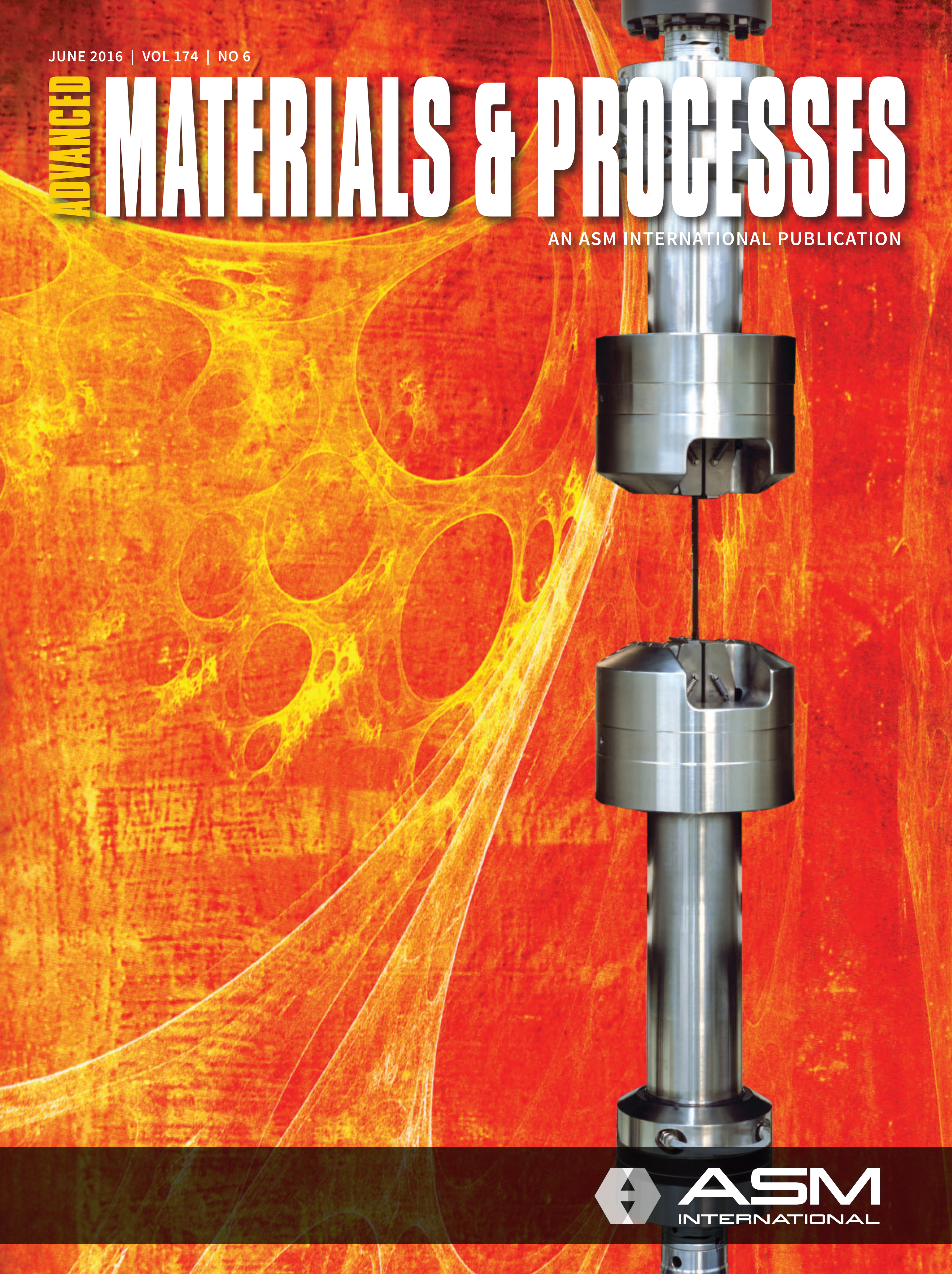
JUNE 2016 | VOL 174 | NO 6

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION



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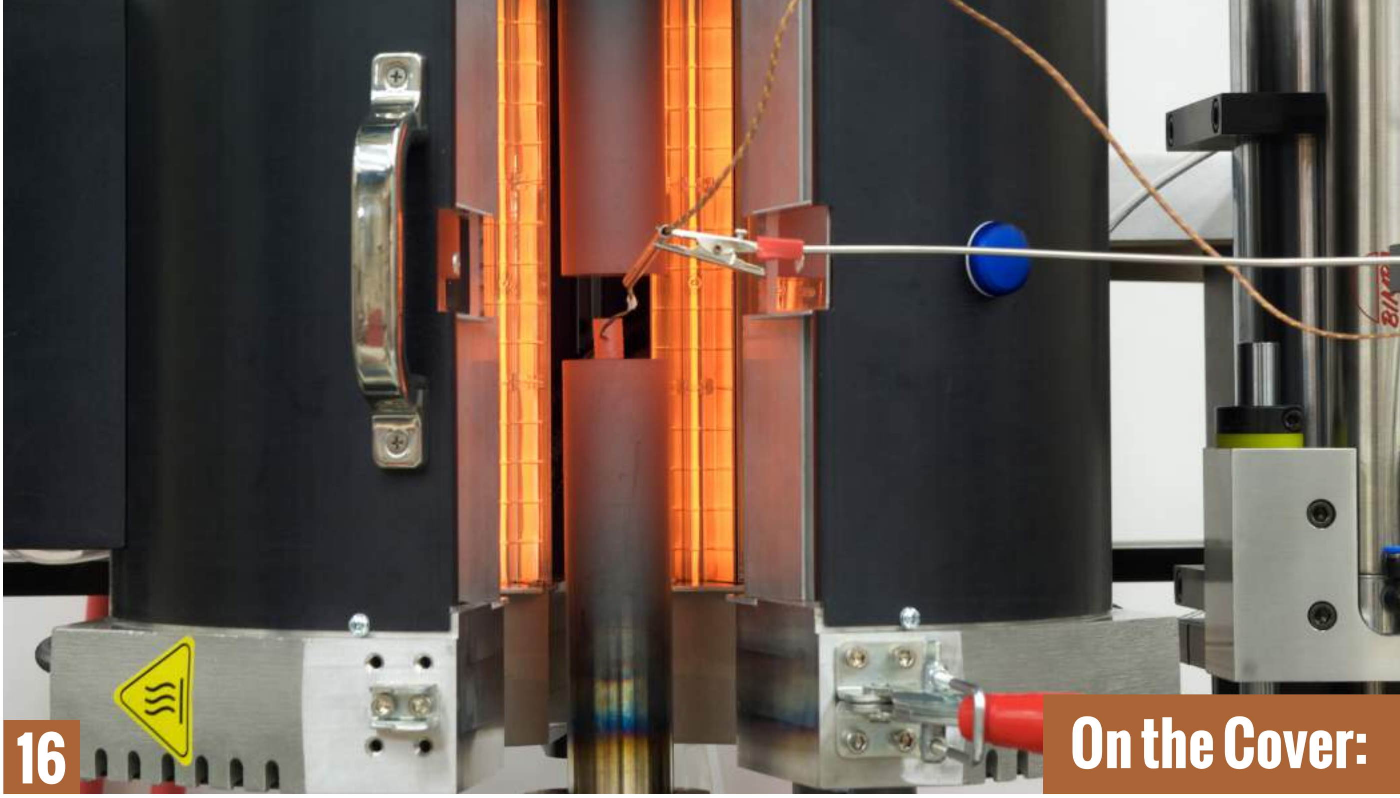
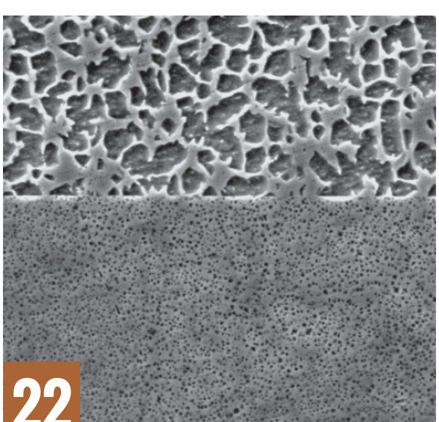


On the Cover:

For high-temperature testing, it is important to understand the entire system—heating, gripping, and sensing—and how it all works together. Courtesy of MTS Systems Corp., www.mts.com.



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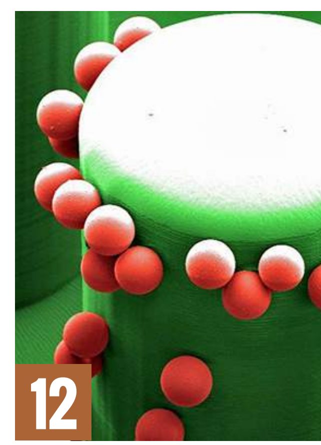
FEATURES



TRENDS

INDUSTRY NEWS

DEPARTMENTS

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THE INTERNET OF THINGS– YES, 'IT'S A THING'

I recently returned from a whirlwind visit of Germany, as a guest of Germany Trade and Invest, the country's economic development agency. The organization promotes Germany as a business and technology location and supports companies with global market information. During the tour, we visited several companies, universities, research institutions, and finally, Hannover Messe, the world's largest industrial trade fair. For the first time in the fair's history, the U.S. was the partner country. As part of the festivities, President Obama and German Chancellor Merkel did a special "walkaround" during the opening morning of the exhibit. Obama's participation at this event was the first for a sitting U.S. President.

Hannover Messe is actually five shows in one, with separate pavilions for industrial automation, industrial supply, digital factory, energy, and research and technology. The overall theme was Industry 4.0, which the U.S. often calls the Internet of Things (IoT) or the Industrial Internet. In any case, Germany is on it: The country is investing heavily in making sure all of its companies, universities, and research organizations are on the same page regarding what is widely being called the fourth Industrial Revolution. As Kuka Robotics' chief technology officer said during a panel discussion, "Data is the new oil." New algorithms for collecting and making sense of data—aka *big data*—is the starting point. The premise is that by analyzing huge volumes of data, more intelligent manufacturing can be achieved, among other goals.

German Chancellor Merkel and President Obama visit with MakerGear at Hannover Messe.

Another key idea is decentralized control, where every part of a production system has its own intelligence. From this type of setup, companies will be able to nimbly move from mass production to mass customization. During our tour, we visited a few companies doing just that. Kärcher, a manufacturer of cleaning equipment, makes hundreds of slightly different versions of its machines with very little changeover involved, simply by managing all of its production assets digitally as orders arrive. Another company called Sensitec, located on a former 5000-employee IBM campus near Frankfurt, is fabricating its own wafers and building customized sensors with just 170 employees. Some of these sensors live on NASA's Mars rovers including Curiosity, Spirit, and Opportunity. They are also used on wind turbines, electric vehicles, train wheels, and robot joints. More than 90% of these sensors are custom built, just the kind of tool able to collect the data required by Industry 4.0.

Overall, the tour made me wonder what the materials community is doing with regard to IoT initiatives. If a lesson can be learned from the Germans, it is one of having a united and organized approach to moving its industry forward into the digital future. If you have an opinion on how these ideas will impact materials science and engineering, we'd like to hear it.

F. Richards

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MARKET SPOTLIGHT

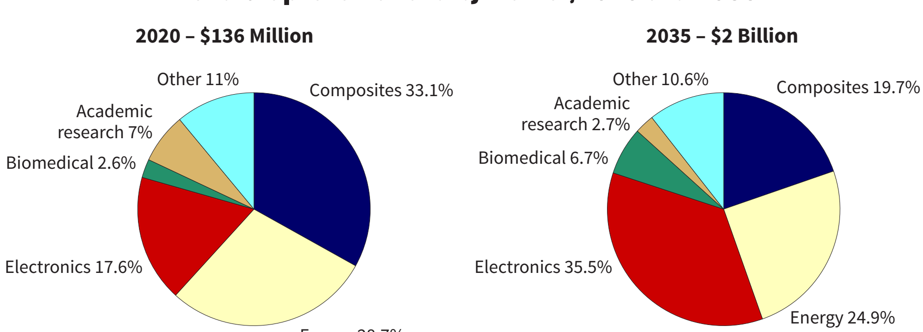
GLOBAL GRAPHENE MARKET TO REACH $2 BILLION BY 2035

By 2035, the world graphene market is forecast to reach over $2 billion, supported by a significant wave of commercialized products in applications such as supercapacitors, high-frequency transistors, sensors, and biomedical technologies. In the short term, the global market is expected to grow more than 600% through 2020 to $136 million, supported by improved manufacturing technologies and falling prices, as well as ongoing development of novel graphene-enhanced products. These and other trends are presented in *World Graphene,* a new study from The Freedonia Group, Cleveland.

Graphene-based composites feature the most promising near-term commercialization prospects of any market. Thermal stability and impermeability drive graphene use in food packaging, piping, and protective apparel applications, while high mechanical strength and light weight make the material desirable for composites used in motor vehicles, aircraft, and military equipment. In the energy storage sector, Li-Ion battery producers use graphene materials to improve energy density. Graphene is also expected to find growing adoption in supercapacitors, as these are increasingly used in electrical grids and renewable energy systems.

The U.S. is forecast to remain the leading market for graphene through 2035, bolstered by growing use in high-performance composites and energy storage devices, as well as rising research and development spending in advanced electronics fields such as optoelectronics. The Asia/Pacific region will rank as the top graphene consumer, driven by the advanced electronics and energy storage industries of Japan, China, and South Korea, according to analysts. Like the U.S., these countries will remain at the forefront of graphene R&D, funding nanotechnology projects to further explore the material's potential. Western Europe will also remain an important regional market, as Germany, the UK, France, and Spain help lead development and commercialization initiatives, particularly in advanced energy sectors. *For more information, visit freedoniagroup.com.*

World Graphene Demand by Market, 2020 and 2035



Courtesy of The Freedonia Group

FEEDBACK

HONORING SINGLE CRYSTAL TURBINE BLADES

I am on the History & Heritage Committee of ASME, and I enjoyed the March "Metallurgy Lane" article about Frank VerSnyder and his team at Pratt & Whitney. I recently sent this article to committee members to support my nomination to have the Pratt & Whitney Aircraft single crystal turbine blade work become an ASME Landmark. It is nice to have another technical society (ASM) say that the work was a breakthrough—thanks!

It is also interesting to see the different attitudes of the OEMs toward these single crystal blades. In the early days at Pratt, the final research and development work was aimed at developing the technology to get it out to vendors. Pratt did not want to go into the casting business. In more recent times, competitor Rolls-Royce now has its own SX casting efforts and considers this a key part of its manufacturing.

Lee Langston

ERRATA

An error appeared in the article "An Overview of Popular Materials Testing Systems," April issue. Table 1 listed values of 50 to 60 Hz for electromechanical systems and a value of 50 Hz for servohydraulic systems. The values should have read up to 1 Hz for electromechanical systems and up to 100 Hz for servohydraulic systems.

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS

Transparent wood is made by removing the lignin in the wood veneer. Courtesy of Peter Larsson.

WOODEN WINDOWS SEE BRIGHT FUTURE

Windows and solar panels could one day be made from one of the best—and least expensive—construction materials known: wood. Researchers at KTH Royal Institute of Technology, Sweden, developed a new transparent wood material suitable for mass production. “Transparent wood is a good material for solar cells, because it’s a low-cost, readily available, and renewable resource,” says Professor Lars Berglund. “This becomes particularly important in covering large surfaces with solar cells.” The optically transparent wood is a type of wood veneer in which lignin—a component of the cell walls—is chemically eliminated. “When lignin is removed, the wood becomes beautifully white. But because wood is not naturally transparent, some nanoscale tailoring is required,” he says. The white porous veneer substrate is impregnated with a transparent polymer, and the optical properties of the two are then matched. *www.kth.se/en.*

SELF-HEALING MATERIAL ACTS AS ARTIFICIAL MUSCLE

A new, extremely stretchable polymer film created by researchers at Stanford University, Calif., can repair itself when punctured, an important feature in a material that could act as artificial muscle. Damaged polymers typically require a solvent or heat treatment to restore their properties, but this new material has a remarkable ability to heal itself at room temperature, even if damaged pieces are aged for days. Researchers even found that it could self-repair at temperatures as low as -4°F (-20°C), about as cold as a commercial walk-in freezer.

Jolting a new polymer material with an electrical field causes it to twitch in a muscle-like fashion. It can also stretch to 100 times its original length and repair itself if punctured.

The team attributes the extreme stretching and self-healing ability of its new material to critical improvements to a chemical bonding process known as crosslinking. This process, which involves connecting linear chains of linked molecules in a fishnet pattern, has previously yielded a tenfold stretch in polymers. *For more information: Zhenan Bao, zbao@stanford.edu, baogroup.stanford.edu.*

NANOWIRE ARRAY COOLS CLOTHING

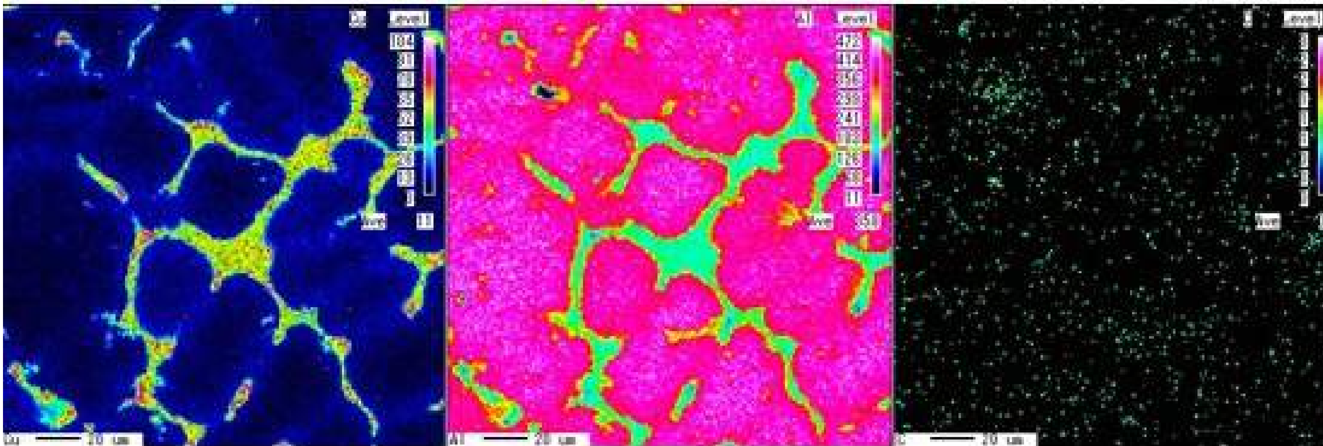
Firefighters entering burning buildings, athletes competing in the broiling sun, and workers in foundries may eventually be able to carry personal lightweight cooling units, thanks to a nanowire array that cools. “Most electrocaloric ceramic materials contain lead,” says Qing Wang, professor of materials science and engineering at Pennsylvania State University, State College. “We try not to use lead. Conventional cooling systems use coolants that can be environmentally problematic as well. Our nanowire array can cool without these problems.”

The vertically aligned ferroelectric barium strontium titanate nanowire array can cool about 5.5°F using 36 V—an electric field level safe for humans. A 500 gram battery pack about the size of an iPad could power the material for roughly two hours. The material is grown in two stages. First, titanium dioxide nanowires are grown on fluorine doped, tin oxide coated glass. Researchers use a template so all the nanowires grow perpendicular to the glass surface and to the same height. Then, barium and strontium ions are infused into the titanium dioxide nanowires. A nanosheet of silver is applied to the array to serve as an electrode. This nanowire forest can then be moved from the glass substrate to any substrate—including clothing fabric—using a sticky tape. *psu.edu.*

Flexible electrocaloric fabric of nanowire array can provide personal cooling. Courtesy of Qing Wang/Penn State.

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

METALS | POLYMERS | CERAMICS



Color mapping images of Al-5Cu-0.3C alloy with carbon additives, left to right, (a) copper, (b) aluminum, and (c) carbon. Courtesy of Business Wire.

BRIEFS

Argosy International Inc., N.Y., started construction on a 39,000 ft^2 honeycomb core facility in Alabama. Its commercial grade aluminum honeycomb core is noncombustible and can be manufactured in multiple cell sizes with two different density options for each size. Chrome and non-chrome coatings are available. The new facility will be certified to ISO 9001 and features a cutting room (vertical band saw), industrial dust collection system, and material staging area. *argosyinternational.com.*

Commercial Metals Co., Irving, Texas, started construction on its second technologically advanced micromill in Durant, Okla. The company's micromill technology uses a continuous-continuous manufacturing process that melts, casts, and rolls steel from a single uninterrupted strand, producing higher yields and consuming less energy than traditional minimill processes. *cmc.com.*

CARBON STRENGTHENS ALUMINUM COPPER ALLOY

Metal and Technology Inc. and Shirogane Co. Ltd., both in Japan, successfully added carbon particles to an aluminum-copper alloy and homogeneously dispersed these carbon particles within the alloy. The new material changes the microscopic crystal structures and is expected to dramatically improve mechanical strength.

Adding carbon to nonferrous metals other than iron has traditionally been difficult. Researchers were successfully able to add carbon to lead-free solder alloys and pure copper, improving mechanical strength by making the crystal structures microscopic. A tensile strength test confirmed the improvement but shows it depends on the amount of carbon added and the heat treatment temperature. The resulting tensile strength is at least twice that of the alloy without carbon, indicating that the aluminum-copper alloy with carbon additives can be used as a material for practical applications. *www.metal-techno.jp/english.*

TRANSPARENT METAL FILM HOLDS PROMISE FOR SMARTPHONES

Touchscreens are an essential feature of many modern devices, but the material that gives most screens their

NanoSteel automotive sheet. Courtesy of Business Wire.

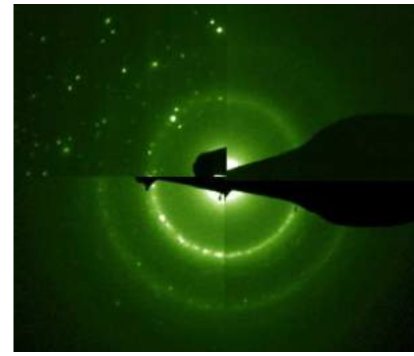
NanoSteel, Providence, R.I., delivered its first advanced high strength steel (AHSS) to **General Motors** for initial testing. The sheet steel is poised to accelerate vehicle lightweighting initiatives focused on affordably meeting rising global fuel-economy regulations. Production of the material, targeted to the $100 billion automotive steel market, is the result of a development program between NanoSteel and **AK Steel Corp.,** West Chester, Ohio. *nanosteelco.com, aksteel.com.*

A transparent printed metal film may one day coat smartphone screens. Courtesy of Westend61/Getty.

touch sensitivity is in short supply. Xin-Quan Zhang from the Singapore Institute of Manufacturing Technology (A*Star) and colleagues are working on a promising alternative—touch-sensitive film, a printed, mesh-like pattern of ultra-fine metal lines, created using roll-to-roll gravure printing. This method traditionally uses an etched mold to transfer ink onto paper. Here, the etched cylindrical mold transfers a precise pattern of conductive metal ink onto the touch-sensing substrate. Light from the screen passes through the holes in the printed mesh. Before this study, the finest lines that could be printed this way were ~50 µm wide, which blocked more than a third of the screen's light. The team overcame this limitation through diamond microengraving. Instead of using a laser to etch the grid-like pattern of tiny inkwells into the printer's cylindrical mold, a tiny diamond-tipped cutting tool to pattern the roller using ultraprecision machining technology is used. *www.a-star.edu.sg/simtech.*

IMPACT-RESISTANT STEEL COULD PROTECT TROOPS

Researchers from the University of California, San Diego, the University of Southern California, and the California Institute of Technology developed and tested a type of steel with a record-breaking ability to withstand an impact without deforming permanently. The new steel alloy could be used in a wide range of applications, from drill bits to body armor to meteor-resistant satellite casings. The material is an amorphous steel alloy, a promising subclass of steel alloys made of arrangements of atoms that deviate from steel's classical crystal-like structure, where iron atoms occupy specific locations.



Transmission electron microscopy image of different levels of crystallinity in the amorphous alloy. Courtesy of Jacobs School of Engineering/UC San Diego.

Researchers believe their work on the steel alloy, SAM2X5-630, is the first to investigate how amorphous steels respond to shock. SAM2X5-630 has the highest recorded elastic limit for any steel alloy, according to the researchers. It can withstand pressure and stress up to 12.5 GPa or about 125,000 atmospheres without undergoing permanent deformation. *ucsd.edu.*

TESTING | CHARACTERIZATION

Dan Hussey in the shielded cave where the neutron microscope will be housed at NIST.

NEUTRON MICROSCOPE COMING INTO FOCUS

In the quest to produce the world's first workhorse neutron microscope, scientists from NIST's Physical Measurement Laboratory (PML), in collaboration with NASA and MIT researchers, are approaching a milestone—a new prototype for a neutron lens. The lens is based on a *Wolter optic,* a series of nested conical mirrors made of thin layers of highly polished nickel. The design allows neutrons, which pass through mirrors unless they strike them at a low angle of incidence, to be concentrated onto a specimen. The lens in development will consist of about 10 nested mirror shells, with a maximum diameter of approximately 5 cm, a total length of approximately 20 cm, and a resolution of 20 µm. Eventually the researchers will test a second lens capable of 1-µm resolution, allowing for an estimated 10-fold increase in spatial resolution over what is currently possible.

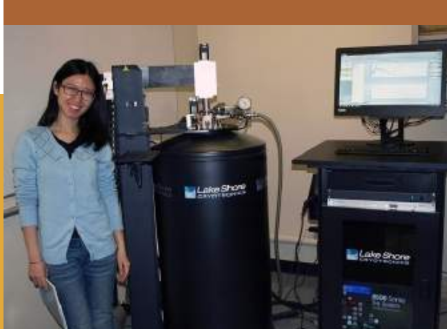
Neutron imaging allows scientists to see aspects of objects not visible with light, such as the inner workings of batteries and metals under strain. For example, the new microscope could look inside the catalyst layer of a hydrogen fuel cell, which is on the order of 1-10 µm, and give scientists a first look at the water transport processes taking place there. *nist.gov.*

ELECTRODE RECONFIGURATION, ENHANCED INFORMATION

Researchers at Argonne National Laboratory, Lemont, Ill., demonstrated that a new configuration of reference electrodes—devices used to measure voltage in individual electrodes within a battery cell—can improve the quantity and quality of information obtained from lithium-ion battery cells during cycling. Previously, Argonne researchers used only one reference electrode, based on a lithium-tin (Li-Sn) alloy. However, the team discovered that sandwiching a Li-Sn reference electrode between the positive and negative electrodes, with a pure lithium reference electrode positioned next to the stack, provided insight into electrode state-of-charge shifts, active material use, active material loss, and impedance changes.

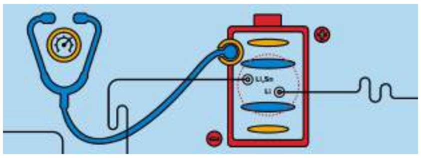
BRIEFS

A THz-frequency materials characterization system from **Lake Shore Cryotronics,** Westerville, Ohio, was installed in the lab of professor Dan Mittleman at **Brown University,** Providence, R.I. Mittleman's team is exploring how frequencies within the terahertz band of the electromagnetic spectrum can advance spectroscopic studies of materials, and the 8500 Series system will be used primarily to study THz-frequency magneto-optical responses of semimetals, iron-base superconductors, and other novel materials. *lakeshore.com.*



Unique CW-THz spectroscopy system will aid the Mittleman Lab in materials research.

Thermal management technology developer **Gentherm,** Northville, Mich., acquired **Cincinnati Sub-Zero Products** (CSZ). CSZ manufactures custom environmental test chambers used for product testing in industrial manufacturing. The company had revenues of approximately $63 million in 2015 and will be operated as a subsidiary of Gentherm, with its headquarters in Cincinnati and operations in Ohio and Michigan. *gentherm.com.*



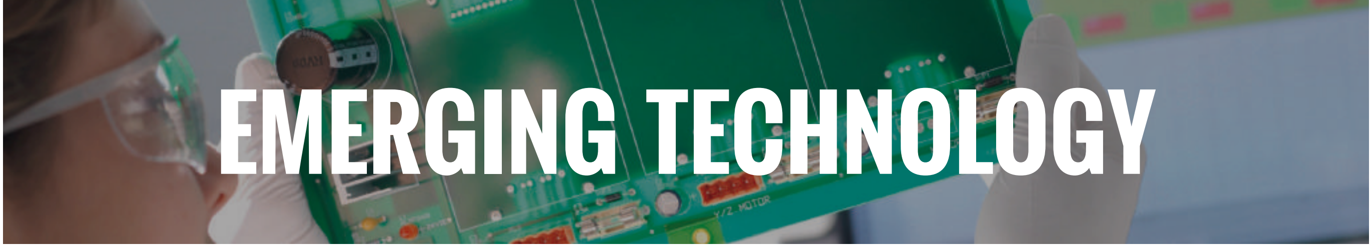
Two reference electrodes within a battery cell.

To test the new configuration, researchers used a cell containing a lithiated oxide cathode, a silicon-graphite anode, and various electrolytes, including ones containing fluoroethylene carbonate (FEC) or vinylene carbonate (VC) additives. While silicon-containing electrodes could double the energy stored in lithium-ion cells—a boon for extending electric vehicle driving range—these cells degrade more quickly. The Argonne team used the new configuration to test the impact of the FEC and VC additives, and confirmed their beneficial effects, not only at reducing capacity loss but in mitigating the impedance rise in cells without them. *anl.gov.*

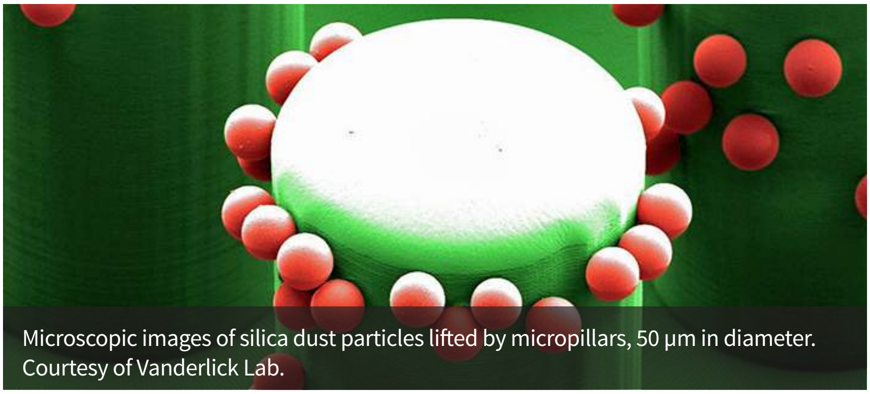
IMAGING A BETTER FUTURE FOR UK STEEL

Manuch Soleimani, a researcher from the University of Bath, UK, received a grant to develop a real-time, nondestructive, reliable measurement method for detecting defects or failures in molten steel during continuous casting. The process involves positioning a contactless bracelet around the billet to continually measure the electrical conductivity of the different states of the solidifying steel, providing an image of the structural composition of the steel as it cools. Soleimani, associate professor in the department of electronic and electrical engineering, received a three-year EU Horizon 2020 grant to develop the method, which uses induction tomography, an emerging, noninvasive imaging technique already employed in applications such as medical diagnostics, geophysical exploration, and civil engineering. He will collaborate with colleagues at the Fundacion Tecnalia Research and Innovation, Spain, as well as Italian steel companies Ferriere Nord and Ergolines Lab on the so-called Shell-Thick project. Hopes are high that the process could boost the competitiveness and sustainability of the UK and EU steel industries, which face stiff competition from highly subsidized steel production in China. *www.bath.ac.uk.*

Manuch Soleimani is leading a three-year project to develop new technology to support the UK & EU steel industry.



EMERGING TECHNOLOGY



Microscopic images of silica dust particles lifted by micropillars, 50 μm in diameter. Courtesy of Vanderlick Lab.

POLYMER, EAT MY DUST

Researchers at the Yale School of Engineering and Applied Science, New Haven, Conn., developed a non-damaging method for removing dust particles from surfaces using a polymer film. When elastic, nonstick polydimethylsiloxane (PDMS) is tapped against an object, dust is attracted to the polymer by electrostatic charge and absorbed around millions of tiny columns on the polymer's surface. Columns range in diameter from 2-50 μm—although bigger particles require bigger pillars. Laboratory tests on various surfaces show total cleaning of silica dust particles and no damage to the object being cleaned, even with dust particles smaller than 10 μm. Traditional methods used to clean dust particles this small are either only moderately effective or can harm the objects being cleaned.

In developing the new approach, Yale postdoctoral associate Hadi Izadi drew on his previous research into the sticky mechanisms on gecko feet, which also incorporate microscopic pillars and electrostatic charge. Unlike those micropillars, however, the ones used for cleaning dust are specifically designed not to be sticky. While PDMS produces enough electrostatic charge to detach dust from a surface, it has minimal interaction with the surface itself. The polymer method could be a potential boon to aerospace engineers, the electronics industry, and art conservators, among others. *yale.edu.*

NEW TOPOLOGICAL METAL COULD QUICKEN COMPUTING

Physicists at the DOE's Ames Laboratory, Iowa, discovered a topological metal composed of platinum and tin ($PtSn_4$) with a unique electronic structure that could lead to advances in computing speed. Electrons in topological quantum materials can travel close to the speed of light due to a unique property called *Dirac dispersion.* Until now, only isolated points—Dirac points—with relatively small numbers of conduction electrons were known to exist in such materials. In $PtSn_4$, however, scientists not only discovered a high density of conduction electrons, but also a large number of closely positioned Dirac points forming extended lines, or Dirac node arcs.

Adam Kaminski and his ARPES equipment.

"This type of electron transport is very special," explains Adam Kaminski, professor of physics and astronomy at Iowa State University. "Our research has been able to associate the extreme magnetoresistance with novel features in their electronic structure, which may lead to future improvements in computer speed, efficiency, and data storage." The discovery was made using a device that Kaminski developed at Ames—a laser-based, angle-resolved photoemission spectroscopy (ARPES) instrument that provides high-resolution details of the electronic properties of materials. *ameslab.gov.*

BRIEF

An independent nonprofit founded by **Massachusetts Institute of Technology,** Cambridge, was selected to lead a new, $317 million public-private partnership called the Advanced Functional Fabrics of America Institute (AFFOA), designed to accelerate innovation in high-tech, U.S.-based manufacturing involving fibers and textiles. AFFOA includes 32 universities, 16 industry members, 72 manufacturing entities, and 26 startup incubators spread across 27 states and Puerto Rico. *mit.edu.*

PROCESS TECHNOLOGY

Martin Thuo with a vial of liquid-metal particles. Courtesy of Christopher Gannon.

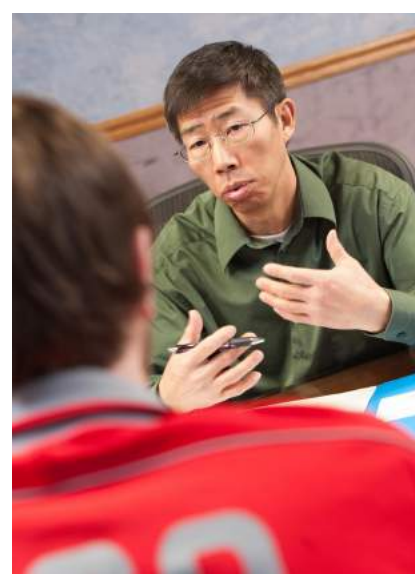
SOLDERING METHOD KEEPS ITS COOL

Researchers at Iowa State University, Ames, demonstrated a method of producing microscale, liquid-metal particles for use in heat-free soldering and material healing at room temperature. Scientists have long used a method called undercooling—in which liquid metal is prevented from returning to a solid state even below its melting point—to study metal structure and processing. However, producing large and stable quantities of undercooled metals has proved challenging. The team hypothesized that covering tiny droplets of liquid metal with a thin, uniform coating could result in stable particles of undercooled liquid metal. Using a high-speed rotary tool, they sheered liquid metal into droplets within an acidic liquid, then exposed the particles to oxygen, forming an oxidation layer that encapsulated the liquid metal. Researchers proved the concept by creating liquid-metal particles 10 µm in diameter containing Field's metal (an alloy of bismuth, indium, and tin) as well as particles of the same size containing an alloy of bismuth and tin.

Martin Thuo, assistant professor of materials science and engineering, says the project is a good example of "frugal innovation," a guiding principal for his lab, which strives to solve problems using the fewest resources. The team demonstrated healing damaged surfaces and joining metals at room temperature without high-tech instrumentation, complex material preparation, or a high temperature process. *iastate.edu.*

MACHINING BRITTLE MATERIALS WITH CRACK CONTROL

Shuting Lei, professor of industrial and manufacturing systems engineering at Kansas State University, Manhattan, received a $300,000 grant from the National Science Foundation to develop better methods of machining ultrathin precision parts. "Precision parts made from brittle materials such as glass and ceramics have broad applications in the health care, biomedical, energy, and photonics areas," says Lei. "A major problem in machining these materials is random crack propagation into the work piece. This results in subsurface cracks and thus degrades the strength of the machined parts." His award will support development of a novel machining process that overcomes this limitation using controlled crack propagation. The new method will enable high-efficiency machining of brittle materials without compromising part quality. *k-state.edu.*

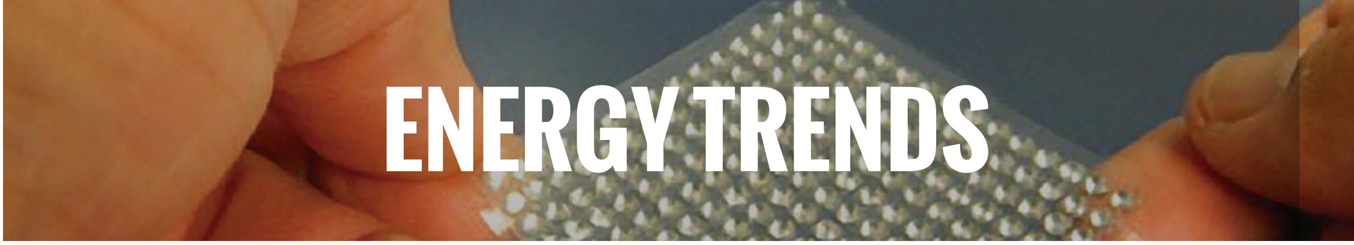


Shuting Lei is working on better ways to machine ultrathin precision parts.

BRIEF

Constellium N.V., the Netherlands, opened the Constellium University Technology Center (UTC) at **Brunel University,** UK, to design, develop, and prototype aluminum alloys and automotive structural components. The new center will feature industrial-size aluminum casting and extrusion equipment as well as rapid prototyping, which is expected to reduce development time by at least 50% for the advanced alloys used in automotive lightweighting. *constellium.com, www.brunel.ac.uk.*

Constellium



ENERGY TRENDS

Cara Doherty examines a cactus-inspired membrane.

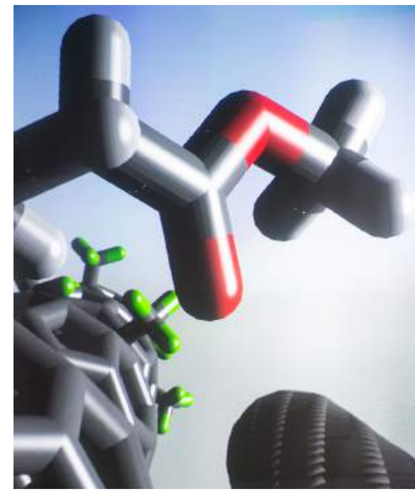
CACTUS-LIKE MEMBRANE BOOSTS FUEL CELL EFFICIENCY

Researchers discovered a new type of membrane that could potentially boost the performance of fuel cells and transform the electric vehicle industry. The membrane, developed by scientists from CSIRO, Australia, and Hanyang University, Korea, features a water-repellent skin, and can improve the efficiency of fuel cells by a factor of four when heated. According to Aaron Thornton at CSIRO, the skin works in a similar way to a cactus plant, which thrives by retaining water in harsh and arid environments. "Fuel cells, like the ones used in electric vehicles, generate energy by mixing together simple gases, like hydrogen and oxygen. However, in order to maintain performance, proton exchange membrane fuel cells need to stay constantly hydrated," says Thornton. This is currently achieved by placing the cells next to a radiator, water reservoir, and humidifier, which require significant space and power. The cactus-inspired solution offers a new approach: Water is generated by an electrochemical reaction, which is then regulated through nano-cracks within the membrane's skin. The cracks widen when exposed to humidifying conditions and close when it is drier. The result is fuel cells that can remain hydrated without the need for bulky external humidifier equipment. *For more information: Aaron Thornton, aaron.thornton@csiro.au, www.csiro.au.*

NANOTUBE SEMICONDUCTORS IMPROVE PV SYSTEMS

Researchers at the National Renewable Energy Laboratory (NREL), Golden, Colo., discovered that single-walled carbon nanotube semiconductors could be used in photovoltaic (PV) systems because they can potentially convert sunlight to electricity or fuel without much energy loss. The research builds on the work of Rudolph Marcus, who developed a fundamental tenet of physical chemistry that explains the rate at which an electron can move from one chemical to another.

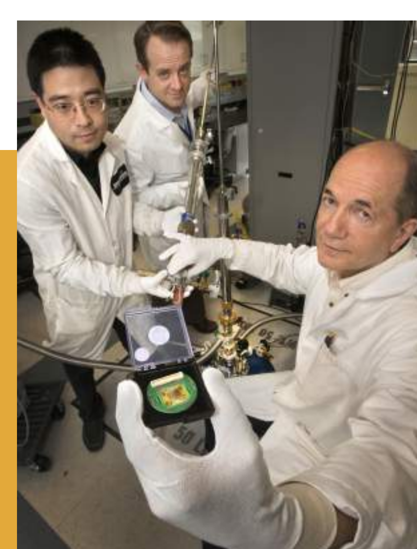
In organic PV devices, after a photon is absorbed, charges generally need to be separated across an interface so they can live long enough to be collected as electrical current. The electron transfer event that produces these separated charges comes with a potential energy loss as the molecules involved must structurally reorganize their bonds. This loss is called reorganization energy, but NREL researchers found little energy was lost when pairing single-walled carbon nanotube semiconductors with fullerene molecules. "What we found is this particular system—nanotubes with fullerenes—has an exceptionally low reorganization energy and the nanotubes themselves probably have very, very low reorganization energy," says Jeffrey Blackburn. *www.nrel.gov.*



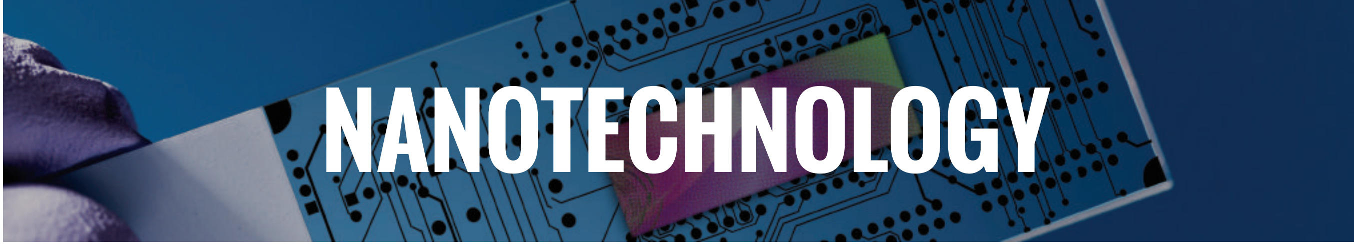
Nanotube semiconductors. Courtesy of NREL.

BRIEF

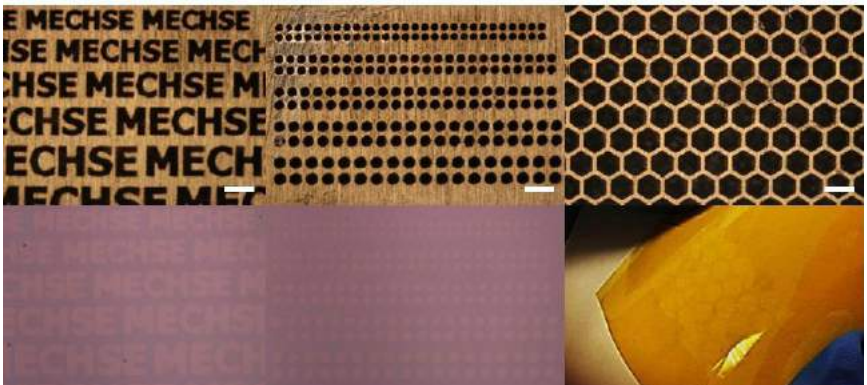
Scientists from the DOE's **Brookhaven National Laboratory,** Upton, N.Y., synthesized ultrathin films containing multiple samples of a copper-oxide compound to study its electronic behavior at near absolute zero. The technique helps understand electron behavior as the material transitions from being an insulator to a superconductor capable of carrying electric current with no resistance. *science.energy.gov.*



Jie Wu, Anthony Bollinger, and Ivan Bozovic (left to right) load a sample in an apparatus capable of reaching a temperature one-third of a degree above absolute zero.



NANOTECHNOLOGY



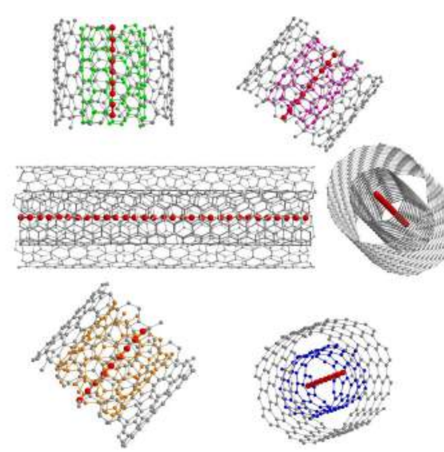
Optical microscope images and photographs of various stencil masks with sophisticated microscale features (top row) and corresponding graphene array patterns transferred onto SiO_2 substrate and flexible Kapton film (bottom row). Scale bars: 300 μm. Courtesy of University of Illinois.

SCALING UP GRAPHENE PRODUCTION

Researchers from the University of Illinois at Urbana-Champaign developed a one-step, facile method to pattern graphene by using stencil mask and oxygen plasma reactive-ion etching, and subsequent polymer-free direct transfer to flexible substrates. "In conjunction with the recent evolution of additive and subtractive manufacturing techniques, we developed a simple and scalable graphene patterning technique using a stencil mask fabricated via a laser cutter," says Professor SungWoo Nam. "Our approach to patterning graphene is based on a shadow mask technique that has been employed for contact metal deposition. Not only are these stencil masks easily and rapidly manufactured for iterative rapid prototyping, they are also reusable, enabling cost-effective pattern replication. And because our approach involves neither a polymeric transfer layer nor organic solvents, we are able to obtain contamination-free graphene patterns directly on various flexible substrates." *For more information: SungWoo Nam, swnam@illinois.edu, www.illinois.edu.*

NEW MATERIAL OUTSHINES DIAMOND

Researchers from the University of Vienna, Austria, led by Thomas Pichler, developed a novel approach to grow and stabilize carbon chains with a record length of 6000 carbon atoms, improving the previous record by more than one order of magnitude. They use the confined space inside a double-walled carbon nanotube as a nanoreactor to grow ultra-long carbon chains on a bulk scale. The existence of the chains was confirmed by using a multitude of sophisticated, complementary methods including temperature dependent near- and far-field Raman spectroscopy with different lasers to investigate electronic and vibrational properties, high resolution transmission electron spectroscopy to directly observe carbyne inside carbon nanotubes, and x-ray scattering to confirm bulk chain growth. According to theoretical models, carbyne's mechanical properties exceed all known materials, outperforming both graphene and diamond. Further, carbyne's electrical properties suggest novel nanoelectronic applications in quantum spin transport and magnetic semiconductors. *www.univie.ac.at/en.*



Schematic of confined ultra-long acetylenic linear carbon chains inside different double walled carbon nanotubes. Courtesy of Lei Shi, University of Vienna.

Cleanroom resources at Georgia Tech.

BRIEF

The National Science Foundation selected **Georgia Tech's Institute for Electronics and Nanotechnology (IEN),** Atlanta, to serve as the coordinating office of the National Nanotechnology Coordinated Infrastructure (NNCI) program. The NNCI will train a globally competitive nanotechnology workforce and provide efficient access to resources for innovation and commercialization of nanotechnology. *ien.gatech.edu.*

EVALUATING TRADEOFFS IN HIGH-TEMPERATURE TESTING

Erik Schwarzkopf
MTS Systems Corp.
Eden Prairie, Minn.

Systems integration expertise is valuable for innovative high-temperature testing because it reduces data variability and allows for fewer tests in order to achieve accurate results.

Traditional high-temperature mechanical test systems with extension rods extended into a furnace hot zone.

Designers of ultra-efficient aircraft, automobiles, and power generation systems need materials with high strength-to-weight ratios as well as those that can withstand high operating temperatures for extended time periods. In both cases, fuel efficiency is the goal. To achieve this, researchers must accurately and precisely measure material properties at elevated temperatures.

However, *elevated temperature* means different things to different researchers. In general, there are three distinct temperature ranges for materials with the highest strength-to-weight ratios. The first range, 200°-425°C, applies to polymer matrix composites (PMCs). The second range, 800°-1200°C, is used for metals. The third range is suitable for ceramic matrix composites (CMCs), which are tested to 1500°C. For PMCs, traditional use temperature is limited by the glass transition temperature (T_g) of the matrix resin, where the matrix becomes soft and rubbery. Aerospace materials generally use epoxy resins with a T_g of approximately 200°C or lower.

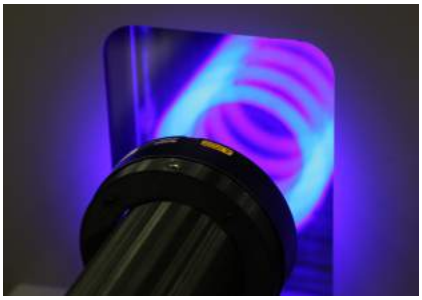
Composites that use polyimide resins with much higher T_g values report use at temperatures as high as 371°C. For metals, many mechanisms can define high temperature because the traditional use temperature is limited by loss of strength, onset of creep deformation, change in material microstructure, or the appearance of high temperature corrosion. Single crystal Ni-base alloys and some refractory alloys are used in the air to roughly 1200°C. For the most advanced CMC applications, associated testing requirements reach nearly 1500°C, with even higher temperatures envisioned for the future. In each range, there are tradeoffs that test engineers need to carefully consider in order to run effective tests, measure material properties at elevated temperatures, and acquire high-quality results.

These tradeoffs directly affect the accuracy and precision of mechanical test data, because any object that needs to hold, touch, or be placed near the specimen may increase data scatter. In other words, grips, extensometers, furnaces, and environmental chambers are potential sources of experimental error. Variability that arises from these components tends to be systemic, so solving an issue with one tends to raise issues with another.

HIGH-TEMPERATURE SPECIMEN EXAMINATION

To understand how these interrelated issues manifest during test setup, consider a typical specimen. PMC and CMC specimens are flat and cannot be gripped in the same way as round, threaded, or button-head metallic specimens. For PMCs, cost effective and easy-to-use hydraulic wedge grips are usually appropriate. PMC specimens often lack compressive strength across their thinnest cross section, and the evenly applied pressure from the hydraulic wedges protects the fibers in the polymer matrix. These hydraulic grips not only prevent the fibers from being crushed, but also help maintain correct pressure as the chamber and grip wedge head heat up.

The tradeoff is that grip wedge heads are relatively large, and for best results, must fit inside an environmental chamber. The chamber for these lower temperature PMC tests is often larger than the furnaces required for higher temperature metal or CMC tests. Although larger equipment usually is less efficient, the thermal mass of the grips and chamber leads to very stable test environments.

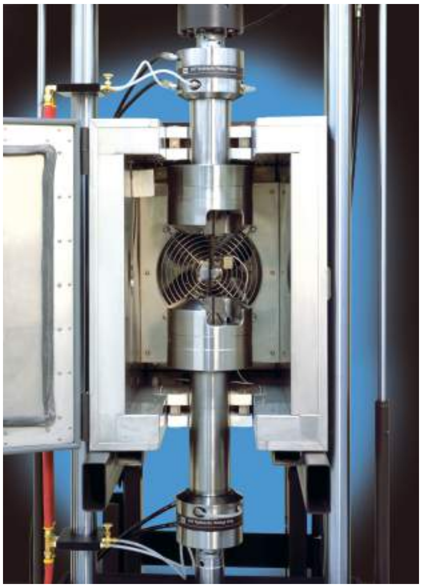


Blue LEDs illuminate chamber during PMC test.

On the other hand, the larger chamber makes using inexpensive contact extensometers difficult. With a smaller furnace, extensometers can be situated outside the chamber, allowing them to translate motion from the contact arm to the capacitor plates or strain-gaged beam. But with a larger chamber, the motion is not effectively translated because the arms become too long and cause additional measurement variability. A short arm extensometer needs to be positioned inside the chamber, but the elevated temperature would damage its sensitive electronics.

One way to solve this problem is with video extensometry and digital image correlation, which can be situated outside the chamber. A chamber with a window lets these technologies look inside and measure specimen motion

Temperature profiling of a button-head metallic specimen in 1200°C grips.



Remotely actuated hydraulic grips for PMC specimen at temperatures to 425°C in real-time. But this approach also has challenges. A light inside the chamber is necessary to illuminate the specimen for the camera. At some temperatures, the specimen's illumination (or blackbody radiation) reduces the contrast and accuracy of the video extensometry. To address this, a method was developed that uses blue LEDs to illuminate the chamber in concert with optical filtering, which minimizes blackbody effects and enhances contrast.

IN-SERVICE MATERIALS CHALLENGES

Testing a material that has been in service adds even more complexity because it is often impossible to obtain a large enough portion of the material to make a round metallic specimen. These *sub-sized* specimens challenge gripping technologies as well as heating and sensing technologies.

Sometimes researchers must extract a small specimen from a larger component—specifically, turbine blades from jet engines. The blades that see the hottest application temperatures are grown from single crystal seeds with cooling holes to let air through. These intricately shaped blades do not have enough bulk to create a round specimen. When the interdendritic spacing of a single crystal is similar to the specimen dimensions, the specimen might act quite differently than a bulk, round sample, and hence the sub-sized specimen may better represent service reality.

Thermocouples bonded to the specimen are used to measure thermal gradients.

TRADEOFFS VARY WITH TEMPERATURE

These tradeoffs change considerably within each of the three temperature ranges for PMCs, metals, and CMCs. For example, grips that are the same temperature as the specimen are recommended for most high-temperature applications. But the CMC range exceeds 1000°C—the upper limit for traditional metal grips—and would cause the grips to lose strength. Ideally, researchers want the grip to be as close as possible to the specimen temperature to minimize the specimen's thermal gradient, but not so hot that the grip itself starts to get soft and lose strength.

If a specimen is long enough, cold grips at ambient temperature could be used outside the furnace. But some specimens cannot be made long enough, for the same reasons that they cannot be made round. Even if cold grips could be used, they would introduce temperature gradients in the specimen, making more tests necessary due to test data variations caused by the gradients. This adds considerable expense to the process.

Dealing with the hottest temperature range presents some of the most complex tradeoffs, because testing is often done at temperatures hotter than gripping materials can withstand. For these applications, a grip that is actively cooled in two different ways, depending on the required temperature range, was developed.

Both kinds of grip cooling techniques work according to the same concept, in which the grip is positioned in an area of the furnace that is relatively less hot than the center zone where the specimen resides. Multi-zone furnaces, while slightly less cost effective, achieve better results because gradients in the specimen are minimized. If the center zone is 1200°C, for example, the top and bottom zones are closer to 1000°C. With active, localized cooling, the grip can stay in the less-hot part of the furnace and still hold the specimen in place while minimizing thermal gradient. For testing metals up to 1200°C, a grip that is moderately cooled was developed while a grip that is more aggressively cooled was developed for testing CMCs up to 1500°C.

INTEGRATION IMPORTANCE

These examples illustrate the importance of understanding the entire test system (heating, gripping, and sensing) and its interdependencies from back to front. Today, very few commercial off-the-shelf solutions exist for high-temperature materials testing. As a result, many test labs attempt to build these solutions in-house by assembling components from different providers. But as illustrated, the challenge is that the tradeoffs require a system-level approach for best results.

In other words, even a contact extensometry expert may not understand how to make their product work through a window or inside a chamber. Grip experts may be able to make cold grips work in a cost-effective manner, but the specimen gradient becomes so large that it calls the test results into question and conversely, hot grips might work well for one type of test (i.e., tensile) but might be unusable or fail prematurely for different loading conditions (i.e., fatigue).

When grips are the same temperature as the specimen, the resulting environmental chamber might require unique solutions for sensing specimen deformation. The ability to integrate the entire solution is vital. Systems integration expertise is valuable for innovative high-temperature testing because it reduces data variability and allows researchers to run fewer tests in order to achieve accurate results. **~AM&P**

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IN-SITU EBSD TECHNIQUE CHARACTERIZES MICROSTRUCTURE EVOLUTION OF MAGNESIUM ALLOY

An in-situ annealing technique combined with EBSD characterizes the microstructural evolution of an Mg alloy as a function of temperature.

Ajith Chakkedath, Carl Boehlert, and David Hernandez, Michigan State University, East Lansing*

Jan Bohlen, Sangbong Yi, and Dietmar Letzig, Magnesium Innovation Centre MagIC, Germany

In-situ scanning electron microscopy (SEM) enables microstructure evolution to be studied under various loading conditions. Modern SEMs incorporate heating assemblies so they can be tilted to the optimum angle for electron backscatter diffraction (EBSD) analysis. This, combined with the fast indexing capabilities of fully automated modern EBSD systems, enables microstructure evolution to be captured during in-situ heating experiments.

In-situ EBSD heating experiments are typically performed to enable understanding of phase transformations and/or recrystallization behavior as a function of temperature and/or time[1]. Such experiments have been used to study the microstructural evolution and recrystallization in aluminum alloys, copper, titanium, and steel[1]. Similar studies help explain the microstructural evolution in wrought magnesium (Mg) alloys, in which the crystallographic texture has significant influence on elongation-to-failure[2] and anisotropy in mechanical properties[3].

Control of the crystallographic texture in wrought Mg alloys is of commercial interest. Conventional Mg alloys tend to form strong texture during wrought processing and retain that texture after annealing[4,5], which makes further processing difficult. Rare earth (RE) containing Mg alloys form weaker textures during wrought processing (and subsequent annealing)[6,7]. However, the underlying mechanisms responsible for this texture development in Mg alloys during annealing are not well understood[8,9]. Therefore, an in-situ annealing technique combined with EBSD was developed in order to characterize the microstructural evolution as a function of temperature in a RE-containing Mg alloy, Mg-2Zn-0.2Ce (wt%) (ZE20).

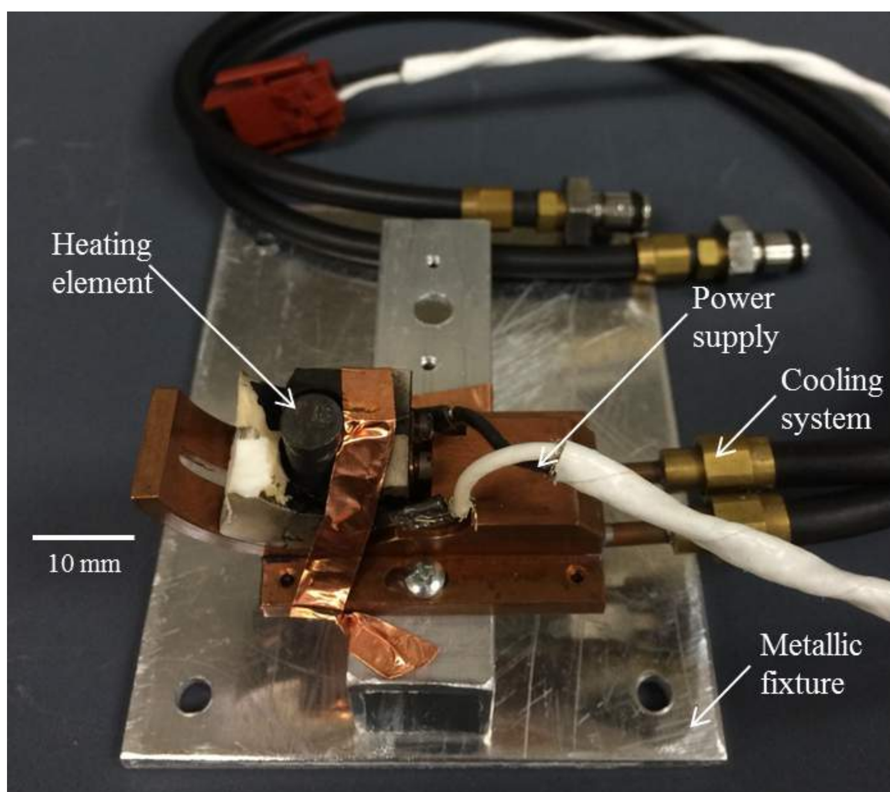


Fig. 1 — Heating stage used for in-situ heating experiments. The sample (not shown) was placed directly on top of the heating element during experiments.

*Member of ASM International

EXPERIMENTAL METHOD

The ZE20 alloy features a measured composition of Mg-1.9Zn-0.2Ce (wt%). The alloy was first gravity cast, and then rolled at 673 K. For the in-situ annealing experiments, flat rectangular samples with ~10 mm width and ~15 mm length were cut from the as-rolled sheets (~1.3 mm thick) using a diamond saw. Samples were mechanically polished using silicon carbide grinding papers. To further improve sample surface quality for EBSD, specimens were electropolished using a solution of 30% nitric acid and 70% methanol as an electrolyte and a Struers TenuPol-5 double jet system.

Figure 1 shows the experimental setup used for the in-situ annealing experiments. A 6-mm-diameter tungsten heating element (connected to a constant-voltage power supply) was mechanically fixed to a customized metallic platform to control sample temperature. The sample was placed directly on top of the heater and secured using copper tape. The platform was then mechanically attached to a Tescan Mira3 SEM stage. Temperature was monitored using a fine gage K-type thermocouple spot welded to the specimen. Inside the SEM chamber, vacuum was maintained below $2x10^{-6}$ torr throughout the experiments.

An EBSD orientation map of a ~100 × 100 μm microstructural patch was initially acquired at 298 K using EDAX TSL OIM Data Collection v6.1 software. The specimen was heated to a target temperature (423 K) and held for ~15 minutes to homogenize and stabilize temperature. An EBSD map of the same microstructural patch was then acquired while the sample was held at the desired temperature. A step size of 0.5 μm was used. The EBSD orientation map was typically acquired in ~45 minutes. No significant microstructure change was observed during this time. Specimen temperature was maintained within ±3 degrees of the target while the EBSD maps were acquired. The heating and subsequent EBSD mapping cycle was then continued up to a desired temperature. EBSD maps were acquired at 298 K, 423 K, and at 473 to 598 K with 25° increments. It took approximately 10 minutes to heat the sample to a temperature 25° higher.

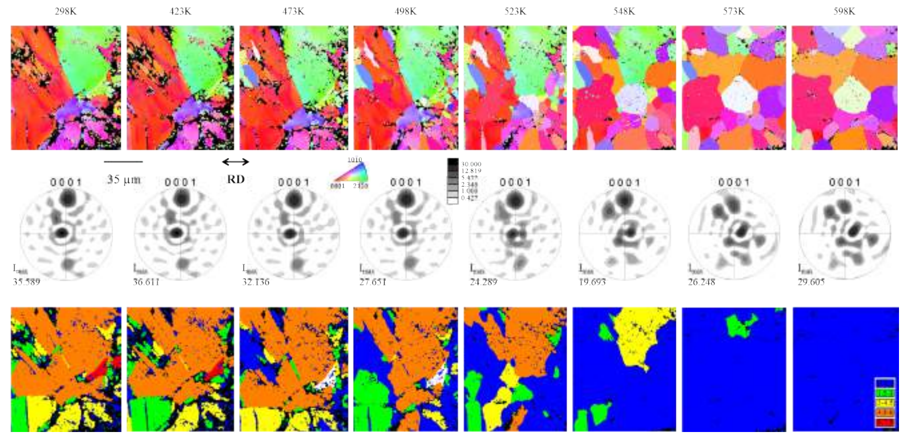


Fig. 2 — EBSD IPF map (top), corresponding texture in the form of {0001} pole figures (along the normal direction of the sample) (middle), and grain orientation spread map (bottom) of the same microstructural patch depicting the evolution of microstructure in rolled ZE20 as a function of temperature. Black regions in the maps are un-indexed points. I_{max} is the maximum intensity values observed in the pole figures.

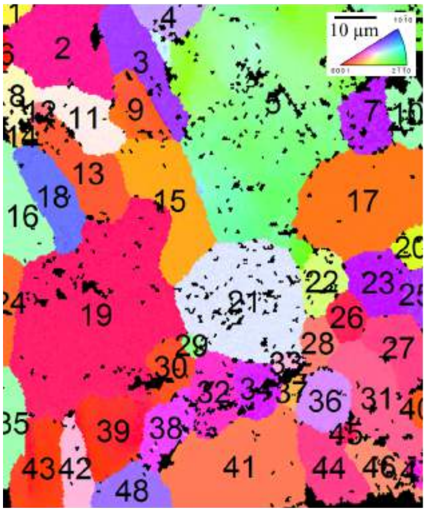
EBSD data was analyzed using EDAX TSL OIM Analysis v6.1 software. Post-processing clean-up procedures of the raw data removed erroneous data points formed due to un-indexed or inappropriately indexed patterns. Input parameters for clean-up procedures were selected based on an overall average confidence index value of the raw data in an effort to minimize the number of points modified. For the maps taken at temperatures below 523 K, ~20-25% of the total points were modified during the clean-up procedure. For maps taken at temperatures above 523 K, ~15% of the total points were modified during the same clean-up procedure. Thus, the quality of EBSD indexing increased with an increase in temperature as the microstructure consisted mainly of newly recrystallized, relatively strain-free grains.

MICROSTRUCTURE EVOLUTION IN ZE20

Figure 2 shows the EBSD inverse pole figure (IPF) map, corresponding texture in the form of {0001} pole figures (along the normal direction of the sample), and the grain orientation spread map of the same microstructural patch depicting microstructure evolution as a function of annealing temperature. During the annealing process, new grains appeared during the heating step from 423 to 473 K (Fig. 2). As expected, with new grain formation, the texture intensity in the microstructural patches decreased (Fig. 2). However, texture intensity increased slightly during the final annealing steps, which included temperatures above 548 K. This was expected to be due to grain growth and therefore fewer grains were present in the given microstructural patch analyzed. The orientation spread within the grains was less than 1.5° in the area analyzed after the 548-573 K heating step, suggesting that the grains were relatively free of strain accumulated during rolling. At ~573 K, a completely recrystallized microstructure was observed.

The orientation relationship of the newly formed grains with respect to their neighbors after each heating step was investigated. Specifically, the misorientation angles and corresponding misorientation axis across the newly formed grain boundaries were examined. The grain boundaries with misorientation angles greater than 15° were only considered in the analysis. For example, Fig. 3 shows an EBSD IPF map of the microstructural patch after reaching the 548 K heating step. Ten new grains were formed during this step, resulting in 44 unique grain boundaries. The misorientation angle-axis relationships for the newly formed grain boundaries are tabulated in Fig. 3.

This analysis was performed for each heating step and the characteristics of the grain boundaries formed during



Newly-formed grains (ID)	Neighboring grain (ID)	Misorientation angle (degrees)	Misorientation axis
1	2	43.6	$\langle\bar{1}100\rangle$
2	3	80.4	$\langle 0\bar{1}10\rangle$
	11	49.2	$\langle 31\bar{4}0\rangle$
4	3	56.2	$\langle 0\bar{1}10\rangle$
	5	60.6	$\langle\bar{2}02\bar{1}\rangle$
7	5	27.1	$\langle 01\bar{1}2\rangle$
	10	43.8	$\langle\bar{1}010\rangle$
	17	59.8	$\langle 1\bar{2}1\bar{1}\rangle$
15	13	42.2	$\langle 1\bar{1}00\rangle$
	19	18.2	$\langle 1\bar{1}0\bar{1}\rangle$
	21	67.7	$\langle 0\bar{1}10\rangle$
17	20	46.7	$\langle 1\bar{2}10\rangle$
	22	67.3	$\langle 0\bar{1}10\rangle$
	23	43.6	$\langle 12\bar{3}0\rangle$
19	39	21.7	$\langle\bar{2}11\bar{1}\rangle$
	42	56.4	$\langle\bar{1}\bar{1}20\rangle$
	43	20.4	$\langle 1\bar{2}11\rangle$
23	25	85.6	$\langle\bar{1}\bar{1}20\rangle$
	26	50.9	$\langle\bar{3}120\rangle$
	27	49.1	$\langle 1\bar{1}00\rangle$
25	20	26.2	$\langle 1\bar{1}0\bar{2}\rangle$
	27	83.4	$\langle\bar{1}\bar{1}20\rangle$
26	22	59.5	$\langle\bar{1}010\rangle$
	27	31.8	$\langle 01\bar{1}0\rangle$
	28	39.8	$\langle 11\bar{2}\bar{2}\rangle$

Fig. 3 — EBSD IPF map (along the normal direction of the sample) after achieving 548 K. The ID for each grain is highlighted. Ten new grains were formed during this heating step, which resulted in 44 unique grain boundaries. The misorientation angle-axis relationships highlighted by grey, purple, and tan shades correspond to $\{10\bar{1}2\}$ extension twin, $\{10\bar{1}1\}$ contraction twin, $(10\bar{1}2)$ – $(01\bar{1}2)$ and extension double twin boundaries, respectively.

TABLE 1 — CHARACTERISTICS OF THE NEWLY FORMED GRAINS IN ROLLED ZE20 DURING IN-SITU HEATING

Characteristic	New grains
Number of new grains formed	59
Number of resulting unique grain boundaries	159
Grain boundaries with $\{10\bar{1}2\}$ extension twin relationship (%)	9
Grain boundaries with $\{10\bar{1}1\}$ contraction twin relationship (%)	6
Grain boundaries with $(10\bar{1}2)$ – $(01\bar{1}2)$ extension double twin relationship (%)	18
Grain boundaries with $\langle 10\bar{1}0\rangle$ rotation axis (%)	41
Grain boundaries with $\langle 11\bar{2}0\rangle$ rotation axis (%)	23
Grain boundaries with $\langle 10\bar{1}1\rangle$ rotation axis (%)	12

the heating process are listed in Table 1. As shown in Table 1, among the misorientation relationships observed between the newly formed grain boundaries, rotation axis about $\langle 10\bar{1}0\rangle$, $\langle 11\bar{2}0\rangle$, and $\langle 10\bar{1}1\rangle$ were prevalent. Grain boundaries with orientation relationships corresponding to $\{10\bar{1}2\}$ extension twinning (86° about $\langle 11\bar{2}0\rangle$), $\{10\bar{1}1\}$ contraction twinning (56° about $\langle 11\bar{2}0\rangle$), and $(10\bar{1}2)$ –$(01\bar{1}2)$ extension double twinning (60° about $\langle 10\bar{1}0\rangle$) were also commonly observed. This was expected to be due to the recovery and growth of twins formed during the rolling process.

SUMMARY

An in-situ experimental technique, which involves annealing inside an SEM combined with EBSD analysis, was developed to understand the microstructural evolution and recrystallization behavior of rolled ZE20. Recrystallization started at 423-473 K. A completely recrystallized microstructure with relatively equiaxed and strain-free grains was observed at 548-573 K, and grain growth was observed afterward. Misorientation angle-axis relationship analysis for the newly formed grains reveals grain boundary formations with various twin relationships. The characterization methodology developed in this work sets the stage for future experiments to understand and control the recrystallization behavior of commercial alloys. Future work is targeted at employing this technique to understand the effect of RE content on the recrystallization behavior of Mg alloys. **~AM&P**

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Acknowledgments

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FIELD ASSISTED SINTERING TECHNOLOGY UPDATE–PART II

Field assisted sintering technology (FAST) enables hybrid components for aerospace to be designed with reduced weight—without sacrificing performance.

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Technological benefits of field assisted sintering technology (FAST) compared with conventional processes include: high flexibility; 100 to 1000 times faster processing cycle, which significantly reduces manufacturing costs; retention of a submicron grain microstructure, which provides superior component properties; achieving 100% density; and significant energy savings of 60 to 70%. The technology enables engineering of new materials and designing and developing prototype components with salient features not economically feasible using conventional manufacturing methods.

Part I of this article (February 2016 *AM&P*) discussed the use of FAST to produce thermally managed components and net-shape Ti-alloy and refractory material components. Part II discusses using FAST to design lightweight hybrid components for the aerospace industry without sacrificing the performance of traditional components.

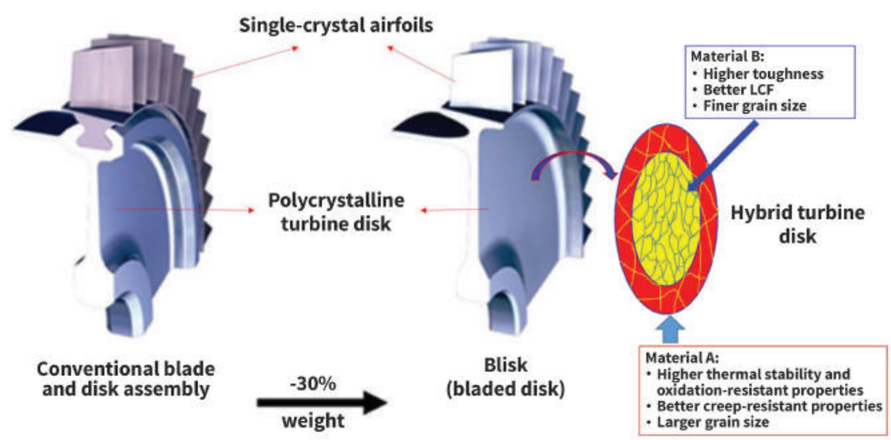

Fig. 1 — Bladed-disk (blisk) structure offers significantly reduced weight compared with a conventional blade and disk assembly.

LIGHTWEIGHTING AEROENGINE COMPONENTS

A major goal in the manufacture of modern aeroengine gas turbines is doubling the thrust-to-weight ratio of the engine, which is achievable by reducing the weight of turbine components and increasing the speed of rotating components. Single-crystal nickel-base superalloy blades are attached to a superalloy disk using a *fir-tree* blade-to-disk arrangement—known conventionally as a blade and disk assembly. Joining single crystal blades to a polycrystalline disk (called blisks) requires significantly less material because the weight of blade roots, disk lugs, and the disk structure required to support these features is eliminated (Fig. 1). This results in a weight savings of up to 30%, enabling higher blade speeds, and thus a higher pressure ratio per stage.

Linear friction welding (LFW) is used to manufacture polycrystalline titanium blisks, where the materials are easily deformed. However, using LFW to join single crystal blades and polycrystalline Ni-base superalloys is challenging because the single crystal is difficult to deform. Also, some characteristics of LFW including localized melting, heat-affected zones, material deformation, and micro-cracks near the interface can be problematic. In addition, residual stresses and large grain size near the interface can contribute to catastrophic failure.

NASA developed low-density, single-crystal (LDS) nickel-base superalloys for turbine blade applications, which offer significant improvements in the thrust-to-weight ratio. To take advantage of potential weight savings, researchers looked at joining LDS Ni-base superalloys via FAST. Materials were joined to each other at the Applied Research Laboratory Penn State University. A cross section of the interface (Fig. 2) shows what appears to be perfect bonding.

Nickel-base superalloys intended for advanced disk applications require high creep resistance and dwell crack growth resistance in the rim region to withstand temperatures exceeding 650°C and high strength and fatigue resistance in the bore and web regions, which operate at temperatures of 500°C or less. Strength-dependent properties of a disk with a uniform coarse

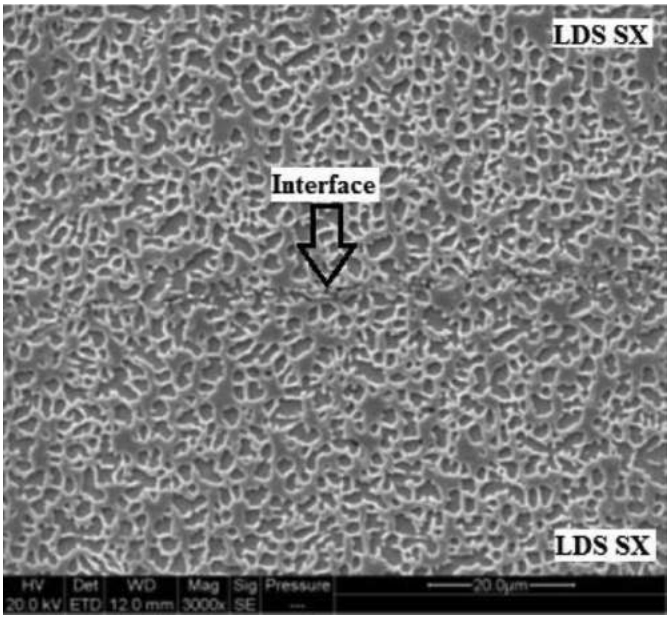

Fig. 2 — Scanning electron micrograph (SEM) of LDS Ni-base superalloys joined via FAST shows high-quality bond.

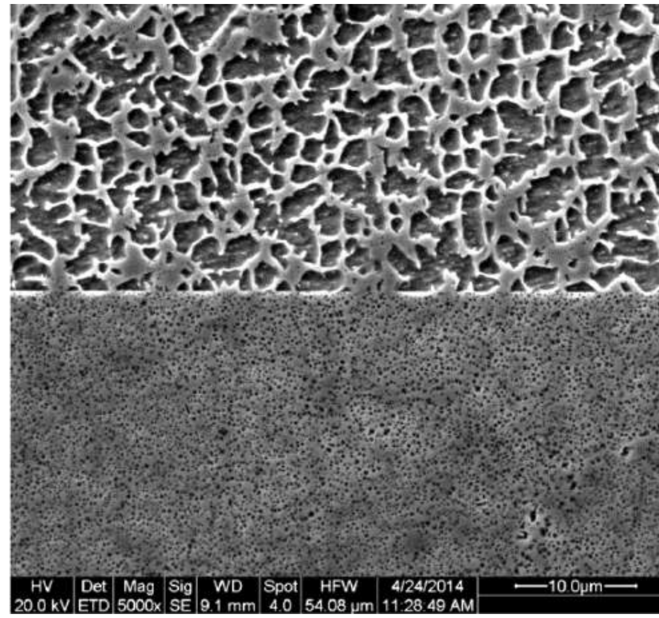

Fig. 3 — SEM of LDS Ni-base superalloy joined to LSHR Ni-base superalloy via FAST at 900°C.

grain microstructure are compromised at intermediate temperatures in the bore and web. Creep resistance and dwell crack growth resistance in the rim region are compromised in a disk with a uniform fine grain microstructure. Therefore, an optimal disk should have a dual microstructure consisting of fine grains in the bore and web and coarse grains in the rim. Low-solvus, high-refractory (LSHR) Ni-base superalloy turbine disks were processed using a dual microstructure heat treatment producing a microstructural gradient consisting of coarse grains in the rim and fine grains in the bore. Figure 3 shows a good bond between LDS and LSHR Ni-base superalloys using FAST at a temperature of 900°C.

DEVELOPMENT OF HYBRID COMPONENTS

Turbine disks. The industry wants to increase the operating temperature of turbine disks from 650° to 760°C by means of a dual phase microstructure with superior time-dependent mechanical properties. This is achievable using hybrid turbine disks (Fig. 4). Two approaches used to fabricate these disks include solid state joining of two different materials with a sharp interface, and using two different powder materials compacted and sintered together forming a hybrid disk without a sharp interface, as shown in Fig. 4. Mechanical properties of the interfaces are now being evaluated.

Gears. Replacing steel helicopter components with Ti alloys reduces weight by 50%, which, in turn, increases maneuverability, fuel efficiency, and pay load capability. The weight of a helicopter ranges from 6000-7000 kg, and the weight of carburized steel transmission gears ranges from 200-800 kg. Ideally, carburized steel gears can be replaced with nitrided Ti alloys. An alternative approach is to replace the steel core of the gear with a Ti alloy, and use carburized steel gear teeth, reducing gear weight by 30-40%.

Body armor ceramic tiles. SiC and B_4C materials are commonly used for body armor, with B_4C the preferred material due to its lighter weight. SiC ceramic tiles are produced using pressureless sintering while B_4C ceramic tiles are produced using a hot process. In general, sintering B_4C materials is challenging and it takes a long time to produce ceramic tiles. Using FAST produces ceramic tiles more cost effectively (25-35% less) compared with the hot process. Ballistic performance of FAST B_4C ceramic tiles with a new architecture is better than baseline

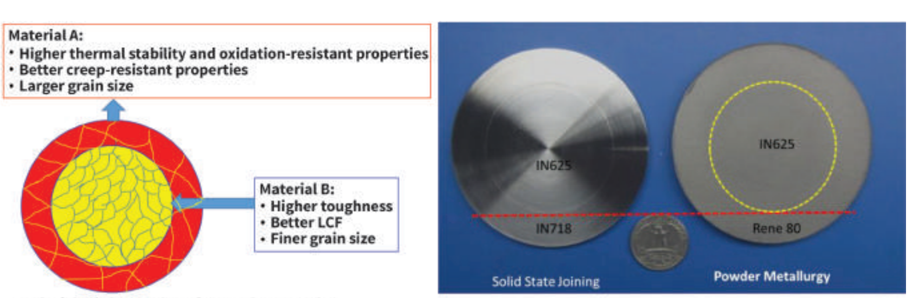

Fig. 4 — (a) Schematic of hybrid disk fabricated by solid state joining of two different materials having different properties producing a sharp interface; (b) fabricated hybrid disk produced via solid state joining (left) and by compacting and sintering two different powder materials using FAST (right).

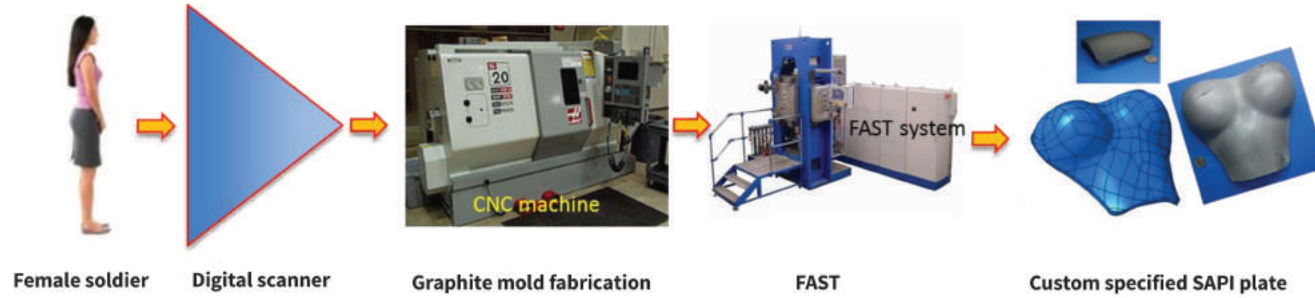

Fig. 5 — Manufacturing steps to produce subscale and custom small arms protective insert (SAPI) plates for female soldiers.

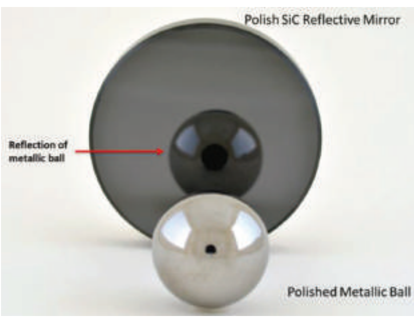

Fig. 6 — Highly reflective surface of SiC disk with a theoretical density of >99.7% produced from powder materials using FAST.

performance. Tailoring B_4C chemistry reduces stress-induced phase transformation, changes the crack propagation path, and delays penetration, which also indicates dispersion of the incoming focused energy across interfaces within the ceramic tiles. FAST is an enabling technology to custom manufacture SAPI (small arms protective insert) plates (body armor) for female soldiers, both quickly and cost effectively (Fig. 5).

Lightweight, thermally managed optics for space applications. SiC and B_4C offer a beneficial combination of physical and mechanical properties including high hardness, resistance to contamination, light weight, stability in ionizing radiation, and good elastic modulus. B_4C is an excellent lightweight material for mirrors. Its high elastic modulus (460 GPa) and low density (2.52 g/cm^3) provide a modulus-to-density ratio (specific modulus) that exceeds SiC, beryllium, and other ceramic materials. It can be finished to better than 19 Å, and provides a bidirectional reflectance distribution function suitable for many applications.

Currently, SiC mirrors are produced using chemical vapor deposition (CVD) at elevated temperatures. CVD produces a columnar structure with intergranular porosity, which is removed by hot isostatic pressing (HIP) at elevated temperature. The combination of CVD and HIP contributes to high cost and long lead times. These issues are addressed by using SiC powder followed by compaction and sintering using FAST, producing dense SiC disks with a theoretical density >99% and a submicron polycrystalline microstructure (Fig. 6). After fine polishing, the SiC disk surface exhibits properties similar to highly reflective optics.

SUMMARY

FAST is an enabling manufacturing technology to produce metal, ceramic, and composite components with tailored properties using a powder metallurgy approach. In many cases, it is a one-step, cost-effective manufacturing process. The technology is ready to be transferred to private industry for production of net-shape components. **~AM&P**

For more information: Jogender Singh is director, FAST-Center of Excellence, Department of Materials Science and Engineering, Pennsylvania State University, University Park, PA 16801, 814.863.9898, jxs46@psu.edu, www.psu.edu.

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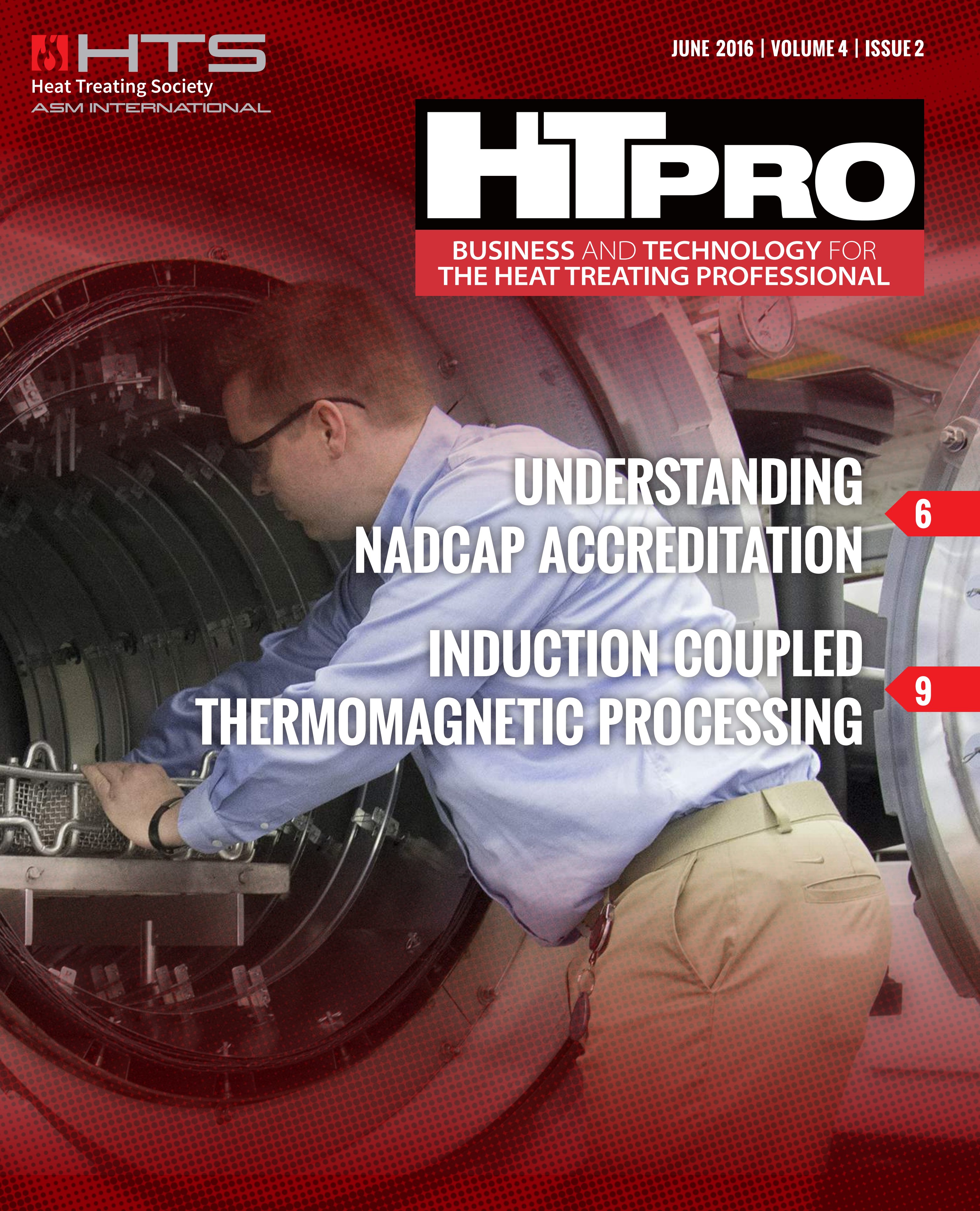
HTPRO

BUSINESS AND TECHNOLOGY FOR THE HEAT TREATING PROFESSIONAL



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DEPARTMENTS

ABOUT THE COVER

Parts must be carefully arranged during loading of the furnace for proper heat treatment to take place. Courtest of Ipsen, ipsenusa.com

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EDITORIAL OPPORTUNITIES FOR *HTPro* IN 2016

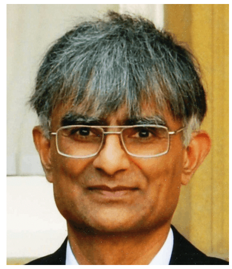
The editorial focus for *HTPro* in 2016 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

October Thermal Processing in Automotive Applications

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.



The same material can achieve a huge range of properties by exploiting heat treatment. Thus, steel can be made weaker than aluminum or stronger than millimeter-sized graphene or carbon nanotube samples. The properties of metals rely on size, shape, chemical composition, mechanical processing, and thermal treatment. The technologies available for thermal treatments are now astounding in their versatility. It is important therefore for engineers to appreciate some basic principles of heat treatment.

Heat treatment involves the motion of atoms. Because the extent to which atoms can move in the solid state depends exponentially on the inverse of temperature, and linearly with time, it follows that temperature has a much bigger effect than time. So an 80-ms heat treatment of steel at 600°C is about seven orders of magnitude more potent than holding a steel at 200°C for 10 days. On the other hand, very large components cannot be heat treated uniformly in short pulses of time. Thus, designing steel that transforms at low temperatures where the time scales required are long can be a positive advantage.

Concealed within this simple description of time and temperature is variety, because these two independent parameters can be varied suddenly, gently, or in complex combinations to affect the structure and properties of metals. For example, the Flash Bainite of Gary Cola relies on short time scales where the steel is not able to homogenize its carbon concentration even on a microscopic scale so that different regions transform to unexpected microstructures during rapid cooling. In contrast, the same phases require many days to evolve when very large chunks of steel are induced into a uniform nanocrystalline state.

Using fluids to cool metals during heat treatment is another fascinating technology. Red-hot forgings that are 300 tonnes in weight can now be quenched into violently flowing water without generating steam or bubbles of any sort! Likewise, minute regions of metal surfaces can be altered using pulsed lasers.

I hope that in these few words I have been able to convey the excitement of the subject. I recommend the proceedings of IFHTSE 2016, which includes articles that cover the plunging of red-hot swords into slaves and using ionic liquids as quenchants.

Sir Harry Bhadeshia
Tata Steel Professor of Metallurgy
Department of Materials Science & Metallurgy
University of Cambridge

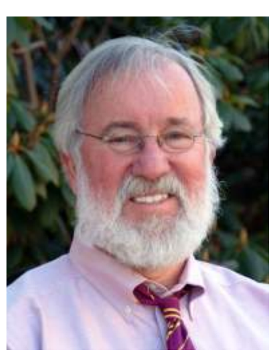
CAI WINS 2016 HTS/ BODYCOTE BEST PAPER IN HEAT TREATING AWARD

Winner of the HTS/Bodycote 2016 Best Paper in Heat Treating Award, Xiaoqing Cai.

The winner of the 2016 HTS/Bodycote Best Paper in Heat Treating Award is entitled, "Microstructure Development in AISI 4140 Steels During Tempering," by **Xiaoqing Cai,** a Ph.D. student in materials science and engineering at Worcester Polytechnic Institute (WPI). Cai received assistance from her advisor, Richard D. Sisson, FASM. She is currently working on a research project focused on furnace and induction tempering of steel. Cai has published three papers and given four presentations, and she plans to graduate in May 2017.

The award will be presented at WPI's Center for Heat Treating Excellence in June. The ASM Heat Treating Society established the Best Paper award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or shows a clear advancement in managing the business of heat treating. The award includes a plaque and $2500 prize endowed by Bodycote Thermal Process-North America.

SISSON RECEIVES WPI AWARD



Richard D. Sisson, FASM, received Worcester Polytechnic Institute's (WPI) 2016 Board of Trustees' Award for Outstanding Research and Creative Scholarship. The award recognizes continuing excellence in research and scholarship by faculty members over a period of at least five years. Sisson is the George F. Fuller Professor of Mechanical Engineering, director of WPI's Manufacturing and Materials Engineering Programs, and technical director of the WPI Center for Heat Treating Excellence. He is currently principal investigator for a multi-million-dollar, multi-institution project aimed at developing new metallurgical methods and new lightweight alloys to help the military build more effective and durable vehicles and systems.

HIGHLIGHTS FROM THE 23RD IFHTSE CONGRESS

Contributed by Scott MacKenzie, FASM

The 23rd IFHTSE Congress, held April 18-22 in Savannah, Ga., was very well attended with 20 countries and each continent represented. The conference attracted approximately 171 attendees and 20 exhibitors, and was sponsored by Houghton International and Linde Gas. The first keynote presenter was Prof. H.K.D.H. Bhadeshia, who was awarded the IFHTSE Medal and gave an interesting talk on "Very Short and Very Long Heat Treatments in the Processing of Steel." It was an excellent presentation, sprinkled with humor, and showed a real connection with the audience. Bhadeshia's talk was thought provoking and demonstrated some fundamental concepts in a unique manner. The second keynote was presented by Tobias Steiner, past winner of the Linde Tom Bell Young Author Award in Munich (2014). His presentation on "Alloying Element Nitride Development in Ferritic Fe-based Materials upon Nitriding" was intriguing and demonstrated fully why he was chosen for the Tom Bell Award. The final keynote was given by Prof. Dr.-Ing. habil. Rolf Zenker, Zenker Consult Mittweida, on "Surface Treatment by Electron Beam in Combination with Other Heat Treatment Technologies."

Presentations on quenching, modeling, nitriding, and other advanced thermal processes were held throughout the conference. One interesting paper on extending the life of furnace and fixture alloys by surface engineering was discussed by Anbo Wang of Worcester Polytechnic Institute (student of Prof. Rick Sisson). This paper examined the practical benefits of prolonging the life of expensive, high nickel alloy fixtures.

The winner of the Linde Tom Bell Young Author Award for this Congress was Matteo Villa, Technical University of Denmark, for his talk "The Sub-Zero Celsius Treatment of Stainless Steels: Experiments and Perspective."

A special symposium on residual stress prediction, control, and measurement was held in conjunction with the IFHTSE Congress. This symposium brought together many aerospace experts, including the USAF Materials Laboratory, Pratt & Whitney, Rolls-Royce, Lockheed Martin, and Boeing, as well as experts from IWT Bremen, including Prof. Hans-Werner Zoch, and others from the automotive industry. It was a very exciting symposium with an excellent idea exchange between very different industries. A great deal of networking was accomplished as well.

A special riverboat cruise on the Savannah River featuring a delicious dinner and perfect weather was a highlight of the conference. This IFHTSE Congress provided many opportunities for fellowship and networking. It was well organized and attendees from all over the globe enjoyed themselves. Special thanks goes to the domestic and international organizing committees, ASM staff including Jeanelle Harden and Lindy Good, and sponsors Houghton International Inc. and Linde Gas for a successful conference.

REGISTRATION NOW OPEN FOR HEAT TREAT MEXICO

The ASM Heat Treating Society will present a new global event, **Heat Treat Mexico: Advanced Thermal Processing Technology Conference and Expo,** scheduled for September 20-23 at the Fiesta Americana in Queretaro. The conference is designed for maintenance supervisors, metallurgists, and production engineers and will provide a bridge for relevant new technology for thermal processing and how it is applied to the production environment in Mexico. In addition to comprehensive technical programming, exhibitors will have the opportunity, in a classroom environment, to present the implementation of their technologies and products applicable to heat treating. Each presentation will be reviewed for technical merit and will include minimal sales-oriented content. For more information or to register, visit asminternational.org/web/htmexico.

CALL FOR PAPERS NOW OPEN FOR HEAT TREAT 2017

Heat Treat 2017, the biennial co-located show from the ASM Heat Treating Society and the American Gear Manufacturers Association, is now seeking papers. Conference organizers are looking for original, previously unpublished, noncommercial papers for both oral and poster presentations. Technical areas of interest include additive manufacturing, advanced processes, advances in heat treating, applied energy, atmosphere technology, automotive lightweighting, cryogenic treatment, induction heat treating, microstructure development, non-ferrous alloys, quenching and cooling, surface engineering, thermal mechanical processing, vacuum processes and technology, and more. **Submit your abstract by December 30 to be considered for the Heat Treat 2017 technical program.** For more information, visit asminternational.org/web/heat-treat-2017/cfp.

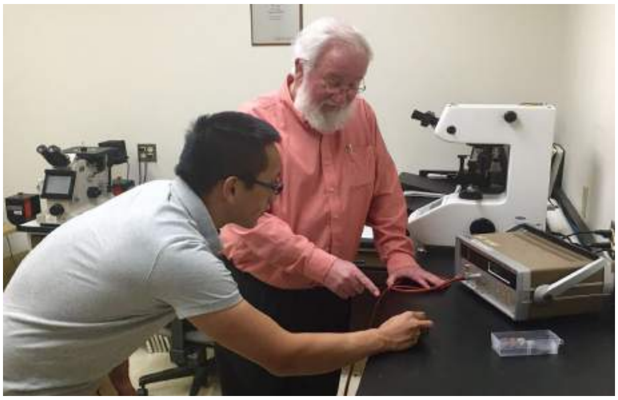
CHTE UPDATE

RESEARCH PROGRESS: NONDESTRUCTIVE MEASUREMENT TECHNIQUES

The Center for Heat Treating Excellence (CHTE) at Worcester Polytechnic Institute (WPI) in Massachusetts has spent the past three years working on a research project aimed at measuring surface hardness and case depth on carburized steels for process verification and control. CHTE is an alliance between the industrial sector and university researchers that addresses heat treating needs. The expectation is that project results will enable companies to improve the quality of heat treated products faster and more cost effectively.

According to lead researcher Richard Sisson, Jr., George F. Fuller Professor of Mechanical Engineering at WPI, and CHTE technical director, the heat treating industry needs accurate, rapid, and nondestructive techniques to measure surface hardness and case depth on carburized steels for process verification and control. "Current measurement methods require destructive testing with traveler specimens that cannot always represent the configurations of the production part, nor the associated subtleties of thermal history, carbon atmosphere, and geometry influenced diffusion. Our research will eliminate much of the guesswork," says Sisson.

Another challenge with the traveler specimen measurement method is that it often requires periodic production part cut-ups to validate the hardness and case depth of parts after carburization, especially for critical shaft and gear teeth configurations. A key issue for researchers is to distinguish between hardness and residual stress, as most techniques currently used to measure case depth are not only sensitive to hardness distribution, but also residual stress.



Lei Zhang (left) and Rick Sisson (right) perform research aimed at measuring surface hardness and case depth on carburized steels.

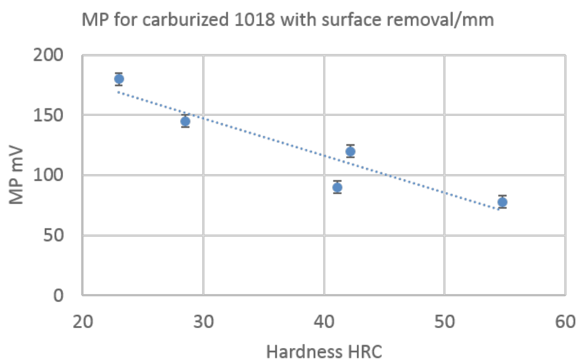


Fig. 1 — Magnetic parameter (MP) changes with surface hardness.

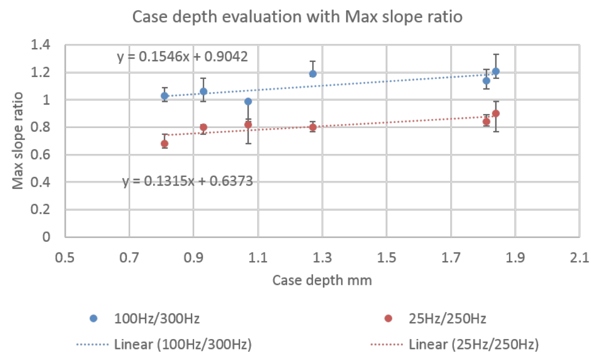


Fig. 2 — Maximum slope ratio changes with case depth.

PROJECT STEPS

The team analyzed several surface hardness and case depth measurement techniques, including eddy current, meandering winding magnetometer (MWM), and alternating current potential drop (ACPD), before concluding that Barkhausen noise testing and ACPD best support the project objectives. (Note: More work needs to be done on ACPD before insights can be shared.) Several widely used alloy steels including AISI 8620/9310/1018/5120 were carburized and fully characterized with destructive testing. Samples were also tempered. The concentration profile, hardness profile, and retained austenite percentage were experimentally determined. The team is now determining correlations among nondestructive test measurements and hardness and microstructure for standards, and then verifying the effectiveness of nondestructive test techniques in industry applications.

THE PROCESS

CHTE measured the properties of steel with Barkhausen testing and found a good correlation between surface hardness and the Barkhausen noise result. Magnetic parameter (MP) was measured with the Rollscan 350 unit from American Stress Technologies (AST). Carburized AISI 1018 samples were prepared using the surface removal method. Samples display different surface hardness due to the carbon concentration difference. MP is sensitive to hardness as shown in Fig. 1.

Due to the industry's need for case depth evaluation, additional testing with Barkhausen noise is being conducted by CHTE, which includes the effects of grain size, tempering condition, and microstructure. Working with AST, researchers used the magnet voltage sweep method for case depth testing. The Rollscan 350 unit can measure the MP by scanning the exiting voltage from 0 to 18 Vpp. Data is collected with software and the maximum slope of the curve is recorded. With measurement from two different frequencies, properties of the sample from different depths can be evaluated. The slope ratio of the two frequencies is then correlated with case depth as presented in Fig 2. Completion of this CHTE research project is expected in December.

For more information: Visit wpi.edu/+chte, call 508.831.5592, or email Rick Sisson (sisson@wpi.edu) or Diran Apelian (dapelian@wpi.edu).

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 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.

PART I

OBTAINING NADCAP ACCREDITATION: HELPFUL GUIDELINES FOR PASSING YOUR AUDIT

Learn how to simplify the process of obtaining Nadcap accreditation for your heat treating facility by paying heed to some of the challenges others have experienced.

Nathan Durham, Ipsen USA, Cherry Valley, Ill.

Heat treatment is a critical part of the manufacturing process for a wide range of products, such as those used in consumer goods, power generation, automobiles, aerospace, and many others. The quality and safety of heat treated products is of utmost importance to both the companies that produce them and consumers. Maintaining global quality standards in heat treating not only helps ensure the highest quality of components used in aerospace applications, but also helps heat treaters continually improve and refine their processes to provide the best product quality for all applications. Aerospace Material Specification (AMS) standards and Nadcap (National Aerospace and Defense Contractors Accreditation Program) play key roles in ensuring that manufacturers performing heat treating and other special processes adhere to consistent, high-quality standards for producing aerospace products.

A series of articles, beginning with this one, will discuss questions and challenges that can arise about the Nadcap accreditation process, specifications involved, and other process considerations. Recommended best practices and steps from those who have undergone Nadcap accreditation are presented to help simplify the process, including:

- Tips on preparing for internal and official Nadcap audits, including networking with other suppliers and establishing an approved quality system.
- Where to locate key documents and specifications that help you prepare for the audit process.
- Review of common nonconformances (NCR) to better understand certain specifications and requirements.

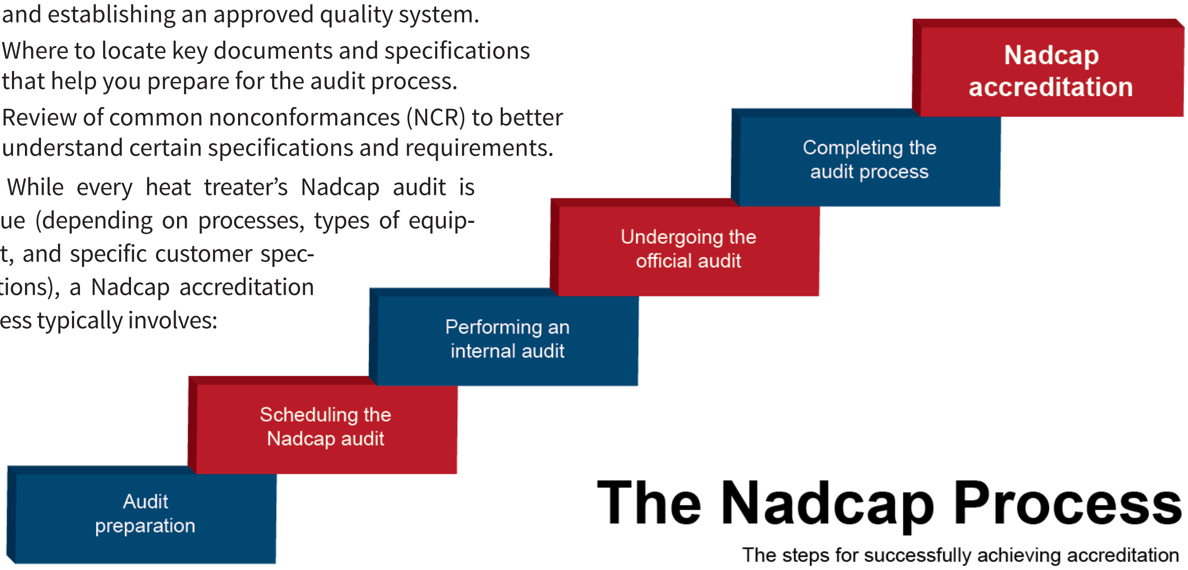
While every heat treater's Nadcap audit is unique (depending on processes, types of equipment, and specific customer specifications), a Nadcap accreditation process typically involves:

- Requesting and scheduling an audit
- Performing an internal audit
- Implementing corrective actions for findings from the internal audit
- Undergoing an official audit
- Reviewing and responding to NCR findings
- Applying corrective actions to resolve remaining issues
- Receiving Nadcap accreditation
- Whether participating in a Nadcap audit for the first time, or going through the reaccreditation process, many companies continually refine their audit process based on NCRs found during the internal and official audit.

PREPARING FOR AN AUDIT

The Nadcap audit process is lengthy and complex, but those who adequately prepare are able to make it through this endeavor without difficulty. Often, the biggest challenge is knowing where to start. Considering the following preparatory actions will help:

Locating key documents and specifications. To prepare for a quality audit, the first step is to know which documents



Overview of the typical Nadcap accreditation process, which often depends on specific primary contractor specifications, processes, equipment, and more. Courtesy of Ipsen.

During the process segment of the Nadcap audit, the auditor will spend a significant portion of time reviewing specification checklists and both historical and live jobs. Courtesy of Ipsen.

to reference and which specifications to adhere to throughout the process. Those who have gone through Nadcap accreditation recommend starting by visiting eAuditNet.com, a web-based software program. This program supports and improves efficiency in auditing and accreditation systems of industry-managed programs administered by the Performance Review Institute (PRI). PRI administers special process accreditation programs such as Nadcap. The website provides access to a range of supplemental materials, which can be referenced during the Nadcap audit. It also provides procedure documents on pre- and post-audit processes, which include detailed information on response timeframes, how to decrease audit frequency, and what to do about a failed audit.

Sources commonly referenced during the audit process include the *Heat Treating Task Group Audit Handbook* and the *Heat Treating Task Group Pyrometry Reference Guide*. These materials provide useful information, including:

- Definitions
- Supplier guidelines for auditing to Nadcap audit criteria
- General heat treatment items (e.g., testing and inspection details, vacuum considerations)

Overall, the handbook and reference guide offer guidelines to help better understand and meet items listed on the audit checklist.

Audit checklists and customer requirements. Nadcap accreditation is available for a range of programs such as coatings, fasteners, heat treating, and materials testing laboratories. In the case of a Nadcap audit for heat treating, basic audit checklists that apply to all disciplines within the heat-treating category include:

- AC7102 Revision H – Nadcap Audit Criteria for Heat Treating
- AC7102/8 – Nadcap Audit Criteria for Heat Treating Pyrometry
- AC7102/S Revision F – Nadcap Supplemental Audit Criteria for Heat Treating

Additional checklists could apply depending on the specific process for which the company is seeking accreditation. A complete list of checklists for the heat-treating category can be found on eAuditNet.

Supplemental checklist AC7102/S provides additional requirements for companies seeking accreditation by specific aerospace primary contractors (primes). Primes are companies that take on the total responsibility for any given project and typically build the major elements of a product in their own plants (e.g., Boeing, UTC, Snecma). However, they often subcontract to other companies for various required parts and systems. Therefore, it is essential to be familiar with both common industry standards and the customer's requirements and specifications before moving forward in the audit process. It is also very important to be familiar with and adhere to these documents, as they are the standards by which the company will be audited.

Consulting and networking with suppliers. In addition to becoming familiar with key documents and specifications, consulting and networking with other suppliers (companies that process components used by primes, calibration labs, furnace manufacturers) helps identify additional best practices to prepare for an audit. PRI holds three annual meetings that provide an opportunity to discuss audit experiences of other companies. These meetings also allow suppliers to discuss industry requirements directly with primes and gain clarification on checklist items. Notes from these meetings include information on what was discussed and conclusions on how to best handle certain issues and/or specifications; they can be reviewed on the eAuditNet website.

Discussions with other quality managers about their Nadcap audit experiences provide different points of view and help companies gain a better understanding of certain specifications. In addition, open discussions about best practices and recommended methods help companies better regulate themselves and ensure they consistently adhere to a global quality standard.

SCHEDULING A NADCAP AUDIT

Once a company reviews and understands the applicable checklists, reference materials, and customer requirements, and is confident they are fully prepared to perform an internal audit, it is time to schedule the official Nadcap audit through the eAuditNet website. It is important to know the answers to a few important questions before this step, including:

Q. Will you have either real parts for an aerospace customer, or have time to run sample aerospace parts during the scheduled audit?

A. It is recommended that you inform PRI in advance if you will be using sample aerospace parts.

Q. Do you know the scope of accreditation (i.e., processes and specifications) for which you want to be audited?

A. It is important to know the scope of accreditation beforehand, as you will be required to define the scope when scheduling the audit, as well as verify it at the beginning of the official audit.

Q. Do you already have quality system approval (e.g., AS/EN/JISQ 9100 and AS/EN 9110; ISO/IEC 17025)?

A. If you do not have an acceptable quality system approval, a standard audit process adds AC7004 (Aerospace Quality Systems) to the scope of accreditation. In this case, Nadcap auditors include a one-day quality system audit as part of the official audit process to verify that you adhere to this specification. If you already have acceptable quality system approval, you must provide evidence of such when scheduling, or at the start of the official audit. If you are unable to provide documentation, the auditor performs the quality system audit.

Q. Is there sufficient time between scheduling the audit and when the audit takes place to prepare for and perform an internal audit?

A. The accreditation process requires an internal audit (a form of self-assessment used to measure strengths and weaknesses against Nadcap audit requirements[1]) with results submitted at least 30 days prior to the official audit. However, it is recommended that the internal audit is conducted from three to six months prior to the official Nadcap audit. It is also important to factor in sufficient time to not only prepare for and conduct the internal audit, but to also identify the ultimate root cause and implement a corrective action for each NCR.

CONCLUSION

These are just a few helpful guidelines to consider before and during scheduling of an official audit. While this is just the initial step on the road to accreditation, the more prepared you are from the very beginning, the more successful you will be once the process is underway. Subsequent articles in this series will discuss details regarding the internal audit process, common NCRs, the official audit process, and auditor interactions.

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INDUCTION COUPLED THERMOMAGNETIC PROCESSING: A DISRUPTIVE TECHNOLOGY

Properties and performance of lower cost "simple" alloy steels processed using induction coupled thermomagnetic processing can rival those of conventionally processed, expensive specialty alloys.

Aquil Ahmad,* (retired), Eaton Corp., Cleveland; **George Pfaffmann, FASM,*** Ajax Tocco Magnethermic, Madison Heights, Mich.; **Gail Ludtka*** (retired) and **Gerard Ludtka, FASM,*** Oak Ridge National Laboratory, Tenn.

One of the major goals of the U.S. Department of Energy (DoE) is to achieve energy savings with a corresponding reduction in the carbon footprint. With this in mind, the DoE sponsored the Induction Coupled Thermomagnetic Processing (ITMP) project with major partners Eaton Corp., Ajax Tocco Magnethermic, and Oak Ridge National Laboratory (ORNL) to evaluate the viability of processing metals in a strong magnetic field.

Processing materials in such a manner is a novel, game changing concept[1]. Applying a strong magnetic field with controlled-frequency induction heat treatment to metals results in properties not achievable using conventional processing techniques. The magnetic field produces a change in thermodynamics that alters conventional phase diagrams resulting in new phase equilibria and solute solubilities. This provides opportunities to develop alloys with novel microstructures and improved physical and mechanical properties. In addition, phase transformation kinetics, especially for tempering, are dramatically accelerated. This results in improved processing efficiency and refined microstructural features, such as finer martensite-lath populations and large amounts of finer carbides after tempering.

The use of a coupled induction heat treatment with high magnetic field heat treatment enables the development of metals with improved performance using faster processing times and less energy. The technology allows substituting lower cost alloys for more expensive alloys[2] while achieving greater combinations of strength and ductility. In addition, microstructures can be tailored for improved magnetic properties, wear resistance, and mechanical performance. Processing lower cost, simple alloy steels under a strong magnetic field achieves properties comparable to those achieved in highly alloyed steels processed using conventional techniques. In addition, the enhanced strength and toughness in ITMP materials improves power density in a significant number of industrial mechanical components.

This article discusses some of the demonstrated improved mechanical properties achieved for steels in the ITMP project. The technology can also be applied to forging operations resulting in lower temperature formability, thus reducing energy consumption while improving mechanical properties. These results would be beneficial in components such as gears, shafts, net-shape forged valves, and forging dies. The technology is also applicable to non-ferrous alloys. For example, ITMP reduces solution heat treating and aging times by 80% for precipitation hardening aluminum alloys.

MAGNETIC PROCESSING DEFINED

Earth's magnetic field is 60 micro-tesla (μT) at the surface. By comparison, the industrial prototype superconducting magnet system at ORNL is capable of 9 T, 150,000 stronger than the earth's magnetic field. Application of a 9-T magnetic field in heat treat processing achieves properties in low cost alloy steels that rival properties achieved in more expensive higher alloy steels. Figure 1 shows the potential for improvement in steel performance versus cost per pound. The trend line indicates that the potential of thermomagnetic technology is unlimited.

BENEFITS OF ITMP

A strong magnetic field significantly affects the iron-iron carbide (Fe-Fe_3C) phase diagram, as well as the kinetic behaviors of continuous cooling and isothermal transformation. Benefits of ITMP include:

- Accelerated transformation kinetics
- Refined microstructure
- Fine carbide dispersion
- Minimum grain boundary segregation
- Mitigation of segregation banding
- Reduced volume fraction of retained austenite
- Improved mechanical properties including tensile and yield strengths, and ductility (elongation and reduction in area)

Rotating beam bending fatigue was evaluated using R.R. Moore type test equipment according to ASTM E466 "Standard Practice for Conducting Force Controlled Con-

*Member of ASM International; George Pfaffmann is recently deceased.

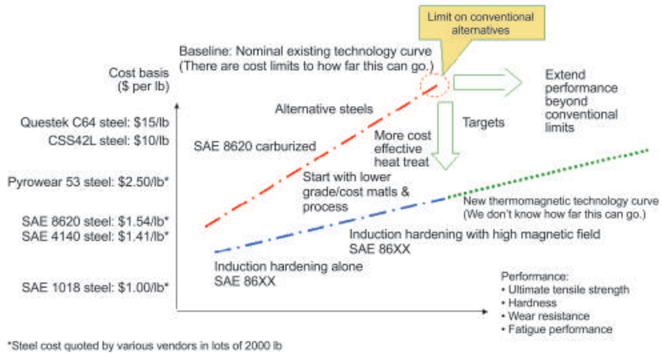

Fig. 1 — ITMP potential for improvement in steel performance versus cost per lb.

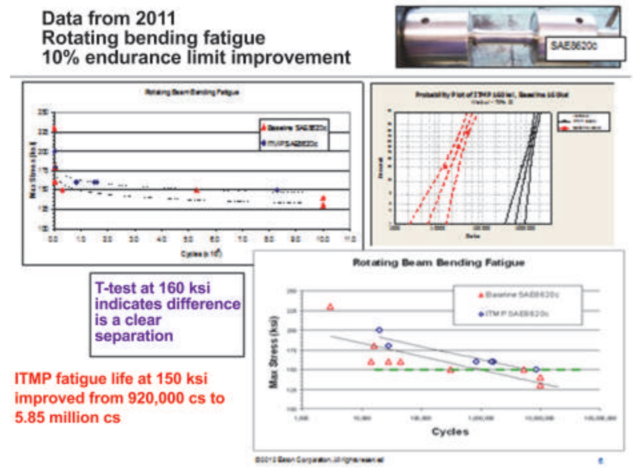

Fig. 2 — Improvement in rotating bending fatigue life of ITMP samples over baseline properties.

stant Amplitude Axial Fatigue Tests of Metallic Materials." Figure 2 shows an improvement of 6.4 times for ITMP samples over baseline carburized samples at a stress of 150 ksi (sample size: 6 in. long with 2 in. taper section; 0.75 in. diam.; 0.375 in. minor diam.).

Evaluation of reverse torsion fatigue in torsion shafts was not completed due to incompatibility of sample size and processing equipment. With the availability of a new industrial prototype thermomagnetic processing facility (Fig. 3), further studies were conducted on gear tooth bending fatigue.

Reverse idler gear single-tooth fatigue. Gears were processed in an 8-in. diameter superconducting magnet system incorporating a 10-30 kHz, 200-kW induction heating power supply with an integral 75 gpm polymer quench capability. Heat treated gears were shot peened to the same parameters as baseline gears. The goal was to improve single tooth bending fatigue by 200%. Technical challenges included developing a fine microstructure-scale understanding of ITMP and performing finite element analysis (FEA) and modeling calculations.

The first of two sets of experimental runs fell short of expectations and processing time and temperature parameters were revised for the second series of experiments. The new parameters for rapid heat up and hold time at temperature were based on Ajax Tocco calculations for achieving appropriate solid solution of carbon in the austenite phase, determined from results of joint research by Colorado School of Mines, ORNL, and Torrington[3]. FEA work was conducted such that the targeted carbon content in austenite before rapid quenching was achieved in the gear root without overheating the gear tip. (Note: Hot root, cool tip, and cold core.)

Single-tooth bending-fatigue test results for the second batch of gears showed an improvement of 2.5 to 5 times that of baseline gears (Fig.4). Probability analysis clearly demonstrates the mean shift in the curve for 202 ksi and 215 ksi. Results are as follows:

Stress level, ksi	Mean cycles Baseline	ITMP	Improvement
174	70,751	360,658	5.1×
202	23,822	75,626	3.17×
215	16,344	40,950	2.5×

Hardness and case depth of ITMP and as-carburized gears are comparable. ITMP dramatically accelerates the tempering process resulting in significant energy efficiency improvements, as well as reducing the carbon footprint. For example, tempering as-carburized gears at 350°F via ITMP required only 10 minutes compared with two hours using conventional processing.

ITMP gears have a refined microstructure with a fine dispersion of carbides and negligible segregation at the grain boundaries compared with the microstructure of baseline gears (Fig. 5). The thermodynamic effect of the strong magnetic field raises the martensite start temperature (M_s), resulting in a reduced volume of retained austenite. Induction hardening alone does not have this fundamental driving force. The lower volume percent of retained austenite and fine dispersion of carbides compared with the baseline microstructure leads to improved properties plus higher wear resistance.

CONCLUSIONS

- ITMP modified processing parameters on the reverse idler gears demonstrated major improvement in fatigue life (~3x) at very high stress levels.
- Tempering parts for 10 minutes in a magnetic field provides improved fatigue life properties compared with the conventional tempering for two hours at 350°F.

Fig. 3 —ORNL industrial prototype magnetic processing equipment includes 8-in. diam. vertical warm-bore superconducting magnet system and Ajax Tocco Magnethermic 200-kW dual-frequency induction heating system with 75-gpm polymer-water quench.

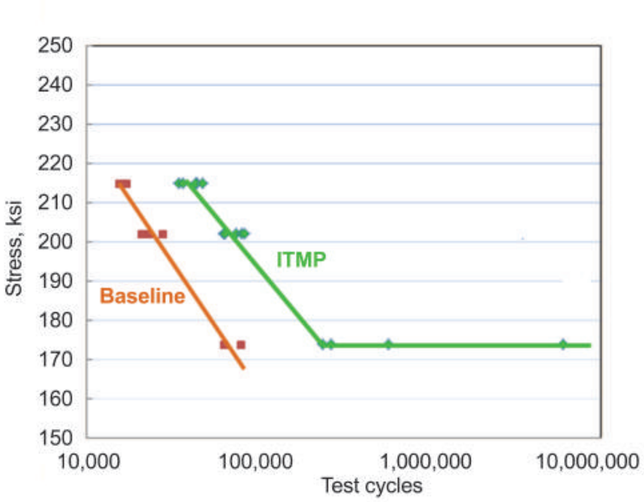

Fig. 4 — Improvement in single-tooth bending fatigue life of ITMP gears over baseline properties.

- From a sustainability perspective, an 85% reduction in energy use is estimated when using ITMP versus conventional processing for the gears.
- As presented in Fig. 1, low cost steels can rival exotic costly alloys in properties and performance when using ITMP.

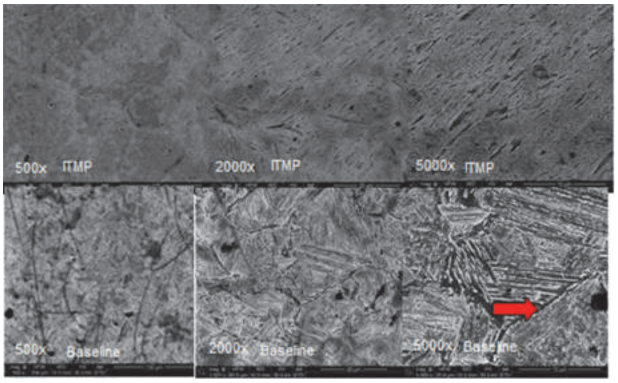

Fig. 5 — Microstructure of ITMP (top) and baseline gear (bottom). ITMP gear has a refined martensitic structure and fine carbides. Grain boundary in baseline gear indicated by red arrow.

Acknowledgment

This report is based on research supported by the U.S. DOE under Award No. DE-FG36-08GO18131 with Eaton Corp. as the primary lead, using the Thermomagnetic Processing Facilities at ORNL, supported by the Office of Energy Efficiency and Renewable Energy.

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ASMNEWS

BOARD NOMINEES ANNOUNCED

Schmidt for VP; Clauser for Treasurer; Hanke, Jones, and Wolodko for Trustees

The ASM Nominating Committee, chaired by Robert Hill, FASM, announced the nominees for ASM vice president and trustee for 2016-17 and three members of the Board of Trustees for 2016-19.

In accordance with the ASM Constitution, these nominees will be voted on at the ASM Annual Business Meeting on October 24, during MS&T16 in Salt Lake City. Once elected, the vice president will automatically become ASM president for 2017-18. In accordance with Article IV, Section 3 of the ASM Constitution, the ASM Board of Trustees has also announced its nominee for ASM Treasurer for 2016-2017.

Officers and members for the Board who will continue serving in 2016-2017 include: Dr. William E. Frazier, FASM, who will become president in October; Jon D. Tirpak, FASM, who will serve as immediate past president; and trustees Dr. Kathryn Dannemann, Dr. Tirumalai Sudarshan, FASM, Dr. David B. Williams, FASM, Dr. Ellen K. Cerreta, Dr. Ryan M. Deacon, and Prof. Sudipta Seal, FASM.

Retiring from the Board at this year's Annual Business Meeting will be immediate past president, Dr. Sunniva R. Collins, FASM, and trustees Jacqueline M. Earle, John Keough, FASM, and Dr. Zi-Kui Liu, FASM.

ASM's 2016 Nominating Committee, front row, from left: Christopher Dambra, Elizabeth Huber, Erin Camponeschi, Tresa Pollock, and Donald Muzyka. Back row, from left: Dana Medlin, Steve Kowalski, James Hemrick, and Bob Hill.

About the President-Elect and Board Nominees

Dr. William E. Frazier, FASM
President-Elect

Frazier

Dr. William E. Frazier has been an active member of ASM International since joining the society as a student in 1977. He received his B.S., M.S., and Ph.D. degrees in materials engineering from Drexel University in 1981, 1984, and 1987, respectively. He is a graduate of the Naval Aviation Executive Institute's Senior Executive Management Development Program, and the Defense Systems Management College's Advanced Program Management Curriculum.

Frazier is a Navy executive with 36 years of experience in naval aviation materials science and engineering. His position is Navy Senior Scientist for Materials Engineering and he serves as the chief scientist of the Air Vehicle Engineering Department at the Naval Air Systems Command. In this capacity, he provides technical direction and develops strategic plans for the research, development, and transition of naval aviation technologies.

Frazier has also been the technical architect and driving force behind several thrust areas. He developed cross disciplinary, multi-organizational program and R&D roadmaps in the following areas: additive manufacturing of structurally critical metallic components; nano-materials and meta-materials technology; durable aircraft materials and structures; corrosion-resistant alloy development; erosion-resistant rotor blade materials; and integrated structural health management.

Frazier is a recognized expert in materials selection, qualification, and certification, failure analysis, light alloy development, materials processing, and manufacturing technology. He has authored more than 90 technical

In This Issue

ASM INTERNATIONAL
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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

publications, edited six books, and holds two U.S. Patents. He was inducted as an ASM Fellow in 1996, and served as an ASM Trustee from 2003-2007. He has also served on numerous committees including the AeroMat Committee and the Emerging Technologies Awareness Committee. Currently he serves as an associate editor for the *Journal of Materials Engineering and Performance* and he is a key reader for *Metallurgical and Materials Transactions A.*

Dr. Frederick E. Schmidt, Jr., P.E., FASM
Nominee for Vice President


Schmidt

Dr. Frederick E. Schmidt, Jr., P.E., FASM, retired in 2015 after 17 years as a senior managing consultant at Engineering Systems Inc. (ESI). He served as technical director of materials engineering at ESI for many years. He was responsible for a very broad professional engineering practice, which used interdisciplinary teamwork with clients and other experts while working to solve complex “mission impossible” problems. Prior to ESI, he served as chief metallurgist for Remington Arms, a subsidiary of E.I. DuPont De Nemours. He designed and specified all materials, coatings, and processes for advanced weapons, i.e., Navy SEALs, sniper firearms, commercial products, and ammunition optimization for the U.S. Army.

Schmidt was employed by DuPont from 1972 to 1993 as an R&D coordinator of inter-department projects at the Experimental Station, Wilmington, Del. He was appointed a research fellow in 1989 in recognition of his creative solutions to proprietary electronic and materials processing quality control issues. He was also the designated liaison to the engineering development laboratory and DuPont legal department tasked to invent unique products and processes.

Schmidt was commissioned in the U.S. Army in 1968. He served for 12 years in various command positions, as a combat qualified reserve officer, and retired in 1980 as Captain in the Corps of Engineers.

Schmidt is a Fellow of ASM International and Alpha Sigma Mu, where he currently serves as president and chairman of the Board of Trustees, since 2010. He served on the ASM Board of Trustees from 2004-2007 as well as the ASM Materials Education Foundation Board as Trustee from 2007-2010. Schmidt received the ASM International Allan Ray Putnam Service Award in 1991 and the William Hunt Eisenman Award in 2015. He has a Ph.D. and M.S. in materials science and engineering from Drexel University, and a B.S. in metallurgical engineering from Drexel Institute of Technology. He became a professional engineer in the State of Pennsylvania in 1981 and currently holds P.E. licenses in eight states. Schmidt has earned the National Council of Examiners for Engineering and Surveying (NCEES) designation as a Model Law Engineer.

Craig D. Clauser
Nominee for Treasurer


Clauser

Craig D. Clauser is president and owner of Craig Clauser Engineering Consulting Inc., which he founded in 2005. The company provides metallurgical engineering services nationwide, primarily in failure analysis and process improvement.

Clauser is a magna cum laude graduate of Lehigh University with a B.S. and M.S. in metallurgical engineering and materials science and is a registered professional engineer. He joined Westinghouse Electric Power Generation as a metallurgical engineer in the Materials Engineering Laboratory after graduating and subsequently became laboratory manager. The laboratory serviced the Steam Turbine, Gas Turbine, and Heat Transfer Divisions at Lester, Pa. In 1977, Clauser joined Phoenix Steel Corp. where he served as technical director. Phoenix produced carbon and alloy plate in Claymont, Del., and heavy wall, pilger forged tubing in Phoenixville, Pa., and was a leader in clean steel technology. In 1986, he joined Consulting Engineers and Scientists Inc. in Malvern, Pa., where he was an engineer and senior vice president until starting his own firm.

Clauser joined ASM in 1967 and was Philadelphia Chapter Chairman in 1983. He also served as chairman of the ASM Chapter Operations Committee and the Handbook Committee. He is currently a member of the ASM Content, Failure Analysis, and Handbook Committees as well as the ASM Finance and Investment Committees. He was the Delaware Valley Metals Man of the Year in 1993 and Philadelphia Liberty Bell Chapter Albert Sauveur Lecturer in 2001. Clauser is also a member of NSPE, ASTM, NACE, ASME, and AWS.

Larry D. Hanke, P.E., FASM
Nominee for Trustee


Hanke

Larry D. Hanke, P.E. FASM, is the principal engineer and founder of Materials Evaluation and Engineering Inc. in Minneapolis. The company provides materials engineering and product testing services to manufacturers and end-users for a wide variety of industries, including medical devices, microelectronics, power generation, and consumer products. Although managing a company and supervising a team of engineers takes up much of his time, Hanke is happiest when he is at a microscope looking at a fracture or a microstructure.

ASM has played an important role in Larry's professional life since joining the society as a student member. He was a founding member and officer of the student chapter at Iowa State University, has chaired two local chapters, and served on four national committees including terms as chair of the Handbook Committee and Failure Analysis Committee. Along the way, he has also taught ASM education courses, chaired symposia, and mentored at materials camps.

Hanke is a registered professional engineer in multiple states and is also a member of SPE, NACE, AWS, ASTM, and three ASM Affiliate Societies, the Shape Memory and Superelastic Technologies Society, Failure Analysis Society, and International Metallographic Society.

Roger A. Jones
Nominee for Trustee

Jones

Roger A. Jones is corporate president of Solar Atmospheres. He attended Hocking Technical College and then joined ABAR Corp. in 1975. At the founding of Vacuum Furnace Systems in 1978, he began working at the company along with his father, William R. Jones, FASM. In 1983, Jones assisted the founding of Solar Atmospheres Inc. as vice president, moving up to corporate president in 2001. Early on, he established Solar Atmospheres' strategic management team. Today, Solar is the largest privately owned vacuum heat treating company in North America, with four heat treat facilities.

A member of the Metal Treating Institute (MTI) since 1983, Jones served as chairman of the Atlantic Coast Chapter in 1994. He has been on the Program Committee since 1995 and is currently co-chair. A member of the Board of Trustees since 1998, Jones was president of the Institute from 2004-2005. He was called back onto the Board in 2009 for a third term.

Jones has chaired nine committees since becoming a member of ASM's Philadelphia Liberty Bell Chapter in 1983. He became his company's sustaining member representative in 1986 and was Chapter chairman for 1993-1994. At the national level, Jones served on and chaired numerous committees, including the Membership Committee in 1996-1997. He also chaired the Heat Treating Society (HTS) Immediate Needs Committee as well as its Education Committee, and continues as a member. He served on the Nominating Committee for two separate terms. He is also a member of the HTS T&P Committee. In 2005, Jones was appointed to the HTS Board and continues to serve.

Jones received many local awards from the Philadelphia Chapter, and was the recipient of the William Hunt Eisenman Award in 2001 as well as the Distinguished Service Award in 2004. In 2009, he received the President's Award. Honors from MTI include the President's Award and Program Service Award in 2002. He received the Distinguished Service Award in 2009 and The Award of Merit 2011. Jones has given talks and published various technical papers in *Industrial Heating*, *Advanced Materials & Processes,* and *Heat Treating Progress*.

Dr. John Wolodko, P. Eng., FASM
Nominee for Trustee

Wolodko

Dr. John Wolodko is currently the AITF Strategic Chair in Bio and Industrial Materials, and an associate professor at the University of Alberta in Edmonton, Canada. His main research focus is in novel materials from sustainable sources and materials for the energy sector. Specific areas of research include development of bio-based composites, bio-based textile structures, characterization of degradation mechanisms, characterization of wear/abrasion in oil sands mining, microbially influenced corrosion (MIC) in pipeline systems, and product life cycle assessment.

Wolodko is a former executive director at Alberta Innovates – Technology Futures (AITF) in Edmonton and has over 20 years of research and development experience in advanced materials, manufacturing, testing, and engineering design. He is also the former director of the Materials and Reliability in Oil Sands research program, a consortium focused on applied R&D and technology development for the oil sands sector.

Wolodko obtained his Ph.D. in mechanical engineering from the University of Alberta in 1999, and has been an active ASM member over the past 15 years. He is a past chair of ASM Canada Council and the ASM Volunteerism Committee. He has also participated in various roles at both the local and national levels including former chair of the ASM Edmonton Chapter, member of the ASM Nominating Committee, and regular presenter at MS&T. In addition to his committee roles, he has organized ASM Teachers Materials Camps for the Edmonton Chapter over the past decade, and has been a volunteer for outreach programs including the Edmonton Regional Science Fair and the Alberta Teachers Association Science Conference.

In addition to his volunteer roles with ASM, Wolodko has also been an active member of NACE International and the Association of Professional Engineers and Geoscientists of Alberta (APEGA). He has been on the organizing committee of several conferences including the NACE Northern Area Western Conference (2008 and 2014), the Oil Sands and Heavy Oil Integrity Workshop (2008-2012), and the 10th Pacific Rim Biocomposites Symposium (2010). He is the recipient of the distinguished 2015 G. MacDonald Young Award from ASM International, 2010 Brian Ives Lectureship Award, and has garnered the AITF Leaders Award in both 2011 and 2013.

ASM forms Strategic Alliance with Society of Vacuum Coaters

On April 13, ASM International and the Society of Vacuum Coaters (SVC) entered into a strategic alliance. SVC is the international, industry-leading resource for learning, applying, and advancing vacuum coating, surface engineering, and related technologies. For 59 years, SVC has been dedicated to providing a global forum to inform, educate, and engage its members, the technical community, and the public on all aspects of such technologies. The new alliance brings the complementary strengths of both organizations together to better serve their global members and the community at large. As part of this alliance, ASM will begin providing comprehensive association management services to SVC and the SVC Foundation starting July 1.

"Going forward, the SVC/ASM alliance will extend and enhance the collaborative opportunities to address complex industrial and academic opportunities from basic research through process optimization in materials, coatings, and surface science technologies," says Professor Wolfgang Diehl, SVC president.

Thomas Dudley, interim managing director of ASM, commented, "ASM International brings an organizational critical mass and complementary set of affiliate organizations to deploy comprehensive solutions and training in a depth and breadth that was not previously possible." Jon Tirpak, president of ASM International, added that he looks forward to a long working relationship with SVC for the benefit of both organizations.

Incoming SVC president Gary Vergason says, "ASM's headquarters houses a world-class, hands-on training facility that will greatly enhance our year-round educational program for technicians and engineers. Bringing PVD equipment into ASM's equipment lab will provide a wide tutorial range from system design and troubleshooting through process techniques and development. Both organizations are excited about the synergies that will come together with the combination of surface engineering and materials science."

ASM Nominations

The ASM International Constitution provides that members of the Society may submit additional nominations after the Nominating Committee has made its official report. Article V, Section 6 of the ASM Constitution reads: "After publication of the Nominating Committee's report on nominees, and the Board report on its nominee for Treasurer, and at any time prior to July 15 of the same year, additional nominations for any or all of the vacancies may be made in writing to the Secretary at Headquarters. Such nominations must be signed by at least five individuals or Chapter Sustaining Members, each from any combination of at least 10 Chapters and/or ASM Committees. Such nominees shall be processed by the Secretary for compliance with Section 4 of this Article. This shall be the only way in which additional nominations may be made. The membership of ASM International shall be duly notified of such additional nominations."

Official ASM Annual Business Meeting Notice

The Annual Business Meeting of members of ASM International will be held in conjunction with MS&T16 on:

Monday, October 24

4:00–5:00 p.m.

Salt Palace Convention Center,

Salt Lake City

The purpose of the ASM Annual Business Meeting is the election of officers for the 2016-17 term and transaction of other Society business.

From left, Gary Vergason, Tom Dudley, and Bryant Hichwa signed a strategic alliance agreement on April 13 at ASM's headquarters in Materials Park, Ohio.

ASM Signs MOU with Indian Foundry Organization

On April 11 at an event held in Mumbai, ASM International India signed a memorandum of understanding (MOU) with the Indian Foundry Organization (IFO). The MOU is the first step in involving the IFO membership with ASM and increasing awareness of ASM in India. Similar MOUs are in the works with the Indian Institute of Welding and the Indian Institute of Engineers.

From left, Ashok Kumar Tiwari, Prem Aurora, H. Sundara Murthy, and P.B. Rastori.

IMS Board of Directors Calls for Nominations

IMS is soliciting nominations for candidates for the IMS Board of Directors. Open positions include three directors who serve for four years. Terms begin August 1, 2017. Any member of IMS in good standing is encouraged to nominate themselves or another member for one of these positions. Current Board members whose terms are expiring may be eligible for nomination and possible re-election on an equal basis with any other candidate. **Nominations for Board Members are due June 20, 2016.** For more information, visit asminternational.org/web/ims/membership/nominations.

Microscopy & Microanalysis 2016

The Microscopy & Microanalysis 2016 Conference and the 49th International Metallographic Society Annual Meeting will take place July 24-28 at the Columbus Convention Center in downtown Columbus, Ohio. Plan to attend the diverse technical program, educational short courses, vendor exhibits, and social activities. Topics of particular interest to IMS members are listed below and the full list of events can be found through the IMS website at metallography.net.

- P07 – Failure Analysis Applications of Microanalysis, Microscopy, Metallography & Fractography
- P08 – Microscopy of Additive Manufacturing and 3D Printing in Materials and Biology

M&M 2016
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- P09 – From Nanometers to AU: Studies of Planet-Forming Materials
- P10 – Microscopy and Characterization of Ceramics, Polymers and Composites
- P11 – Metallography and Microstructural Characterization of Metals

FAS Seeks Students and Emerging Professionals as Board Members

The newly formed ASM Failure Analysis Society (FAS) is seeking applicants for its inaugural student board member and emerging professional board member positions. FAS is an affiliate society of ASM International, dedicated to advancing the important role that failure analysis plays in the materials science industry. Students must be a registered undergraduate or graduate during the 2016-2017 academic year and must be studying or involved in research in an area closely related to failure analysis. Emerging professionals must be within five years of graduation with an interest in the field of failure analysis. **Application deadline is July 1.** For more information, visit http://bit.ly/1TLurW0.

New Volunteer Recognition Campaign Begins

Volunteers are the heart of ASM and we want to celebrate that by putting our people front and center with our new "Catch Volunteers in Action" campaign. The following are great places to catch our volunteers in action:

- Monthly technical meetings
- Chapter social events
- Materials camps
- Local science fairs
- Local colleges or universities

Everyone gets excited to see people and events they are familiar with and the cumulative effect of capturing the wide range of activities accomplished by volunteers enhances our sense of community. Social media provides a perfect platform for celebrating volunteers. Give a shout out to the ASM volunteers you know by posting and tagging photos with **#ASMvolunteersinaction** on Facebook, Twitter, LinkedIn, and Instagram. Be sure to include a caption that includes the volunteer's name, chapter affiliation, and a brief description of the activity. Photos can also be submitted to ASM News by emailing frances.richards@asminternational.org.

ASM Materials Education Foundation Names National Merit Scholar


He

The ASM Materials Education Foundation selected Helen He as its 2016 ASM Materials Education Foundation National Merit Scholar. Helen will graduate from William P. Clements High School, Sugar Land, Texas, in 2016. She was selected based on outstanding academic achievements, diverse activities, and her interest in pursuing a career in materials engineering.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Warren Haws, Consultant, Retired from Materion R&D


Haws

After 40 years of volunteering for ASM, Warren Haws laughs and explains, "When I first came to Cleveland, someone asked me to volunteer—and nobody ever asked me to stop!" He is now retired from a successful career in materials engineering, working in research and development for Glidden Metals and then Brush Wellman (now Materion) as an expert in beryllium and aluminum-beryllium used in space and aerospace for its stiff, lightweight, and nuclear properties.

Haws first joined ASM in 1969 as an undergrad at Purdue University, where he also earned his Ph.D. After moving to Cleveland in 1976, he quickly got involved in the local Chapter's student affairs committee and began judging science fairs. He never stopped. Haws has gone through the chairman cycle twice, helped organize the 75th Chapter anniversary celebration (now working on the 100th), served on numerous committees including the National Chapter Council, became an ASM Fellow in 2004, and was added to the Volunteer Honor Roll in 2014.

Teaching is another passion for Haws, from college computer classes in the 1980s to his current role leading ASM classes at various sites, from Houston to the Canadian Nuclear Laboratories. After retiring in 2009, Haws started a consulting business and currently advises a client on 3D printing of metals, helping to improve methods for layering metals and creating complicated parts.

Asked why he continues to volunteer with ASM, he is quick to say, "I just enjoy it! I've had a lot of fun with student affairs and seeing young kids at science fairs, with some later going into metallurgy. I feel a need to give back." Haws still remembers winning a school science fair and how it inspired him. He encourages other professionals to give back, even simply judging a science fair once a year. "I'd like to see corporate cultures support volunteering," he says, "and realize the value to the community."

WOMEN IN ENGINEERING

This new profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with ***Lesley D. Frame,*** *Director of Product Development for Thermatool Corp.*


Frame

What part of your job do you like most?

Learning. Every day that I am faced with technical challenges and opportunities is a good day. Being able to interact with customers to hear their challenges and the ways that they are pushing Thermatool equipment to the extremes is always very exciting for me—that is where innovation starts. I listen to the customer and I merge their requests and concerns with my skill and knowledge. From there we jointly develop new products, new processes, and drive improvements to industry norms.

What is your engineering background?

I fell in love with materials engineering when I was at MIT earning my bachelor's degree, and I decided to stick with the field for the long haul (earning my M.S. and Ph.D. at University of Arizona). I think the reason I appreciate MSE so much stems from my desire to focus on the fundamentals and then zoom out to the application. Studying materials from the atomic arrangements up to the steel bridges and titanium fan blades is wonderful.

I have mostly focused on metallurgy and slag systems, which necessarily includes glasses and ceramics. I also have a keen interest in geology, and throughout my education, I had one foot in archaeology. As a student, I studied ancient technologies alongside modern metallurgical questions and phenomena. You can really learn a lot about a process when you painstakingly reconstruct it based on a finished product.

In my current position, I use the same strategies for modern technologies and processes. I enjoy working with customers to troubleshoot their welding and heat treating processes, and I look for ways to improve the process for better efficiency and quality. When I am brought in to work on these problems, we often start by deconstructing the process to figure out what changed or what went wrong. In many ways it is very similar to reverse engineering an ancient technology.

What attracted you to engineering?

I have always loved puzzles. Being an engineer basically just means that I get to work on larger and more complicated puzzles all the time. At home or at work, I am always figuring out ways to do a task faster, build something new, or make a material that will get the job done better and cheaper. Let's face it, engineering is really fun!

How many people do you work with?

I manage a few different teams, so I get the opportunity to work with several different people every day. I manage software and controls engineers, as we work on new ways to improve data management with our products. I work with materials engineers on various material characterization projects. I manage an R&D team that includes mechanical engineers, electrical engineers, designers, and controls engineers.

I also spend a lot of time with customers in the tube and pipe industry. I love when I am able to get in the field and see the equipment we designed in action and talk to the men and women who use it every day. It is always so exciting and absolutely critical to develop an understanding of where theory intersects with reality. I have worked with customers on induction quench and temper lines and also countless customers using high frequency welding technology. I never get tired of learning more about manufacturing technologies, and I revel in the challenge of figuring out the theoretical and practical explanations that support what we observe in the field.

If a young person approached you for career advice about pursuing engineering, what would you tell them?

The most important consideration when going into any engineering field is to first master the fundamentals. You need to have strong math and physics skills to really thrive. Beyond that, you can build a career in any engineering discipline. Also, don't be afraid to get a little dirty. Hands-on, real world experience will greatly supplement your academic education. Internships are great, but even if you are just taking your car apart and putting it back together again, you are practicing those engineering skills.

Hobbies?

Building things, hiking, camping, baking.

Last book read?

"The Martian." Basically, MacGyver on Mars—what engineer wouldn't love this? And there's even a shout-out to the importance of materials engineers!

For more information about ASM's Women in Materials Engineering Committee, visit asminternational.org/wime.

CHAPTERS IN THE NEWS

Los Angeles Enjoys NASA Talk on Mars Rover

In March, the Los Angeles Chapter held its meeting at Caltech along with the Caltech Chapter of the Materials Research Society. Dr. Ashwin Vasavada of the NASA Jet Propulsion Laboratory spoke on "What NASA's Curiosity Mars Rover has Revealed about the Red Planet's Past."

From left, Chuck Daugherty and John Ogren represent 113 years of ASM membership.

From left, Michael Hahn presents Ashwin Vasavada with a certificate and Los Angeles Chapter pint glass.

HIGHLIGHTS CHAPTERS IN THE NEWS

Hartford Holds Student Night

On April 12, Alpha Sigma Mu Connecticut Alpha Chapter 2016 inductees were recognized during the Hartford Chapter's student night.

From left: Harold Brody (Chapter advisor), Matthew Kall, Jarred Correia, Alyssa Denno, Zachary Kerschner, Jay Latimer, Jordan Kovacs, Zachary Thatcher, and Aaron Gladstein.

Cleveland Presents Technical Educator Award

On May 16, the Cleveland Chapter Technical Educator Award of 2015-2016 was presented to Jen McGeown in recognition of her outstanding performance and sustained success in introducing middle school students to science and engineering practice through science fairs and STEM classes. The award recognizes an ASM member or non-member who has made a substantial contribution to technical education methods and/or is considered to uniquely inspire students to pursue technical fields. The recipient has demonstrated outstanding performance, creative abilities, technical competence, and integrity in the practice of his or her technical discipline.

From left, Rachel Pomerantes and Jen McGeown.

UConn Material Advantage Chapter Assists Materials Camp

On April 18, three STEM high schools sent 33 students and five teachers to the Institute of Materials Science at UConn Storrs to enjoy material demonstrations at the 2016 Hartford Area Materials Camp.

Student volunteers from the UConn Material Advantage Chapter.

Attendees from the University High School for Science and Engineering.

Pittsburgh and NWPA Tour Elliott Company

Elliott Co., the Pittsburgh Chapter's sustaining member, hosted both Pittsburgh and NWPA Chapter members for a plant tour on April 21. The meeting covered the entire production facility in Jeannette, Pa., and also gave an overview of Elliott's business.

Pittsburgh and NWPA Chapter members enjoyed a plant tour of Elliott Co.

MEMBERS IN THE NEWS

Shipilov Named Fellow of CIM

Sergei Shipilov, FASM, a senior R&D staff member at the Materials Science and Technology Division at Oak Ridge National Laboratory (ORNL), was named a Fellow of the Canadian Institute of Mining, Metallurgy and Petroleum (CIM). Prior to joining ORNL in 2015, he was a member of the Metallurgical Consulting Services' team (Calgary, Alberta) that received the 2012 ASM Canada Council John Convey Innovation Award. Shipilov's expertise is in the area of environmental effects on the mechanical properties and integrity of materials. His research findings have been used in nuclear power generation, aerospace, space, naval, medical device, oil and gas, petrochemical, and infrastructure technologies.

CIM President Garth Kirkham (left) presents Sergei Shipilov with the CIM Fellowship Award at the CIM Awards Gala in Vancouver, B.C., on May 2.

Carter Receives NSF Career Grant

Carter

Jennifer Carter, an assistant professor of materials science and engineering at Case Western Reserve University, received a $500,000 Career grant from the National Science Foundation. Funds will be used to help improve durability of turbine discs used in nuclear, coal, and hydro power plants and heat resistance of medical imaging equipment parts, among other initiatives. Carter's lab is investigating the mesoscale structure, interactions, and other features in the boundaries between layers of materials that influence overall part performance. Her lab plans to develop an open-source, big data tool that can be used to design and manufacture materials that optimize the interface to produce desired qualities.

Vander Voort Visits India, Argentina

On March 16, **George Vander Voort, FASM,** presented a workshop on "Metallography for Failure Analysis" for the Mumbai ASM International Chapter, sponsored by Aimil Ltd. and the Indian Institute of Technology in Mumbai. He then flew to Jindal University in Raigarh, India, where he served as keynote speaker at the 2nd International Conference on Advances in Steel, Power and Construction Technology, from March 17-19. He also gave an afternoon seminar on "Mill Metallography." On April 4-5, Vander Voort gave a two-day course on "Specimen Preparation for EBSD" in Bariloche, Argentina, as part of the 4th Congreso Argentino de Microscopia, SAMIC 2016, for the materials characterization groups at the Atomic Energy centers in Bariloche and Buenos Aires.

George Vander Voort with several Indian students.

George Vander Voort with engineers from Argentina's atomic energy laboratories.

HIGHLIGHTS MEMBERS IN THE NEWS

Rosei Named Honorary Professor at Harbin Institute of Technology

Federico Rosei, INRS professor and current director of Énergie Matériaux Télécommunications Research Centre, received the Harbin Institute of Technology's highest honor—the title of honorary professor. The university is one of China's finest and is known for its teaching and research in technology, particularly in the aerospace field.


Rosei

Tirpak Visits Ryerson University

On May 4, ASM President **Jon Tirpak, FASM,** visited the Centre for Near-Net-Shape Processing of Materials, Ryerson University, Toronto, and discussed light metal casting, automotive powertrain efficiency, and the environment.


From left, Horace Chan, Payam Emadi, Anthony Lombardi, Eli Vandersluis, Suleman Ahmad, Jon Tirpak, Ravi Ravindran, FASM, Liping Fang, Rick Blackwell, FASM, Jacob Friedman, and Alan Machin.

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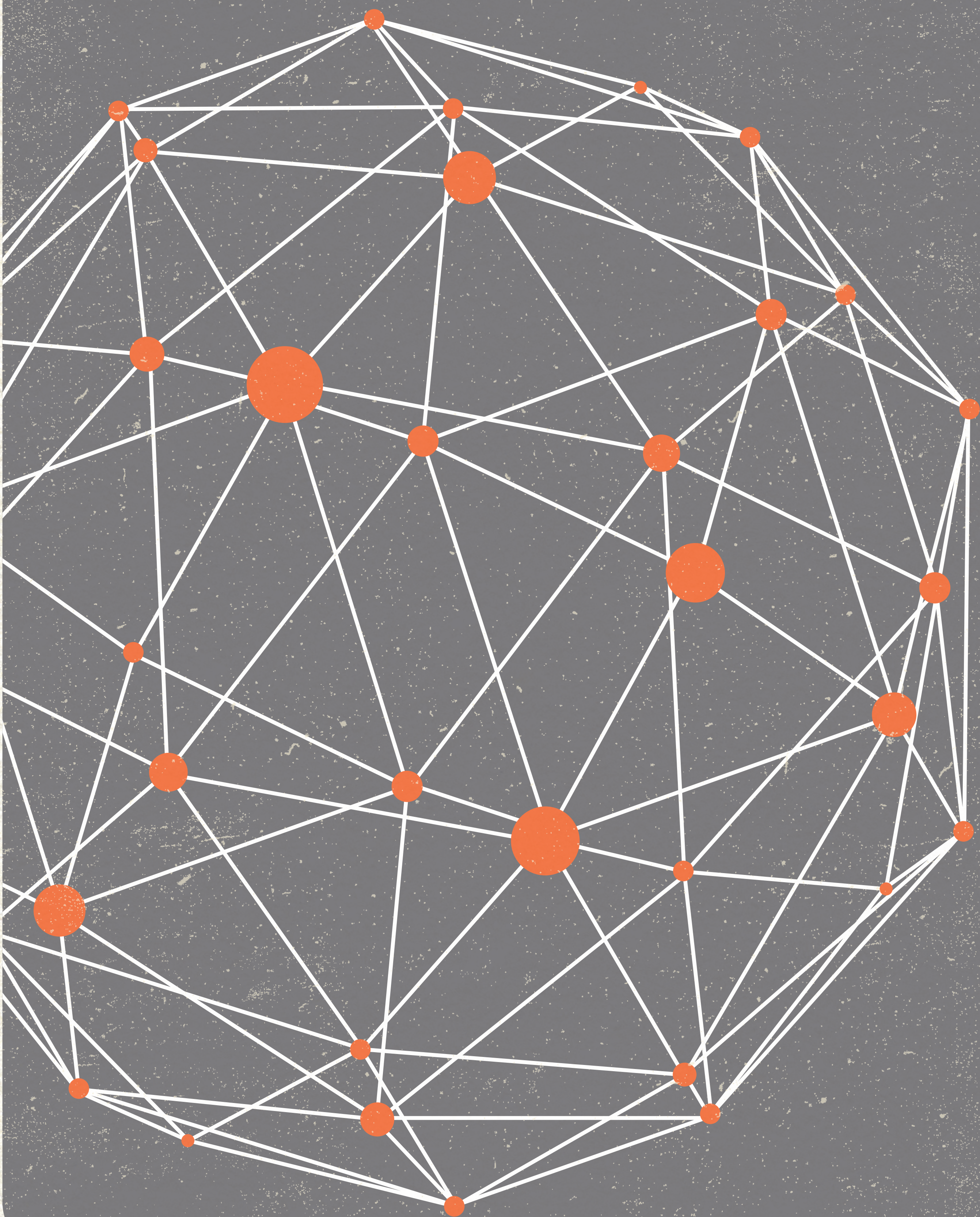

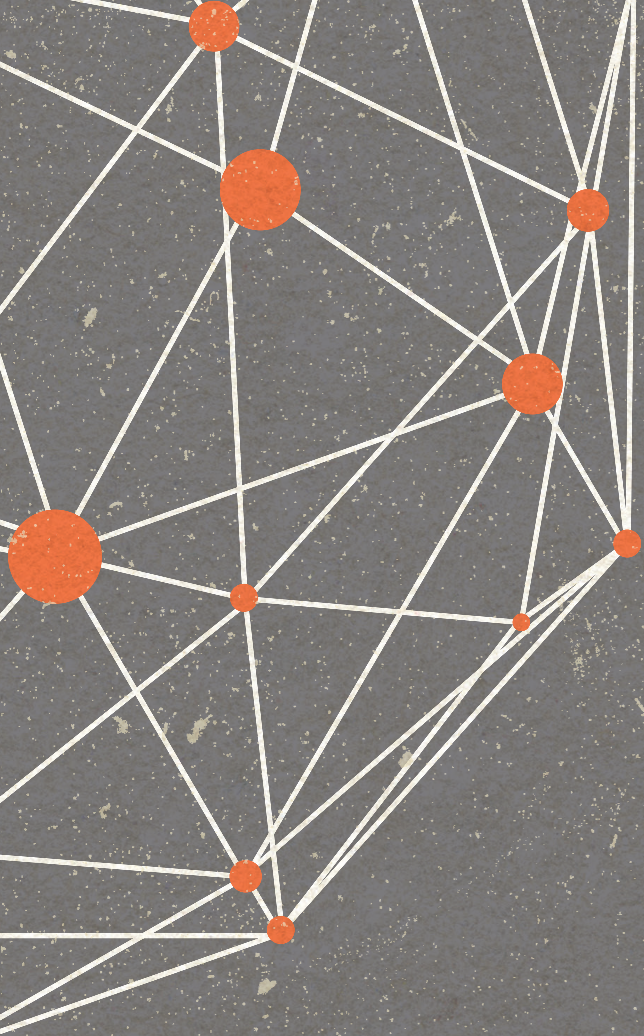

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ASM Handbook Complete Set, see page 5

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ISBN: 978-0-87170-377-4
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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

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Product Code: 06182G

Price: $297 / ASM Member: $225

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

Volume 3: Alloy Phase Diagrams

2016 • 778 pages
ISBN: 978-1-62708-070-5
Product Code: 05442G

Price: $297 / ASM Member: $225

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

Volume 4: Heat Treating

1991 • 1012 pages
ISBN: 978-0-87170-379-8
Product Code: 06184G

Price: $297 / ASM Member: $225

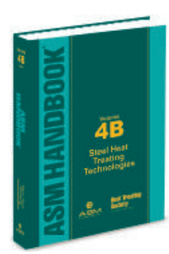
World's best reference guide to heat treating and surface hardening of steel, heat treating equipment, process and QC considerations, plus heat treating of cast irons, stainless steels, heat-resistant alloys, tool steels and nonferrous alloys.

Volume 4A: Steel Heat Treating Fundamentals and Processes

Edited by Jon L. Dossett and George E. Totten
2013 • 784 pages
IBSN: 978-1-62708-011-8
Product Code: 05344G

Price: $297 / ASM Member: $225

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

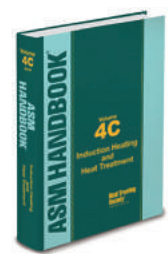


Volume 4B: Steel Heat Treating Technologies

Edited by Jon L. Dossett and George E. Totten
2014 • 582 Pages
ISBN: 978-1-62708-025-5
Product Code: 05434G

Price: $297 / ASM Member: $225

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

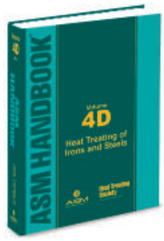


Volume 4C: Induction Heating and Heat Treatment

Edited by Valery Rudnev and George E. Totten
2014 • 820 pages
IBSN: 978-1-62708-012-5
Product Code: 05345G

Price: $297 / ASM Member: $225

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



Volume 4D: Heat Treating of Irons and Steels

Edited by Jon L. Dossett and George E. Totten

2014 • 730 pages

ISBN: 978-1-62708-066-8
Product Code: 05352G

Price: $297 / ASM Member: $225

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

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

2014

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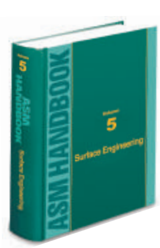

Volume 5: Surface Engineering

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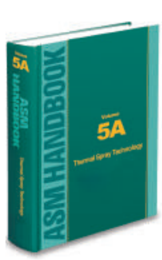
Detailed information on surface cleaning, finishing and coating provided through published articles on testing of coatings and thin films, environmental concerns, and surface engineering of nonmetallic structural materials. Expanded analysis of advanced processes such as chemical and physical vapor deposition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

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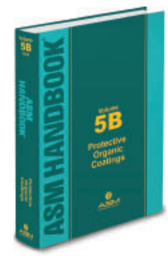

Volume 5B: Protective Organic Coatings

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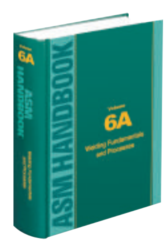
Practical advice on consumable selection and procedure development, as well as joining fundamentals, processes, assemblies and selection. More than 500 illustrations and 400 tables.



Volume 6A: Welding Fundamentals and Processes

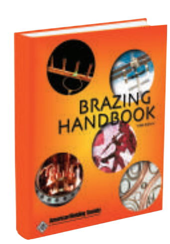
Edited by T. Lienert, T. Siewert, S. Babu, and V. Acoff

2011 • 936 pages

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

Price: $297 / ASM Member: $225

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



Brazing Handbook Fifth Edition

American Welding Society

2007 • 704 pages

ISBN: 0-87171-046-8
Product Code: 05336G

Price: $144 / ASM Member: $115

By agreement between the American Welding Society C3 Committee on Brazing and Soldering and the ASM Handbook Committee, the AWS Brazing Handbook has been formally adopted as part of the ASM Handbook series, and is significantly updated and expanded.

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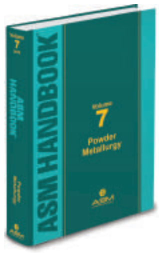

Volume 7: Powder Metallurgy

Edited by Prasan K. Samal and Joseph W. Newkirk

2015 • 907 pages

ISBN: 978-1-62708-089-3
Product Code: 05438G

Price: $297 / ASM Member: $225

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

Volume 8: Mechanical Testing and Evaluation

Edited by H. Kuhn and D. Medlin

2000 • 998 pages

ISBN: 978-0-87170-389-7
Product Code: 06772G

Price: $297 / ASM Member: $225

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

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Edited by G.F. Vander Voort

2004 • 1184 pages

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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.

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1986 • 761 pages

ISBN: 978-0-87170-016-2
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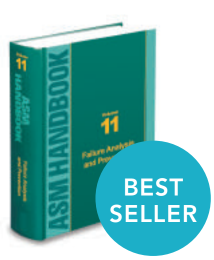


BEST SELLER

Volume 11: Failure Analysis and Prevention

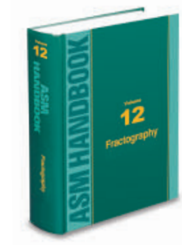
Edited by R.J. Shipley and W.T. Becker

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

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ISBN: 978-0-87170-018-6
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Over 1900 illustrations and fractographs, along with 41 tables, provide engineers with enhanced capability for recognizing and interpreting the various features of a fracture. Supplemental illustrations of failed metal-matrix composites, resin-matrix composites, polymers, and electronic materials.

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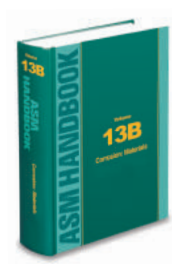

Volume 13B: Corrosion: Materials

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

2005 • 703 pages

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

Volume 13C: Corrosion: Environments and Industries

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

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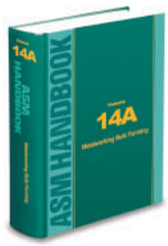

Volume 14A: Metalworking Bulk Forming

Edited by S.L. Semiatin

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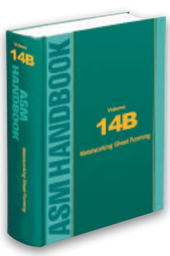
For manufacturing, materials, and design engineers. Covers the process-design relationships needed to select and control metalworking operations that produce shapes from forging, extrusion, drawing, and rolling methods.



Volume 14B: Metalworking Sheet Forming

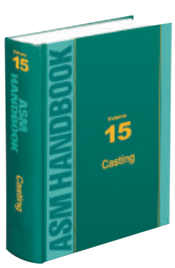
Edited by S.L. Semiatin

2006 • 940 pages

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

Price: $297 / ASM Member: $225

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



Volume 15: Casting

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

2008 • 1256 pages

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

Price: $297 / ASM Member: $225

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

Volume 16: Machining

1989 • 944 pages

ISBN: 978-0-87170-022-3
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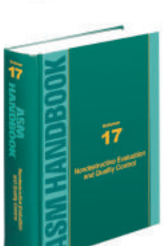
1300 illustrations and 620 tables provide detailed descriptions of various machining and grinding processes. Guidelines for proper selection of cutting tool materials and cutting fluids.



Volume 17: Nondestructive Evaluation and Quality Control

1989 • 795 pages

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

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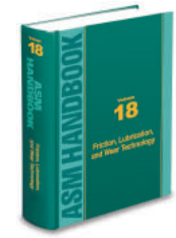
Commonly used methods such as liquid penetrant, magnetic particle, eddy current and radiographic inspection, tomography, and real-time radiography. Basic principles of each method along with its corresponding capabilities are outlined in 23 articles.



Volume 18: Friction, Lubrication, and Wear Technology

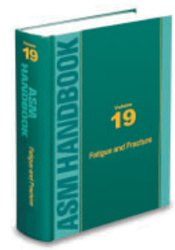
Edited by P.J. Blau

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.



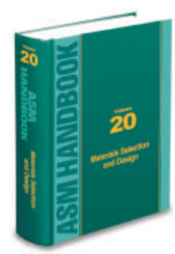
Volume 19: Fatigue and Fracture

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

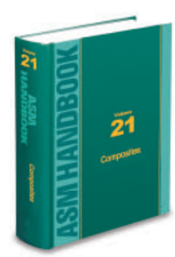
Edited by G.E. Dieter

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.

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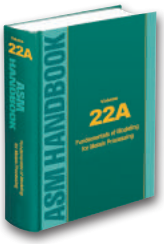

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Edited by David Furrer and Lee Semiatin

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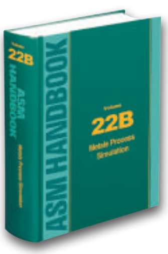
Development of metallic materials and process models that affect nearly every manufacturing industry. A solid foundation of the underlying physics that support many industrial simulation software packages.



Volume 22B: Metals Process Simulation

Edited by David Furrer and Lee Semiatin

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

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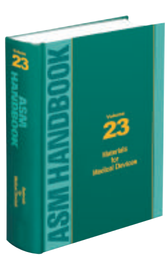
Fundamentals include input data, thermophysical properties and their measurement, phase diagrams, and microstructure. Processes include solidification, casting, metal forming, machining, joining, and heat treatment. Design topics include design optimization, error propagation and uncertainty, and cost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



Volume 23: Materials for Medical Devices

Edited by Roger Narayan

2012 • 396 pages

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Edited by J.R. Davis

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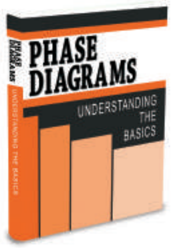

Phase Diagrams: Understanding the Basics

Edited by F.C. Campbell

2012 • 470 pages

ISBN: 978-1-61503-835-0
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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

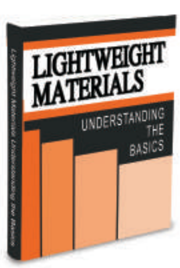
2013 • 1465 pages

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
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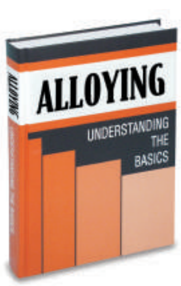
Price: $187 / ASM Member: $135

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

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

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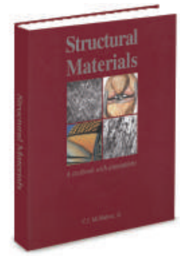
Proceedings from the Materials Science and Technology 2015 Conference, Columbus, OH October 4-8, 2015.



Structural Materials: A Textbook with Animations

By C.J. McMahon, Jr.

2004 • 470 pages

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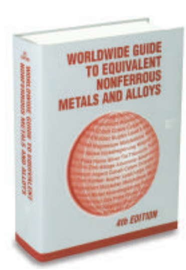

Worldwide Guide to Equivalent Nonferrous Metals and Alloys, 4th Edition

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Product Code:06735G

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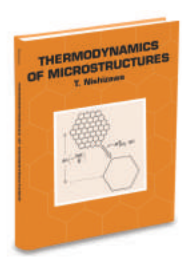
Over 20,000 alloy designations, including a complete listing of UNS designations. Includes comprehensive treatment of current European and Japanese standards.



Thermodynamics of Microstructures

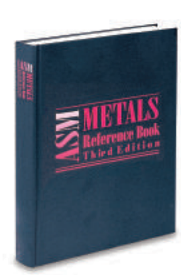
By Taiji Nishizawa, translated by Kiyohito Ishida

2008 • 308 pages

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

Price: $207 / ASM Member: $155

Fundamental relationships governing the behavior of microstructures.



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This completely revised edition provides an all new modern view of the basic principles and current practices of metallurgy. Recommended for anyone who uses, makes, buys or tests metal products.

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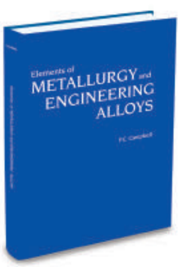

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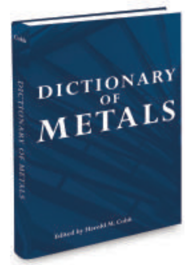
This book describes green engineering concepts to improve energy efficiency by reducing energy losses due to friction and wear in metalworking operations and by extending component life.



Dictionary of Metals

Edited by Harold M. Cobb

2012 • 374 pages

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

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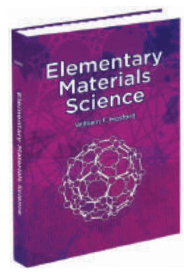
Includes historical overview beginning with the seven metals of antiquity. Showcases each metallic element, the discoverer and date, naming and its meaning, major applications, significance of the discovery and physical properties.



Elementary Materials Science

By William F. Hosford

2013 • 188 pages

ISBN: 978-1-62708-002-6
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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.

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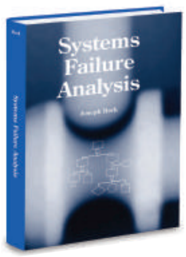

Systems Failure Analysis

By Joseph Berk

2009 • 214 pages

ISBN: 978-1-61503-012-5
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Price: $107 / ASM Member: $75

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

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Handbook of Case Histories in Failure Analysis Volume 2

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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.

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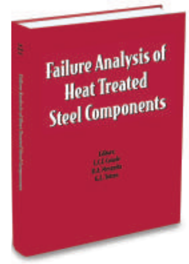

Failure Analysis of Heat Treated Steel Components

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.

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.

Life Lessons of a Failure Analyst

By McIntyre R. Louthan, Jr.

2016 • 202 pages

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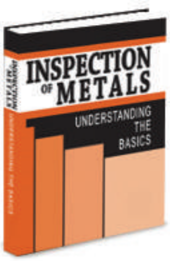
Product Code: 05921G

Price: $29 / ASM Member: $22

This compilation of editorials written by popular instructor of the ASM course Metallurgy for the Non-Metallurgist™ and the former editor-in-chief of the *Journal of Failure Analysis and Prevention* is applicable to failure analysts and all others looking to achieve success in almost any career. Presented through entertaining personal stories, the editorials focus on learning good communication skills, leadership, and strength in character from a seasoned failure analysis professional.

METALLOGRAPHY & MATERIALS CHARACTERIZATION



Inspection of Metals: Understanding the Basics

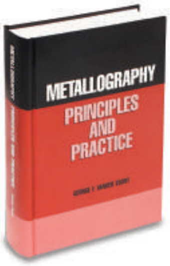
Edited by F.C. Campbell

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

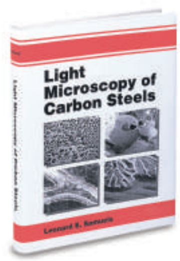
By G. Vander Voort

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

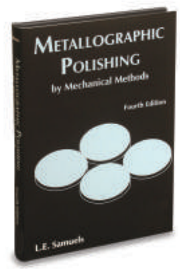
By L.E. Samuels

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

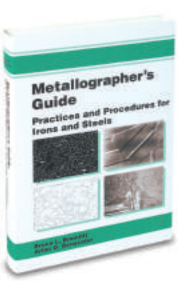
By Brian S. Hayes and Luther M. Gammon

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

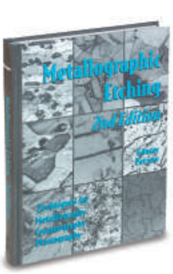
By B.L. Bramfitt and A.O. Benscoter

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

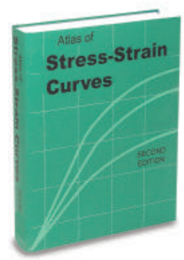
By G. Petzow

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.



Atlas of Stress-Strain Curves, 2nd Edition

2002 • 816 pages

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

Price: $307 / ASM Member: $231

More than 1400 curves normalized in appearance to aid making comparisons among materials. All diagrams include metric (SI) units, and many also include U.S. customary units captioned with standard designation, the primary source of the curve, mechanical properties, condition of sample, strain rate, test temperature, and alloy composition.

Tensile Testing, 2nd Edition

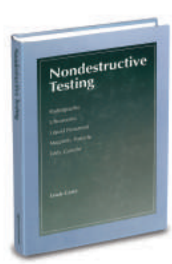
Edited by J.R. Davis

2004 • 283 pages

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

Price: $137 / ASM Member: $105

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



Nondestructive Testing

By L. Cartz

1995 • 229 pages

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

Price: $107 / ASM Member: $75

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

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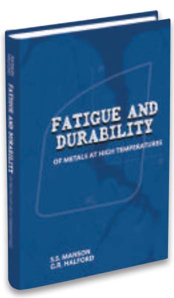
Focuses on metallic materials but also addresses unique capabilities of important nonmetals.



Fatigue and Durability of Metals at High Temperatures

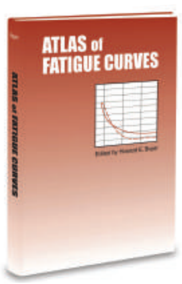
By S.S. Manson and G.R. Halford

2009 • 268 pages

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

Price: $257 / ASM Member: $185

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



Atlas of Fatigue Curves

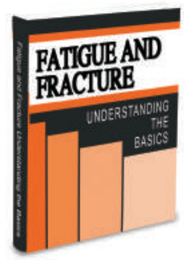
Edited by H.E. Boyer

1986 • 518 pages • Illustrated

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

Price: $307 / ASM Member: $231

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



Fatigue and Fracture: Understanding the Basics

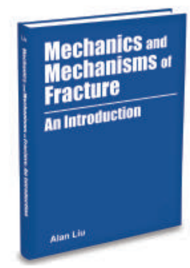
Edited by F.C. Campbell

2012 • 698 pages

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

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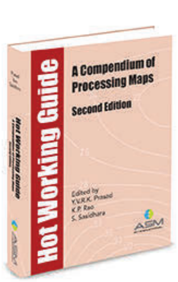
Newest edition. Overview of extrusion processes, equipment, and tooling. Metallurgical fundamentals of extrusion are covered in detail.



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

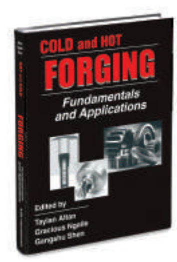
Edited by Y.V.R.K. Prasad, K.P. Rao, and S. Sasidhara

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.



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.

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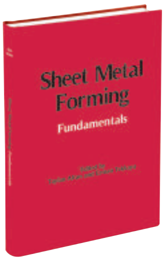


Sheet Metal Forming: Fundamentals

Edited by Taylan Altan and A. Erman Tekkaya

2012 • 314 pages

ISBN: 978-1-61503-842-8
Product Code: 05340G

Price: $207 / ASM Member $155

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

Sheet Metal Forming: Processes and Applications

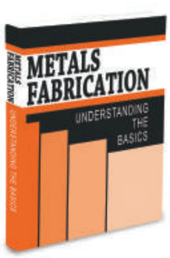
Edited by Taylan Altan and A. Erman Tekkaya

2012 • 382 pages

ISBN: 978-1-61503-844-2
Product Code: 05350G

Price: $207 / ASM Member: $155

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



Metals Fabrication: Understanding the Basics

By F.C. Campbell

2013 • 439 pages

IBSN: 978-1-62708-018-7
Product Code: 05374G

Price: $187 / ASM Member: $135

This book can be read and understood by anyone with a technical background. It is especially useful to those who deal with metals including designers, mechanical engineers, civil engineers, structural engineers, material and process engineers, manufacturing engineers, faculty, and materials science students. This volume covers the basics of metal fabrication, delving deep into the technology of metals fabrication.

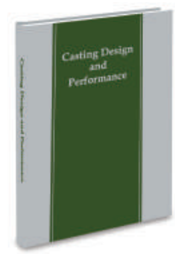
ASM Specialty Handbook® Tool Materials

Edited by J.R. Davis

1995 • 501 pages

ISBN: 978-0-87170-545-7
Product Code: 06506G

Price: $307 / ASM Member: $231



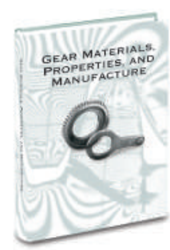
Casting Design and Performance

2009 • 272 pages

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

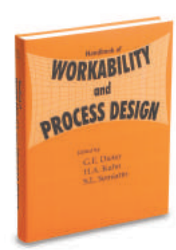
Edited by J.R. Davis

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

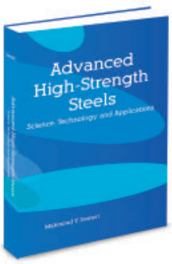
Edited by G.E. Dieter, H.A. Kuhn, and S.L. Semiatin

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

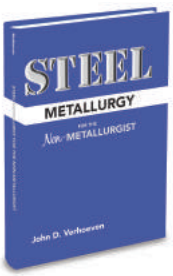
Edited by Philip Harvey

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

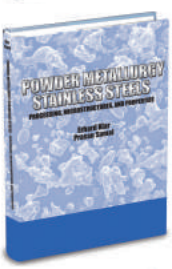
By John D. Verhoeven

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.



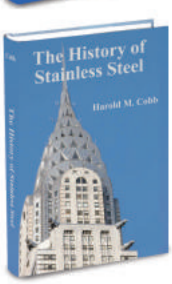
Powder Metallurgy Stainless Steels: Processing, Microstructures, and Properties

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.

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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.

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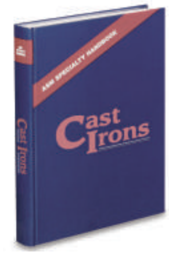


ASM Specialty Handbook® Cast Irons

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

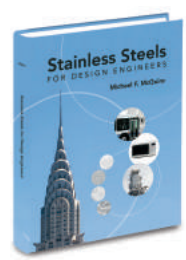
By George Krauss

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

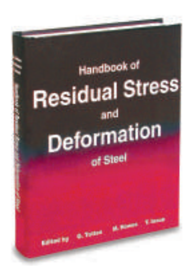
By Michael F. McGuire

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

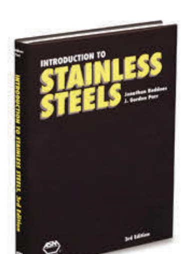
Edited by G. Totten, M. Howes, and T. Inoue

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

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Product Code: 06685G

Price: $53 / ASM Member: $42

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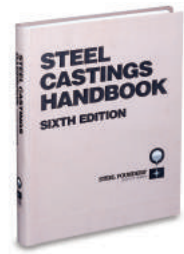
The CD version offers flexible and powerful capabilities, including the ability to search for steels by designation, chemical composition, and mechanical/physical properties.



Steel Castings Handbook, 6th Edition

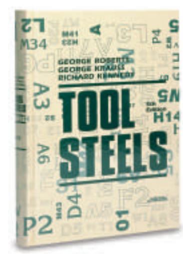
Co-published by Steel Founders' Society of America and ASM International

1995 • 472 pages

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

Price: $233 / ASM Member: $175

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



Tool Steels, 5th Edition

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

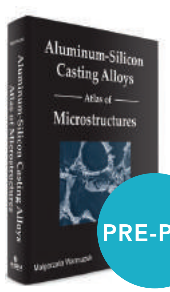
1998 • 364 pages

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

Price: $207 / ASM Member: $155

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

NONFERROUS METALS



PRE-PUB

Aluminum-Silicon Casting Alloys Atlas of Microstructures

By Małgorzata Warmuzek

2016 • Approximately 186 pages

ISBN: 978-1-62708-108-5
Product Code: 05919G

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

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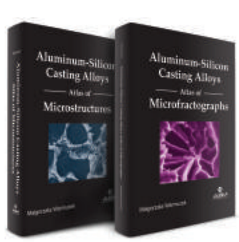

Aluminum-Silicon Casting Alloys Atlas of Microstructures and Aluminum-Silicon Casting Alloys Atlas of Microfractographs Set

By Małgorzata Warmuzek

Product Code: 05928G

Set Price: $278 / ASM Member: $213

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.

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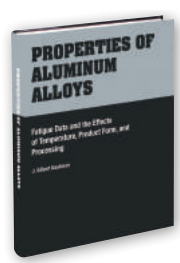


Properties of Aluminum Alloys: Fatigue Data and the Effects of Temperature, Product Form, and Processing

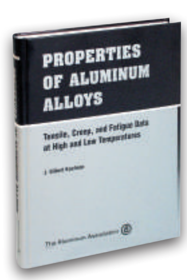
Edited by J.G. Kaufman

2008 • 574 pages

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

Price: $257 / ASM Member: $195

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



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

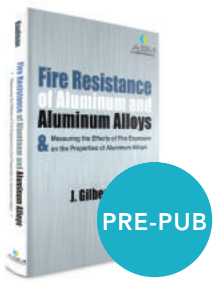
Edited by J.G. Kaufman

1999 • 311 pages

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

Price: $257 / ASM Member: $195

Co-published by the Aluminum Association and ASM International.



Fire Resistance of Aluminum and Aluminum Alloys

& Measuring the Effects of Fire Exposure on the Properties of Aluminum Alloys

By J. Gilbert Kaufman

2016 • Approximately 100 pages

ISBN: 978-1-62708-106-1
Product Code: 05917G

Contains valuable information about the fire resistance of aluminum and aluminum alloys including what occurs when aluminum is in a fire and how the effects of fire damage are evaluated. All aspects of aluminum's fire resistance are described, and reliable methods to estimate the extent of damage resulting from exposure to fire are presented, most notably the relationship between hardness and electrical conductivity with strength.

Price: ~~$149~~ / ASM Member: ~~$109~~
Prepublication Price: $139 / ASM Member: $99
Prepublication price good through June 30, 2016!

Aluminum Reference Library DVD, 2011 Edition

2011 • More than 15,000 pages in PDF format.

ISBN: 978-1-61503-723-0
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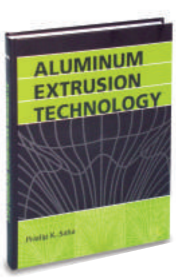
A complete guide to the selection, designations, processing, properties, and performance of aluminum and aluminum alloys. All commercial and standard grades of aluminum and aluminum alloys are covered.

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

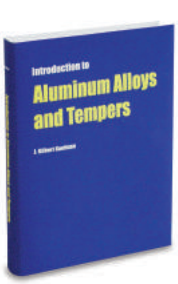
By P.K. Saha

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

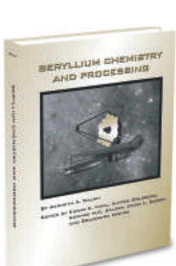
By J.G. Kaufman

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

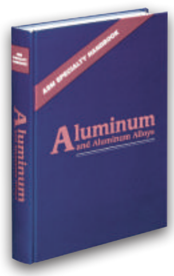
By K.A. Walsh • Edited by E.E. Vidal, A. Goldberg, E. Dalder, D.L. Olson, and B. Mishra

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.



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).

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

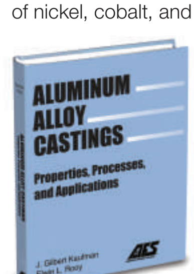
Price: $307 / ASM Member: $231

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

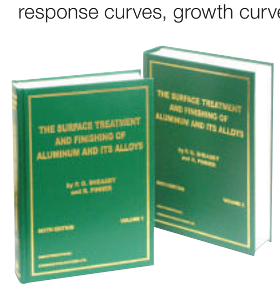
2004 • 340 pages

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.

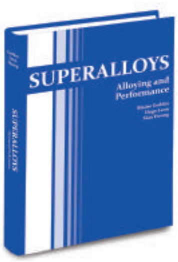
Superalloys Reference Library DVD, 2011 Edition

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: Alloying and Performance

Blaine Geddes, Hugo Leon, and Xiao Huang

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

Price: $107 / ASM Member: $75

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

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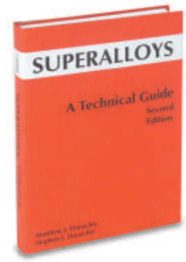
Aluminum Quick Reference App

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



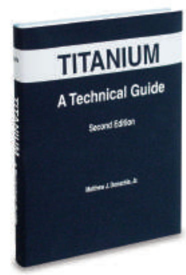
Superalloys: A Technical Guide, 2nd Edition

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.



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

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ISBN: 978-1-61503-721-6
Product Code: 05318V

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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

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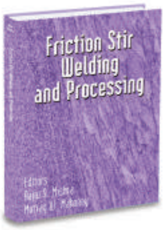
ISBN: 978-0-87170-792-5
Product Code: 06244G

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.

Joining: Understanding the Basics

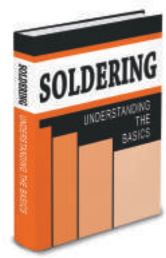
Edited by F.C. Campbell

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.



Soldering: Understanding the Basics

By M.M. Schwartz

2014 • 184 pages

IBSN: 978-1-62708-058-3
Product Code: 05338G

Price: $187 / ASM Member: $135

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

Brazing, 2nd Edition

By M.M. Schwartz

2003 • 421 pages

ISBN: 978-0-87170-784-0
Product Code: 06955G

Price: $157 / ASM Member: $115

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

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

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

1996 • 669 pages

ISBN: 978-0-87170-565-5
Product Code: 06325G

Price: $307 / ASM Member: $231

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

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

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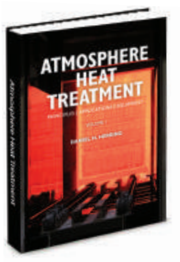


Atmosphere Heat Treatment: Principles, Applications, Equipment, Volume 1

By Daniel H. Herring • Publisher: BNP Media

2014 • 700 pages

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

Price: $154.99 / ASM Member $139.49

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

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

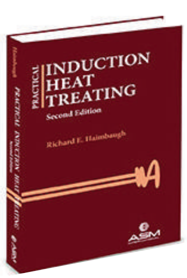
By Daniel H. Herring • Publisher: BNP Media

2015 • 824

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

Price: $154.99 / ASM Member $139.49

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



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

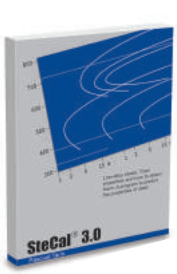
By A.K. Rakhit

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.

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Irons & Steels

Edited by G. Vander Voort

1991 • 804 pages • 1839 diagrams

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

Price: $307 / ASM Member: $231

Nonferrous Alloys

Edited by G. Vander Voort

1991 • 474 pages • 500 diagrams

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

Price: $307 / ASM Member: $231

Heat Treating Reference Library DVD, 2012 Edition

2012 • ASM International

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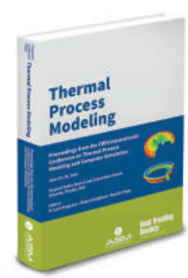
Product Code: 05347V

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

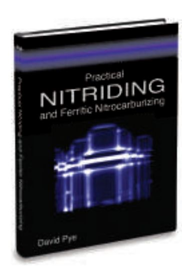
Edited by B.L. Ferguson, R. Goldstein, and R. Papp

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

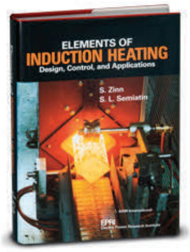
By David Pye

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.



Elements of Induction Heating: Design, Control, & Applications

By S. Zinn, S.L. Semiatin

1988 • 335 pages

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

Price: $107 / ASM Member: $75

Practical Heat Treating, 2nd Edition

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

2006 • 296 pages

ISBN: 978-0-87170-829-8
Product Code: 05144G

Price: $147 / ASM Member: $105

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

Surface Hardening of Steels: Understanding the Basics

Edited by J.R. Davis

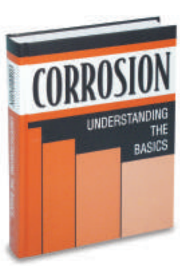
2002 • 364 pages

ISBN: 978-0-87170-764-2
Product Code: 06952G

Price: $147 / ASM Member: $105

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

CORROSION



Corrosion: Understanding the Basics

Edited by J.R. Davis

2000 • 563 pages

ISBN: 978-0-87170-641-6
Product Code: 06691G

Price: $197 / ASM Member: $145

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

Handbook of Corrosion Data, 2nd Edition

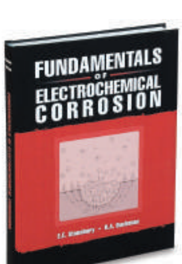
Edited by B. Craig and D. Anderson

1995 • 998 pages

ISBN: 978-0-87170-518-1
Product Code: 06407G

Price: $307 / ASM Member: $231

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



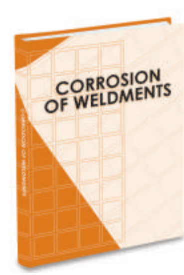
Fundamentals of Electrochemical Corrosion

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

2000 • 487 pages

ISBN: 978-0-87170-676-8
Product Code: 06594G

Price: $157 / ASM Member: $115



Corrosion of Weldments

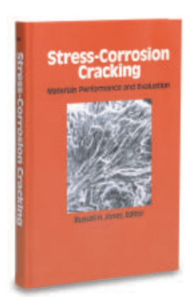
Edited by J.R. Davis

2006 • 236 pages

ISBN: 978-0-87170-841-0
Product Code: 05182G

Price: $207 / ASM Member: $155

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



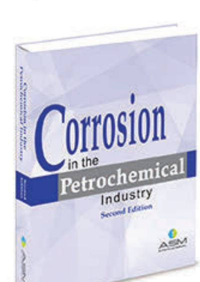
Stress-Corrosion Cracking: Materials Performance and Evaluation

Edited by R.H. Jones

1992 • 448 pages

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

Price: $207 / ASM Member: $155



Corrosion in the Petrochemical Industry, Second Edition

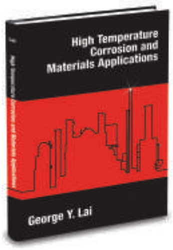
Edited by Victoria Burt

2015 • 426 pages

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

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

Price: $219 / ASM Member: $165



High-Temperature Corrosion and Materials Applications

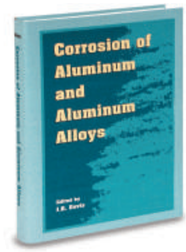
By George Y. Lai

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 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

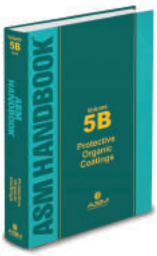
By Y. Tamarin

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.



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.

High Pressure Cold Spray: Principles and Applications

Edited by C.M. Kay and J. Karthikeyan

2016 • Approx. 300 pages

ISBN: 978-1-62708-096-5
Product Code: 05446G

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

Price: ~~$199~~ / ASM Member: ~~$179~~
Prepublication Price: $179 / ASM Member: $129
Prepublication price good through June 30, 2016!

Surface Engineering for Corrosion and Wear Resistance

Edited by J.R. Davis

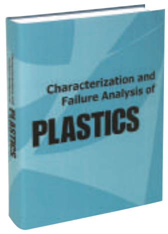
2001 • 279 pages

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.

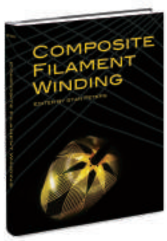


Characterization and Failure Analysis of Plastics

2003 • 482 pages
ISBN: 978-0-87170-789-5
Product Code: 06978G

Price: $247 / ASM Member: $185

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



Composite Filament Winding

Edited by S.T. Peters
2011 • 174 pages
ISBN: 978-1-61503-722-3
Product Code: 05286G

Price: $167 / ASM Member: $125

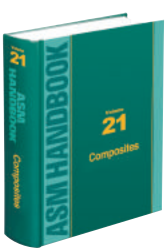
Topics include capabilities and limitations of filament winding, practical issues such as fiber and resin handling, winding theory, software and numerical control, history of the process, and more.

Optical Microscopy of Fiber-Reinforced Composites

By Brian S. Hayes and Luther M. Gammon
2010 • 284 pages
ISBN: 978-1-61503-044-6
Product Code: 05303G

Price: $177 / ASM Member: $135

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



Volume 21: Composites

Edited by D.B. Miracle and S.L. Donaldson
2001 • 1201 pages
ISBN: 978-0-87170-703-1
Product Code: 06781G

Price: $297 / ASM Member: $225

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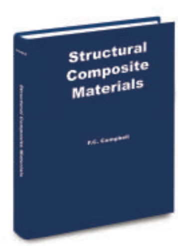


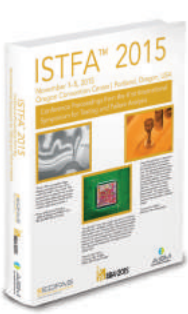
Structural Composite Materials

By F.C. Campbell
2010 • 630 pages
ISBN: 978-1-61503-037-8
Product Code: 05287G

Price: $167 / ASM Member: $125

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

MICROELECTRONICS



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

Edited by Richard J. Ross
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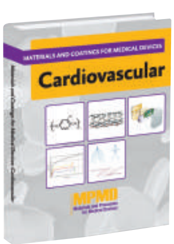
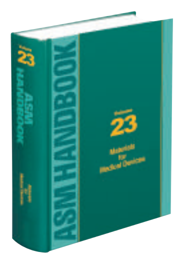


Materials and Coatings for Medical Devices: Cardiovascular

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.



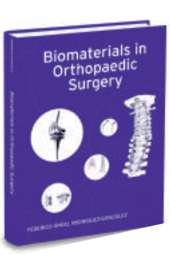
Volume 23: Materials for Medical Devices

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.



Biomaterials in Orthopaedic Surgery

By Federico Ángel Rodríguez-González
2009 • 236 pages
ISBN: 978-1-61503-009-5
Product Code: 05233G

Price: $137 / ASM Member: $105

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

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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.

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Handbook of Ternary Alloy Phase Diagrams
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Edited by Pierre Villars, Alan Prince, and Hiroaki Okamoto

1995

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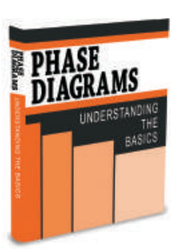
Price: $8514 / ASM Member: $8417

More than 18,000 ternary diagrams.



Phase Diagrams: Understanding the Basics

Edited by F.C. Campbell

2012 • 470 pages

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

Price: $187 / ASM Member: $135

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

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.

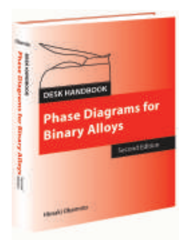
Pearson's Desk Edition

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.



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

By Hiroaki Okamoto

2010 • 855 pages

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

Price: $358 / ASM Member: $286

Includes 2421 diagrams of which 450 are new or greatly revised; among these, 87 are not in the First Edition. Approximately 600 crystal structure tables of systems for which phase diagrams are unknown.

STRESS RELIEF

MATERIAL GIRLS OF THE MIDDLE AGES

According to an archaeologist in the Netherlands, women in the Middle Ages wore better quality clothes than men.

Women in the Middle Ages often wore better quality clothes than men, according to Chrystel Brandenburgh at Leiden University, the Netherlands. Brandenburgh studied textile remnants from the period 400 to 1000 A.D., and also found many regional variations in textile use. Women in Rhenen and Wijchen, for example, were mostly buried in linen cloth, whereas twill cloth was found in the graves of men in the region. In other countries, research on textiles has really taken off in recent decades, but no comparable development has been seen in the Netherlands, Brandenburgh explains.

Beyond skin coverage and protection, clothing provides valuable information about people. “It’s functional, but it also expresses the identity or position of the wearer,” she says. Brandenburgh regards her research as the starting point for further studies on textiles. “I only concentrated on textile remnants because so little research has been done in this field. But there is more information to be gained from other contents of the grave,” she adds. New excavation techniques like computed tomography and 3D scans and isotope research make it possible to draw further conclusions about clothing. *For more information: Chrystel Brandenburgh, +31 71 527 1626, www.universiteitleiden.nl/en.*

PRINT YOUR FAVORITE SNACK

Researchers are developing advanced food manufacturing technologies by combining expertise in food, materials science, and 3D printing.

Researchers at VTT Technical Research Centre of Finland Ltd. aim to develop advanced food manufacturing technologies by combining expertise in food, materials science, and 3D printing. Researchers have the long-term vision of developing high-tech vending machines that provide customized purchases. In initial trials, starch and cellulose-based materials for 3D food prototypes were tested. Researchers are also working on printability of protein concentrates of both plant (oat and faba bean) and dairy (whey protein) origin.

“A great deal of work is needed in order to proceed to industrial-scale production. Equipment needs to be developed in addition to materials. Such equipment could be developed for domestic 3D food printing as well as vending machines,” says Nesli Sözer, principal scientist at VTT. *For more information: Nesli Sözer, +358401523875, nesli.sozer@vtt.fi, vttresearch.com.*

NOW THAT’S STRONG COFFEE

Professor Arul Arulrajah and Ph.D. candidate Teck-Ang Kua compressed a mixture of coffee grounds and slag with a liquid alkaline solution to create a product as strong as common cement.

Engineers at Swinburne University of Technology, Australia, turned used coffee grounds into building materials for roads. Professor Arul Arulrajah, who leads the geotechnical group in the Centre for Sustainable Infrastructure, has been investigating the use of recycled materials, such as crushed brick or glass and concrete, for use in road construction. He is also an avid coffee drinker. “I would see baristas throwing away the used coffee grounds and wondered if it could be used as a building material,” he says. Arulrajah and his team collected used coffee grounds from cafés near campus, dried them in an oven at 50°C for five days, and then sieved the grounds to filter out lumps. They then mixed seven parts coffee grounds with three parts slag from steel manufacturing. A liquid alkaline solution helped bind everything together. The mixture was compressed into cylindrical blocks that proved strong enough to use as the subgrade material that sits under a road surface. *For more information: Arul Arulrajah, aarulrajah@swin.edu.au, www.swinburne.edu.au/global.*

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AD INDEX

3D PRINTSHOP

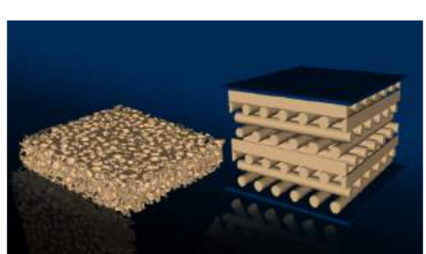
EOS OPENS TEXAS FACILITY

EOS, Germany, celebrated the grand opening of its newest U.S. facility in Pflugerville, Texas, in early May. The new location primarily provides increased service and support for the company's growing North America market, which topped $100 million in 2015. The site features an innovations laboratory (iLab), where application engineers interact directly with customers, a showroom that displays the company's additive manufacturing (AM) systems, and an AM Ventures division to help support start-up ideas. EOS Materials, also known as Advanced Laser Materials (ALM), will remain in Temple, Texas. This facility produces polymer powder for both EOS systems and other powder-based AM technologies. The Novi, Mich., site continues to be an important regional technical center for the company. Future U.S. expansion plans include Boston and Northern California. *eos-na.com.*

3D-PRINTED FOAM OUTPERFORMS STANDARD MATERIALS

Scientists at Lawrence Livermore National Laboratory (LLNL), Calif., discovered that 3D-printed foam works better than standard cellular materials in terms of durability and long-term mechanical performance. Traditionally, foams are created by processes that lead to a highly nonuniform structure with significant dispersion in cell size, shape, thickness, connectedness, and topology. As an alternative, a team at LLNL's additive manufacturing lab recently demonstrated the feasibility of 3D printing uniform foam structures through a process called direct-ink-write. However, because 3D printing requires the use of polymers of certain properties, it is important to understand the long-term mechanical stability of such printed materials before they can be commercialized. This is especially vital in applications such as support cushions, where the foam material is subjected to long-term mechanical stresses.

To address the stability question, accelerated aging experiments in which samples of both traditional stochastic foam and 3D-printed materials were subjected to elevated temperatures under constant compressive strain were performed. The stress condition, mechanical response, and structural deformation of each sample were monitored for one year or longer. A method called time-temperature-superposition was then used to model the evolution of such properties over a period of decades under ambient conditions. The study shows that 3D-printed materials age slowly compared to their traditional counterparts. Interestingly, the native rubber (i.e., elastomer) comprising each foam showed the opposite effect, as the rubber in the printed material aged faster than the corresponding rubber used in the traditional foam. *llnl.gov.*



Microstructures of two different foam materials. Left, traditional open-cell stochastic foam; right, 3D-printed foam with face-centered tetragonal lattice structure.

NEW CENTER SUPPORTS MEDICAL APPLICATIONS

Stratasys Ltd., Minneapolis, is partnering with the Jacobs Institute, Buffalo, N.Y., to create a new center of excellence to advance the use of 3D printing for a variety of medical applications. The center will use Stratasys' 3D printing technology to develop and test new medical devices using 3D-printed prototypes and models, as well as enrich clinical education and training. The facility will also serve as a referral center for hospitals and medical research organizations considering 3D printing labs. Stratasys will collaborate with Jacobs on technical and clinical case studies that include 3D-printed applications and will also provide financial support for vital research projects. *stratasys.com.*

Vascular testing model used to validate new medical devices that treat brain aneurysms, produced on the Stratasys Objet500 Connex3 3D Printer. Courtesy of Jacobs Institute.