	337
E.A. Fischione Instruments	218
Electron Microscopy Sciences	520
Evans Analytical Group	335
Expresslo LLC	521
FEI Co.	133
Flir Systems Inc.	534
Fraunhofer Cam	214
Gatan	101
Hamamatsu Corp.	119
HiLevel Technology Inc.	432
Hitachi – HDI Solutions	107
Hitachi High Technologies	427
IBSS Group	209
IR Labs	113
JEOL USA	327
Jiaco Instruments	527
Keysight Technologies	326
Latticegear LLC	220
Left Coast Instruments/RKD	313

Company	Booth
Leica Microsystems	316
Materials Analysis Technology Inc.	208
Mentor Graphics	227
Micromanipulator	203
Muegge GmbH	529
Nanolab Technologies	433
Nanosurf Inc.	206
Neocera LLC	234
Nippon Scientific Co. Ltd.	535
Nisene Technology Group	318
Nordson Dage	115
Olympus America	532
Oxford Instruments	217
Quantum Focus Instruments	319
Quartz Imaging Corp.	416
RKD Engineering Corp.	313
Robson Technologies	236
Samco Inc.	308
Sela USA Inc.	437
Semicaps	334
Sonoscan Inc.	300
South Bay Technology	435
SPI Supplies	426
Synopsys Inc.	213
Ted Pella Inc.	304
Teraview Ltd.	105
Tescan USA Inc.	312
TMC Ametek	109
Trion Technology	103
Ultra Tec	419
XEI Scientific	428
Yxlon Feinfocus	200
Zurich Instruments AG	207

**Exhibitor list current as of September 2.*

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 II

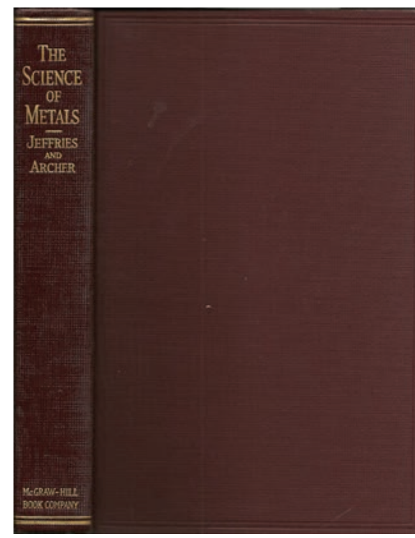
AMONG HIS PEERS, ZAY JEFFRIES WAS CONSIDERED THE ELDER STATESMAN OF AMERICAN METALLURGY.

The first generation of metallurgists to teach the new field of metallography includes Henry Marion Howe of Columbia's School of Mines, Albert Sauveur of Harvard, and C.H. Mathewson of Yale. Their students would go on to advance the knowledge of metallurgy as we know it today. The first of these graduates was Isaiah (Zay) Jeffries, who studied mining engineering at the South Dakota School of Mines. After a brief time working in the mining industry, Jeffries spent his career working in metallurgy. He became the most widely known metallurgist in America during the 1920s for his work on tungsten for lamp bulbs, research into grain size and its influence on mechanical properties, the many aluminum alloys he helped invent, and the behavior of high-speed steel during secondary hardening. He also trained many young metallurgists who worked with him at his laboratories in Cleveland.

Jeffries was born in the Dakota Territory in 1888, one year before it became the state of South Dakota. His parents, Johnson and Florence Jeffries, had moved west from Illinois for ranching and farming opportunities. Zay grew up in Fort Pierre, a small community on the Missouri River. As a teenager he helped on the farm, which consisted mainly of capturing wild horses and breaking them for riding. He attended high school in Pierre, a larger community across the Missouri River, where he discovered an interest in geology, which he hoped to pursue in college.

Jeffries enrolled in 1906 at the new South Dakota School of Mines in Rapid City. However, he found limited educational opportunities in geology and soon transferred to mining engineering. He received some metallurgical and metallographic training from the university's president and professor, Charles Fulton, who had studied under Howe at Columbia University. Jeffries graduated in 1910 in a class of 10 out of a total enrollment of 44 students. After working in the mining industry for one year, Jeffries received an invitation from Fulton, who was then a professor of metallurgy at the Case School of Applied Science in Cleveland, to join him as an instructor of metallurgy and metallography. He immediately accepted the offer and moved to Cleveland in 1911. For the next two years, Jeffries devoted all of his time to teaching and learning the available knowledge in metallurgy and metallography. By 1914, he was prepared for consulting assignments.

Zay Jeffries.



Zay Jeffries and Robert Archer worked together throughout the 1920s to develop aluminum alloys for castings and forgings, and coauthored *The Science of Metals* in 1924.

CONSULTING WORK

Jeffries' first major consulting assignment was with the General Electric Lamp Division, which was transitioning to tungsten filaments for light bulbs. He successfully solved several problems involving microstructure, especially with regard to grain size. This was groundbreaking science before x-ray diffraction showed that grains were crystalline with different orientations in space. Jeffries' most influential work was his research on grains and grain size and their impact on the mechanical properties of metals. Of special interest at the time was what held grains together, that is, what filled the space between grains where different orientations meet.

A theory advanced at the time was that this space was filled with *amorphous metal*—metal without crystal structure. This amorphous metal acted as a cement that held grains together during plastic strain, such as hot and cold working. Elongation of grains during cold working was believed to

Automotive engine pistons, cross-sectional view. Jeffries and Archer developed an aluminum-silicon alloy used in auto engines since the 1920s. Courtesy of Mj-bird, Wikimedia Commons.

Jeffries and Archer developed a forging alloy for propellers used on WWII aircraft, such as the Republic P-47N Thunderbolt shown here. Courtesy of U.S. Air Force.

produce amorphous material—until a few years later when x-ray diffraction showed that no matter how far grains are distorted, they still retain their crystalline structure. As late as 1924, Jeffries could find no solution to grain boundaries other than the amorphous cement theory.

Jeffries took another consulting assignment at the Aluminum Casting Co. The company was having problems with casting defects in parts being exported to countries allied against Germany in WWI. Even though the company was partially owned by Alcoa, they did not have the knowledge to help their customers with technical problems. This work led to Jeffries' expertise in aluminum metallurgy.

In 1917, he ended his teaching career and enrolled in a graduate program at Harvard University under Albert Sauveur. Jeffries spent a year in residency at Cambridge with his family, though it was an unusual time for him to leave his consulting practice with the war going on. He then returned to Cleveland to finish his degree by publishing his work "Grain Structure in Metals."

ALLOY DEVELOPMENT

In 1920, Alcoa acquired the Aluminum Casting Co. laboratory for nonpayment of aluminum purchases, so Jeffries was now a consultant to Alcoa. He was joined by Robert Archer, a recent chemical engineering graduate from the University of Michigan. Jeffries and Archer worked on improved alloys for forging and casting during the 1920s, sharing patents and papers on all their work. During this time, they invented casting alloys using 5% and 7% silicon (355 and 356), an aluminum-copper alloy (195), an aluminum-magnesium alloy (220), and an automotive piston alloy (132) containing 12% silicon. Their new forging alloys included adding 0.75% silicon to Duralumin (14s) and a copper-free alloy containing magnesium and silicon (25s). Alloy 25s would be used to make aircraft propellers during WWII. Jeffries and Archer shared in 10 patents and 13 published papers during this decade, and coauthored the book *The Science of Metals* in 1924.

This assignment, along with his work at General Electric, lasted throughout the 1920s. Jeffries was joined by many new metals researchers who would train under him and make a reputation of their own in later years. One of these associates was Edgar Bain, who worked with Jeffries on problems with high-speed tool steels that failed during the drawing of tungsten wire. They published a research paper on slip interference by alloy carbides for the secondary hardening of these steels. This theory was accepted until it was refined when dislocations were discovered to be the mechanism for plastic deformation.

Jeffries remained at Alcoa until 1936 when he left to assume full-time duties at General Electric. Of all the years he worked at Alcoa, it was just a part-time assignment while he continued to serve as a consultant at General Electric. This dual arrangement provided him with an income well above most engineers of the time. His new full-time career at General Electric included primary responsibility for developing a commercial business in tungsten carbide tools. This was an area of technology that interested Jeffries after Samuel Hoyt showed him that the new tungsten carbide tooling could solve the problem of machining the new high-silicon piston alloy. Tungsten carbide later became a tool material that was ideal for severe machining applications and Jeffries played a large role in promoting this business into a major industry. After WWII, Jeffries was appointed a vice president of General Electric's new chemical division.

AWARDS AND HONORS

Among Jeffries' many awards are ASM's Albert Sauveur Achievement Award in 1935, ASM's first Gold Medal Award in 1943, and the prestigious John Fritz Medal in 1946. He was elected to the National Academies of Science, Engineering Division in 1939, and served as a consultant to Arthur Compton during WWII on the Manhattan Project. For his wartime work, Jeffries was awarded the Medal for Merit, the highest civilian honor by the U.S. government. During his active career, Jeffries played leading roles in several technical organizations, including serving as president of the American Society for Metals in 1929. Among his peers, Jeffries was considered the elder statesman of American metallurgy. After retirement, he served as chairman of the ASM World Congress in 1951 and again in 1956. Jeffries died of cancer in 1965 at age 76.

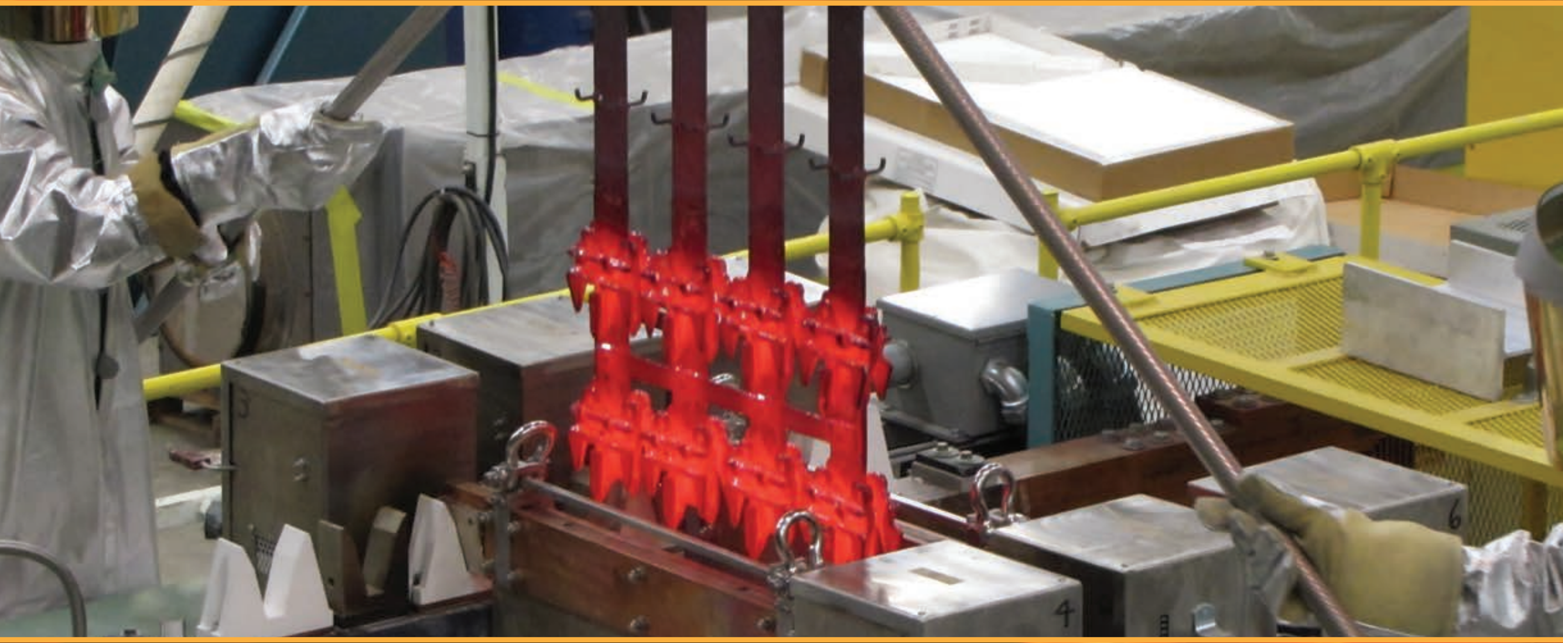
For more information: Charles R. Simcoe can be reached at crsimcoe1@gmail.com.

Heat Treating Society
ASM INTERNATIONAL

OCTOBER 2015 | VOLUME 3 | ISSUE 3

HTPRO

BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL



COMPUTER MODELING OPTIMIZES GEAR PERFORMANCE

ADVANCED DESIGNS EXTEND INDUCTOR LIFETIMES

hts.asminternational.org

HTS
Heat Treating Society
ASM INTERNATIONAL

HTPRO

BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL

EDITORIAL OPPORTUNITIES FOR *HTPro* IN 2015

The editorial focus for *HTPro* in 2015 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

November Atmosphere/Vacuum Heat Treating

To contribute an article to one of the upcoming issues, contact Frances Richards at frances.richards@asminternational.org.

To advertise, contact Erik Klingerman at erik.klingerman@asminternational.org.

DEPARTMENTS

ABOUT THE COVER

Industrial parts are removed from ANL's large-scale ultrafast boriding furnace after treatment. Courtesy Argonne National Laboratory, www.anl.gov.

HTPro is published quarterly by ASM International®, 9639 Kinsman Road, Materials Park, OH 44073, 440.338.5151, asminternational.org. Vol. 3, No. 3.

LETTER FROM THE PRESIDENT

Heat Treat 2015 is right around the corner. With today's rapid advancements in heat treating equipment and process technology, it's extremely important to stay abreast of these developments to ensure that your company maintains the highest level of competitiveness. Thomas Friedman, in his book *The World is Flat*, says that globalization is happening at a lightning pace and that countries, companies, communities, and individuals must adapt to this "flattening" of the globe. Disruptive technologies require an organization that is ready, willing, and capable of supporting them. The Heat Treating Society's premier heat treating conference and exposition provides an opportunity to learn about some of the latest developments in the industry to stay at the leading edge of heat treating-related technology.

The Heat Treating Society (HTS) is the world's largest network of heat treaters with a worldwide membership of commercial and captive heat treaters, equipment manufacturers, leading academic and government researchers, and technical experts from various industries. The collective knowledge of HTS members is invaluable. The Society offers a venue to network with these experts, share insights, and build life-long friendships. HTS members also can serve as mentors to young academicians, engineers, and practitioners, laying the foundation for future generations. There is vast experience that resides with longtime members who will be retiring over the next 10-15 years. This needs to be captured and passed on, lest it be lost to later generations. Participation in the Society affords the opportunity to both share and gain this knowledge.

Consider joining HTS for the educational and networking opportunities and stay for the fun! If you are already a member, or are becoming a new member, get involved, get connected, and get ahead by becoming a HTS volunteer. Remember, volunteerism should be fun! It must be about the people, and it's very rewarding to gain and give knowledge while building relationships. Stop by the Heat Treating Society booth at the show, and see how you can benefit from active membership and participation.

I hope to see you in Detroit!

Stephen G. Kowalski
President, ASM Heat Treating Society

HTS NAMES NEW BOARD MEMBERS FOR 2016

The Heat Treating Society (HTS) board, at the recommendation of the HTS Awards and Nominating Committee, named new officers including **Jim Oakes** to serve as vice president for the 2015–2017 term; **Nathan Chupka, Michael Pershing,** and **Craig Zimmerman,** to serve on the HTS Board for the 2015–2018 term; **Olga Rowan** for the 2015–2016 term (filling the unexpired term of Jim Oakes); **Rachel Sylvester** to serve as student board member for the 2015–2016 term; and **Hannah Noll** to serve as young professional board member for the 2015–2016 term. Terms begin September 1. Continuing on the board are **Timothy De Hennis** (member), **Eric Hutton** (member), **Stephen Mashl, FASM** (member), **Jin Xia** (member), and **Zbigniew Zurecki, FASM** (member). **Roger Jones** becomes past president and **Stephen Kowalski** becomes president on September 1.

Leaving the board are **Thomas Clements** (past president), **William Disler** (member), **Robert Goldstein** (member), **Richard Howell** (member), **Piyamanee Komolwit** (young professional board member), and **Lee Rothleutner** (student board member).

Stephen Kowalski is president of Kowalski Heat Treating Co., Cleveland, assuming the position in 1997 for the second-generation family business. He earned his B.Sc. degree in business administration from Miami University in 1984. Kowalski is a member of the Metal Treating Institute and was a founding member of the ASM Heat Treating Society. He served on the HTS board from 2003–2010, served as chair of the HTS Membership Committee from 2006–2013, and also served as chair of the ASM Membership Committee from 2012–2013. Kowalski has served on many nonprofit boards working to enhance private and public partnerships. He has also worked with local, state, and national employment organizations to develop and implement training programs to enhance worker retention rates. Kowalski published several papers on furnace systems controls, high-pressure gas quenching, and government financing of business development.

Jim Oakes is vice president of business development for Super Systems Inc. (SSi), Cincinnati. Since joining SSi in 2005, Oakes has overseen marketing, helped develop product innovation strategies, and drives SSi's commitment to quality and continuous improvement in the company's heat treating-related products. Prior to joining SSi, he worked at Oracle Corp., Redwood City, Calif., helping organizations leverage technology to become more competitive and improve processes with enterprise software solutions. Oakes serves on the Metal Treating Institute board and is a member of several committees focused on bringing value back to the members. He has been involved with ASM for many years at the local chapter level and contributed to the revised ASM Handbook on heat treating.

Nathan Chupka is manufacturing engineering supervisor for the gear and shaft manufacturing operations at John Deere Waterloo Works. He started at John Deere in 1998 as a materials engineer and became manufacturing engineer in 2001 for the carburizing, carbonitriding, press quenching, and tempering operations, as well as development and implementation of heat treatment processes for drivetrain components. He was involved with the startup of a new automated batch carburizing facility and press quench operations from 2003–2006. In 2005, he became manufacturing engineering supervisor for heat treat operations. Recent activities involve developing heat treatment training programs, supporting equipment installation for new product introductions and capacity expansion, and developing new heat treating technology. Chupka has been a member of ASM since 1995 and a member of the Northeast Iowa Chapter since 1998. He has served as chair and vice chair for the local chapter.

Michael Pershing held positions at Caterpillar in heat treat engineering, casting simulation development, and gear materials before becoming team leader for heat treat R&D in 1998. Pershing worked at Caterpillar's Powder Metal Focus Facility in Rockwood, Tenn., from 2000–2003, then joined the Oak Ridge National Laboratory Materials Processing Group for three years before returning to Caterpillar's Engine Materials Technology group in 2006. He was engineering manager for East Peoria's Heat Treat Engineering for three years, and now is senior heat treat technology steward. Pershing has been involved with the Center for Heat Treating Excellence, WPI, Worcester, Mass., since 2007, was board chairman from 2012–2014, and received the CHTE Distinguished Service Award in 2014. He also held several leadership positions in the Peoria and Oak Ridge ASM Chapters, including Peoria Chapter chair for 2008–2009.

Craig Zimmerman started his career in heat treating in 1994 at FPM Heat Treating, Milwaukee, working as a second shift lab technician. He then joined Lindberg Heat Treating (acquired by Bodycote Thermal Processing), working eight years at Bodycote's Melrose Park, Ill., facility in several positions including chief metallurgist, quality manager, and both business unit and plant manager. He was promoted to Bodycote's regional staff and served as a regional sales manager-central group and director, technology development-the Americas from 2002–2010. Zimmerman joined Bluewater Thermal Solution in 2010, and is currently corporate director-technical, serving as a technical resource for staff and customers, developing and commercializing new technologies, and improving existing company heat treat technologies. He is also an expert in boronizing/boriding technology. Zimmerman is an active member and past chairman of the ASM HTS Research & Development Committee.

Olga (Olly) Rowan is senior engineer in Advanced Materials Technology, Caterpillar Inc. Rowan was a member of the Center for Heat Treating Excellence, WPI, Worcester, Mass., from 2004–2007, working on gas carburizing atmosphere optimization. She joined Caterpillar in 2007 working in heat treat R&D, NPI, gear heat treat production support, and supplier development. Her areas of expertise include gas atmosphere and vacuum heat treat, energy and business case analysis for new capital introduction, and heat treat process control and optimization. She is a member of ASM, active in the Peoria chapter and on the national level. She was a member of the ASM Emerging Professionals Committee for five years and a member of the ASM Education Committee for four years. She also serves as an ASM Materials Camp organizer and mentor in the Central Illinois area. Rowan co-authored two articles in *Steel Heat Treating Fundamentals and Processes*, Vol 4A, *ASM Handbook*, and has published 18 peer-review journal articles and conference publications and 16 internal technical reports.

Hannah Noll earned her B.Sc. in metallurgical engineering from Missouri University of Science and Technology in 2010, and is pursuing an M.S. in materials science and engineering at North Carolina State University. After graduating from Missouri S&T, she joined ATI Specialty Materials as product engineer, and is currently process engineer at ATI Specialty Materials Richburg Operations responsible for Ni/Ti/Fe-base alloy heat treatment, continuous bar rolling, and coil processing. She is responsible for qualifying equipment and process improvements for materials used primarily in the aerospace, biomedical, and oil & gas industries. Noll has been a member of the executive board of the ASM Carolinas Southern Piedmont Chapter since 2012 and is currently chapter chair. She is a contributing member of engineergirl.org, directed the first Union County JobReady Partnership "Women in Engineering" summer camp for middle school girls in 2014, and will direct the camp in 2015.

Rachel Sylvester is currently a senior at The Ohio State University in the materials science & engineering program, and serves as lead teaching assistant for the first year engineering program. She completed an internship with Cessna Aircraft in metallurgical failure analysis, and is currently interning with Ford Motor Co. in the same capacity. Sylvester attended ASM Materials Camp in 2011 and has been an ASM member since then, currently serving as vice president for the Ohio State Chapter of Materials Advantage. She served as a junior member twice, and traveled to a Materials Camp in Clermont-Ferrand, France. Sylvester is a recipient of the George A. Roberts Scholarship.

ROWAN RECEIVES 2015 ASM HTS/SURFACE COMBUSTION EMERGING LEADER AWARD

Established in 2013, the ASM HTS/Surface Combustion Emerging Leader award recognizes an outstanding early-to-midcareer heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. The award acknowledges an individual who sets the highest standards for ASM Heat Treating Society participation and inspires others to dedicate themselves to the advancement and promotion of vacuum and atmosphere heat treating technologies such as carburizing, carbonitriding, nitriding, annealing, and through hardening. The award will be presented at the HTS General Membership Meeting on Wednesday, October 21, at the ASM Heat Treating Society Conference and Exposition in Detroit.

Olga (Olly) Rowan, senior engineer in Advanced Materials Technology, Caterpillar Inc., is recognized "for a strong combination of extensive carburizing expertise, passion for advancing the science of heat treatment, and recognized leadership."

HTS MEMBERS IN ASM'S 2015 CLASS OF FELLOWS

In 1969, ASM established the Fellow of the Society honor to provide recognition to members for their distinguished contributions to materials science and engineering and to develop a broad-based forum of technical and professional leaders to serve as advisors to the Society. Awards will be presented at ASM's annual Awards Dinner, Tuesday, October 6, in Columbus, Ohio, during Materials Science & Technology 2015.

Dr. Joseph W. Newkirk, FASM, associate professor, Missouri University of Science and Technology, Rolla, is recognized "for outstanding contributions in teaching, mentoring, professional service, and entrepreneurial research in alloy property development, particulate composites, powder metallurgy materials, and property assessment of powder metallurgy and metal injection molded parts."

Prof. Yongho Sohn, FASM, professor, University of Central Florida, Orlando, is recognized "for significant contributions to teaching and research in the fundamental understanding of multi-component diffusion kinetics, analysis and control of microstructures, phase transformations, and the application of advanced materials characterization techniques."

Prof. Chester J. Van Tyne, FASM, FIERF professor, Colorado School of Mines, Golden, is recognized "for significant contributions to understanding the effects of processing and microstructure on the plastic deformation behavior of steels and nickel-base alloys in metal-forming manufacturing processes."

Mr. Zbigniew Zurecki, FASM, senior research associate, Air Products & Chemicals Inc., is recognized "for conceptualization and sustained development of cleaner, safer, and environmentally friendlier alternatives to many conventional methods of processing metals resulting in improved product quality and increased productivity of industrial operations."

HTS MEMBERS RECEIVE ASM 2015 AWARDS

The awards program recognizes achievements of members of the materials science and engineering community. Awards will be presented at ASM's annual Awards Dinner, October 6, in Columbus, Ohio, during MS&T15.

DISTINGUISHED LIFE MEMBERSHIP AWARD

Distinguished Life Membership was established in 1954 and is conferred on leaders who have devoted their time, knowledge, and abilities to the advancement of the materials industries.

Mr. Richard L. Wilkey, president, Fisher-Barton Group, Waukesha, Wis., will receive this year's award "for the entrepreneurial drive in business creation and growth and persistent and aggressive advancement in materials science and engineering and the people and industries who use them."

WILLIAM HUNT EISENMAN AWARD

The William Hunt Eisenman Award was established in 1960, in memory of a founding member of ASM, and its first and only secretary for 40 years. It recognizes unusual achievements in industry in the practical application of materials science and engineering through production or engineering use.

Dr. Frederick E. Schmidt, FASM, senior managing consultant and director, materals technology, Engineering Systems Inc., Aurora, Ill., will receive this year's award "for pioneering industrial developments in electronics, polymer, and chemical processing, wear and corrosion problems, and especially the reduction of scrap in small caliber ammunition production."

BEST PAPER IN HEAT TREATING CONTEST

The ASM HTS/Bodycote award was established by HTS in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advancement in managing the business of heat treating. The award is endowed by Bodycote Thermal Process-North America.

The contest is open to all students, in full-time or part-time education, at universities (or their equivalent) or colleges. It is also open to those students who have graduated within the past three years and whose paper describes work completed while an undergraduate or post-graduate student. The winner receives a plaque and check for $2500.

To view rules for eligibility and paper submission, visit the Heat Treating Society website at hts.asminternational.org/portal/site/hts/HTS_Awards.

Paper submission deadline is December 11. Submissions should be sent to Joanne Miller, ASM Heat Treating Society, 9639 Kinsman Rd., Materials Park, OH 44073, 440.338.5151 ext. 5513, joanne.miller@asminternational.org.

HEAT TREATING ADDITIVELY MANUFACTURED ALLOYS

Applications in additive manufacturing (AM), also known as 3D printing, are growing, especially in the biomedical industry where individually customized parts such as hip joints, knee replacements, and dental applications are in high demand. The Center for Heat Treating Excellence (CHTE) at Worcester Polytechnic Institute (WPI), Mass., is studying the best way to heat treat these parts for optimum performance.

"Because these components become a part of our bodies, we need to determine how to post-process them to remove defects that can initiate fatigue fractures, resulting in a deterioration in the mechanical properties of the material," says Richard Sisson, WPI professor of mechanical engineering and technical director of CHTE.

Titanium and titanium alloys, cobalt alloys, and stainless steels are the four main types of metallic biomaterials. Titanium alloys are preferred in dental and orthopedic implants due to their good mechanical properties, biocompatibility, lack of allergic reaction, and excellent corrosion resistance.

WPI graduate student Yangzi Xu, under the direction of Sisson, is investigating the effects of heat treatment on the microstructure, mechanical properties, and corrosion behavior of additively manufactured Ti-6Al-4V titanium alloy parts fabricated using the direct metal laser sintering (DMLS) process. DMLS uses a laser as the power source to sinter successive layers of metal powder based on a computer-aided design. The technique binds the material together to create a solid structure. Three post heat treatments being investigated include solution treatment and aging, stress relieving, and annealing.

Evaluation of parts includes measuring microindentation hardness, determining microstructure and phase evolution using scanning electron microscopy and x-ray diffraction, and electrochemically measuring corrosion behavior in simulated body fluid at a temperature of 37°C (98.6°F). Research results of the study are expected in 2016.

Surrounded by a traditionally cast metal part, Diran Apelian, director of WPI's Metal Processing Institute, holds an intricate metal object fabricated layer by layer using additive manufacturing.

Other AM-related research is also underway in the areas of modeling, surface finishing, and new AM materials.

Sisson is developing databases and computational models to understand and predict the properties and performance of materials created using cold spray, a related AM process. The multiyear research program is funded by the U.S. Army Research Laboratory (ARL). ARL uses cold spray to repair magnesium gearboxes in helicopters and would like to use AM to produce entire replacement parts for its vehicles.

Associate professor of mechanical engineering Jianyu Liang and her research team are exploring electrochemical finishing techniques that can reduce the vulnerability of AM parts to fatigue and cracking.

Diran Apelian, director of WPI's Metal Processing Institute, is collaborating with researchers at Lawrence Livermore National Laboratory in California (a CHTE member) to explore thixotropic metals that remain semisolid across a range of temperatures. By manipulating both temperature and shear, researchers hope to achieve the kind of precision required to additively manufacture complex metal components.

To learn more about AM research at WPI, visit http://wpiresearch.epubxp.com/i/502587-spr-2015.

ABOUT CHTE

The CHTE collaborative is an alliance between the industrial sector and university researchers to address short-term and long-term needs of the heat-treating industry. Membership in CHTE is unique because members have a voice in selecting quality research projects that help them solve today's business challenges.

Research projects are member driven. Each research project has a focus group comprising members who provide an industrial perspective. Members submit and vote on proposed ideas, and three to four projects are funded yearly. Companies also have the option of funding a sole-sponsored project. In addition, members own royalty-free intellectual property rights to precompetitive research and are trained on all research technology and software updates.

CHTE projects now in progress include:

- Nondestructive Testing for Hardness and Carburization
- Improving Furnace Alloys and Fixtures
- Gas Quench Steel Hardenability
- Induction Tempering

CHTE is located in Worcester, Mass., on WPI's New England campus. The university was founded 150 years ago this year. For more information about CHTE, its research projects, and member services, visit wpi.edu/+chte, call 508.831.5592, or email Rick Sisson at sisson@wpi.edu, or Diran Apelian at dapelian@wpi.edu.


WIN THE HOT iPAD AIR AT THE COOLEST BOOTH AT THE SHOW
Bring This Ad and Your Best PIA (Pain In The @%$) Job! to our booth at
HEAT TREAT 2015
Oct. 20 - 22
BOOTH 732
Cobo Convention Center!
N_2
Introducing:
N_2CLEAN
CONTROLLED ATMOSPHERE PROCESSING
KHT's newest addition in close tolerance *socially responsible* PIA flatwork processing.
Meeting the demand for cleaner finished products, K-Flat with N_2Clean offers over 50 million lbs./year of new controlled atmosphere processing capacity, ideal for your close tolerance high volume automotive, power transmission, saw blades, brake discs, flat bearings and other.
To learn more, give us a call at 216-631-4411, or better yet, just send us your stuff!
KOWALSKI
HEAT TREATING COMPANY
KHTheat.com

REDUCING GEAR SIZE FOR COMPACT TRANSMISSION DESIGN USING COMPUTER MODELING

Modeling shows that achieving required gear performance in a reduced gear size is possible by changing the steel grade and heat treatment parameters during the design stage.

Zhichao (Charlie) Li,* B. Lynn Ferguson,* FASM, and Andrew Freborg,* DANTE Solutions Inc., Cleveland

Gears are the most important components in transmission and actuator designs. In many cases, transmission or actuator design must be reduced to achieve weight or dimensional advantages without decreasing power density. One solution is to reduce gear size while keeping the same output torque capacity. In general, gears used in heavy load conditions are made of steel, and gear tooth residual surface stresses are critical to fatigue performance. Compressive residual stresses in the critical region of a gear improve its fatigue performance. However, many steel gears are not processed to obtain residual surface compression, or the benefit of residual compression is not considered in the gear and transmission design.

Steel gears are heat treated to increase hardness and strength for improved performance. Heat treatment introduces compressive residual stresses in the gear surface, which increases high-cycle fatigue performance[1–2]. Carburization and quench hardening generates compressive residual stresses in the gear surface due to delayed martensite transformation with volume expansion. These stresses reduce the magnitude of actual stresses generated in the critical location of gears under service load. Computer modeling is used to both troubleshoot and design heat treatment processes for steel parts[3–9]. In this article, virtual computer models using DANTE software are applied to help achieve gear size reduction by including steel grade hardenability and heat treatment in the design process.

GEAR GEOMETRY

A CAD model of an AISI 4340 alloy steel spur gear with 16 straight teeth selected for this study is shown in Fig. 1. Gear dimensions are 56 mm OD, 25 mm ID, 44 mm root diameter, and 50 mm thick. Quench hardening in oil is used to meet specified hardness and strength requirements.

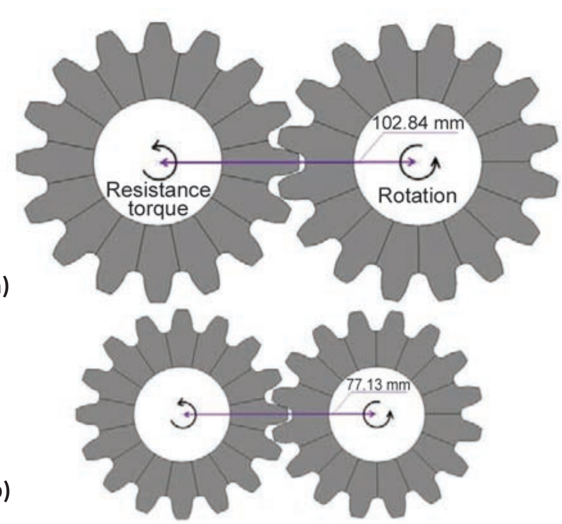
The main concern for this gear is a failure at the gear root fillet during a high cycle bending fatigue test. Previous studies show that tangential stress at the root fillet under fatigue load is the main driver of fatigue crack initiation and propagation. Only one gear mid-plane cross section in the axial direction is used in this study.

High cycle bending fatigue performance is used as the main criterion to evaluate gear strength. To simplify the study, it is assumed that the driver and driven gears are the same size, and input and output torque (resistance) are the same. Figure 2a shows the setup of the gear pair under bending due to rotational torque load for the original gear size design, with a centerline distance of 103 mm. The driven gear is on the left, with a 3287 N·m resistance torque load applied in the direction as shown. A rotational displacement is applied to the gear on the right. Input torque is also 3287 N·m.

DANTE was used to model the oil quench process for the original 4340 steel gear and the magnitude of predicted

Fig. 1 — CAD model and dimensions of original gear.

(a)



(b)

Fig. 2 — Dynamic rotational bending model: (a) original gear size, and (b) scaled reduced gear size.

*Member of ASM International and ASM Heat Treating Society residual stresses is negligible. It is assumed that residual stress from heat treatment of the original size gear is zero. To reduce gear size, a combination of carburization and oil quench is proposed to introduce compressive residual stresses to the gear surface for improved bending fatigue performance. AISI 8620 alloy carburizing grade was selected as the gear material, with a 25% reduction in the *x-y* plane while keeping the same axial dimension (Fig. 2b). Gear dimensions are 42 mm OD, 19 mm ID, 33 mm root diameter, and 50 mm thick. The volume or mass of the smaller gear is 56% that of the original gear, with the centerline distance between the gear pair reduced proportionally to 77 mm.

MODELING HEAT TREATMENT

The smaller gear is gas carburized, followed by oil quenching and low temperature tempering. The entire gear surface is carburized using process conditions of 925°C for 8 hours, with a carbon potential of 0.8%.

Figure 3a shows the predicted carbon-distribution (wt% C) contour. Predicted effective case depth (ECD) is 0.75 mm, assuming 0.4 wt% carbon as the threshold of ECD definition. After carburization, the gear is cooled to 875°C in the furnace, followed by oil quenching and tempering. Predicted martensite distribution is shown in Fig. 3b. The gear tooth is mainly martensite, the core about 20% martensite, and the remaining structure bainite. About 10% retained austenite is predicted on the carburized surface of the as-quenched gear prior to tempering.

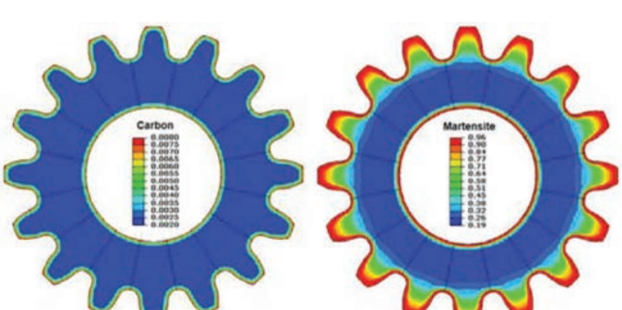
Compressive residual stresses are generated in the gear surface after quenching. Predicted minimum principal stress is shown in Fig. 4a. Both bore and tooth surfaces are under compression due to the delayed martensitic transformation in the high carbon case. The root fillet has higher compressive stress compared with that at the tooth flank region, which is due to the stress concentration of the geometry effect during quenching.

The directions of minimum principal stresses vary at different locations of the gear. Minimum principal residual stress at the root fillet is in the tangential direction after quench hardening. Tangential stress also directly relates to fatigue crack initiation and propagation at the root fillet. A local cylindrical coordinate system is defined to plot the tangential stresses in the gear root fillet (Fig. 4b). The center of the cylindrical coordinate system matches the center of the gear fillet. The highest residual compression at the fillet is about 700 MPa, close to the center of the root. Using the local coordinate system, the stress contour close to the root fillet represents tangential stress, but stresses in this direction are meaningless for locations far away from the fillet.

MODELING GEAR STRESSES UNDER LOAD

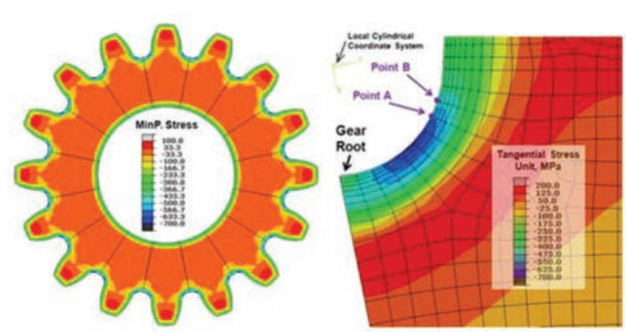
Using the rotational bending setup shown in Fig. 2, stress evolution under a constant torque load of 3287 Nm is modeled using a linear elastic model. The highest tensile stress occurs at the root fillet during gear rotation. Without considering residual stresses from the heat treatment, snapshots with the highest stress magnitude are shown in Figs. 5a and 5b for both gear pair sizes. Reducing the gear size by 25% in the *x-y* plane generates 1075 MPa tensile stress at the root fillet compared with 600 MPa for the original size gear.

Compressive residual stresses introduced by heat treating significantly benefits the gear's high-cycle bending fatigue strength. In this study, residual stresses from the hardening process shown in Fig. 4 are imported to the torsion load model. Under the same constant torque load of 3287 Nm, predicted maximum principal stress contour is shown in Fig. 6. To more clearly show the effect of residual stresses, the values are imported to the left (driven) gear only. The highest stress generated at the surface of the root fillet is slightly below 600 MPa, significantly lower than the value of 1075 MPa without considering residual stresses. From the contour plots shown in Fig. 6b, the highest stress is under the surface. The location under the surface could have a lower probability of crack initiation than that at the surface, even with higher tensile stress.



(a) (b)

Fig. 3 — Predicted distributions of (a) carbon, and (b) martensite after hardening.



(a) (b)

Fig. 4 — Distribution of residual stresses after carburization and oil quench: (a) minimum principal stress (MPa), and (b) tangential stress along the root fillet of gear using defined local cylindrical coordinate system.

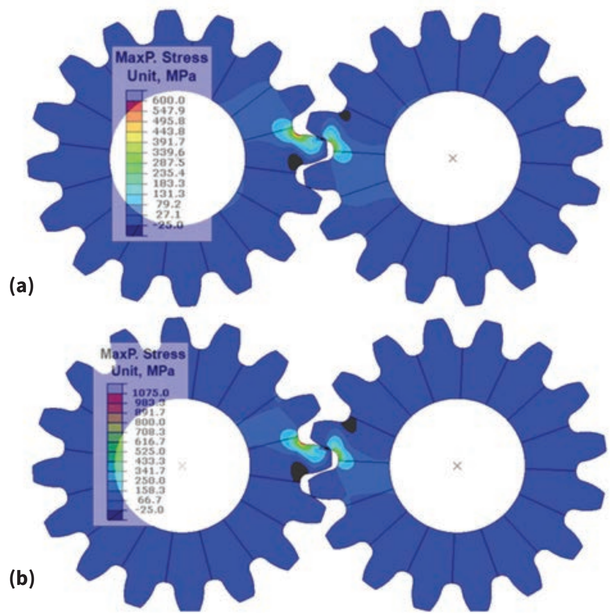


Fig. 5 — (a) Maximum principal stress generated in root fillet of gear under torsion load for (a) original size gear, and (b) reduced size gear.

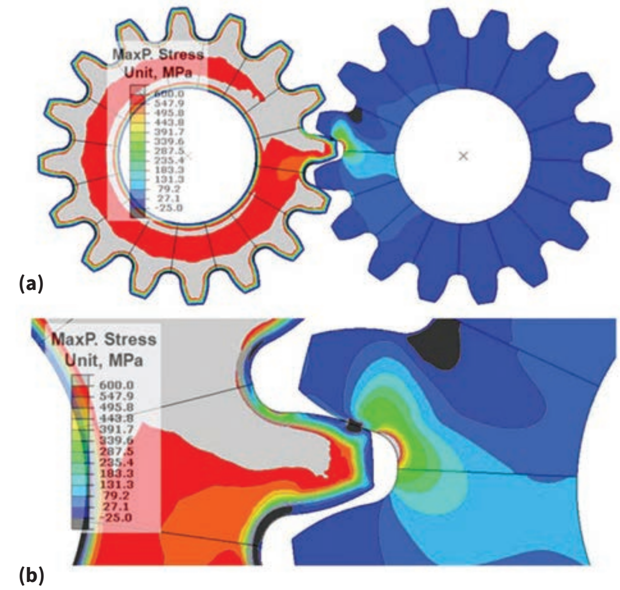


Fig. 6 — (a) Maximum principal stress generated in root fillet of gear under rotation bending load of reduced size gear (with heat treatment residual stresses in the left gear), and (b) zoomed-in contour of contact teeth.

DISCUSSION

Carburizing and oil quenching the 8620 steel gear introduces compressive residual stresses in the gear surface, which significantly reduces the magnitude of actual stresses at the root fillet under torsional load. Using the local cylindrical coordinate system described in Fig. 4b, predicted actual stresses in the tangential direction of the root fillet under the same torsional load of 3287 N·m are compared for the following three cases:

Case 1: Original gear size (4340 steel) without residual stresses from heat treatment

Case 2: Reduced gear size (8620 steel) with residual stresses from carburization and oil quench

Case 3: Reduced gear size (4340 steel) without residual stresses from heat treatment

For Case 1, the highest stress at the root fillet is about 625 MPa, located at point A (Fig. 7a). For Case 2, the highest stress is reduced to 600 MPa, and is located at point B, as shown in Fig. 7b, moving slightly from the root toward the gear tip, which is due to the nonuniform compressive residual stress at the root fillet. The combination of residual stresses and the applied stresses is shown in Fig. 7b. Based on the logic described above, the benefit of compressive residual stresses to fatigue performance is further improved by optimizing gear geometry and heat treatment, so the highest applied tensile stress location matches the highest compressive residual stress location after heat treatment.

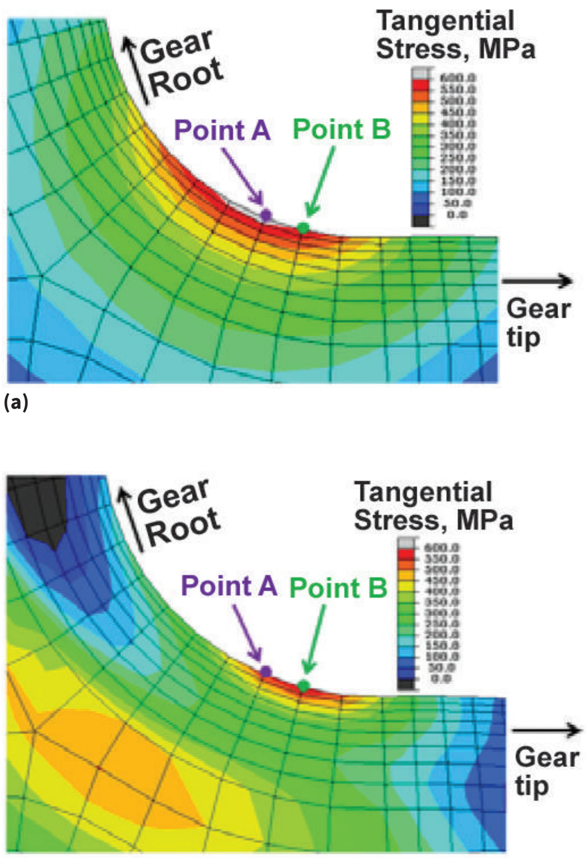
During rotational bending, the history plot of tangential stresses at the most critical positions (points A and B in Fig. 7) of the root fillet are compared in Fig. 8 for the three cases. Either point A or B is used depending on which location has the highest actual stress under load. Peak stress is considered the main driver of bending fatigue failure. The comparison shows the significant effect of compressive surface residual stresses on bending fatigue performance.

CONCLUSIONS

The selection of gear material and heat treatment process is critical to bending fatigue performance. Carburizing and oil quenching gears made of a carburizing steel grade generates compressive residual stresses in the surface of the hardened case. These stresses benefit the high cycle bending fatigue performance of gears. The concept is validated by both modeling and previous experiments. In this study, the concept is further applied to reduce gear size without reducing its torque load capacity. A mass or volume reduction of 44% is compensated for by taking advantage of the compressive residual stresses generated by heat treatment. Material selection is also critical; clean material is preferred to reduce potential crack initiation sites under the hardened case, where residual tension exists to balance surface compression.

References

1. A. Banka, et al., Applying CFD to Characterize Gear Response during Intensive Quenching Process, *Proc. 24th HTS Conf. & Expo*, p 147–155, 2007.
2. D. Lohe, et al., Residual Stresses and Fatigue Behavior, *Handbook of Residual Stress and Deformation of Steel*, ASM International, p 27–53, 2002.



(b)

Fig. 7 — Tangential stresses along root fillet under torsional load of 3287 Nm. (a) Case 1—original gear size without heat treatment residual stresses, and (b) Case 2—reduced gear size with heat treatment residual stresses.

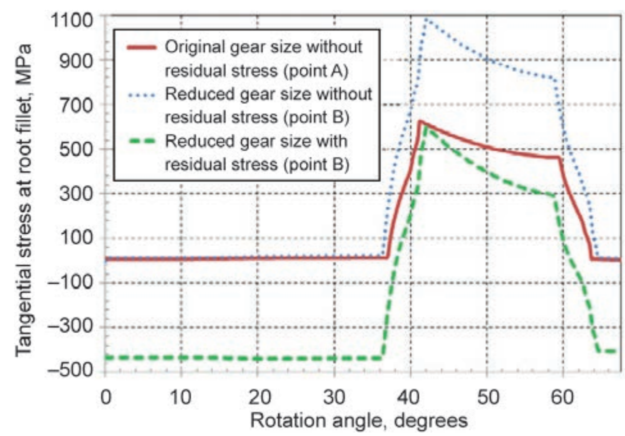


Fig. 8 — Comparison of tangential stresses at root fillet during rotation under torque load.

3. B. Ferguson and W. Dowling, Predictive Model and Methodology for Heat Treatment Distortion, NCMS Report #0383RE97, 1997.
4. T. Inoue and K. Arimoto, Development and Implementation of CAE System "HEARTS" for Heat Treatment Simulation Based on Metallo-Thermo Mechanics, *J. Mater. Eng. Perform.*, Vol 6, p 51–60, 1997.
5. P. Carlone and G.S. Palazzo, Development and Validation of a Thermo-Mechanical Finite Element Model of the Steel Quenching Process Including Solid-Solid Phase Changes, *Int. Appl. Mech.*, Vol 46, p 955–971, 2011.
6. M. Lusk, et al., On the Role of Kinematics in Constructing Predictive Models of Austenite Decomposition, *Proc. of TMS*, p 311–331, 2003.
7. D. Bammann, et al., Development of a Carburizing and Quenching Simulation Tool: A Material Model for Carburizing Steels Undergoing Phase Transformations, *Proc. 2nd Intl. Conf. on Quenching and Control of Distortion*, p 367–375, 1996.
8. V. Warke, et al., FEA Model for Predicting the Response of Powder Metallurgy Steel Components to Heat Treatment, *Mater. Sci. Eng. A*, Vol 518(1–2), p 7–15, 2009.
9. Z. Li, et al., Data Needs for Modeling Heat Treatment of Steel Parts, *Proc. Matls. Sci. & Tech. Conf.*, p 219–226, 2004.

For more information: Zhichao (Charlie) Li, DANTE Solutions Inc., 7261 Engle Rd., Suite 105, Cleveland, OH 44130, charlie.li@dante-solutions.com, www.dante-solutions.com.

SINCE 1865

HOUGHTON™

Pioneering the Commitment
to Customer Success

KEYS TO LONG-LASTING HARDENING INDUCTORS: EXPERIENCE, MATERIALS, AND PRECISION

Valery Rudnev,* FASM, Aaron Goodwin, Steven Fillip,* William West, Jim Schwab, and Steve St. Pierre, Inductoheat Inc.

Induction coils are considered the weakest link in an induction hardening system, so advanced designs and precise fabrication are paramount to ensure long life while producing high quality treated parts.

The terms hardening inductor, inductor, induction coil, and coil are all used interchangeably to describe the electrical component that provides the induction heating effect in an induction heating system. A hardening inductor is often simply called a coil, but its geometry does not always resemble the classic circular coil shape. Figure 1 shows a sample of numerous coil designs. A particular coil configuration depends on several factors such as workpiece geometry, temperature uniformity and required heat pattern, and production rate, among others. Alternating current flowing in the inductor generates a time-varying magnetic field that provides an electromagnetic link between the inductor and workpiece, resulting in contactless heating of either the entire workpiece, or selected areas.

Coils are considered the weakest link in an induction hardening system because they carry significant electrical power and operate in harsh environments exposed to high temperatures, water, and other coolants, while being subjected to mechanical movement and accidental part contact. Advanced coil designs and precise fabrication can ensure long life while producing high quality treated parts.

MATERIAL SELECTION

Copper and copper alloys are almost exclusively used to fabricate induction coils due to their reasonable cost, availability, and a unique combination of electrical, thermal, and mechanical properties. Proper selection of copper grade and purity for a coil is crucial to minimize the deleterious effects of factors that contribute to premature coil failure including stress-corrosion and stress-fatigue cracking, galvanic corrosion, copper erosion, pitting, water leaks, overheating, and work hardening. Cooling water pH also affects copper susceptibility to cracking.

Oxygen-free high-conductivity (OFHC) copper should be specified for most hardening inductors despite its higher cost. Besides superior electrical and thermal properties, OFHC copper dramatically reduces the risk of hydrogen embrittlement. The higher ductility of OFHC copper is also important, because coil turns are subjected to flexing and high electromagnetic forces. The higher cost of OFHC copper usually is offset by improved hardening inductor life.

FABRICATION TECHNIQUES

Two traditional techniques used to fabricate hardening inductors are banding and brazing of square, rectangular, and round copper tubing. The ability to precisely and repeatably fabricate banded or brazed inductors of complex geometry has always been a legitimate concern, which requires an extensive and costly validation process after installing a new set of inductors.

Silver-base braze material is used to fill joint gaps in brazed copper tubing. The fact that electrical and thermal properties of pure silver are superior to those of copper has led some coil builders and practitioners to assume that the filler metal provides electrical contact between brazed components as good as with solid copper, which is not the case.

Porosity and the presence of oxides and other elements increase the electrical resistance of the brazed joint area compared with that of solid copper. As a result, excessive heat is generated in the copper joint area, unless the joint is located in a portion of the coil that does not carry electrical current. Excessive heat generation causes deterioration of brazed joints, shortening coil life.

A complex geometry inductor that contains numerous brazed joints, and 90° joints in particular, could experience impeded water flow in cooling coil turns, a problem more likely to occur in a coil fabricated with small-diameter tubing. This situation could require the use of booster pumps to provide sufficient water flow to cool the coil. However, this can be counterproductive as excessive water pressure adds to the electromagnetic forces and thermal stresses experienced by the copper coil, which could further weaken brazed joints, leading to cracking and water leaks. Also, brazed joints and the copper itself can weaken due to work hardening during coil service, becoming brittle and developing fatigue cracks. Eliminating or significantly reducing the number of brazed joints, particularly in current-carrying areas, is a key factor in fabricating long-lasting inductors.

CNC MACHINING AND QUALITY ASSURANCE

At Inductoheat, most high power-density hardening inductors are CNC machined from a solid copper bar regardless of complexity. This repeatable machining process produces rigid, durable inductors. CAD/CAM/CNC software programs are created that provide appropriate cutter-to-copper

*Member of ASM International and ASM Heat Treating Society

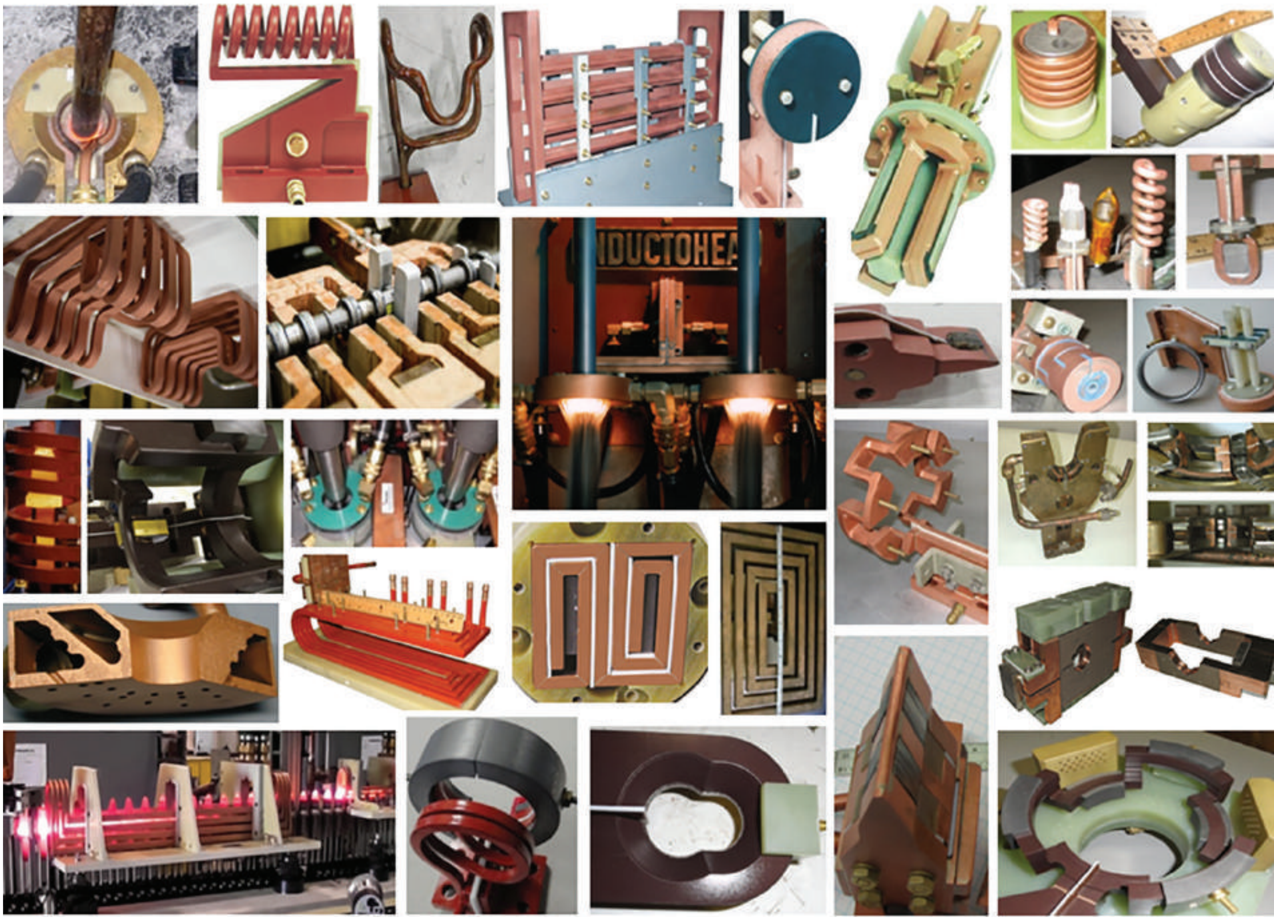


Fig. 1 — Array of different induction coil designs.

spatial relationships, which produce inductors of the required shape and precision. Figure 2 shows a variety of finished and semifinished CNC-machined hardening inductors. In the past, most of these inductors were fabricated by brazing and banding coils. CNC machining is a superior method to achieve accurate, robust inductors for use in automotive, aerospace, defense and other industries where high process repeatability is critical.

Brazing is completely eliminated with some CNC-machined inductors, such as those used in Inductoheat's nonrotational SHarP-C processes for hardening crankshafts and camshafts. Brazing is minimized in other applications, used only to encapsulate water-cooling channels.

Some inductors, especially those used in selective hardening, have very complex geometries. A computerized 3D metrology laser scanner is used to verify coil dimensional accuracy and alignment precision within about 25 microns (0.001 in.) after fabrication and assembly (Fig. 3).

CONVENTIONAL INDUCTORS

Steel shafts and shaft-like components are among parts that traditionally are induction hardened using scanning or single-shot heat treating. With the single-shot method, neither the shaft nor coil move relative to each other; the part typically rotates instead. The entire region to be hardened is heated at the same time.

A single-shot inductor consists of two legs and two crossover segments, also known as bridges or horseshoe half-loops (Fig. 4). Crossover segments encircle only half of the workpiece circumference, and induced eddy currents primarily flow along the length of the part. An exception is crossover segments where the flow of eddy current is half circumferential. Longitudinal leg sections are profiled by relieving selected regions of the copper to accommodate workpiece geometrical features, such as changes in diameter or irregularities. Section(s) of a single-shot inductor with narrower heating surfaces facing the shaft increase induced power density in desirable regions(s).

For a workpiece containing fillets, it is often necessary to increase heat intensity in the fillet region to heat the greater volume of metal. Also, the larger metal mass in the proximity of the heated fillet and behind the region to be hardened produces a substantial "cold sink" effect. This draws heat from the fillet due to thermal conduction, which must be compensated for by inducing additional heating energy in

Fig. 2 — Variety of finished and semifinished CNC-machined hardening induction coils.

the fillet area. The required energy surplus can be achieved by narrowing the current carrying face of the appropriate section of the single-shot inductor. For example, if the current carrying portion of the inductor heating face is reduced by 50%, there is a corresponding increase in current density, as well as the eddy current density induced within the respective shaft region. According to the Joule effect, doubling the induced eddy current density increases induced power density by a factor of four. Also, attaching a magnetic flux concentrator to certain areas of the hardening inductor (Fig. 4) further enhances localized heat intensity.

The effects of intensifying heat generation in selected areas of the shaft (i.e., excessive current densities in inductor sections combined with intense heat radiation from the workpiece surface) can cause localized copper overheating. This promotes water vaporization and the formation of a steam vapor barrier, which essentially functions as a thermal insulator inside the water-cooling pocket. Thus, copper cooling is severely restricted even when it appears that there is sufficient water-cooling flow and regardless of the use of high-performance pumps. To help prevent overheating, water-cooling pockets are placed as close as possible to the current carrying face of an inductor. However, coil overheating can still occur and cause accelerated deterioration of the copper surface, which speeds up the onset of inductor copper cracking (due to stress fatigue and stress corrosion, for example) and eventual premature coil failure. As a result, coil life is often shortened to 22,000-24,000 heat cycles (industry average). Therefore, the number of instances where coil current density is increased should be kept to a minimum.

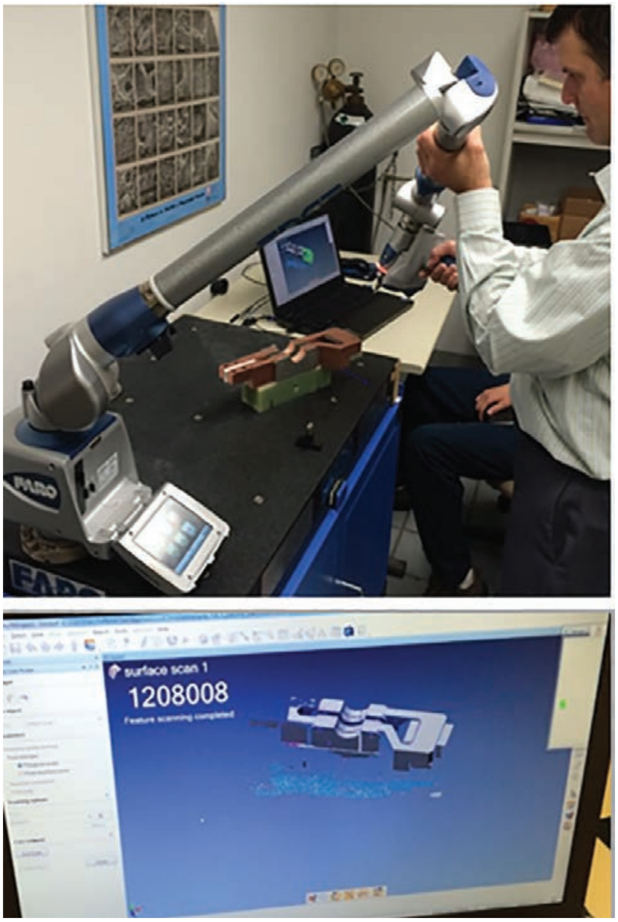


Fig. 3 — A computerized 3D metrology laser scanner is used to evaluate fabricated coils to ensure geometrical accuracy and alignment, storing measurement data for inductor certification.

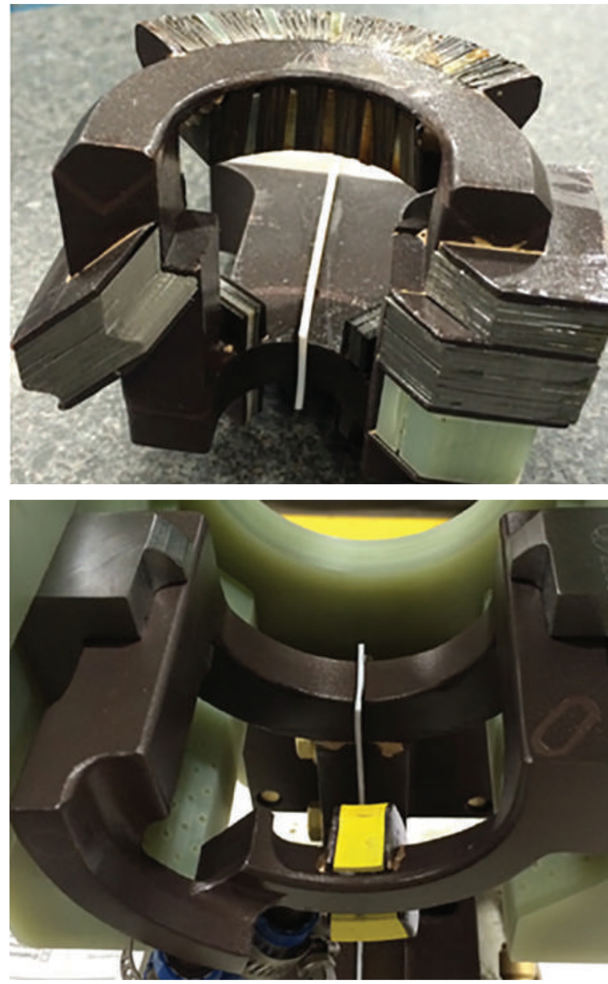


Fig. 4 — A magnetic flux concentrator is attached to certain areas of the hardening inductor coil to enhance localized heat intensity.

Conventionally fabricated single-shot inductors exhibit high process sensitivity, which has a negative effect on the repeatability of part heating and the quality of hardened components. High sensitivity is associated with an electromagnetic proximity effect. A change in positioning of the shaft inside the single-shot inductor due to bearing wear, incorrect part loading in the inductor, and other factors produces an immediate variation of heating intensity, particularly within the fillet region. This results in a local heat deficit and therefore reduced hardness depth.

INDUCTOR BREAKTHROUGH

Inductoheat recently developed a new inductor design (patent pending) that dramatically reduces localized coil current density in areas prone to overheating and cracking (Fig.5). The presence of a two-collar section reduces coil current by one half, which dramatically reduces localized heat generation in the copper and significantly extends coil life.

In addition, for a shaft positioned asymmetrically within the inductor, there is a reduced heating effect produced in one of the two half-collar sections that has an increased inductor-to-shaft gap. This is offset by an increased induced heating effect produced in the other half-collar section that has a reduced inductor-to-shaft gap. Consequently, process sensitivity associated with positioning the shaft within the inductor is reduced over that with a conventionally designed single-shot inductor.

Fig. 5 — Novel inductor design (patent pending) dramatically extends coil life in single-shot hardening of complex shaft-like components.

In one application of the new inductor, one of the world's largest suppliers of automotive parts achieved a nine-fold increase in a single-shot coil life compared with that for conventional inductors. This is verified by the manufacturer's tool-room tag showing that the inductor (which the customer named "magic coil") was still considered in good shape after 225,000 heat cycles (Fig. 6). Other benefits include measurable improvement in process robustness, coil reliability, and maintainability.

Portions of this article are adapted from the chapter "Systematic Analysis of Induction Coil Failures and Prevention" in *Induction Heating and Heat Treating*, Vol 4C, *ASM Handbook*, V. Rudnev and G. Totten (Editors), ASM International, 2014.

Coil design details and benefits will be presented in a paper at Heat Treat 2015, taking place October 20-22 at Cobo Convention Center in Detroit.

For more information: Valery Rudnev, FASM, is director, science and technology, Inductoheat Inc., an Inductotherm Group Co., 32251 N. Avis Dr., Madison Heights, MI 48071, 248.629.5055, rudnev@inductoheat.com; www.inductoheat.com.

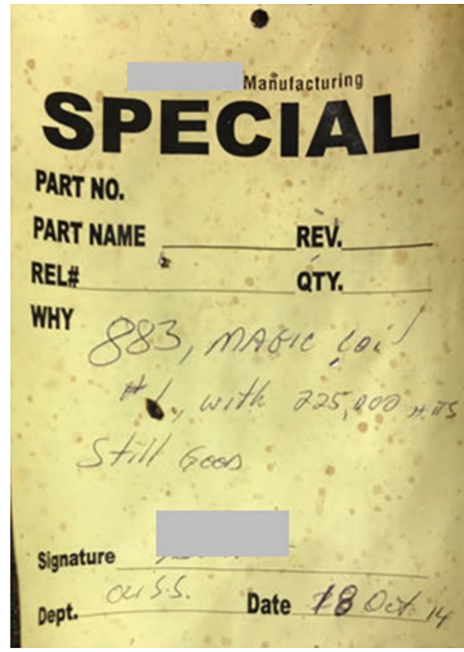


Fig. 6 — Automotive component manufacturer's tool-room tag indicates that Inductoheat's newly designed inductor is still considered in good shape after 225,000 heat cycles, a nine-fold increase in single-shot coil life compared with that for conventionally designed inductors.

Energy Smart Cooling

Start Counting Your Savings

RULE #1.
Choose the least expensive heat rejection technology

When choosing a cooling system consider your climate and the maximum operating temperature of your equipment for optimum efficiency. Lower fluid temperatures increase energy usage and operating costs.

TYPE	OPERATING COST	TEMPERATURE
Air Cooled	$	105°F
Evaporative	$$	85°F
Chiller	$$$$	65°F

Air cooled heat exchanger

Evaporative cooling tower with outdoor mechanical room

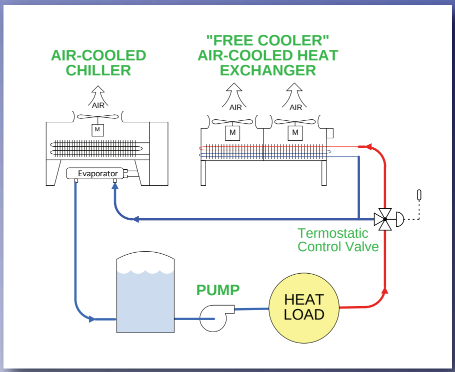
Chiller (mechanical refrigeration)

RULE #2.
Use hybrid systems to save energy

Combine different types of systems to achieve the best features of each with the greatest energy savings.

The "free cooler" shown at right eliminates the need for refrigeration compressors to run in a cold winter climate, saving energy and wear and tear on the chiller.

Another hybrid example is to "trim cool" an air cooled heat exchanger with an evaporative tower used in summer only. Substantial savings are realized in water, chemicals and electricity.



RULE #3.
Get some expert advice. Make it pay to go green!

Dry Coolers Inc.

ISO 9001:2000

Find us at Booth 415

call **800-525-8173**

Fax: 248-969-3401

575 S. Glaspie Street • Oxford, MI 48371

www.drycoolers.com

30 years serving the Heat Treating Industry.

ENERGY-SMART COOLING SOLUTIONS FOR ALL TYPES OF PROCESS EQUIPMENT

ULTRAFAST BORIDING: A TRANSFORMATIONAL TECHNOLOGY

An ultrafast, efficient industrial-scale boriding process can drastically reduce costs, increase productivity, and improve the performance and reliability of a variety of machine parts. Component surfaces are converted into thick, hard boride layers in minutes, which dramatically increases resistance to degradation due to wear, abrasion, erosion, scuffing, and corrosion. By comparison, achieving such layer thicknesses using traditional pack boriding requires several hours, and surface hardness levels and other properties are lower than those produced using the new process.

The novel, environmentally friendly technology, developed at Argonne National Laboratory, Ill., enables treating thousands of industrial components in one batch, without creating solid or liquid waste and gaseous emissions. The key ingredient used during boriding is a natural borax mineral, which is safe to handle. Researchers say the new process is a transformational technology that can complement many current surface treatment processes, such as conventional boriding, carburizing, nitriding, carbonitriding, and physical and chemical vapor deposition (PVD and CVD).

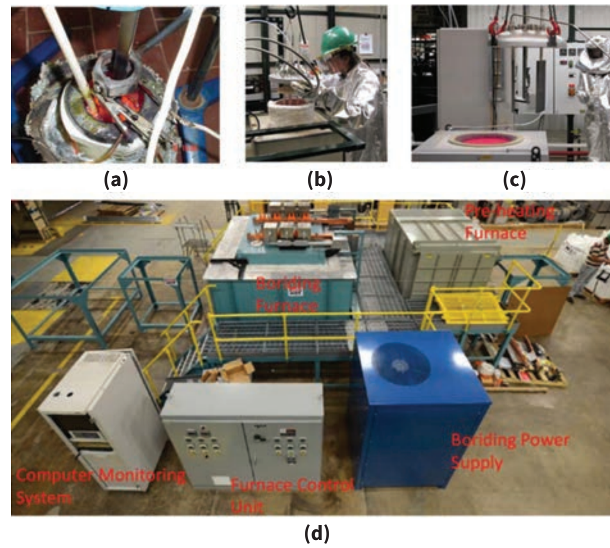


Fig. 1 — Evolution of boriding units: (a) initial (1.75 in. diameter), (b) intermediate (4 and 6 in. diameters), (c) pilot-scale (22 in. diameter), and (d) large-scale (43 in. long × 57 in. wide × 54 in. deep) production units.

PROCESS DEVELOPMENT

The ultrafast, large-scale boriding process is the result of a collaborative effort involving Argonne (lead partner), Bodycote, and Istanbul Technical University, stemming from a project funded by the U.S. Department of Energy-Advanced Manufacturing Office. The initial part of the project involved scale-up of a small proof-of-concept unit (1.75-in. diameter unit with 250-g electrolyte capacity) to 4- and 6-in. diameter intermediate units, and then to a pilot-scale unit with a 22-in. diameter crucible size featuring a capacity of 130 kg of electrolyte. This led to building a production-scale unit with a melt capacity of 4000 kg. The evolution of the large-scale boriding technology from inception to large-scale implementation is shown in Fig. 1.

The ultrafast method uses a battery-like design, where each electrochemical cell contains a positively charged cathode, negatively charged anode, and molten borax-based electrolyte. Bath temperature is roughly 1400°F. Parts are attached to the cathode, and when the unit is connected to a power source, ions flow from the anode to the cathode, depositing boron on the cathode and attached workpieces. Boron subsequently diffuses into the metal and reacts to convert near-surface regions into metal borides. The process is completed in minutes, producing a denser, more uniform coating, and requires 85% less energy than conventional boriding. Traditional pack-boriding, by comparison, involves baking parts in a complex mixture of powders at a temperature around 1800°F, often for 10 hours or longer.

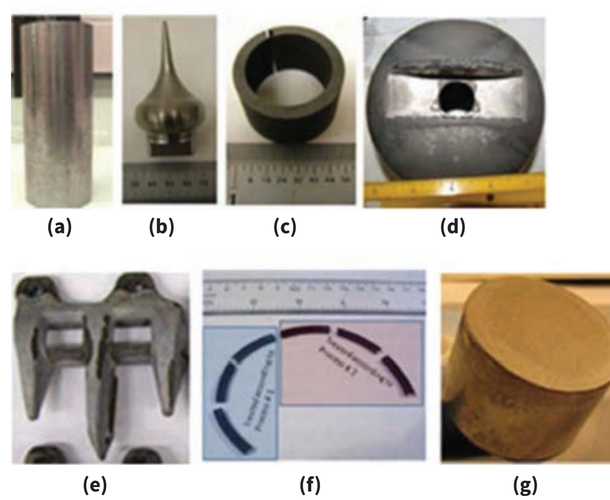
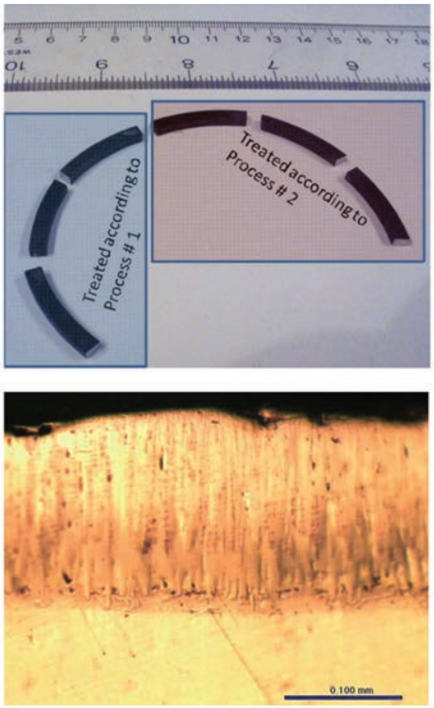
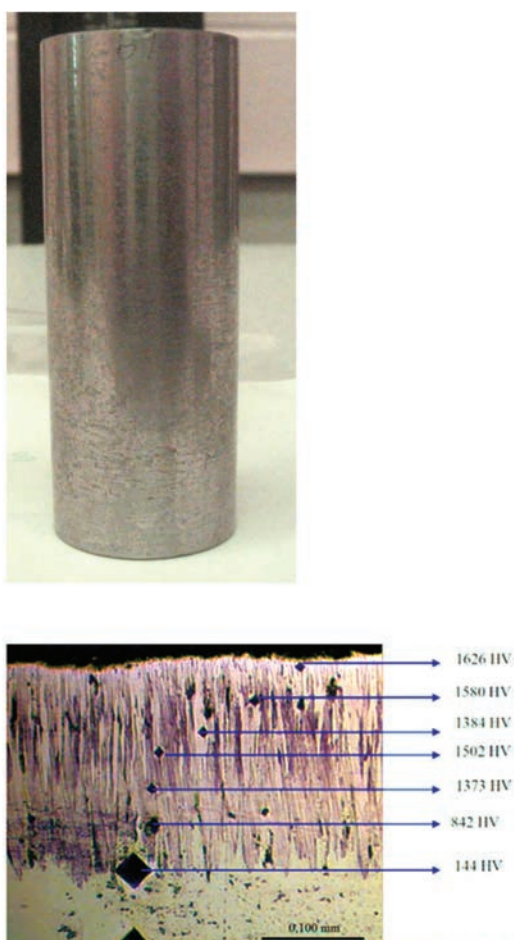


Fig. 2 — Industrial parts treated using ultrafast boriding: (a) engine piston pin, (b) titanium textile guide, (c) superalloy bearing part, (d) Inconel 718 ball valve, (e) agricultural knife guard, (f) engine piston ring, and (g) engine tappet.

Ferrous and nonferrous metals and alloys (e.g., titanium, tantalum, zirconium, tungsten, niobium, molybdenum, most nickel- and cobalt-base superalloys, and cobalt-chrome alloys), intermetallics, cemented carbides, and cermets (which are not possible to treat using conventional boriding methods) can be treated with the new process. Surface hardness is increased by factors of 3 to 10 (i.e., 15 to 45 GPa), depending on the specific alloy. For example, a 300-µm thick complex boride layer was formed on Ni_3Al intermetallic material in 15 minutes,



(a)



(b)

Fig. 3 — Treated engine parts and cross-sectional microstructures: (a) piston ring, (b) piston pin.

providing a surface with five times the hardness of the base material. Figure 2 shows examples of treated industrial parts. The microstructures and hardness of an ultrafast borided piston ring and pin are shown in Fig. 3. The superior properties produced by the process offer substantially longer product life, which indirectly reduces costs and energy consumption by minimizing repair and/or replacement of failed parts.

The electrochemical nature of the boriding process requires expertise in electrical engineering, electrochemistry, materials science, ceramics, furnace design, and various types of electrical power sources. Researchers from ANL include Ali Erdemir (ANL project lead), surface engineering expert Osman Eryilmaz, Gregory Krumdick (safety and quality control), and postdoctoral scientist Vivekanand Sista (boriding furnace instrumentation and operation). Experts from the Istanbul Technical University include Servet Timur, Guldem Kartal, and Ozgenur Kahvecioglu Feridun. Mario Ciampini from Bodycote served as liaison in many aspects related to the industrial-scale boriding system specification, benchmarking, field evaluation, and technology transfer issues.

For more information: Ali Erdimir, FASM, is an Argonne Distinguished Fellow and senior scientist, Energy Systems Div. Argonne National Laboratory, 630.252.6571, erdemir@anl.gov, www.anl.gov.

CARLISLE
BRAKE & FRICTION

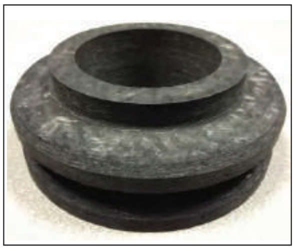
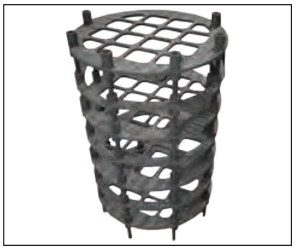
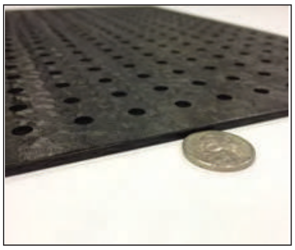
Carbon/Carbon Composite Materials

CARBON GROUP

Carlisle Carbon Group, a division of Carlisle Brake & Friction, manufacturers carbon/carbon composites using a unique process that allows our engineers to change material properties. We alter porosity, thermal conductivity, or density to optimize the machinability of rack or tray systems for improved process performance, and we can also add holes, threads, and fabricate complex shapes.

Our carbon/carbon composite materials stay flat for parts that require extreme flatness, and its fracture toughness makes this material an ideal energy-friendly alternative to ceramics. Our composites also have a low heat capacity that enables rapid heating and cooling of sinter hardening furniture and improves part metallurgy.



ATTRIBUTES

Flatter Parts
Avoid warped furniture

Greater Throughput
Thinner plates, discs, rings, pucks & racks

Complex Designs
Machine threads, holes & contours

Quickly Heats & Cools
Shorter cycle times

Rapid Gas & Liquid Quench Times
Thermal shock resistant & low porosity

Long Lasting Furniture
Fracture tough parts won't crack

Heat Parts vs. Furniture
Low thermal mass

CARLISLE
BRAKE & FRICTION

Contact Carlisle for more information at 855 403 9083 or sales@carlislecbf.com
Visit carlislecbf.com/products/carbon

ASMNEWS

ASM Materials Education Foundation Announces 2015 Scholarship Winners

William Park Woodside Founder's Scholarship

The William Park Woodside Founder's Scholarship was established in 1996, by a gift from Mrs. Sue Woodside Shulec in honor of her grandfather. William Park Woodside founded our Society as the Steel Treaters Club more than 100 years ago and later served as president of ASM. The scholarship was established to support an ASM student member studying materials science and engineering at the junior or senior level who demonstrates strength in leadership, character, and academics. Tuition of up to $10,000 for one academic year and a certificate of recognition are awarded to the recipient.

Anna Bretzke
Missouri University of Science & Technology

Bretzke originally declared ceramic engineering as her major, but changed her mind after one week of working in a steel foundry. Internships at GE Aviation and Phillips Petroleum strengthened her desire to learn more, and as president of her Material Advantage chapter, she looks forward to "opening up the world of materials engineering to students of all ages."

The Lucille and Charles A. Wert Scholarship

The Lucille and Charles A. Wert Scholarship was established in 2006 through a generous bequest by the couple. It serves as an expression of their commitment to education and the materials science and engineering community. Tuition of up to $10,000 for the academic year is awarded through this scholarship.

John Coffey
The Ohio State University

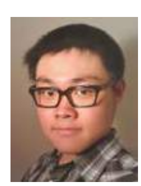
Coffey, a chemical engineering major, received his first taste of materials science at the Eisenman Materials Camp. "My experiences with ASM made me seriously consider MSE for my major," he says, "but I decided to go for a chemical engineering major so that I can use the knowledge I have gained to work with a broader range of topics, including polymers, nanotechnology, process design, and problem solving." Last year, John returned to Eisenman Materials Camp, this time as a mentor.

George A. Roberts Scholarships

The George A. Roberts Scholarships were established in 1995 through a generous contribution from Dr. George A. Roberts, FASM, past president and retired CEO of Teledyne, to the ASM Foundation as an expression of his commitment to education and the materials science and engineering community. Scholarships are awarded to outstanding undergraduate members of ASM at the junior or senior level who demonstrate exemplary academic and personal achievements, and interest and potential in metallurgy or materials science and engineering. Five scholars were selected this year and will be presented with a certificate and check for $6000 toward educational expenses for one academic year.

Mary Cole
University of Akron

The combination of Materials Camp and a guest presentation about corrosion engineering convinced Cole to study materials. "In my career, I plan to be a corrosion specialist and would like to work in the oil and energy industry," she says. She has also volunteered at ASM Teachers Camps and the ASM Eisenman Camp.



Ziyin Huang
Drexel University

Motivated by his interest in materials for biomedical and electronic applications, Ziyin has worked on a variety of projects, including characterization of polymer crystallization at curved liquid-liquid interfaces. He also serves as president of the Drexel Material Advantage Chapter.

In This Issue

Submit news of ASM and its members, chapters, and affiliate societies to Frances Richards, editor, ASM News | ASM International
9639 Kinsman Road | Materials Park, OH 44073 | P 440.338.5151 ext. 5563 | F 440.338.4634 | E frances.richards@asminternational.org
Contact ASM International at 9639 Kinsman Road, Materials Park, OH 44073 | P 440.338.5151 ext. 0 or 800.336.5152 ext. 0 (toll free in U.S. and Canada) | F 440.338.4634 | E MemberServiceCenter@asminternational.org | W asminternational.org

HIGHLIGHTS SCHOLARSHIP WINNERS

Colin Lunstrum
University of Idaho

Because energy production and storage "are powerful issues that need a better solution," Lunstrum's focus is on photoelectrochemical and electrochemical storage devices. He was recently recognized by the ASM Inland Empire Chapter for his paper on bismuth oxide-based solar hydrogen generation materials.

Rachel Sylvester
The Ohio State University

After attending the ASM Eisenman Camp in 2010, Sylvester was hooked. She has built on her materials knowledge at Ohio State, and summers at Cessna Aircraft and Ford have added to her desire to pursue a career in materials. "Eventually, I hope to own my own consulting company," says the Material Advantage chapter vice president.

Cyrus Thompson
University of Wisconsin-Madison

To pursue his degree in biomaterials, Cyrus has incorporated several fields into what he calls his biomaterial engineering toolkit. "What I learn in materials science and engineering has given me the confidence to work across an enormous range of materials disciplines including processing, synthesis, characterization, and modification," he says.

William & Mary Dyrkacz Scholarships

The William & Mary Dyrkacz Scholarships were established in 2011 through a generous contribution from the couple to the ASM Foundation. Dyrkacz, an ASM Fellow, remembered the scholarships he received while an undergraduate student at Carnegie Tech from 1939–1942. Scholarships are awarded to outstanding undergraduate members of ASM at the junior or senior level who demonstrate exemplary academic and personal achievements, and interest and potential in metallurgy or materials science and engineering. Four scholars were selected this year and will be presented with a certificate and check for $6000 toward educational expenses for one academic year.

Taylor Brown
University of Alabama at Birmingham

Brown has worked as an intern on lost foam casting projects and steel production, participated on student teams that have won casting competitions, and loves to work around the UAB furnace facility. He has also helped construct a mobile aluminum furnace. "I strive to be hired by a steel company after graduation," he says.

Katrina Catledge
Wright State University

Experiences in the metallography lab have given Catledge valuable experience in sample preparation techniques, while the mechanical and materials testing lab has shown her the finer points of impact and fatigue testing. "From my internships and course experiences, I favor a career in materials research, focusing on metals," she says.

Nathaniel Griffen
Missouri University of Science & Technology

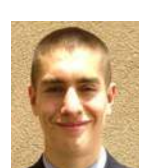
Griffen discovered the science of heat treating on his grandfather's farm. While making hay bale forks, he noticed that the blade on a chop saw cut through some heavy duty angles with ease, but made little progress on a two-inch steel rod. His grandfather suggested that he get a non-heat treated rod to cut, and he was amazed. Griffen hopes to expand the use of stronger, lighter steels "to make safer buildings and lighter vehicles."

Zach Jensen
University of Wisconsin-Madison

While Jensen's main materials interests are in computational experiment simulation, nanomaterials, and computer science, he says he lives to do research. After receiving his undergraduate degree, he plans to attend a top graduate school "where I can develop both laboratory and computational experimental skills."

David J. Chellman Scholarship

The David J. Chellman Scholarship was established in 2014 by Mrs. Arline Denny in honor of her husband, a longstanding Senior Technical Fellow with Lockheed Martin Corp. and ASM Life Member who enthusiastically served on the AeroMat Conference Organizing Committee for more than 25 years. The scholarship is an expression of his commitment to education and the materials science and engineering community. Tuition of $2500 for the academic year is awarded through this scholarship.



Peter Barber
LeTourneau University

Barber achieved the rank of Eagle Scout before turning 15 and has also shown initiative by learning basic arc welding and custom knifemaking during breaks at his summer job, where he assisted with assembling and shipping turbine parts. He was accepted into the U.S. Marine Corps Officer Program, aspires to become a Marine aviator, and looks forward to someday entering and advancing the welding industry.

Ladish Co. Foundation Scholarship

Established in 2011, the Ladish Co. Foundation Scholarship is awarded to an outstanding undergraduate member of ASM who has demonstrated exemplary academic and personal achievements as well as interest and potential in metallurgy or materials science and engineering. (Student must be a Wisconsin resident and must attend a Wisconsin university to qualify.) Two scholars were selected this year, and each will receive a certificate and check for $2500 toward educational expenses for one academic year.

Misty Pulcine
University of Wisconsin-Madison

A summer internship at NASA Langley Research Center involving synthesizing novel composites of boron nitride nanotubes and polymers gave Pulcine a taste for research. “I can see my future career involving research of materials such as spider silk, medical implants, or other biologically related materials,” she says.

Allison Weber
University of Wisconsin-Madison

From the time she first saw the effect of liquid nitrogen on a rubber band in junior high school, to exploring biomimicry as a freshman in college, Weber has been fascinated by the importance of polymers and biomaterials, “not only for technological advancements but to make everyone’s lives better.”

Outstanding Scholar Awards

The Outstanding Scholar Awards were established to recognize students who demonstrate exemplary academic and personal achievements as well as interest and potential in metallurgy or materials science and engineering. The awards are funded by the ASM Materials Education Foundation. Three $2000 awards are presented each year.

Allison Fraser
Lehigh University

Since declaring a materials science major, Allison has worked as a materials technician and in chemistry labs, investigated additive manufacturing of wear-resistant alloys, and created a graduated steel tube to be welded into power plants to avoid premature failure. She also serves as a tour guide for Lehigh’s Materials Department.

Alexander Lark
University of Utah

Ever since his grandfather worked for NASA as a chemical engineer, Lark has been increasingly interested in using materials science to advance technology, and these interests have pointed him toward metallurgical engineering. In the immediate future, he plans to pursue a master’s degree in physical metallurgy.

Theresa Saenz
Purdue University

Saenz’s research and studies at Purdue have focused on electrical materials with a minor in electrical engineering. Her next step is a year in Australia at the University of New South Wales’ School of Photovoltaic Engineering as she continues pursuit of her goal to become a photovoltaic materials researcher at a national lab.

Edward J. Dulis Scholarship

The Edward J. Dulis Scholarship was established in 2003 and is awarded to an outstanding undergraduate member of ASM at the junior or senior level who demonstrates exemplary academic and personal achievements, as well as interest and potential in metallurgy or materials science and engineering. One scholar was selected this year and will be presented with a certificate and a check for $1500 toward educational expenses for one academic year.

Daniel Balder
University of Minnesota

Balder is pursuing a double major in materials science and engineering and chemistry and plans to continue with a master’s degree in materials science. “I plan to work as a materials engineer, designing procedures to produce desired structures, so they have the properties needed to achieve the required performance,” he says.

John M. Haniak Scholarship

The John M. Haniak Scholarship was established in 2003 and is awarded to an outstanding undergraduate member of ASM at the junior or senior level who demonstrates exemplary academic and personal achievements as well as interest in metallurgy or materials science and engineering. One scholar was selected this year and will be presented with a certificate and check for $1500 toward educational expenses for one academic year.

Alexander Hall
The Pennsylvania State University

After attending a Materials Camp in Pittsburgh and the Eisenman Camp in Cleveland, Alex was hooked—first on chemistry and then on materials science. An internship with an auto manufacturer could be his ticket to full-time employment after graduation, followed by a master’s degree in welding engineering from Ohio State.

Jim Curiel named 2015 Kishor M. Kulkarni Distinguished High School Teacher

The Teacher Award Committee of the ASM Materials Education Foundation is proud to announce the selection of **Jim Curiel** of Don Bosco Technical Institute, Rosemead, Calif., as recipient of the 2015 Kishor M. Kulkarni Distinguished High School Teacher Award.

The award, $2000 plus $500 toward travel to MS&T, was established in 2007 through a generous donation by Dr. Kishor M. Kulkarni, past trustee of ASM International, and his family to recognize the accomplishments of one U.S. high school science teacher who demonstrates a significant and sustained impact on pre-college age students. The award will be presented on October 5 at the ASM Leadership Awards Luncheon at MS&T15 in Columbus, Ohio.

Curiel is a longtime ASM member and has served on the executive committee of the Los Angeles Chapter, is a past instructor of ASM education courses, and organized and hosted Materials Camps for area middle schools. He also organized ASM's only student chapter at the high school level.

"What sets Mr. Curiel apart is his passion towards the materials science, engineering, and technology field and his students succeeding in all their classes."

—Dustin Kelso, Class of 2016

Terry F. Mosier Named ASM Managing Director

On the recommendation of the Managing Director Executive Search Committee, and with the approval of the ASM 2014-2015 Board of Trustees, ASM is pleased to announce the selection and promotion of Terry F. Mosier to ASM Managing Director. He is the seventh individual to hold this position since ASM was founded more than 100 years ago.

The Search Committee was formed in January 2015, comprised of current and former ASM Board members. In June, Dise and Co. was selected to manage the search, which identified a pool of almost 500 individuals. Nearly 30 candidates were selected for further interviews. In September, the Committee completed its review and made its recommendation.

Mosier joined ASM in November 2008 as controller and was promoted to the director of finance position one year later. He has a degree in industrial engineering from Marietta College and an M.B.A. from Case Western Reserve University in Cleveland. Mosier comes from a family of engineers and scientists. His 20 years of diverse experience ranges from smaller, entrepreneurial private firms to large multinational public corporations, both profit and nonprofit. In addition to his seven years at ASM, he has worked in manufacturing (chemicals, food, equipment, and metals), the service industry, and as owner of his own technology company. A formal announcement will be made on October 5 during the Annual Business Meeting at MS&T15 in Columbus, Ohio.

2015 Undergraduate Design Competition Winners Announced

The ASM Materials Education Foundation and Design Competition Committee are pleased to announce the winners of the 2015 Undergraduate Design Competition. First prize goes to **California State Polytechnic University, Pomona** for "Design of Diffusion Coatings: Effect of Process Control on Microstructural Evolution." Team members include Sutine Sujittosakul, Cory Gaines, Armando Coronado, Shahan Kasnakjian, and faculty advisor Vilupanur Ravi. The team will receive $2000, $500 travel assistance for MS&T15, and $500 to the department for support of future design teams.

Second prize goes to **Carnegie Mellon University** for "Recycling of Specialty Metal Plant By-Products." Team members include Patrice Daniel, Kate Groschner, Kellie Painter, Dylan Quaintana, industry representative Wyatt Ochadlick, ATI Inc., and faculty advisor Robert Heard. The team will receive $1500 and $500 travel assistance for MS&T15. Third prize goes to **Michigan Technological University** for "E357 Alloy Design to Increase Elongation and Maintain Strength." Team members include Jordan Pontoni, Shane Anderson, Austin DePottey, Calvin Nitz, team advisor Tom Wood, and faculty advisor Paul Sanders. The team will receive $1000 and $500 travel assistance for MS&T15. Winners will be recognized on October 5 at the ASM Leadership Awards Luncheon at MS&T15 in Columbus, Ohio. To view abstracts of the winning projects, visit asmfoundation.org.

Student Papers Sought for ASM HTS/Bodycote 'Best Paper in Heat Treating' Contest

The ASM Heat Treating Society established the Best Paper in Heat Treating Award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advancement in managing the business of heat treating.

The award, endowed by **Bodycote Thermal Process-North America,** is open to all students, in full time or part-time education, at universities (or their equivalent) or colleges. Students who have graduated within the past three years and whose paper describes work completed while an undergraduate or post graduate student are also eligible. The winner will receive a plaque and a check for $2500.

To view rules for eligibility and paper submission, visit the HTS community website at hts.asminternational.org and click on Membership & Networking and Society Awards. Paper submission deadline is **December 11.** Send submissions to Joanne Miller, ASM Heat Treating Society, 9639 Kinsman Rd., Materials Park, OH 44073; 440.338.5151 ext. 5513; joanne.miller@asminternational.org.

Member Needs Survey Update

The ASM Membership Committee extends thanks to all members who participated in the 2015 ASM Member Needs Survey this summer. The input will help ASM leadership and staff enhance the value of ASM membership. A special congratulations goes to the following Grand Prize winners for participating in the survey:

- Jack G. Simon, Aiken, S.C.
- Joan Kadaras, Chelmsford, Mass.
- Dennis F. Baker, Tuolumne, Calif.
- Neal Alberson, Virginia Beach, Va.
- Kameshwaran Swaminathan, Houston

Jacquet-Lucas Award for Excellence in Metallography

The ASM Metallographic Award was established in 1946 for the best entry in the annual ASM metallographic competition. In 1958, it became known as the Francis F. Lucas Metallographic Award and has been endowed since that date by Adolph I. Buehler. In 1972, ASM joined with The International Metallographic Society (IMS) in sponsoring the Pierre Jacquet Gold Medal and the Francis F. Lucas Award for Excellence in Metallography. This award has been endowed by Buehler Ltd. since 1976.

The 2015 recipient of the Jacquet-Lucas Award is **Peter Kirbiš** from the University of Maribor, Slovenia, for his entry entitled *"Welding of Novel High Carbon Bainitic Steel."* Kirbiš is currently working as a doctoral candidate at the faculty of mechanical engineering at this university. His thesis is titled "Modeling of Rapid Bainite Formation at Very Low Temperatures" and is a continuation of his master's degree work in mechanical engineering.

He earned his master's in 2014, with the work titled "Development of Nanostructured Bainitic Steels," under the mentorship of Prof. Dr. Ivan Anžel. This resulted in development of three steels, which form fully carbide-free bainitic microstructures during air cooling. The same year, a segment of the work was submitted in Class 3 of the International Metallographic Contest and won third place. In the field of metallography, he grew fond of tint etching and one of his images can be seen in the current Buehler calendar.

Seeking Nominations for 2016 ASM/TMS Distinguished Lectureship in Materials & Society

Qualifications of the lecturer include:

- An eminent individual who has an overall understanding of technology and society, and how both are affected by developments in materials science and engineering.
- Experienced in national or industrial policymaking in the field of materials science and engineering.
- Associated with government, industry, research, or education.

Nominations may be proposed by members of either Society. Submit nominations by **November 15.** For complete details, visit asminternational.org/membership/awards.

Nomination Deadline for the 2016 Class of Fellows is Fast Approaching!

The honor of Fellow of the Society was established to provide recognition to members for distinguished contributions in the field of materials science and engineering, and to develop a broadly based forum for technical and professional leaders to serve as advisors to the Society. Criteria for the Fellow award include:

- Outstanding accomplishments in materials science or engineering
- Broad and productive achievement in production, manufacturing, management, design, development, research, or education
- Five years of current, continuous ASM membership

Deadline for nominations for the class of 2016 is **November 30, 2015.** Complete information including the rules, interpretive comments, and online nomination forms are available at asminternational.org/membership/awards/asm-fellows or by contacting Christine Hoover at 440.338.5151, ext. 5509, christine.hoover@asminternational.org.

Nominations Sought for ASM-IIM Visiting Lecturer for 2016

The cooperative Visiting Lecturer program of ASM International and the Indian Institute of Metals (IIM) is seeking lecturers for 2016. Criteria for the 2016 ASM-IIM Visiting Lecturers include:

- ASM members who visit India
- Experience delivering technical presentations of interest to government, industrial, or academic organizations
- Able to lecture on current technological conditions in India
- Available between April 1 and December 31
- Definite travel plans to and from India using own funds

The award carries with it an $800 honorarium to be used for travel expenses within India during the lecturer's visit and a certificate of recognition to be presented at the ASM Leadership Awards Luncheon scheduled for October 2016 in Salt Lake City during MS&T16. Deadline for application is **December 1.**

Nominations Due for 2016 ASM Nominating Committee

ASM International is seeking members to serve on the 2016 ASM Nominating Committee. The committee will select a nominee for 2016–2017 vice president (who will serve as president in 2017–2018) and three nominees for trustee.

Committee candidates may only be proposed by a Chapter through its executive committee, an ASM committee or council, or an affiliate society board. Nominations are due by **December 15.**

For more information, contact Leslie Taylor at 440.338.5151 ext. 5500, leslie.taylor@asminternational.org, or visit asminternational.org/about/governance/nominating-committee.

IMS
International Metallographic Society
ASM INTERNATIONAL

IMS Salutes Corporate Sponsors

The International Metallographic Society (IMS) relies on corporate financial support to maintain its excellent awards program. IMS extends sincere appreciation to the following companies for their support.

IMS Benefactors: Buehler, Metkon Instruments Inc., and Precision Surfaces International

IMS Patrons: Allied High Tech Products Inc. and Struers Inc.

IMS Associates: Carl Zeiss Microscopy LLC, Evans Analytical Group, Hoeganaes Corp., MetLab Corp., PACE Technologies Corp., and Ted Pella Inc.

IMS Sponsors: Exponent, IMR Test Labs, Leco Corp., Nikon Metrology Inc., and Scot Forge Co.

CanmetMATERIALS colleagues.

Canada Council Awards

ASM Canada Council will present their awards during ASM's Leadership Awards Luncheon on Monday, October 5, in Columbus, Ohio, during MS&T15. Congratulations to the following Canadian award recipients:

ASM Canada Council
M. Brian Ives Lecture
Dr. Linruo Zhao
Principal Research Officer
National Research Council of Canada
Ottawa, ON

ASM Canada Council
G. MacDonald Young Award
Dr. John Wolodko
Executive Director
Alberta Innovates–Technology Futures
(formerly Alberta Research Council)
Edmonton, AB

ASM Canada Council John Convey Innovation Award
Mr. Philippe Dauphin
Director
CanmetMATERIALS
Hamilton, ON

Alloy Center Database Fall Release Includes Wealth of New Data

ASM's Alloy Center Database is an online source for metals-focused alloy data, including worldwide equivalencies for alloys, mechanical and physical property data, coatings data, and corrosion characteristics in various environments. The latest release features the following content additions and updates:

- Nearly 5000 new and updated ferrous and nonferrous standards specification records, based on ASTM and ASME standards
- New hot working datasheets, including flow stress data and processing maps for metallurgical interpretation and optimum processing conditions for metals, alloys, intermetallics, and metal matrix composites
- Expanded corrosion performance data, including environments relevant to the oil & gas industry
- New material producers' datasheets
- New magnesium alloy datasheets

An authoritative materials data reference, the database includes more than 100,000 alloy designations, specifications, standards and commercial grades in the U.S. and globally. The database also features thousands of documents in PDF format, including material data sheets from *Alloy Digest* and other ASM publications; heat treating data sheets from the best-selling *Heat Treater's Guides;* time-temperature curves, creep curves, fatigue curves, and stress-strain curves. Additional database components cover material properties, coatings, and corrosion performance data. For more information, contact denise.sirochman@asminternational.org or 440.338.5409.

Teachers enjoy a special Materials Camp focusing on additive manufacturing, hosted by Carnegie Mellon University and Penn State.

Teachers Camp Highlights Additive Manufacturing

Taught by two Master Teachers, Troy Alesi of State College Area High School and Ron Shealer of Mount Nittany Middle School, both in State College, Pa., the ASM Materials Education Foundation launched its inaugural specialty Teachers Camp on additive manufacturing in July. Hosted by Carnegie Mellon University and Penn State, 19 teachers attended the event. Based on the success of the first camp, a second one was held at Cuyahoga Community College, Cleveland, with 15 teachers in attendance. ASM extends special thanks to our sponsors and hosts, including the Leonard Gelfand Center for Service, Learning and Outreach, America Makes, Carnegie Mellon University, Penn State, and Cuyahoga Community College.

FROM THE PRESIDENT'S DESK

Collins

My ASM Year

As I write this column, students are back on campus and my once-quiet office is busy again. My days are filled with meetings, lectures, and class preparations. At the same time, my year as ASM President is drawing to a close. I would now like to take some time to reflect on the past year.

I could tell you about the many Chapter visits I made over the past year (eight and counting), my pizza lunches with Material Advantage Chapters, or my visits at Materials Camps for both students and teachers. I also kept in touch with my ASM Cleveland Chapter and attended the annual dinner-theater social, an Indians game, and an interesting symposium on high precision machining. I put together a couple of new technical talks, one for the ASM Eastern New York technical symposium on materials degradation, and the other for an electronics equipment manufacturer for a "voice of the customer" presentation on trends in materials research.

During my travels, I took the time to seek out and meet with members and volunteers and I am optimistic about the future of ASM. I found our members to be individuals passionate about their Society, curious about materials and their role in making a better world, and proud of their profession. One of my favorite afternoons was spent visiting Bob Halverstadt, a lifelong ASM member, still serving on the ASM Foundation Board at 95. He wanted to make sure that ASM continues its commitment to lifelong learning and workforce development. What a pleasure it was to get his perspective and see his dedication to ASM. I am glad to have met him and was sad to hear of his passing.

My year as ASM President also involved helping to identify and hire new staff leadership capable of assisting our Society to be greater in its next century. The ASM volunteers involved in the selection process feel positive about the result, and we are looking forward to Terry Mosier's leadership. Thank you all for a wonderful year.

Sunniva R. Collins
sunniva.collins@case.edu

MEMBERS IN THE NEWS

Rosei Honored by Chinese Chemical Society

Federico Rosei, FASM, of the INRS Énergie Matériaux Télécommunications Research Centre, Canada, was named Honorary Fellow of the Chinese Chemical Society. He is the only Canadian researcher to make this list. Rosei also received the Chang-Jiang Scholars Award this year, presented by the Chinese government in recognition of his research in the field of organic and inorganic nanomaterials.

ATI Promotes Dalton and Witheford

Allegheny Technologies Inc. (ATI), Pittsburgh, recently announced several management changes. **Hunter Dalton** was named executive vice president, strategic growth initiatives. In this new role, he will be responsible for helping develop ATI's additive manufacturing business strategy and other growth-focused strategies. ATI also announced that **Thomas Witheford** will succeed Dalton as president of ATI Specialty Materials, part of the high performance materials and components segment. Dalton joined ATI in 1981 as an industrial engineer for ATI Specialty Materials, and Witheford joined the company in 1988 as a product engineer at ATI's melt operations in Latrobe, Pa.

IN MEMORIAM

Robert Dale Halverstadt, FASM, passed away on September 13 at age 95. He was born in Warren, Ohio, on January 25, 1920, and served in the Coast Guard during WWII, taking part in the D-Day invasion of Normandy. After the war, he worked as a machinist at Republic Steel and enrolled at Case Institute of Technology to earn his engineering degree. He went on to work at General Electric, where he was a development engineer, laboratory supervisor, and manager of the Thomson Engineering Laboratory. At GE, Halverstadt received three patent awards for his work, including the electrochemical process used to manufacture its first production air-cooled turbine blades. After GE, he served as group vice president of Booz, Allen and Hamilton Inc. and ran several divisions. In 1974, he became president of Special Metals Corp. and then chairman of the board in 1987, a role he filled until 2002 when he became Chairman Emeritus. Halverstadt served as Trustee of ASM from 1982–1985 and as Treasurer from 1988–1991. He joined ASM in 1957, was a Distinguished Life Member (2002), and received Honorary Membership in 2008. He served on the ASM Materials Education Foundation as Trustee from 2007–2015, was a Pillar Society member since 2004, and Chair of the Fund Raising Committee from 2010–2013.

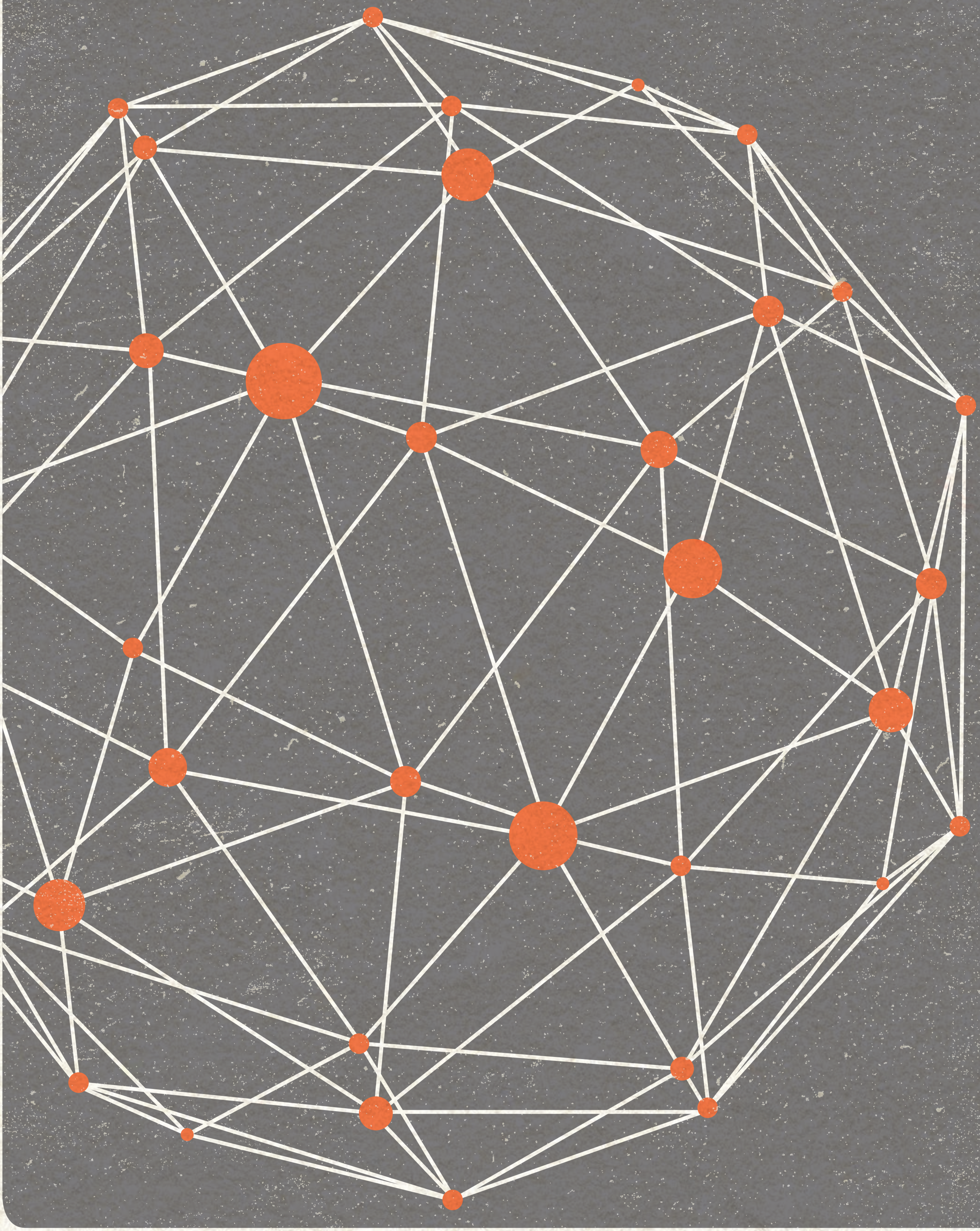
Floyd "Casey" William Wood, of Gainesville, Fla., died on August 24 at age 89. He was born in Eugene, Ore., on May 31, 1926, and grew up in Eugene and Portland. Wood received his engineering degrees from the University of Oregon and Oregon State University and was training to be a Navy pilot in the V5/V12 program when WWII ended. He worked for the U.S. Bureau of Mines in Albany, Ore., and the Jacksonville, Fla., Naval Air Station as a metallurgical engineer. Wood joined ASM in 1966.

Harry Waldron Weart died on August 18 at age 88. He was born in Seneca Falls, N.Y., and graduated as valedictorian from Mynderse Academy High School in 1945. He received a bachelor's degree in metallurgy from Rensselaer Polytechnic Institute in 1951, and a master's and Ph.D. from the University of Wisconsin at Madison. Weart served in the U.S. Army as a member of the Military Police in the Panama Canal Zone from 1945–1947. He later served as a member of the engineering faculty at several universities, and was chairman of the Metallurgy Department at the University of Missouri–Rolla from 1964–1992. Weart joined ASM in 1948.

ASM INTERNATIONAL

REFERENCE PUBLICATIONS CATALOG

INFORM. EDUCATE. CONNECT. | 2015



The Tools to Realize Your Goals

It is our pleasure to present you with the latest ASM Reference Publications Catalog. Our vast, authoritative reference library has the most comprehensive and up to date information to keep you at the top of your profession. We bring everything together so that you can continue forging ahead.

Visit: asminternational.org/referencepubs

The World's Best and Most Comprehensive Materials Reference Guides

All articles are expert-written and peer-reviewed

Each volume of the ASM Handbook® series contains the most up-to-date information in a particular area of interest. Together, the complete set builds on the 90-year tradition of the ASM Handbook as the industry's best-known and most comprehensive source for information on metals and materials technology. Revised volumes and volumes of new topics are being published as warranted by technological advances. Volumes 10, 12, 16 and 17 are now sold as green-covered ASM handbook volumes, but the red-covered 9th Edition Metals Handbook versions are still current.

ASM Handbook Complete Set, see page 5

Order **The Complete ASM Handbook Set** – asminternational.org

SAVE UP TO $87

SET SALE!

Volumes 1 and 2
Product Code: 06062G
Price: $507 / ASM Member: $405

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

1990 • 1063 pages
ISBN: 978-0-87170-377-4
Product Code: 06181G
Price: $297 / ASM Member: $225

Extensive data for alloy designations, compositions, and mechanical/physical properties. Covers performance and selection of cast irons, carbon and low-alloy steels, tool steels, stainless steels, and super alloys. 1,328 photographs, charts and graphs. More than 500 tables.

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

1990 • 1328 pages
ISBN: 978-0-87170-378-1
Product Code: 06182G
Price: $297 / ASM Member: $225

Your best single-volume source on compositions, properties, selection, and applications of nonferrous metals and alloys. Extensive coverage on aluminum, titanium, and copper. 1,800 illustrations, hundreds of tables and data sheets.

Volume 3: Alloy Phase Diagrams

PRE-PUB

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 February 29, 2016!

Volume 4: Heat Treating

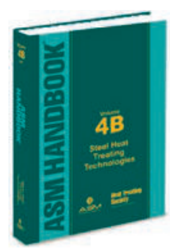
1991 • 1012 pages
ISBN: 978-0-87170-379-8
Product Code: 06184G
Price: $297 / ASM Member: $225

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

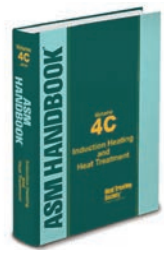
This volume addresses the basics of steel heat treating and thoroughly covers the many steel heat treating processes. Major topics include: the physical metallurgy of steel heat treatment, fundamentals and practical aspects of steel hardness and hardenability, quenching, annealing, tempering, austempering,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

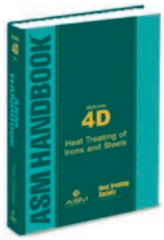
Volume 4B expands coverage on equipment, control, troubleshooting, and problems associated with steel heat treating. New articles extensively address distortion and the prevention of cracking – including the modeling and simulation of distortion. General process and procedure factors also are introduced—including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

ISBN: 978-1-62708-073-6
Product Code: 05449G

Price: $1007 / ASM Member: $755
Save up to $181!

+ THE ASM VOLUME 4 SERIES HEAT TREATING SET is the most affordable way to stock your library with the best, most trusted heat treating information. This set is an essential and comprehensive study in the field of heat treatment.

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

ISBN: 978-1-62708-081-1
Product Code: 05437G

Price: $297 / ASM Member: $225

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

Volume 6: Welding, Brazing and Soldering

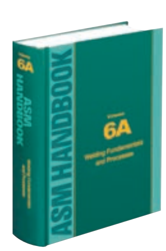
Edited by D.L. Olson, T.A. Siewert, S. Liu, and G.R. Edwards

1993 • 1299 pages

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

Price: $297 / ASM Member: $225

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



Volume 6A: Welding Fundamentals and Processes

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

2011 • 936 pages

ISBN: 978-1-61503-133-7
Product Code: 05264G

Price: $297 / ASM Member: $225

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

+ FOR MORE PRODUCT DETAILS and to join the ASM community, visit **asminternational.org/benefits** to explore all the offerings available.

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

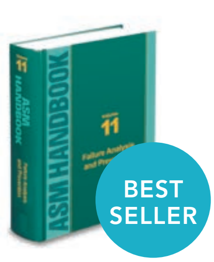
1986 • 761 pages

ISBN: 978-0-87170-016-2

Product Code: 06358G

Price: $297 / ASM Member: $225

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



Volume 11: Failure Analysis and Prevention

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

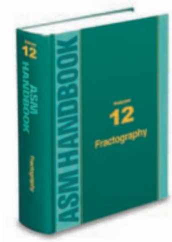
2002 • 1164 pages

ISBN: 978-0-87170-704-8

Product Code: 06072G

Price: $297 / ASM Member: $225

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



Volume 12: Fractography

1987 • 517 pages

ISBN: 978-0-87170-018-6

Product Code: 06365G

Price: $297 / ASM Member: $225

Over 1,900 illustrations and fractographs, along with 41 tables, provide engineers with enhanced capability for recognizing and interpreting the various features of a fracture. Supplemental illustrations of failed metal-matrix composites, resin-matrix composites, polymers, and electronic materials.

SAVE UP TO $104

SET SALE!

Volumes 13A, 13B & 13C

Product Code: 05194G

Price: $787 / ASM Member: $595

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

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

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

2003 • 1135 pages

ISBN: 978-0-87170-705-5

Product Code: 06494G

Price: $297 / ASM Member: $225

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

Volume 13B: Corrosion: Materials

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

2005 • 703 pages

ISBN: 978-0-87170-707-9

Product Code: 06508G

Price: $297 / ASM Member: $225

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

Volume 13C: Corrosion: Environments and Industries

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

2006 • 1168 pages

ISBN: 978-0-87170-709-3

Product Code: 05145G

Price: $297 / ASM Member: $225

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

SAVE UP TO $87

SET SALE!

Volumes 14A and 14B
Product Code: 05193G
Price $507 / ASM Member: $405

Volume 14A: Metalworking Bulk Forming

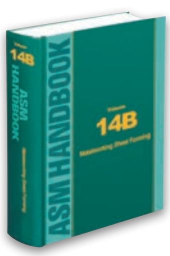
Edited by S.L. Semiatin

2005 • 888 pages

ISBN: 978-0-87170-708-6
Product Code: 06957G

Price: $297 / ASM Member: $225

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



Volume 14B: Metalworking Sheet Forming

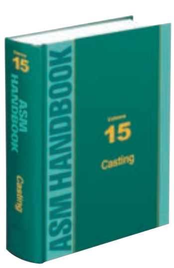
Edited by S.L. Semiatin

2006 • 940 pages

ISBN: 978-0-87170-710-9
Product Code: 05120G

Price: $297 / ASM Member: $225

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



Volume 15: Casting

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

2008 • 1256 pages

ISBN: 978-0-87170-711-6
Product Code: 05115G

Price: $297 / ASM Member: $225

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

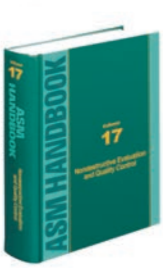
Volume 16: Machining

1989 • 944 pages

ISBN: 978-0-87170-022-3
Product Code: 06022G

Price: $297 / ASM Member: $225

1,300 illustrations and 620 tables provide detailed descriptions of various machining and grinding processes. Guidelines for proper selection of cutting tool materials and cutting fluids.



Volume 17: Nondestructive Evaluation and Quality Control

1989 • 795 pages

ISBN: 978-0-87170-023-0
Product Code: 06070G

Price: $297 / ASM Member: $225

Commonly used methods such as liquid penetrant, magnetic particle, eddy current and radiographic inspection, tomography, and real-time radiography. Basic principles of each method along with its corresponding capabilities are outlined in 23 articles.

Volume 18: Friction, Lubrication, and Wear Technology

Edited by P.J. Blau

1992 • 942 pages

ISBN: 978-0-87170-380-4
Product Code: 06185G

Price: $297 / ASM Member: $225

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.

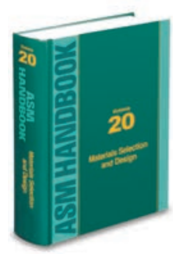
Volume 19: Fatigue and Fracture

1996 • 1057 pages

ISBN: 978-0-87170-385-9
Product Code: 06197G

Price: $297 / ASM Member: $225

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



Volume 20: Materials Selection and Design

Edited by G.E. Dieter

1997 • 901 pages

ISBN: 978-0-87170-386-6
Product Code: 06481G

Price: $297 / ASM Member: $225

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

Volume 21: Composites

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

2001 • 1201 pages

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

Price: $297 / ASM Member: $225

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

Comprehensive Index to ASM Handbooks, 3rd Edition

2011 • 967 pages

ISBN: 978-1-61503-828-2
Product Code: 05332G

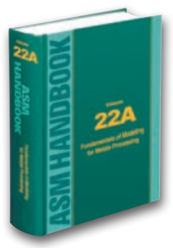
Price: $297 / ASM Member: $225

Composite of all the indexes in the 26-volume series. (Does not include new volumes 3, 4A, 4B, 4C, 4D, 5A, 5B, 6A, 7, and 23.) Comprehensive A-to-Z listing will help users find important handbook content in volumes where they may not have thought to look.

SAVE UP TO $87

SET SALE!

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



Volume 22A: Fundamentals of Modeling for Metals Processing

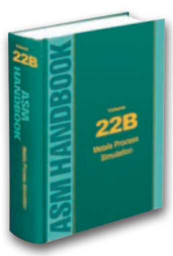
Edited by David Furrer and Lee Semiatin

2009 • 748 pages

ISBN: 978-0-61503-001-9
Product Code: 05215G

Price: $297 / ASM Member: $225

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



Volume 22B: Metals Process Simulation

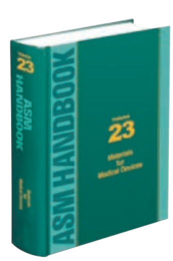
Edited by David Furrer and Lee Semiatin

2010 • 724 pages

ISBN: 978-0-61503-005-7
Product Code: 05281G

Price: $297 / ASM Member: $225

Fundamentals include input data, thermophysical properties and their measurement, phase diagrams, and microstructure. Processes include solidification, casting, metal forming, machining, joining, and heat treatment. Design topics include design optimization, error propagation and uncertainty, and cost estimating.



Volume 23: Materials for Medical Devices

Edited by Roger Narayan

2012 • 396 pages

ISBN: 978-1-61503-827-5
Product Code: 05285G

Price: $297 / ASM Member: $225

Implant materials covered include stainless steels, cobalt-base alloys, titanium, shape memory alloys, noble metals, ceramics, and polymers. Sections on failure analysis, biotribology and implant wear, corrosion, and biocompatibility.

ASM Handbooks Online™

Gain instant access everywhere, anytime

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

Explore the database at:
products.asminternational.org/hbk

BEST SELLER

SET SALE!

ASM Handbook Complete Set

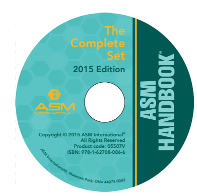
Save up to $1890!

34 Volumes + Index
ISBN: 978-1-62708-026-2
Product Code: 06951G

Price: $8900 / ASM Member: $6675

The ASM Handbook® series contains peer-reviewed, trusted information in every area of materials specialization. The series is the industry's best known and most comprehensive source of information on ferrous and nonferrous metals and materials technology and is packed with over 30,000 pages of articles, illustrations, tables, graphs, specifications and practical examples for today's engineer.

Each complete set includes new ASM Handbooks, Volumes 5B and 7, and the Comprehensive Index, Third Edition. Does not include the new Volume 3, *Alloy Phase Diagrams*, scheduled for release in early 2016.



ASM Handbook Complete Set DVD 2015 Edition

2015 • ASM International

ISBN: 978-1-62708-086-6
Product Code: 05507V

Price: $5908 / ASM Member: $5206

Contains peer-reviewed, trusted information in every area of materials specialization. The current set – 33 volumes, with more than 2,700 in-depth handbook articles, 31,000 pages – available on one disc! Search across the entire series or browse the table of contents for each volume. The content is presented in PDF format, with all of the standard Adobe Reader functions for navigation and finding content within articles. Use with any Windows® platform laptop or desktop PC with a DVD drive. Articles can be printed. Text, tables, and images can be copied and pasted.

Note: Disc files cannot be copied. DVD must be present in the local machine for content access. Purchasers of previous ASM Handbook CD or DVD Complete Sets can receive a special upgrade discount. Contact the ASM Member Service Center for details. Does not include new volumes 3, 5B, and 7.

Metals Handbook® Desk Edition, 2nd Edition

Edited by J.R. Davis

1998 • 1521 pages

ISBN: 978-0-87170-654-6 (Book)
ISBN: 978-0-87170-734-5 (CD)

Print Volume
Product Code: 06542G

Price: $307 / ASM Member: $305

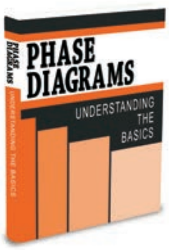
Single-work-station CD
Product Code: 06832C

Price: $307 / ASM Member: $231

Book and Single-work-station CD combination
Product Code: 06047AZ

Price: $457 / ASM Member: $341

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



Phase Diagrams: Understanding the Basics

Edited by F.C. Campbell

2012 • 470 pages

ISBN: 978-1-61503-835-0
Product Code: 05342G

Price: $187 / ASM Member: $135

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

Advances in Materials Technology for Fossil Power Plants

Proceedings from the Seventh International Conference, 2013, EPRI

Edited by: D. Gandy and J. Shingledecker

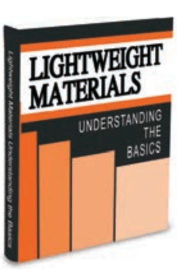
2013 • 1465 pages

ISBN: 978-1-62708-060-6
Product Code: 05440G

Price: $187 / ASM Member $135

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

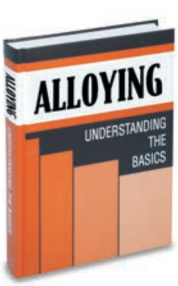
Edited by F.C. Campbell

2012 • 720 pages

ISBN: 978-1-61503-849-7
Product Code: 05355G

Price: $187 / ASM Member: $135

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



Alloying: Understanding the Basics

Edited by J.R. Davis

2001 • 647 pages

ISBN: 978-0-87170-744-4
Product Code: 06117G

Price: $187 / ASM Member: $135

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

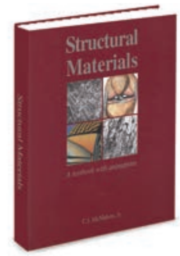
MS&T 2014 CD

Published by MS&T Partner Societies

CD-ROM papers in PDF format
Product Code: 05506A

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

Proceedings from the Materials Science and Technology 2014 Conference, Pittsburgh, PA October 13-16, 2014.



Structural Materials: A Textbook with Animations

By C.J. McMahon, Jr.

2004 • 470 pages

ISBN: 978-0-96465-985-8
Product Code: 05913G

Price: $107 / ASM Member: $81

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.

SAVE UP TO $67

SET SALE!

Worldwide Guide 2-Volume Set
Product Code: 05192G
Price: $547 / ASM Member: $405

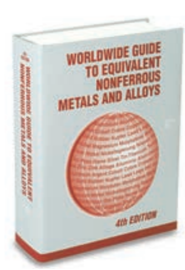
Worldwide Guide to Equivalent Irons & Steels, 5th Edition

2006 • 1416 pages

ISBN: 978-0-87170-822-9
Product Code: 05121G

Price: $307 / ASM Member: $231

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



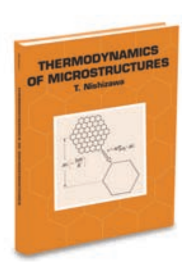
Worldwide Guide to Equivalent Nonferrous Metals and Alloys, 4th Edition

2001 • 1036 pages

ISBN: 978-0-87170-741-3
Product Code:06735G

Price: $307 / ASM Member: $231

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



Thermodynamics of Microstructures

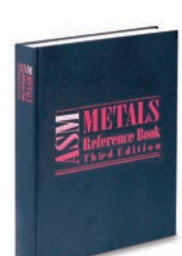
By Taiji Nishizawa, translated by Kiyohito Ishida

2008 • 308 pages

ISBN: 978-0-87170-716-1
Product Code: 05232G

Price: $207 / ASM Member: $155

Fundamental relationships governing the behavior of microstructures.



ASM Metals Reference Book, 3rd Edition

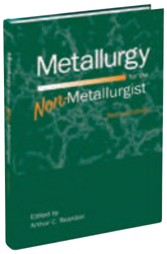
Edited by M.L. Bauccio

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.



THIS NEW EDITION IS A "MUST-HAVE" READY REFERENCE ON METALLURGY!

Metallurgy for the Non-Metallurgist™ 2nd Edition

Edited by Arthur C. Reardon

2011 • 526 pages

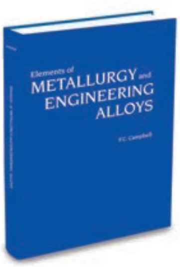
ISBN: 978-1-61503-821-3
Product Code: 05306G

Price: $177 / ASM Member: $135

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.

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



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

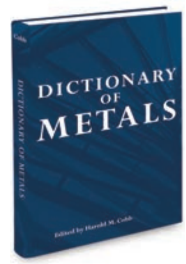
By Ramnarayan Chattopadhyay

2014 • 336 pages

ISBN: 978-1-62708-064-4
Product Code: 05436G

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

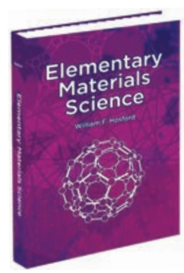
Edited by Harold M. Cobb

2012 • 374 pages

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

Price: $157 / ASM Member: $115

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



Elementary Materials Science

By William F. Hosford

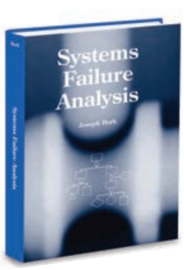
2013 • 188 pages

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

Price: $83 / ASM Member: $65

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.

FAILURE ANALYSIS



Systems Failure Analysis

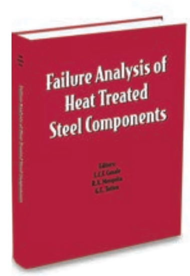
By Joseph Berk

2009 • 214 pages

ISBN: 978-1-61503-012-5
Product Code: 05278G

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.



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.

Understanding How Components Fail, 3rd Edition

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.

SAVE UP TO $47

SET SALE!

Handbook of Case Histories in Failure Analysis 2-Volume Set
Product Code: 06391G
Price: $367 / ASM Member: $275

Handbook of Case Histories in Failure Analysis Volume 1

Edited by K.A. Esaklul
1992 • 504 pages, 115 case histories
ISBN: 978-0-87170-453-5 • Product Code: 06340G
Price: $207 / ASM Member: $155

Handbook of Case Histories in Failure Analysis Volume 2

Edited by K.A. Esaklul
1993 • 583 pages, 120 case histories
ISBN: 978-0-87170-495-5 • Product Code: 06410G
Price: $207 / ASM Member: $155

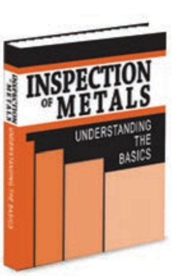
Learn how others have solved failures in various industries such as automotive, aerospace, utilities, oil and gas, petrochemical, biomedical, ground transportation, off-highway vehicles, and more.

Damage Mechanisms and Life Assessment of High-Temperature Components

By R. Viswanathan
1989 • 440 pages
ISBN: 978-0-87170-358-3
Product Code: 06049G
Price: $137 / ASM Member: $105

Brings together the theoretical aspects of high-temperature damage phenomena and the practical aspects of assessing the actual damage on a component-specific basis. Lays the theoretical foundation with respect to toughness, embrittlement phenomena, creep, fatigue, and creep-fatigue interaction.

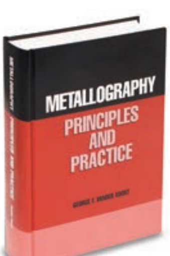
METALLOGRAPHY & MATERIALS CHARACTERIZATION



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

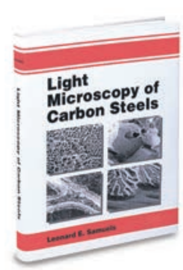
Emphasizes final part inspection at the manufacturing facility or on receipt at the user's facility. Provides an intermediate level overview to the different methods used to inspect metals and finished parts and a more detailed review of the specific inspection methods for important metal product forms. 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

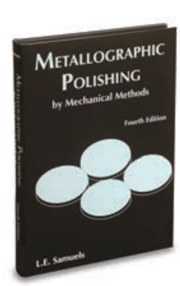
A proven reference work for metallographers, engineers, and technicians as well as students. Thoroughly referenced and well-illustrated with an extensive collection of micrographs and macrographs.



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

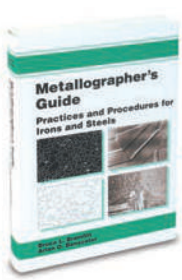
By Brian S. Hayes and Luther M. Gammon

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

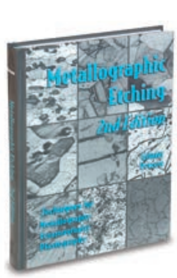
By B.L. Bramfitt and A.O. Benscoter

2002 • 354 pages

ISBN: 978-0-87170-748-2
Product Code: 06040G

Price: $257 / ASM Member: $185

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



Metallographic Etching, 2nd Edition

By G. Petzow

1999 • 240 pages

ISBN: 978-0-87170-633-1
Product Code: 06670G

Price: $127 / ASM Member: $95

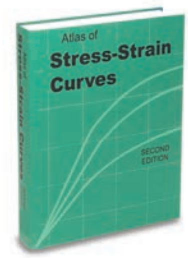
An outstanding source on etchants of all types and electrolytic polishing solutions used by metallographers to reveal the structure of nearly any material to be prepared and examined.

The International Metallographic Society

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

IMS International Metallographic Society ASM INTERNATIONAL

Become a member today.
Visit metallography.net



Atlas of Stress-Strain Curves, 2nd Edition

2002 • 816 pages

ISBN: 978-0-87170-739-0
Product Code: 06825G

Price: $307 / ASM Member: $231

More than 1,400 curves normalized in appearance to aid making comparisons among materials. All diagrams include metric (SI) units, and many also include U.S. customary units captioned with standard designation, the primary source of the curve, mechanical properties, condition of sample, strain rate, test temperature, and alloy composition.

Tensile Testing, 2nd Edition

Edited by J.R. Davis

2004 • 283 pages

ISBN: 978-0-87170-806-9
Product Code: 05106G

Price: $137 / ASM Member: $105

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

Nondestructive Testing

By L. Cartz

1995 • 229 pages

ISBN: 978-0-87170-517-4
Product Code: 06390G

Price: $107 / ASM Member: $75

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

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

SAVE UP TO $57

SET SALE!

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

Fatigue and Durability of Structural Materials

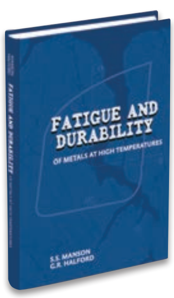
By S.S. Manson and G.R. Halford

2006 • 456 pages

ISBN: 978-0-87170-825-0
Product Code: 06987G

Price: $257 / ASM Member: $185

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



Fatigue and Durability of Metals at High Temperatures

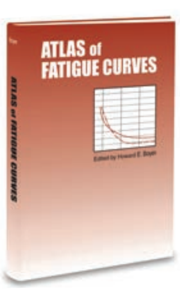
By S.S. Manson and G.R. Halford

2009 • 268 pages

ISBN: 978-0-87170-718-5
Product Code: 05206G

Price: $257 / ASM Member: $185

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



Atlas of Fatigue Curves

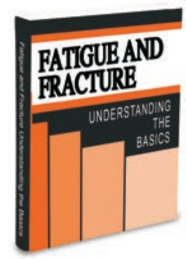
Edited by H.E. Boyer

1986 • 518 pages • Illustrated

ISBN: 978-0-87170-214-2
Product Code: 06156G

Price: $307 / ASM Member: $231

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



Fatigue and Fracture: Understanding the Basics

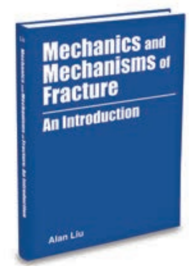
Edited by F.C. Campbell

2012 • 698 pages

ISBN: 978-1-61503-976-0
Product Code: 05361G

Price: $187 / ASM Member: $135

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



Mechanics and Mechanisms of Fracture: An Introduction

By A.F. Liu

2005 • 458 pages

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

ISBN: 978-0-87170-802-1
Product Code: 06954G

Price: $167 / ASM Member: $125

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

Fatigue and Fracture Reference Library DVD 2012 Edition

2012 • ASM International

ISBN: 978-1-61503-981-4
Product Code: 05366V

Price: $703 / ASM Member: $601

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

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

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

MANUFACTURING & DESIGN

Extrusion, 2nd Edition

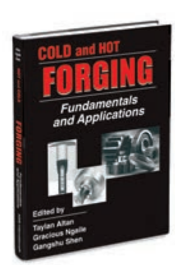
Edited by M. Bauser, G. Sauer, and K. Siegert

2006 • 608 pages

ISBN: 978-0-87170-837-3
Product Code: 06998G

Price: $257 / ASM Member: $185

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



Cold and Hot Forging: Fundamentals and Applications

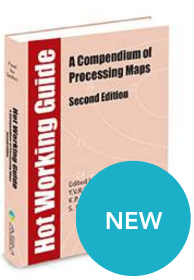
Edited by T. Altan, G. Ngaile and G. Shen

2005 • 341 pages

ISBN: 978-0-87170-805-2
Product Code: 05104G

Price: $207 / ASM Member: $155

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



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

IBSN: 978-1-62708-091-0
Product Code: 05445G

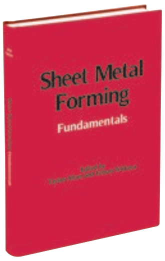
Price: $265 / ASM Member: $199

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

SAVE UP TO $87

SET SALE!

Sheet Metal Forming: 2-Volume Set
Product Code: 05351G
Price: $327 / ASM Member: $245



Sheet Metal Forming: Fundamentals

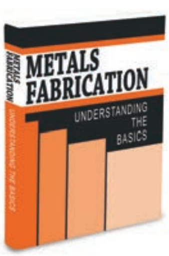
Edited by Taylan Altan and A. Erman Tekkaya
2012 • 314 pages
ISBN: 978-1-61503-842-8
Product Code: 05340G
Price: $207 / ASM Member $155

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

Sheet Metal Forming: Processes and Applications

Edited by Taylan Altan and A. Erman Tekkaya
2012 • 382 pages
ISBN: 978-1-61503-844-2
Product Code: 05350G
Price: $207 / ASM Member: $155

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



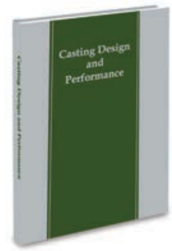
Metals Fabrication: Understanding the Basics

By F.C. Campbell
2013 • 439 pages
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

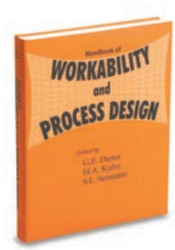
2009 • 272 pages
ISBN: 978-0-87170-724-6
Product Code: 05263G
Price: $197 / ASM Member: $145

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

Gear Materials, Properties, and Manufacture

Edited by J.R. Davis
2005 • 339 pages
ISBN: 978-0-87170-815-1
Product Code: 05125G
Price: $187 / ASM Member: $135

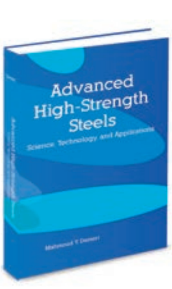
Overview of gears, lubrication and wear; in-depth treatment of metallic alloys (ferrous and nonferrous) and plastic gear materials; gear manufacturing methods (including metal removal, casting, forming, and forging); heat treatment; and failure analysis, fatigue life prediction and mechanical testing.



Handbook of Workability and Process Design

Edited by G.E. Dieter, H.A. Kuhn, and S.L. Semiatin
2003 • 414 pages
ISBN: 978-0-87170-778-9
Product Code: 06701G
Price: $247 / ASM Member: $185

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

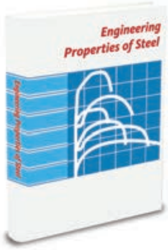
A comprehensive examination of the types, microstructures, and attributes of AHSS as well as a review of current and future applications, the benefits, trends, and environmental and sustainability issues.

Stainless Steels Reference Library DVD, 2011 Edition

ASM International • 2011
Over 11,000 pages in PDF format.
ISBN: 978-1-61503-829-9
Product Code: 05334V
Price: $703 / ASM Member: $601

Complete guide to the selection, designations, processing, properties, and performance of stainless steel alloys.

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

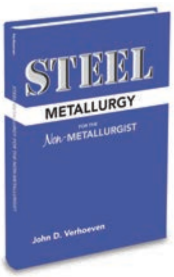
Edited by Philip Harvey

1982 • 509 pages

ISBN: 978-0-87170-144-2
Product Code: 06241G

Price: $157 / ASM Member: $115

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



Steel Metallurgy for the Non-Metallurgist

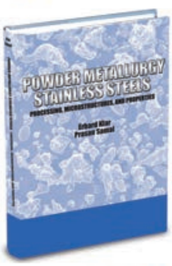
By John D. Verhoeven

2007 • 225 pages

ISBN: 978-0-87170-858-8
Product Code: 05214G

Price: $107 / ASM Member: $75

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



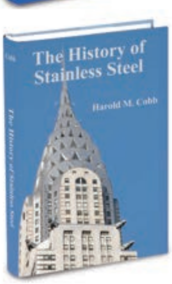
Powder Metallurgy Stainless Steels: Processing, Microstructures, and Properties

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

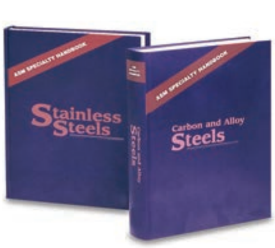
Price: $83 / ASM Member: $65

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.

SAVE UP TO $67

SET SALE!

ASM Specialty Handbook® Steels, 2-Volume Set
Product Code: 06491G
Price: $547 / ASM Member: $405



ASM Specialty Handbook® Stainless Steels

Edited by J.R. Davis

1994 • 576 pages

ISBN: 978-0-87170-503-7
Product Code: 06398G

Price: $307 / ASM Member: $231

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

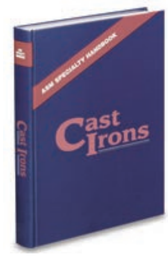
ASM Specialty Handbook® Carbon and Alloy Steels

Edited by J.R. Davis

1996 • 731 pages

ISBN: 978-0-87170-557-0
Product Code: 06611G

Price: $307 / ASM Member: $231



ASM Specialty Handbook® Cast Irons

Edited by J.R. Davis

1996 • 494 pages
ISBN: 978-0-87170-564-8
Product Code: 06613G

Price: $307 / ASM Member: $231

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

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

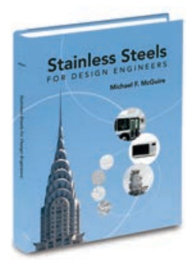
By George Krauss

2015 • 682 pages

ISBN: 978-1-62708-083-5
Product Code: 05441G

Price: $207 / ASM Member: $155

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



Stainless Steels for Design Engineers

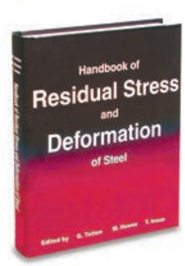
By Michael F. McGuire

2008 • 312 pages

ISBN: 978-0-87170-717-8
Product Code: 05231G

Price: $187 / ASM Member: $135

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



Handbook of Residual Stress and Deformation of Steel

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

2002 • 499 pages

ISBN: 978-0-87170-729-1
Product Code: 06700G

Price: $167 / ASM Member: $125

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

Introduction to Stainless Steels, 3rd Edition

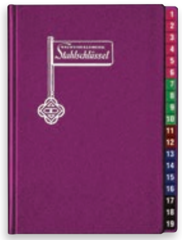
By J. Beddoes and J.G. Parr

1999 • 315 pages

ISBN: 978-0-87170-673-7
Product Code: 06685G

Price: $53 / ASM Member: $42

FOR MORE DETAILS
Visit **asminternational.org/referencepubs** and explore all the offerings available to ASM members.



Stahlschlüssel (Key To Steel) 2013 Edition

By C.W. Wegst

2013 • 850 pages

ISBN: 978-3-922599-29-6
Product Code: 05378G

Price: $233 / ASM Member: $205

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

Stahlschlüssel (Key To Steel) CD-ROM 2013 Edition

By C.W. Wegst

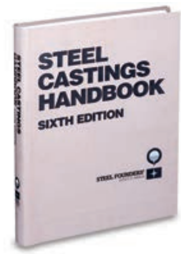
2013

ISBN: 978-3-922599-30-2
Product Code: 05378A

Price: $683 / ASM Member: $605

(Single User Network Installation)

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



Steel Castings Handbook, 6th Edition

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

1995 • 472 pages

ISBN: 978-0-87170-556-3
Product Code: 06820G

Price: $233 / ASM Member: $175

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

Tool Steels, 5th Edition

By G. Roberts, G. Krauss, and R. Kennedy

1998 • 364 pages

ISBN: 978-0-87170-599-0
Product Code: 06590G

Price: $207 / ASM Member: $155

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

NONFERROUS METALS

NEW

Titanium: Physical Metallurgy, Processing, and Applications

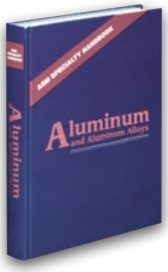
Edited by F.H. Froes

2015 • 404 pages

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

Price: $187 / ASM Member: $135

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



ASM Specialty Handbook® Aluminum & Aluminum Alloys

Edited by J.R. Davis

1993 • 784 pages

ISBN: 978-0-87170-496-2
Product Code: 06610G

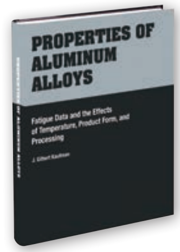
Price: $307 / ASM Member: $231

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

SAVE UP TO $57

SET SALE!

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



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

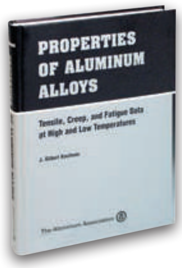
Edited by J.G. Kaufman

2008 • 574 pages

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

Price: $257 / ASM Member: $195

One of the most comprehensive collections of fatigue data yet available for aluminum alloys, temperatures, and products. The data, including over 1,000 curves and numerous tables, are presented in a consistent format, conveniently arranged by alloy and temper.



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

Edited by J.G. Kaufman

1999 • 311 pages

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

Price: $257 / ASM Member: $195

Co-published by the Aluminum Association and ASM International.

ASM Specialty Handbook® Copper and Copper Alloys

Edited by J.R. Davis
2001 • 652 pages
ISBN: 978-0-87170-726-0
Product Code: 06605G

Price: $307 / ASM Member: $231

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

ASM Specialty Handbook® Heat-Resistant Materials

Edited by J.R. Davis
1997 • 591 pages
ISBN: 978-0-87170-596-9
Product Code: 06612G

Price: $307 / ASM Member: $231

ASM Specialty Handbook® Magnesium and Magnesium Alloys

Edited by M. Avedesian and H. Baker
1999 • 314 pages
ISBN: 978-0-87170-657-7
Product Code: 06770G

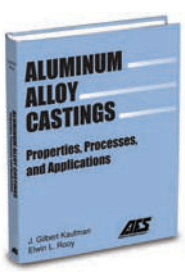
Price: $307 / ASM Member: $231

ASM Specialty Handbook® Nickel, Cobalt, and Their Alloys

Edited by J.R. Davis
2000 • 442 pages
ISBN: 978-0-87170-685-0
Product Code: 06178G

Price: $307 / ASM Member: $231

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
Product Code: 06945G

Price: $477 / ASM Member: $405

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

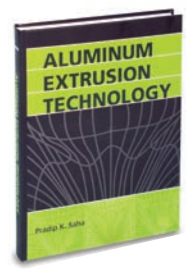
Aluminum Reference Library DVD, 2011 Edition

2011 • More than 15,000 pages in PDF format.
ISBN: 978-1-61503-723-0
Product Code: 05322V

Price: $1,003 / ASM Member: $901

A complete guide to the selection, designations, processing, properties, and performance of aluminum and aluminum alloys. All commercial and standard grades of aluminum and aluminum alloys are covered.

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.

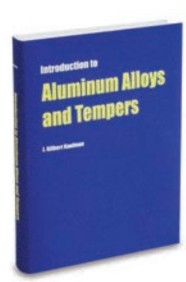


Aluminum Extrusion Technology

By P.K. Saha
2000 • 259 pages
ISBN: 978-0-87170-644-7
Product Code: 06826G

Price: $207 / ASM Member: $165

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



Introduction to Aluminum Alloys and Tempers

By J.G. Kaufman
2000 • 258 pages
ISBN: 978-0-87170-689-8
Product Code: 06180G

Price: $43 / ASM Member: $32

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

Beryllium Chemistry and Processing

By K.A. Walsh • Edited by E.E. Vidal, A. Goldberg, E. Dalder, D.L. Olson, and B. Mishra
2009 • 680 pages
ISBN: 978-0-87170-721-5
Product Code: 05223G

Price: $257 / ASM Member: $191

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

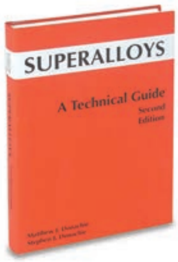
Superalloys Reference Library DVD, 2011 Edition

2011 • Approx. 10,000 pages in PDF format.
ISBN: 978-1-61503-830-5
Product Code: 05335V

Price: $703 / ASM Member: $601

A complete guide to the selection, designations, processing, properties, and performance of superalloys. All commercial grades covered, with extensive coverage on the most widely used nickel-base alloys.

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.



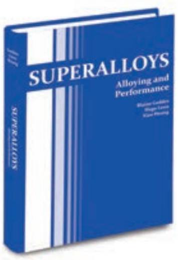
Superalloys: A Technical Guide, 2nd Edition

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

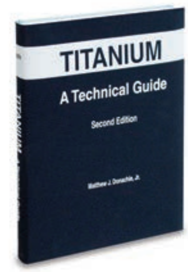
An introduction for understanding the compositional complexity of superalloys and the wide range of alloys developed for specific applications. The basics of alloying, strengthening mechanisms, and structure of superalloys are explained in optimizing particular mechanical properties, oxidation/corrosion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

Available on the App Store

Available on the Android App Store

Aluminum Quick Reference App

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



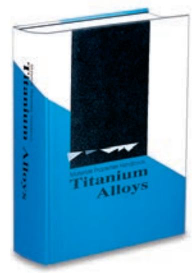
Titanium: A Technical Guide, 2nd Edition

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.

Titanium Reference Library DVD, 2010 Edition

2010 • Almost 10,000 pages of content in PDF format
ISBN: 978-1-61503-721-6
Product Code: 05318V

Price: $703 / ASM Member: $601

A complete guide to the selection, designations, processing, properties, and performance of all commercial grades of pure titanium and titanium alloys. Extensive coverage for alloy Ti-6Al-4V, the industry workhorse.

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.

WELDING, BRAZING & SOLDERING

Joining: Understanding the Basics

Edited by F.C. Campbell

2011 • 346 pages
ISBN: 978-1-61503-825-1
Product Code: 05329G

Price: $187 / ASM Member: $135

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

SAVE UP TO $39

SET SALE!

Principles of Brazing and Principles of Soldering
Product Code: 05124G
Price: $287 / ASM Member: $215

Principles of Brazing

By David M. Jacobson and Giles Humpston

2005 • 268 pages
ISBN: 978-0-87170-812-0
Product Code: 05123G

Price: $167 / ASM Member: $125

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

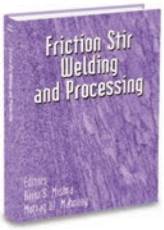
Principles of Soldering

By Giles Humpston and David M. Jacobson

2004 • 271 pages
ISBN: 978-0-87170-792-5
Product Code: 06244G

Price: $167 / ASM Member: $125

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



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

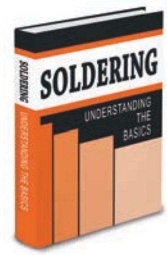
Weld Integrity and Performance

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.

HEAT TREATING

SAVE UP TO $67

SET SALE!

Heat Treater's Guides,
2-Volume Set Product Code: 06489G

Price: $547 / ASM Member: $405

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

1995 • 904 pages

ISBN: 978-0-87170-520-4
Product Code: 06400G

Price: $307 / ASM Member: $231

Each data sheet gives the chemical composition of the alloy, a listing of similar U.S. and foreign alloys, its characteristics, and the recommended heat treating procedure. 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.

SAVE UP TO $67

SET SALE!

Atlas of Time-Temperature Diagrams, 2-Volume Set
Irons & Steels / Nonferrous Alloys
Product Code: 06191G

Price: $547 / ASM Member: $405

Atlas of Time-Temperature Diagrams

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

Irons & Steels

Edited by G. Vander Voort

1991 • 804 pages • 1,839 diagrams

ISBN: 978-0-87170-415-3
Product Code: 06150G

Price: $307 / ASM Member: $231

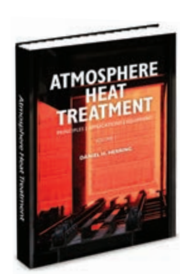
Nonferrous Alloys

Edited by G. Vander Voort

1991 • 474 pages • 500 diagrams

ISBN: 978-0-87170-428-3
Product Code: 06190G

Price: $307 / ASM Member: $231



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: $162.99 / ASM Member $145.49

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.

Available on the App Store
Available on the Android App Store

Heat Treater's Guide Companion

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.

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

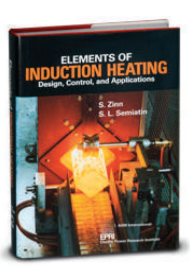
By J.L. Dossett and H.E. Boyer

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.



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.

Heat Treating Reference Library DVD, 2012 Edition

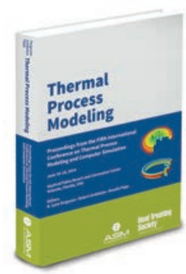
2012 • ASM International

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

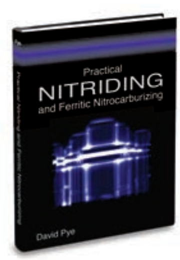
Edited by B.L. Ferguson, R. Goldstein, and R. Papp

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

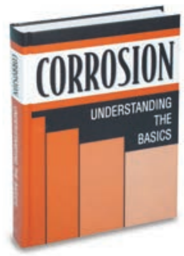
By David Pye

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.



Corrosion: Understanding the Basics

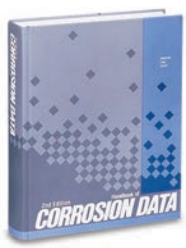
Edited by J.R. Davis

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

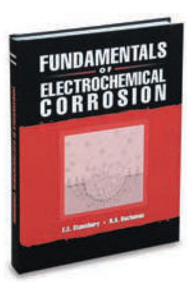
Edited by B. Craig and D. Anderson

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.



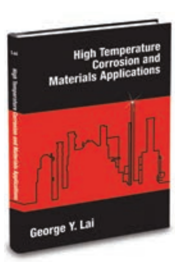
Fundamentals of Electrochemical Corrosion

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

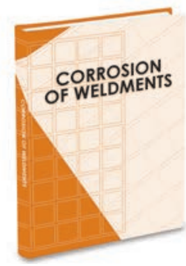
By George Y. Lai

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

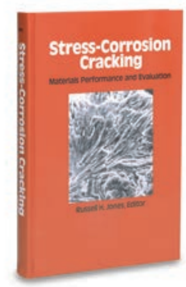
Edited by J.R. Davis

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.



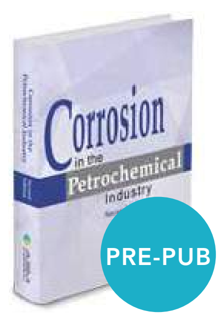
Stress-Corrosion Cracking: Materials Performance and Evaluation

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

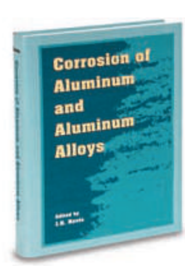
Edited by Victoria Burt

2015 • Approx. 500 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~~
Prepublication Price: $199 / ASM Member: $149
Prepublication price good through November 30, 2015!



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

COATINGS & SURFACE ENGINEERING

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.

Surface Engineering for Corrosion and Wear Resistance

Edited by J.R. Davis

2001 • 279 pages

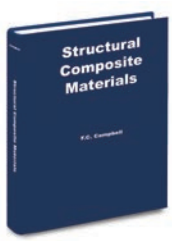
Co-published by IOM Communications and ASM International

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

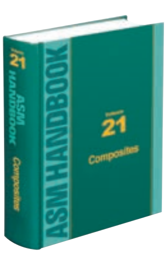
By F.C. Campbell

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

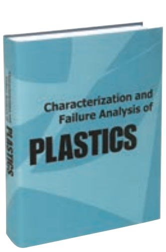
Edited by D.B. Miracle and S.L. Donaldson

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.

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.

SAVE UP TO $164

SET SALE!

Engineered Materials Handbook® 3-Volume Set
Product Code: 06943G
Price: $457 / ASM Member: $405

Engineered Materials Handbook®

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

Volume 2: Engineering Plastics

1988 • 883 pages

ISBN: 978-0-87170-280-7
Product Code: 06248G

Price: $207 / ASM Member: $155

Volume 3: Adhesives and Sealants

1990 • 893 pages

ISBN: 978-0-87170-281-4
Product Code: 06012G

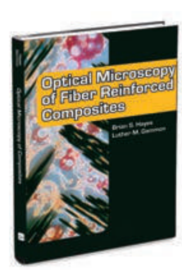
Price: $207 / ASM Member: $155

Volume 4: Ceramics and Glasses

1991 • 1217 pages

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

Price: $207 / ASM Member: $155



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.

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

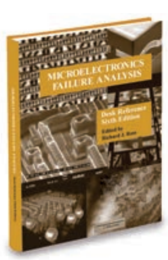
2014 • 560 pages

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.

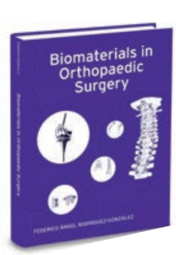
The Electronic Device Failure Analysis Society℠

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

Visit: edfas.asminternational.org

EDFAS
Electronic Device Failure Analysis Society
ASM INTERNATIONAL

MEDICAL DEVICE MATERIALS



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.

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

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

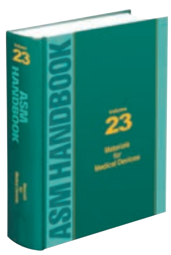
Become a member today: **smst.asminternational.org**

SMST℠
Shape Memory & Superelastic Technology
ASM INTERNATIONAL

SAVE UP TO $127

SET SALE!

ASM Handbook Volume 23 AND Materials Coatings for Medical Devices: Cardiovascular
Product Code: 05368G
Price: $477 / ASM Member: $375



Volume 23: Materials for Medical Devices

Edited by Roger Narayan

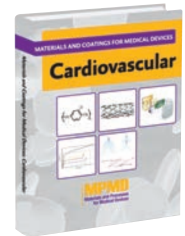
2012 • 396 pages

ISBN: 978-1-61503-827-5
Product Code: 05285G

Price: $297 / ASM Member: $225

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

Price: $307 / ASM Member: $231

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

ALLOY PHASE DIAGRAMS

Pearson's Crystal Data: Crystal Structure Database for Inorganic Compounds®*

Edited by Pierre Villars and Karin Cenzual

2015/16

ISBN: 978-1-62708-098-9
Product Code: 57795A

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.

Named as an Outstanding Academic Title Winner, 2009
- Choice: Current Reviews for Academic Libraries

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

Binary Alloy Phase Diagrams, 2nd Edition

Edited by T.B. Massalski, H. Okamoto, P.R. Subramanian, and L. Kacprzak

1990 • 3589 pages

ISBN: 978-0-87170-403-0 (3-Volume Set)
Product Code: 57718G

Price: $1643 / ASM Member: $1546

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

Pearson's Desk Edition

Edited by Pierre Villars • 1997

ISBN: 978-0-87170-603-4
(2-Volume Set)
Product Code: 57763G

Price: $950 / ASM Member: $850

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

Handbook of Ternary Alloy Phase Diagrams
10-Volume Set

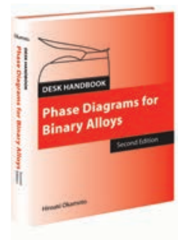
Edited by Pierre Villars, Alan Prince, and Hiroaki Okamoto

1995

ISBN: 978-0-87170-525-9
Product Code: 57706G

Price: $8514 / ASM Member: $8417

More than 18,000 ternary diagrams.



Desk Handbook: Phase Diagrams for Binary Alloys, 2nd Edition

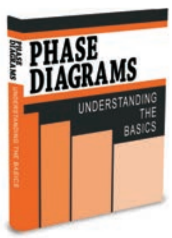
By Hiroaki Okamoto

2010 • 855 pages

ISBN: 978-1-61503-046-0
Product Code: 57751G

Price: $358 / ASM Member: $286

2,421 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.



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.

ADVANCED MATERIALS & PROCESSES
EDITORIAL PREVIEW

NOVEMBER/DECEMBER 2015
Materials Testing & Characterization

Highlighting:
- Joining Nitinol to Stainless Steel
- Atomic Probe Tomography Update
- Advances in Testing Equipment & Processes

Special Supplements:
International Thermal Spray & Surface Engineering newsletter covering emerging technologies in the thermal spray industry.

HTPro newsletter covering heat treating technology, processes, materials, and equipment, along with Heat Treating Society news and initiatives.

Advertising closes October 5

JANUARY 2016
Materials Testing & Characterization

Highlighting:
- Joining with Metallic Glue
- Progress in Linear Friction Welding
- Additively Manufactured Spacecraft Vents

Advertising bonus:
- Corporate Spotlight

Advertising closes December 4

Subscriptions/Customer Service:
800.336.5152 ext. 0
MemberServiceCenter@asminternational.org

Sales Staff:
Skip Wolfe, *Director, Sales and Marketing*
440.338.5151 ext. 5226
skip.wolfe@asminternational.org

***AM&P*/ASM Web Media**
Erik Klingerman, *National Sales Manager*
440.338.5151 ext. 5574
erik.klingerman@asminternational.org

***iTSSe*/Affiliate Sponsorships**
Kelly Thomas, CEM.CMP, *Manager, Events*
440.338.1733
kelly.thomas@asminternational.org

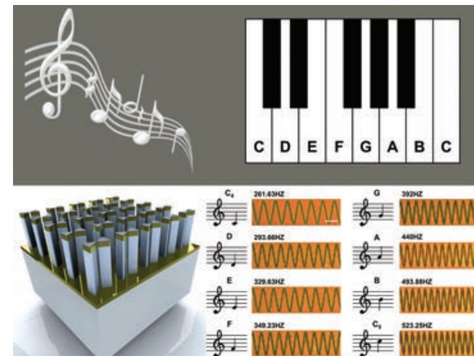
AD INDEX

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

STRESS RELIEF

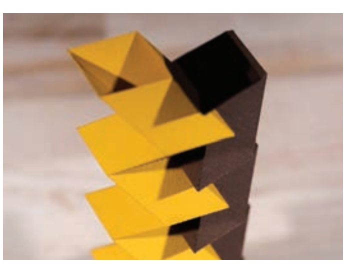
NANO PIANO AMPS UP DATA STORAGE

Researchers from the University of Illinois at Urbana-Champaign demonstrated the first-ever recording of optically encoded audio onto a nonmagnetic plasmonic nanostructure, opening the door to multiple uses in information processing and storage. “The chip’s dimensions are roughly equivalent to the thickness of human hair,” says Kimani Toussaint, associate professor of mechanical science and engineering. Specifically, the photographic film property exhibited by an array of gold, pillar-supported bowtie nanoantennas (pBNAs)—previously discovered by Toussaint’s group—was exploited to store sound and audio files. Compared with conventional magnetic film for analog data storage, the capacity of pBNAs is around 5600 times larger.



Nano piano: Arrays of gold, pillar-supported bowtie nanoantennas (bottom left) can be used to record distinct musical notes, as shown in these dark-field microscopy images (bottom right).

Researchers demonstrated that the pBNAs could be used to store sound information either as a temporally varying intensity waveform or a frequency varying intensity waveform. Eight musical notes were stored on a pBNA chip and then retrieved and played back. Researchers recorded audio signals by using a microscope to scan a sound-modulated laser beam directly on their nanostructures. Retrieval and playback is achieved by using the same microscope to image the recorded waveform onto a digital camera, whereby simple signal processing can be performed. *For more information: Kimani Toussaint, 217.244.4088, ktoussai@illinois.edu, www.illinois.edu.*



“Zippered tube” configuration makes paper structures stiff enough to hold weight yet able to fold flat for easy shipping and storage. Courtesy of Rob Felt/ Georgia Tech.

USING ORIGAMI TO BUILD BRIDGES?

A new “zippered tube” origami configuration makes paper structures stiff enough to hold weight yet able to fold flat for easy shipping and storage. Origami structures would be useful in many engineering and everyday applications, such as a robotic arm that could reach out and scrunch up, a construction crane that could fold to pick up or deliver a load, or pop-up furniture. Glaucio Paulino, professor at Georgia Tech, sees particular potential for quick-assembling emergency shelters, bridges, and other infrastructure in the wake of a natural disaster.

Researchers used a particular origami technique called Miura-ori folding. Precise, zig-zag folded strips of paper are made and then two strips are glued together to make a tube. While the single strip of paper is highly flexible, the tube is stiffer and does not fold in as many directions. Researchers tried coupling tubes in different configurations to see if that added to the structural stiffness of the paper structures and found that interlocking two tubes in zipper-like fashion made them much stiffer and harder to twist or bend. The structure folds up flat, yet rapidly and easily expands to the rigid tube configuration. Paper prototypes were used to demonstrate how a thin, flexible sheet can be folded into functional structures, but the techniques could be applied to other thin materials. Larger-scale applications could combine metal or plastic panels with hinges. *For more information: Glaucio Paulino, 404.385.3996, glaucio.paulino@ce.gatech.edu, www.gatech.edu.*

SQUID TEETH INSPIRE SELF-HEALING MATERIAL

Scientists at the University of Pennsylvania, Philadelphia, are studying the teeth of cephalopods in order to create a material that heals when water is present, in the same way that a squid’s teeth do. Researchers reproduced the type of proteins found in the self-healing teeth and then triggered bacteria to make them in a lab environment. To test the new material’s strength, the team created a dog-bone shaped sample of the polymer and then cut it in half. Using warm water at about 113°F and a slight amount of pressure with a metal tool, the two halves reunited to reform the dog-bone shape. Strength tests show that the healed material is just as strong as the original part. This type of material could be used to coat products such as deep-sea Internet cables or perhaps help biomedical devices achieve longer lifespans. *upenn.edu.*

A new kind of self-healing plastic inspired by squid teeth can heal itself with water. Courtesy of Demirel Lab/Penn State.