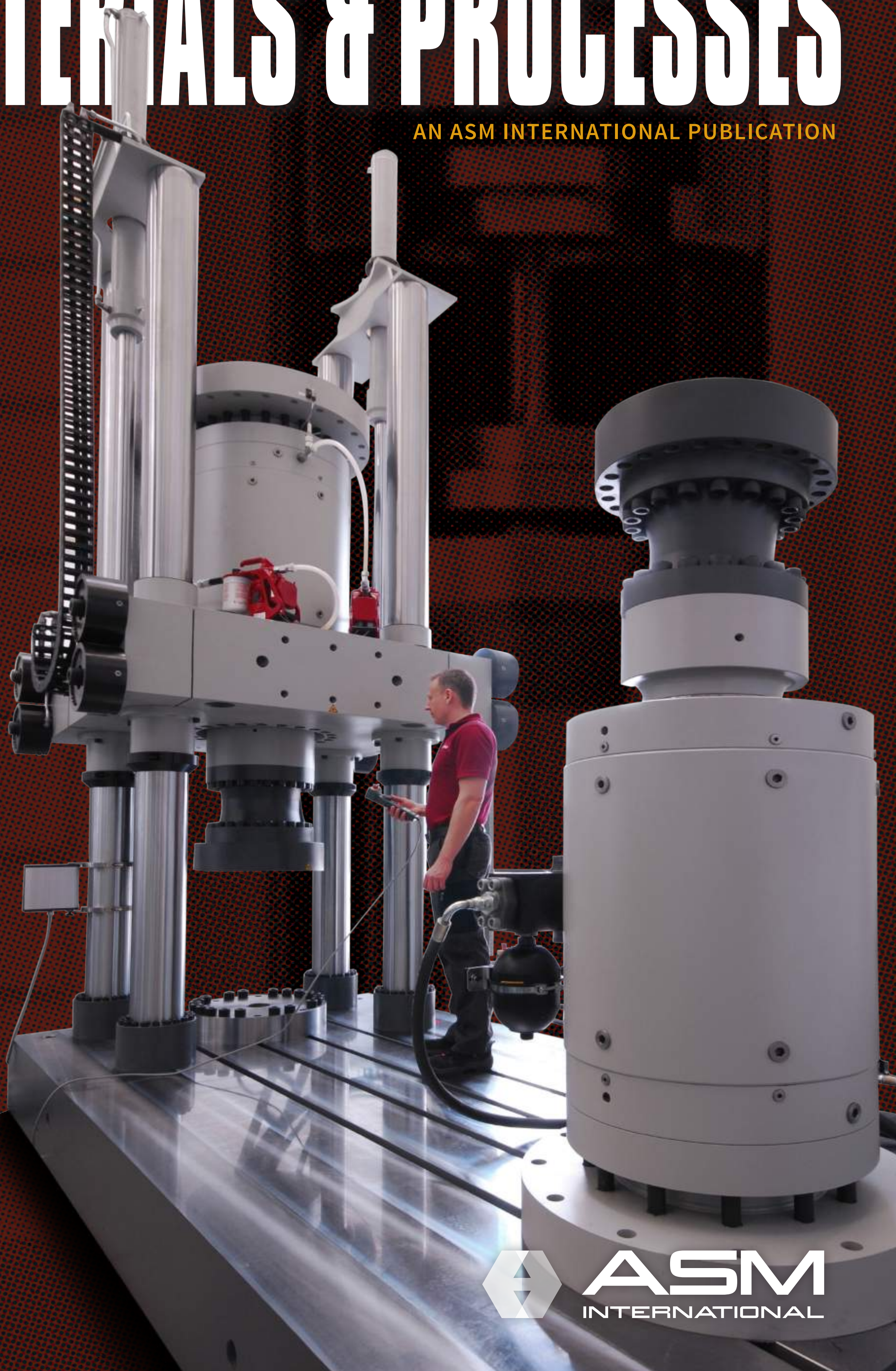
APRIL 2016 | VOL 174 | NO 4

ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION



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Course	Date	Location
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Advanced Metallographic Techniques	5/9-12	ASM World Headquarters
Design for Additive Manufacturing – Materials, Processes, and Geometries	5/16-17	America Makes, OH
Metallurgy of Steel for the Non-Metallurgist	5/16-18	ASM World Headquarters
Practical Induction Heat Treating	5/16-18	ASM World Headquarters
Vacuum Heat Treating	5/19-20	ASM World Headquarters
Metallographic Techniques – Blended (Lab Session)	5/23-24	ASM World Headquarters
Heat Treatment, Microstructures and Performance of Carbon and Steel Alloys	5/23-25	ASM World Headquarters
Stainless Steels	6/6-9	ASM World Headquarters
Advanced High Strength Steels	6/13-14	ASM World Headquarters
Scanning Electron Microscropy	6/13-16	IMR Test Labs, NY
Metallurgy for the Non-Metallurgist™ – Blended	6/14-15	ASM World Headquarters
Introduction to Metallurgical Lab Practices	6/20-22	ASM World Headquarters
Refractory Technology	6/20-22	ASM World Headquarters
Basics of Heat Treating (formerly known as Introduction to Heat Treating)	6/27-29	ASM World Headquarters
Heat Treating Furnaces and Equipment (formerly known as Advanced Heat Treating)	6/30-7/1	ASM World Headquarters

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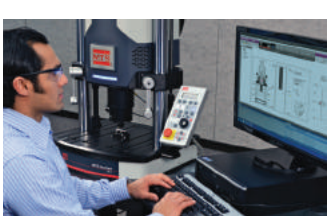


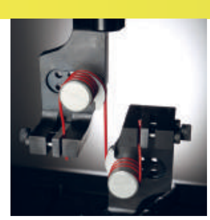
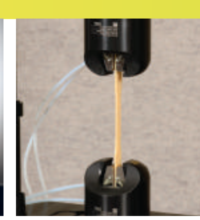
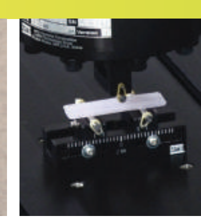

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AN OVERVIEW OF POPULAR MATERIALS TESTING SYSTEMS

Materials testing systems must be robust and flexible, capable of determining the mechanical properties of a broad range of materials and components.

On The Cover:

The HB3500 servohydraulic testing machine is applicable for testing large components used in construction applications. Courtesy of Zwick/Roell, Ulm, Germany. zwick.com.

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AEROMAT 2016 SHOW PREVIEW

The 27th AeroMat Conference and Exposition, May 23-25 in Bellevue, Washington, features more than 125 technical presentations, daily plenary sessions, exhibits, networking events, and more.

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METALLURGY LANE
THE INTEGRATED STEEL INDUSTRY–PART I

Charles R. Simcoe

The beginning of the big integrated steel industry began with the formation of the United States Steel Corporation in 1901.

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ASM NEWS

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

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SPRING HAS SPRUNG: ASM IS GROWING SHOOTS

Spring has arrived at last! For those of us toiling away in the industrial Midwest, it's a welcome relief from the dreary winter. Daffodils have broken ground and tiny buds and leaves are emerging on all sides. In the spirit of new growth, ASM is branching out as well. Most exciting is the debut of our newest affiliate society, the Failure Analysis Society (FAS). This new affiliate grew out of an existing ASM committee that has offered failure analysis programming for several years. In other news at the Dome, ASM is in the midst of a major overhaul of its education laboratories. A wide range of classes are taught year-round in these labs, from heat treating and thermal spray courses to metallurgy and failure analysis. Adding state-of-the-art equipment—including a Zeiss scanning electron microscope—to the existing lab facilities will significantly enhance the learning experience for the many students who attend classes every year. Look for longer articles in the May issue about the goals of our latest society and further details about the lab renovation.

Beyond these homegrown efforts, plenty of spring travel opportunities are popping up. During April 18-21 in Savannah, Georgia, the ASM Heat Treating Society and the International Federation of Heat Treatment and Surface Engineering are partnering to host the 23rd IFHTSE Congress, which focuses on thermal processing, heat treating, and surface engineering. In May, two blockbuster events will take place. First up is ITSC 2016, the International Thermal Spray Conference & Exposition, taking place May 10-12 in Shanghai. This conference is jointly organized by the German Welding Society (DVS), ASM's Thermal Spray Society, and the International Institute of Welding. Next, the 27th AeroMat Conference and Exposition will be held May 23-25 in Bellevue, Washington. All of these conferences feature excellent technical programming, top-notch plenary lectures, and extensive networking opportunities. DVS will then present the 11th International Conference on Brazing, High Temperature Brazing, and Diffusion Bonding, to be held June 7-9 in Aachen, Germany.

On a personal note, I will be joining a small group of American editors on a trip to see some of the engineering and industrial highlights around Germany, sponsored by Germany Trade & Invest, the economic development agency of the Federal Republic of Germany. The lineup includes a whirlwind schedule of visiting the German Research Center for Artificial Intelligence, a briefing at one of the Fraunhofer Institutes, a meal with the state economic development agency, a tour of Kuka robotics in Augsburg, a visit to the new IBM Watson Center in Munich, and finally the Fraunhofer Institute research center in Garching. Rounding out the trip will be a visit to Hannover Messe, the world's largest industrial fair. On Sunday, April 24, President Obama will give an address prior to the fair opening. The next day, an opening tour will take place featuring a walk around with President Obama and German Chancellor Angela Merkel. Look for a recap in our June issue.

In the meantime, enjoy the spring and we hope to see you at an upcoming event!

F. Richards

frances.richards@asminternational.org


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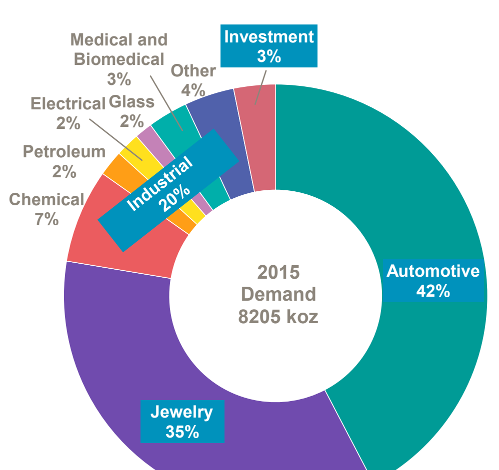
MARKET SPOTLIGHT

AUTOMOTIVE DEMAND FOR PLATINUM ON THE RISE

The World Platinum Investment Council recently announced publication of its sixth *Platinum Quarterly,* a free quarterly analysis of the global platinum market. The report incorporates analysis of supply and demand during the fourth quarter of 2014 and for all of 2015. It also provides a 2016 forecast. The report is based on research and detailed analysis conducted by SFA (Oxford) Ltd., UK, an independent authority on the platinum group metals market. The global platinum market ended 2015 in deficit by 380,000 ounces (380 koz), with key drivers of the shortfall including:

- 2015 saw a 5% increase in automotive demand, reaching 3455 koz, up from 3290 koz in 2014 and 3160 koz in 2013. Despite the impact of the Volkswagen diesel investigation, 2015 demand growth was led by Western Europe vehicle sales growth, up 9% year-on-year, where the imposition of the new Euro 6 legislation increased platinum loading per car. Automotive demand from India also grew by 9%.
- Industrial demand increased by 4% during 2015, buoyed by a 2% rise in chemical demand growth driven by North America, Western Europe, and China. Greater global demand for oil refining and a swing from refinery reductions to net capacity expansion saw demand from the petroleum sector more than doubling—from 65 koz in 2014 to 160 koz in 2015.
- Jewelry sales contracted by 4% over the year, affected by a fall in Chinese demand. In contrast, demand for platinum in India surged by 26% on the back of strong bridal growth and increased sales of men's jewelry.
- Refined production grew by 24% over the year, led by a 41% increase in output from South Africa, where operations affected by the 2014 strikes returned to pre-strike levels and producer sales again exceeded refined production.
- Global supply from recycled platinum fell by 15% over the year to 1725 koz, as lower platinum group metals prices reduced the flow of scrap catalysts from collectors, while depressed steel prices reduced the scrapping of vehicles.

For more information, visit platinuminvestment.com.



Source: SFA (Oxford) Ltd.

FEEDBACK

SILVER SPOONS

Thank you for including the very interesting story of Dr. Edgar C. Bain ("Metallurgy Lane," January 2016). After reading the article, I thought I might pass along my recollection of Dr. Bain. It is brief but indelible. In the fall of 1969, Dr. C.S. Smith was to address a meeting of the ASM Pittsburgh Chapter. Another young metallurgical engineer and I were assigned by the Chapter to deliver Dr. Smith to the meeting from Dr. Bain's home in Sewickley, Pennsylvania. By prior arrangement, we two metallurgists were to arrive at Dr. Bain's home in the late afternoon to collect Dr. Smith. Upon our arrival, Mrs. Bain escorted us to Dr. Bain's study where he and Dr. Smith were discussing the future of scientific discovery, whether it should be based on atomic considerations of metals and materials or on biological pursuits.

Mrs. Bain, a wonderful hostess, offered coffee to us two "coachmen." Being young and polite, we accepted. In a short time, the coffee arrived in fine china cups, with saucers, cream and sugar, and of course, spoons with which to serve ourselves. At this point, I recollect Drs. Bain and Smith may have been secretly conspiring to test our metallurgical knowledge. We added sugar and cream to the coffee and without much thought commenced to stir the coffee. Immediately the room echoed two very distinct clinks—the sound of spoons dropped and clattering within the cups, caused by the painful sensation of heat conducted through the silver spoons (not likely silver alloy) from the hot coffee to our youthful, unprepared fingers. Whether or not this is accurate, I recall both Drs. Bain and Smith being quietly amused at the lesson on thermal conduction being given to us that day.

Dr. Bain was a metallurgical giant. I am proud of having made his personal acquaintance that fall day. I wish his demeanor could guide more young people into our field.

Tim Kosto

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS

First gold coin ever struck. Courtesy of PRNewsFoto/Austin Rare Coins and Bullion.

EARLIEST GOLD COIN CHANGES HANDS

An extremely rare version of the first gold coin ever struck in human history was purchased from Austin Rare Coins and Bullion, Texas, by an Austin collector for a six-figure sum. The obverse, or "heads" side of the coin, depicts a lion and bull confronting each other. Instead of a reverse design, the "tails" side shows two overlapping squares, the double-incuse mark left by the punch that was struck to force the gold into the obverse die. Issued by King Croesus in Lydia (now Turkey), the coin dates to approximately 560 B.C. and is preserved in near-mint condition. While the earliest coins were made from electrum, a naturally occurring alloy of gold and silver, Croesus abandoned the alloy in favor of pure gold and pure silver. Soon afterward, nearly every mint in the Greek and Persian world began issuing pure metal coins. *austincoins.com.*

MICRO AIR VEHICLE WINGS SHAPE SHIFT ON THE FLY

Researchers from the University of Southampton, UK, and Imperial College London designed bat-inspired membrane wings that can adapt in-flight to the forces they experience. The wings have no mechanical parts, but instead function like artificial muscles, incorporating electroactive polymers that allow them to stiffen and relax in response to an applied voltage. The development paves the way for a new class of unmanned micro air vehicles (MAVs) with improved aerodynamic properties, longer flight ranges, and an economic advantage over current models. "This is a paradigm shift in the approach to MAV design," notes Dr. Rafael Palacios of Imperial's department of aeronautics. "Instead of a traditional approach of scaling down existing aircraft design methods, we constantly change the membrane shape under varying wind conditions to optimize aerodynamic performance." Sometimes as small as 15 cm across, MAVs are increasingly used in a wide variety of civil and military applications, such as surveying remote and dangerous areas. *www.southampton.ac.uk, www.imperial.ac.uk.*

Southampton-Imperial MAV. Courtesy of University of Southampton.

WOOD-BASED CAR BATTERY LIGHTENS THE LOAD

The world's first model car with a roof and battery made of a wood-based carbon fiber composite was produced jointly by Swedish researchers from the KTH Royal Institute of Technology and research groups Innventia and Swerea. Although built on a toy scale, the prototype vehicle represents a significant step toward reducing vehicle weight using renewable materials. The key ingredient in the carbon fiber composite is lignin, a constituent of plant cell walls and the second most abundant natural polymer in the world, surpassed only by cellulose. Lignin batteries can be produced from renewable raw materials, in this case the byproduct from paper pulp production. "The lightness of the material is especially important for electric cars because then batteries last longer," explains Göran Lindbergh, professor of chemical engineering at KTH. "Lignin-based carbon fiber is cheaper than ordinary carbon fiber. Otherwise batteries made with lignin are indistinguishable from ordinary batteries." Lindbergh says carbon fiber bodywork and batteries eventually could be combined to simultaneously manage mechanical loads and store electrical energy. *www.kth.se.*

Model car with carbon fiber roof and battery electrodes made of wood. Courtesy of KTH.

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

Mohsen Esmaily in his atmospheric corrosion laboratory. Courtesy of Mats Tiborn.

RHEOCASTING REDUCES MAGNESIUM REACTIVITY

Mohsen Esmaily, an atmospheric corrosion researcher at Chalmers University of Technology, Sweden, discovered that magnesium alloys produced by rheocasting are up to four times more corrosion resistant than those same alloys produced by conventional high-pressure die casting. This could lead to increased use of magnesium in automobiles, reducing their weight and fuel consumption. At 30% lighter than aluminum, magnesium is the lightest construction metal, but it is also the most reactive, which has historically made it ill-suited for use in vehicles. While magnesium producers have attempted to address reactivity by developing new alloys and coatings, Esmaily's research shows the potential of microstructure manipulation in reducing magnesium's corrosiveness. *www.chalmers.se.*

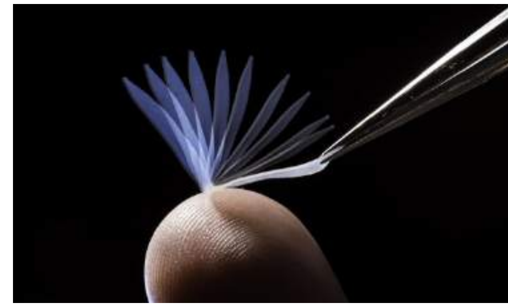
BRIEFS

Houghton International, Valley Forge, Pa., received approval from **Pratt & Whitney,** East Hartford, Conn., to use Hocut 4940 Metalworking Fluid in the production of its aircraft engines and military power units. *houghtonintl.com.*

Global Tungsten & Powders Corp. (GTP), Towanda, Pa., announced a partnership with **Dynalloy Industries Inc.,** Houston, for distribution of GTP's thermal spray powders. Dynalloy will also provide service to Louisiana, Arkansas, Oklahoma, and parts of Canada. GTP manufactures tungsten and molybdenum products. *globaltungsten.com, dynalloyinc.com.*

SCRA, Columbia, S.C., was selected to lead the **Navy Metalworking Center,** Johnstown, Pa., a U.S. Navy Manufacturing Technologies Center of Excellence, chartered by the **Office of Naval Research.** The award is an indefinite delivery/indefinite quantity contract with an order maximum of $99,000,000 over five years. SCRA will operate and manage the Center in partnership with **EWI,** Columbus, Ohio. *scra.org.*

SHAPE MEMORY POLYMER TRIGGERED BY BODY HEAT



Time-lapse photo of a new shape memory polymer reverting to its original shape after exposure to body temperature. Courtesy of Adam Fenster/University of Rochester.

Researchers at the University of Rochester, N.Y., created a shape memory polymer triggered by body heat alone to snap back to its original shape after deformation. As the material is stretched, small segments of the polymer align in areas called crystallites. These crystallites fix the material into a temporary shape that becomes increasingly stable as their numbers increase. The team discovered that this crystallization process is inhibited by molecular linkers. By altering the number, type, and distribution of these linkers, they were able to precisely set the temperature at which the crystallites break apart—triggering the recoil—to 35°C, just below body temperature. The polymer could have a variety of applications, including sutures, artificial skin, and body-heat assisted medical dispensers. *rochester.edu.*

CONSORTIUM ON CYLINDER HEAD DESIGN

Southwest Research Institute (SwRI), San Antonio, formed the Aluminum Head Evaluation, Analysis, and Durability (AHEAD) consortium, which aims to reduce weight and improve durability of aluminum cylinder heads used in both gasoline and diesel

SwRI engineers are leading the AHEAD consortium, which seeks to reduce weight and improve durability of aluminum cylinder heads. Courtesy of SwRI.

engines. AHEAD will target areas such as casting processes, structural design, measurement and prediction of residual stresses, and aluminum alloy materials that resist high temperatures. More advanced projects could include new alloy development, cylinder head transient analysis, and materials characterization. The four-year program will launch this summer and is open to automotive OEMs and suppliers. Depending on membership level, benefits may include meeting attendance, reports, and royalty-free access to intellectual property, as well as project selection rights. *swri.org.*

NEW STEEL SHEET AVAILABLE FOR COLD STAMPING

Many of today's automotive OEMs use hot and cold rolled high and ultra-high strength steel sheets for cold stamping with strengths of 140-180 ksi and elongation of 11-18%. Newly designed high strength steel sheets for cold stamping (HSCS steel) from Advanced Materials Development Corp., Toronto, now offer an alternative to these steels for automotive, defense, oil and gas, and construction applications.

Ingots of the HSCS steel were air melted in an induction furnace, homogenize annealed, and hot rolled to 0.060-0.065-in. thick sheets, 16-18 in. wide. After annealing, ASTM standard tensile specimens were cut in the longitudinal direction. Specimens were heat treated by gas quenching and further tempered at 400°-500°F (low tempering) or 1000°-1200°F (high tempering). ASTM standard tensile tests show the following room temperature properties after several heat treatments.

Group 1 specimens feature ultimate tensile strength (UTS) of 140-150 ksi, yield strength (YS) of 130-140 ksi, and elongation of 14-16% after gas quenching and high tempering; microstructure consists of ferrite and fine carbides. Group 2 exhibits UTS of 170-180 ksi, YS of 160-170 ksi, and elongation of 10-12% after gas quenching and high tempering at a temperature slightly lower than Group 1; microstructure consists of ferrite and fine carbides. Group 3 shows UTS of 260-265 ksi, YS of 190-195 ksi, and elongation of 8-9% after gas quenching and low tempering; microstructure consists of small packets of martensite laths, retained austenite, and fine carbides. Development of HSCS steel sheet with UTS of 200-220 ksi and elongation of 14-16% is now in progress. *For more information: Gregory Vartanov, 289.400.1154, info@amdoncorp.com, www.amdoncorp.com.*

TESTING | CHARACTERIZATION

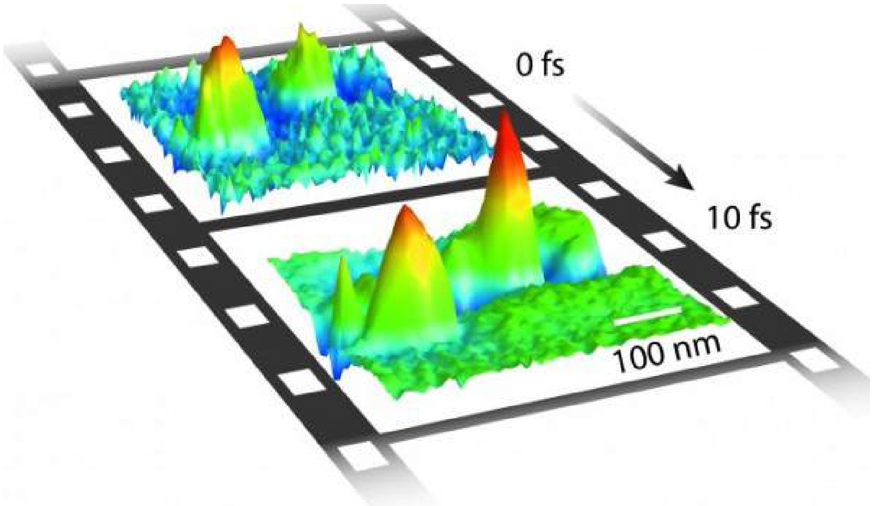


Image captured by an ultrafast optical microscope shows clouds of electrons oscillating in gold material in space and time. Courtesy of University of Colorado Boulder.

ULTRAFAST OPTICAL MICROSCOPE DEBUTS

University of Colorado Boulder researchers recently demonstrated the world's first ultrafast optical microscope, allowing them to probe and visualize matter at the atomic level with incredible speed. The ultrafast microscope assembled by the research team is 1000 times more powerful than a conventional optical microscope, says physics professor Markus Raschke. The image frame rate is one trillion times faster than the blink of an eye, allowing researchers to make real-time, slow-motion movies of light interacting with electrons in nanomaterials, in this case a thin gold film.

"This is the first time anyone has been able to probe matter on its natural time and length scale," explains Raschke. "We imaged and measured the motions of electrons in real space and time, and we were able to make it into a movie to help us better understand the fundamental physical processes." The team used a technique called plasmonic nanofocusing to focus extraordinarily short laser pulses into tiny bits of gold film matter using a nanometer-sized metal tip. Unlike electron microscope approaches, the new technique does not require ultrahigh vacuum techniques and is particularly promising for studying ultrafast processes like charge and energy transport in soft matter, including biological materials, say researchers. *colorado.edu.*

PROCESS MONITORS MATERIALS DURING MANUFACTURING

The Energy Department's National Renewable Energy Laboratory (NREL), Golden, Colo., was recently issued a patent for a novel method that rapidly characterizes specialized materials during the manufacturing process. According to NREL scientists, this approach significantly improves on standard quality control techniques by allowing for complete monitoring of materials without interrupting workflow.

"This technique enables materials manufacturers to detect potential problems early without slowing or stopping the manufacturing process," says Bhushan Sopori, inventor of the On-line Monitoring in Solar Cell and Fuel Cell Manufacturing technology. Commercial use could benefit manufacturing of fuel cell components, semiconductor wafers, glass, and coatings. The new method would likely have the largest impact on reducing cost in high-throughput environments, such as roll-to-roll processing facilities, because it can characterize materials at a speed of tens of feet per minute, according to the team.

Characterization of materials using this method is accomplished via wide-angular illumination on the conveyor belt or roll-to-roll processing

BRIEFS

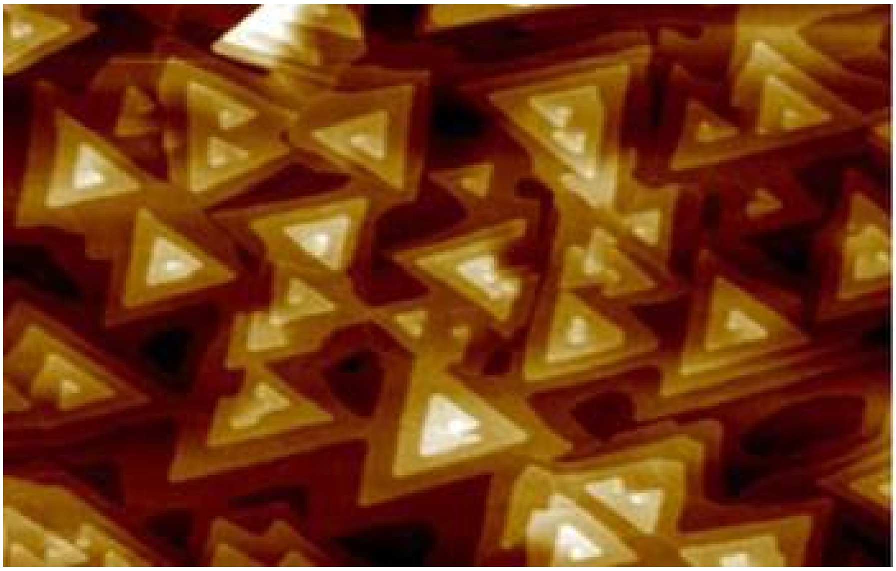
Thermo Fisher Scientific, Tewksbury, Mass., acquired **INEL Inc.,** France, a provider of real-time x-ray diffraction systems. The business will be integrated into Thermo Fisher's analytical instruments segment. *thermofisher.com.*

Instron Corp., Norwood, Mass., celebrated its 70th anniversary on March 15. The company was established in 1946 by Harold Hindman and George Burr, who were working together at the Massachusetts Institute of Technology to investigate suitable substitutes for silk that could be used in the manufacture of parachutes. After discovering there was no testing machine accurate enough to meet their requirements, the men designed a materials testing instrument. The prototype was so successful that Instron was formed. In 2005, it was acquired by **ITW** as the first company in their test and measurement platform. *instron.com.*

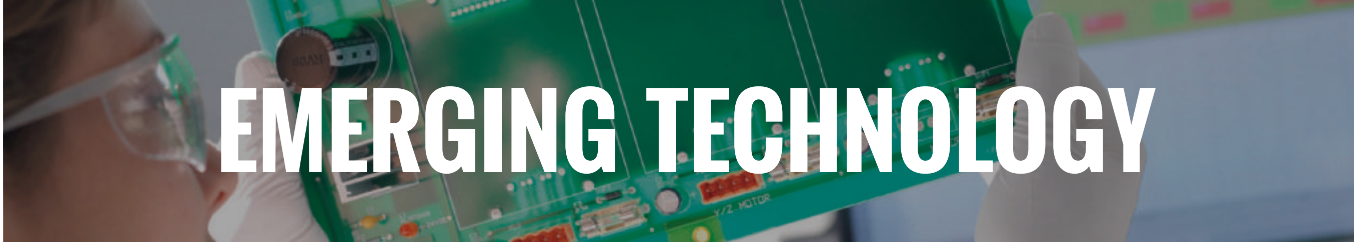
platform. Spectral imaging and reciprocal optics are then utilized to assess a number of material features including thickness, surface conditions, and uniformity. *erin.beaumont@nrel.gov, www.nrel.gov.*

FUNDING SUPPORTS CRYSTALLINE HARD MATERIALS RESEARCH

A new Materials Innovation Platforms (MIPs) program that aims to significantly accelerate materials research and development has made its first awards, to Penn State University and Cornell University. The institutions will serve as platforms to develop new bulk and thin film crystalline hard materials through state-of-the-art instrumentation. The Cornell award is a multi-institution effort in collaboration with Johns Hopkins University, Clark Atlanta University, and Princeton University. The National Science Foundation will provide up to $25 million over the next five years to support the platforms, with each eligible for a one-time, five-year renewal. The effort aims to accelerate development of technologies in a wide range of areas, such as microelectronics, fuel and solar cells, and new biomaterials, generating economic gains for the nation. The effort is data-intensive and researchers not directly involved with the platform will also have access to the generated data. Cornell will focus primarily on oxide and oxide-based 2D films on new substrates—physical materials for advanced electronics. Penn State will study metal chalcogenide materials including sulfides, selenides, and tellurides. *nsf.gov, paradigm.cornell.edu, mri.psu.edu/mip.*



The surface of bismuth selenide film shows the triangular layer structure that is characteristic of 2D chalcogenide materials. Courtesy of Joan Redwing, Penn State University.



EMERGING TECHNOLOGY

Technician Eric Breden installs a transmission cable on the silver disk that is the new pulsed-power machine's central powerflow assembly. Courtesy of Randy Montoya.

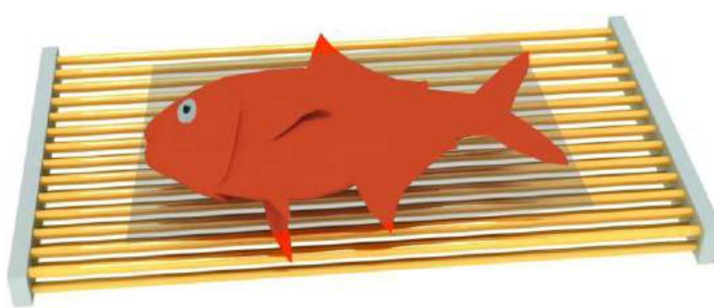
THOR ACCELERATOR SMASHES Z MACHINE IN EFFICIENCY

A new accelerator developed by Sandia National Laboratories, Albuquerque, N.M., is expected to be 40 times more efficient than their Z machine, the world's largest and most powerful pulsed-power accelerator. Named Thor, the new device will be used to study materials under extreme conditions. "Thor's magnetic field will reach roughly one million atm, about the pressures at Earth's core," says David Reisman, lead theoretical physicist on the project. Though unable to match Z's 5 million atm, Thor will be smaller—2000 ft^2 rather than 10,000 ft^2—and considerably more efficient because it uses hundreds of small capacitors instead of Z's few large ones.

While Z's elephant-sized capacitors require large switches to shorten the machine's electrical pulse from 1 μs to 100 ns, Thor's small switches immediately discharge current in a 100-ns pulse, eliminating energy loss from compression. The new architecture also allows for tailored pulse shapes, avoiding the shocks that force materials to change state. While it can take days for Z machine users to determine how to create the ideal pulse shape for a desired compression curve, Thor users will be able to do the same after just moments at a computer. Sandia is building Thor in stages and has already assembled materials for two intermediate "first light" machines expected in 2016. *sandia.gov.*

METAMATERIALS ENHANCE MRI

A group of researchers from Russia, Australia, and the Netherlands developed a technology that can dramatically increase magnetic resonance imaging (MRI) efficiency, resolution, and safety by using metamaterials—artificial periodic structures that interact with electromagnetic radiation. The scientists—from ITMO University, Ioffe Physical-Technical Institute, and the Institute of Experimental Medicine RAMS (all in Russia), Australian National University, and University Medical Center Utrecht, the Netherlands—determined that placing a specially designed metamaterial under the studied object in an MRI scanner increases the signal-to-noise ratio in the scanned area. As a result, either a higher resolution image can be obtained over the same scanning time, or an image of normal resolution can be produced in less than half the time. Additionally, the metamaterial suppresses the electric field, which is responsible for tissue heating, a phenomenon that may compromise patient safety. Implementation of the metamaterial solution does not require any intervention into the MRI hardware, but simply involves an inexpensive add-on device that can be used with any scanner. *en.ifmo.ru/en.*

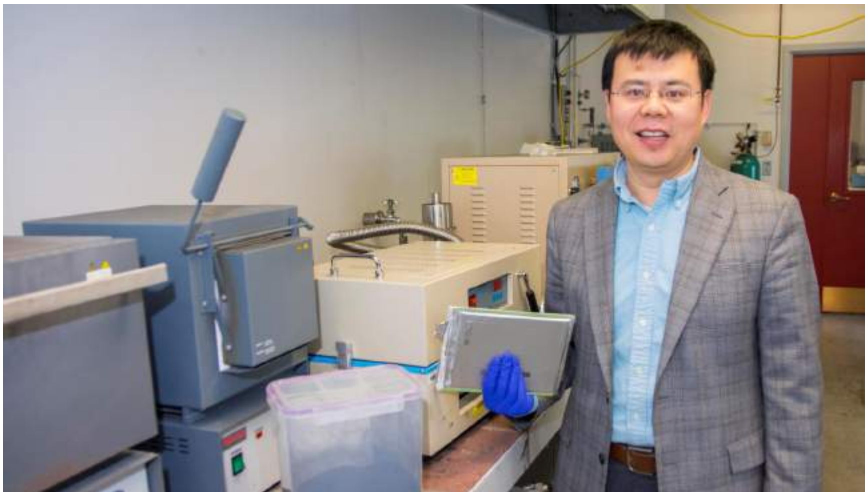


Placing a unique metamaterial under an object in an MRI scanner boosts the signal-to-noise ratio in the scanned area.

BRIEF

A research team from the faculty of engineering at the **National University of Singapore** has achieved a world's first by successfully converting paper waste into green cellulose aerogels that are nontoxic, ultralight, flexible, extremely strong, and water repellent. This novel material is well suited for applications such as oil spill cleaning, heat insulation, and packaging. Additionally, it can potentially be used as a coating in drug delivery and as smart material for various biomedical applications. *www.nus.edu.sg.*

PROCESS TECHNOLOGY



Yan Wang holds a Li-ion battery cell used in electric vehicles. His process breaks down the batteries to produce the powder shown on the left.

NO-SORT BATTERY RECYCLING

A team of researchers at Worcester Polytechnic Institute (WPI), Mass., developed a novel process for recycling lithium-ion (Li-ion) batteries and using the recovered cathode material to produce new plug-in hybrid electric vehicle battery cells. Because commercially produced Li-ion batteries use a variety of chemistries for their cathodes, recyclers must sort these batteries, a labor-intensive and expensive process. The new method works with any cathode chemistry, so little to no sorting is required. Batteries are shredded, and the steel, aluminum, iron, copper, and plastics are recovered and recycled. Cathode materials—lithium, nickel, manganese, and cobalt—are recovered and used to synthesize new cathodes in a formula that can be adapted based on industry needs. Using this process, the WPI team was able to recycle up to 80% of the cathode materials from unsorted batteries. Researchers say their approach could cut the cost of cathode materials for vehicle batteries by more than 30%. Further, WPI received a $1 million contract from The United States Advanced Battery Consortium LLC to scale-up the process from coin cells to 25 Ah cells. *wpi.edu.*

HEAT IS ON IN MATERIALS JOINING

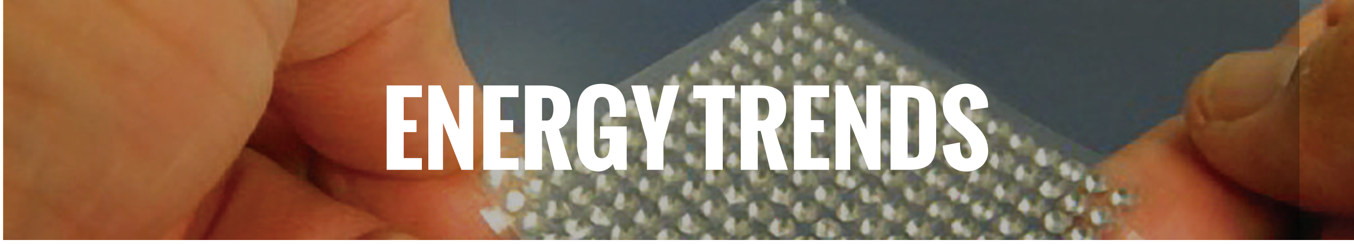
Materials such as fiber-reinforced plastics and light metals have led to low-density components in the automobile, aircraft, and aerospace industries, although joining these materials has proved challenging. Researchers from the Institute for Machine Tools and Industrial Management at the Technical University of Munich (TUM) developed a secure joining technique that uses heat application. Their process involves texturing the metal surface with a laser beam to produce tiny hollows, pressing the metal and plastic together, and then applying heat until the plastic melts and flows into the hollows. On cooling, a stable bond is formed between the two materials.

Depending on the particular plastic, researchers vary the depth of the laser-beam grooves from nanometers to a few millimeters. A groove pattern a few tenths of a millimeter deep is suitable for plastics reinforced with short fibers, while fine surface structures are effective for continuous fiber-reinforced plastics. Different methods of heating are used as well. A laser beam can melt plastic, while friction press joining creates thermal energy by pressing a rotating cylindrical tool against the metal surface. For a fast bond, researchers use NanoFoil, which can briefly reach a temperature as high as 1000°-1500°C when ignited. One possible application of this technology is the rapid joining of metal cable clips to an aircraft fuselage via a thermoplastic intermediate layer. *www.iwb.tum.de/en.*

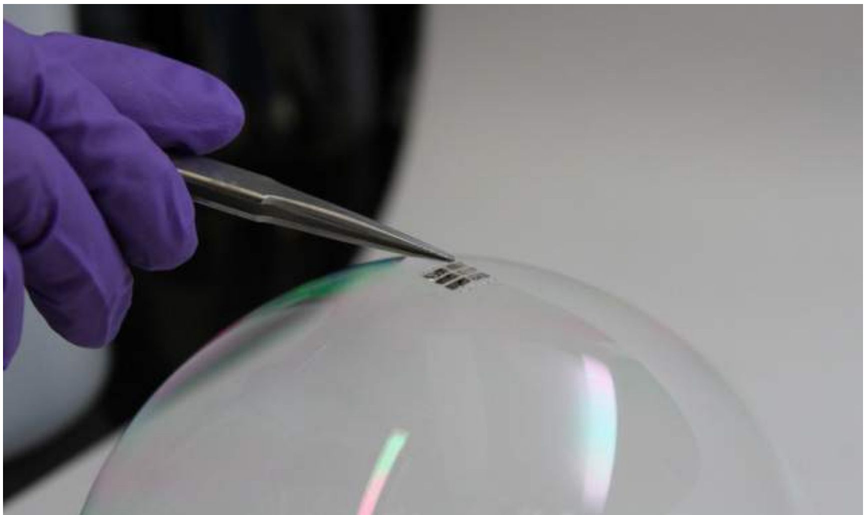
Doctoral candidate André Heckert is working with a laser to fuse plastics with metals. Courtesy of Ulrich Benz/TUM.

BRIEFS

UTC Aerospace Systems, Charlotte, N.C., opened a Materials and Process Engineering (MPE) laboratory in Windsor Locks, Conn., to support research, engineering, and production. The lab has 3D printing capabilities for fabricating metal and plastic engineering development parts, as well as high-temperature composite capabilities for developing carbon-carbon and silicon carbide-based composites. UTC also established the Materials Engineering Center of Excellence at the **University of Connecticut** (UCONN). The agreement includes a five-year, $1 million commitment to work with UCONN in areas such as additive manufacturing, high-temperature composites, and thermoplastics. *utcaerospacesystems.com.*



ENERGY TRENDS



Ultrathin solar cell rests atop a soap bubble. Courtesy of Joel Jean and Anna Osherov.

ULTRATHIN SOLAR CELLS GROWN IN A VACUUM

Researchers at Massachusetts Institute of Technology, Cambridge, developed a novel approach to solar cell production that resulted in the thinnest, lightest photovoltaic cell ever made—a cell so lightweight and flexible, it can be draped on a soap bubble without popping it. Key to the new approach is making the solar cell, substrate, and protective coating in one process. Unlike current solar cell construction practices, the entire procedure takes place in a vacuum chamber at room temperature and does not involve solvents.

In their proof-of-concept cell, researchers use a glass carrier—the flexible polymer parylene—as both the substrate and overcoating. An organic material called DBP serves as the primary light-absorbing layer. Both the substrate and solar cell were grown using established vapor deposition techniques. After construction, the entire parylene/solar cell/parylene stack was peeled off the carrier with a frame of flexible film. The final cells are about 2 μm thick—just one-thousandth the thickness of equivalent cells on glass substrates—but they are just as efficient, and their power-to-weight ratio is reportedly among the highest ever achieved. Whereas a typical silicon-base solar module may produce about 15 W per kilogram, the new cells have an output of 6 W per gram—about 400 times higher. *mit.edu.*

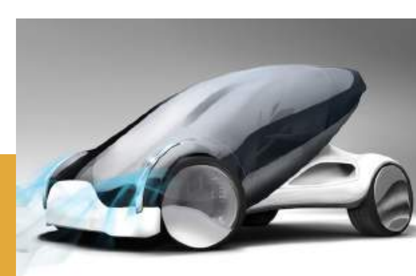
DOE ESTABLISHES MATERIALS NETWORK

The U.S. Department of Energy launched its Energy Materials Network (EMN), a National Laboratory-led initiative that will address one of the major challenges to widespread commercialization of clean energy technologies—the design, testing, and production of advanced materials. The $40 million effort, funded by DOE's Office of Energy Efficiency and Renewable Energy, will facilitate collaboration between National Labs, industry, and academia as it solicits proposals for joint R&D projects and establishes four initial consortia to focus on specific classes of materials.

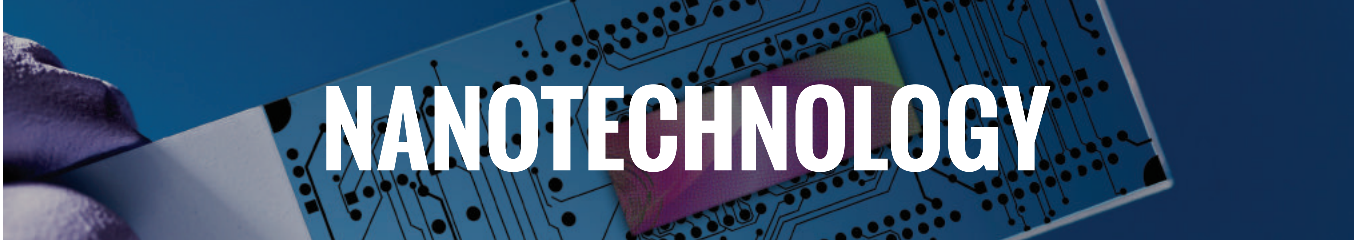
For example, the Lightweight Materials Consortium (LightMat), led by Pacific Northwest National Laboratory, Richland, Wash., will design specialized alloys and carbon fiber reinforced polymer composites that can be manufactured on a large scale; the Electrocatalysis Consortium (ElectroCat), led by Argonne National Laboratory, Lemont, Ill., and Los Alamos National Laboratory, N.M., will seek more abundant and inexpensive alternatives to the platinum group metals currently used in hydrogen fuel cells; and the Caloric Cooling Consortium (CaloriCool), led by Ames Laboratory, Iowa, will seek to develop, demonstrate, and deploy "caloric" refrigerant materials that could increase cooling efficiency. *energy.gov/eere/energy-materials-network/energy-materials-network.*

BRIEF

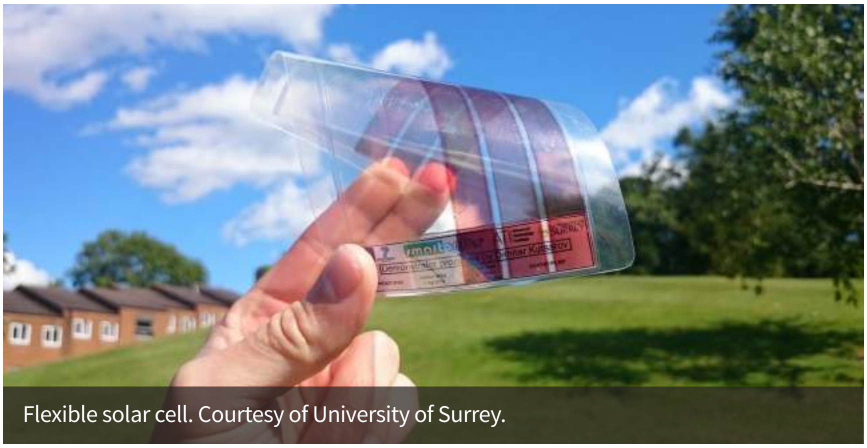
The Global Climate and Energy Project (GCEP) at Stanford University, Calif., awarded $7.6 million to research teams at their university and three others to support work on advanced energy technologies for industrialized countries and the developing world. Among the recipients is Reinhold Dauskardt, a Stanford professor of materials science and engineering, whose team will work on transportation vehicle lightweighting with polymeric glazing and moldings. The team will use a novel glazing process to create lightweight polymer materials to replace conventional glass windows and metal frames. *stanford.edu.*



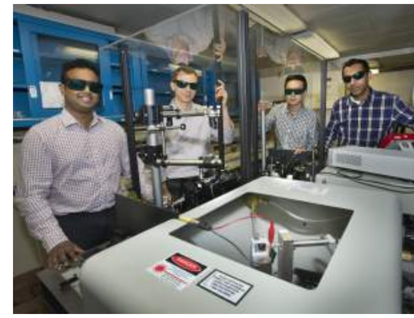
Reinhold Dauskardt is developing a technology to enable use of lightweight polymers in aerodynamic vehicles. Courtesy of Antii Eskeli.



NANOTECHNOLOGY



Flexible solar cell. Courtesy of University of Surrey.



From left, Nanditha Dissanayake, Matthew Eisaman, Yutong Pang, and Ahsan Ashraf in a laser lab at Brookhaven.

LIGHT ABSORBING GRAPHENE PATTERNED AFTER NATURE

Using a technique known as nanotexturing, which involves growing graphene around a textured metallic surface, researchers from the Advanced Technology Institute (ATI) at the University of Surrey, UK, created ultrathin graphene sheets designed to more effectively capture light. Graphene has remarkable electrical conductivity and mechanical strength, but is traditionally inefficient at light absorption. To combat this, the team used nanopatterning to localize light into the narrow spaces on the textured surface, increasing the amount of light absorbed by the material from 2-3% to about 95% across a broad spectrum—from UV to infrared.

The team takes its inspiration from nature. "Moths' eyes have microscopic patterning that allows them to see in the dimmest conditions. These work by channeling light towards the middle of the eye with the added benefit of eliminating reflections," explains professor Ravi Silva, head of the ATI. His group used the same technique to pattern the graphene. The material could be used in a variety of applications from solar cells that could harvest very dim light to optoelectronic technologies. *www.surrey.ac.uk.*

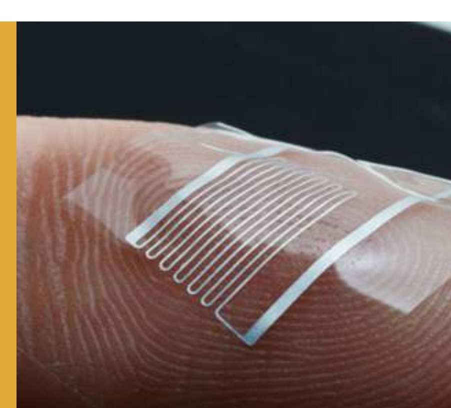
GRAPHENE GETS DOPED UP ON GLASS

In an unexpected twist, researchers discovered a simple and powerful way to create resilient, customized, and high-performing graphene: Layer it on top of common glass. This scalable and inexpensive process helps pave the way for a new class of microelectronic and optoelectronic devices—from efficient solar cells to touchscreens. The collaboration was led by scientists at the U.S. Department of Energy's Brookhaven National Laboratory, Upton, N.Y.; Stony Brook University, N.Y.; the U.S. Photovoltaic Manufacturing Consortium, Albany, N.Y.; and SUNY Polytechnic Institute, Albany, N.Y.

The team initially set out to optimize a solar cell containing graphene stacked on a semiconductor stacked on a substrate of industrial soda-lime glass, the type of glass commonly found in windows and bottles. To maximize the graphene's electronic properties, they planned to dope it, which is typically done by introducing external chemicals. However, preliminary tests revealed that the graphene was already optimally doped. After isolating the graphene on the glass, the team discovered that the sodium in the substrate automatically created high electron density within the multilayered graphene. Crucially, the effect remained strong even when the devices were exposed to air for several weeks—a clear improvement over competing doping techniques. *science.energy.gov.*

BRIEF

Researchers at the École **Polytechnique Fédérale de Lausanne** (EPFL), Switzerland, developed conductive tracks that can be bent and stretched up to four times their original length. Unlike conventional conductive tracks that are usually hard printed on a board, those developed at EPFL are almost as flexible as rubber. They can undergo a million stretches without cracking or compromising conductivity, and could be used in artificial skin, connected clothing, or on-body sensors. *www.epfl.ch.*



Stretchable electronics from EPFL can quadruple in length.

AN OVERVIEW OF POPULAR MATERIALS TESTING SYSTEMS

Materials testing systems must be robust and flexible, capable of determining the mechanical properties of a broad range of materials and components ranging from metals to composites and from plastics to natural, bio-based materials.

Mechanical testing plays a major role in research and education, product development and design, and quality control. Tests can be conducted using a wide range of static and dynamic materials testing machines, which engineers and scientists frequently use during product development. Mechanical testing incorporates a wide range of techniques, from common tensile and compression tests to flexural or torsional characterization. Testing may also occur under ambient or non-ambient conditions, with widely varied temperatures and environmental conditions.

ELECTROMECHANICAL SYSTEMS

Electromechanical (EM) testing systems are often applied to static testing applications in tensile or compressive mode. Two types of load frames are available for EM testing systems, single-column and dual-column frames. Dual-column systems come in benchtop and floor-standing models. Additional elements of EM systems include a load cell, a crosshead, and a means of measuring extension, also commonly referred to as elongation. A load cell is a transducer that creates an electrical signal whose magnitude is directly proportional to the force being measured. A moveable crosshead moves up or down at a given rate of speed specified by the standard to which the test is being conducted. Some applications require a constant rate of extension while others require a ramped rate.

As an example, EM testing systems from Zwick incorporate modern design elements to deliver the most reliable test results possible. In these systems, AC drive technology couples virtually maintenance-free operation with the advantages of digital control. In addition, an innovative motor feedback system ensures excellent constant velocity properties, even at very low speeds. These test machines are also equipped with a patented, flexurally stiff hollow profile with a guide cylinder, while long crosshead guides with a large surface area provide extremely precise guidance. This combination minimizes undesirable mechanical influences on the specimen.

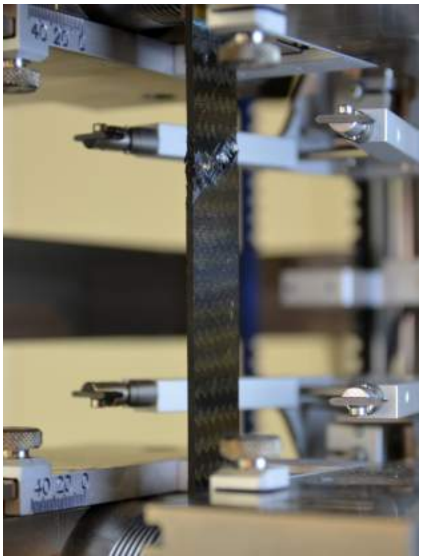
EM testing systems are particularly beneficial for applications that call for high levels of precision. Applications that require support for measuring complex strain may be addressed through the use of an extensometer. The requirements to be met by an extensometer are determined primarily by the characteristics of the material to be tested. This includes its shape and dimensions, test requirements, and the formal standards that must be met. These define the gage length, accuracy, test sequence, and environmental conditions, such as the test temperature. During the tensile test, the elongation of the gage section is recorded against the applied force. Typically, elongation is measured between two fixed points on the specimen.

The primary scope of tests addressed by EM systems are classic static materials tests such as tensile, flexure, or bending tests. EM represents the most suitable technology because for these kinds of tests, especially tensile tests, a high degree of control and precision in strain rate measurement is relevant. This is only possible with EM systems. In addition to materials tests, EM systems are also applicable to component tests when high precision is necessary.

SERVOHYDRAULIC SYSTEMS

Servohydraulic testing machines may be used in static, dynamic, or fatigue materials testing applications. They operate through a closed-loop system consisting of a bidirectional hydraulic actuator linked to the test specimen; a servo valve and controller for adjusting actuator position, velocity, and force; a load frame with close-coupled hydraulic power source; and an electrical feedback loop enabling the test variables to be controlled utilizing position and load transducers. Although they require infrastructure for both electrical and hydraulic connections, servohydraulic testing machines can be a cost-effective static testing choice at very high forces (where screw-driven electromechanical machines may be expensive to produce) or if a high testing speed is required.

Electromechanical testing systems within the AllroundLine contain dual test areas to support efficiency in testing.



The makroXtens extensometer incorporates unique knife edges that remain in contact with the test specimen up through breakage. Pictured here is a carbon fiber composite specimen undergoing brittle failure.

TABLE 1—TESTING SYSTEMS AT-A-GLANCE

Type of system	Load range	Frequency range	Mode of operation
Electromechanical	0.5 to 2500 kN	Up to 1 Hz	Primarily static
Servohydraulic	5 to 2500 kN	Up to 100 Hz	Both static and dynamic
Vibrophore high-frequency pulsator	50 to 1000 kN	30 to 300 Hz	Both static and dynamic

Strain measurement primarily applies when servohydraulic systems are used for static tests. In these cases, typically a sensor arm extensometer, such as Zwick's makroXtens device, will accommodate the need for a high precision form of strain measurement. With this extensometer, deformations on the specimen are acquired in the elastic and plastic deformation ranges during the entire tensile test up to specimen break. Tiltable knife edges avoid the onset of damage to the specimen up to the breaking point.

Clip-on extensometers may also be used. As the name implies, these devices are mounted directly onto the specimen. The mechanical parts that transfer extension, via knife edges, from the specimen to the internal transducer are short and stiff. Practically no relative movement occurs between the specimen and extensometer, resulting in a highly accurate measurement.

For dynamic tests, a simple clip-on extensometer can be used as well as an optical system such as a noncontact video extensometer. Video extensometers require measurement marks to be attached to the specimen that are optically distinct from the surrounding area of the specimen. Marks are clipped, tacked, or glued onto the specimen, or the specimen is marked with a colored pen.

LOW CYCLE AND HIGH CYCLE FATIGUE TESTS

In industry, the focus of servohydraulic machines is mainly the testing of components, though they are indeed applicable for materials characterization as well. Applications typically call for a form of fatigue testing to support lifecycle determination. Fatigue testing involves subjecting a component or specimen to cyclic loading. Two common types of fatigue testing are regularly investigated with servo hydraulic systems—low cycle fatigue (LCF) and high cycle fatigue (HCF).

Components that are subject to extreme thermal and mechanical forces can only be designed in the range of short-term strength, that is, up to a maximum of 10^5 cycles. Prime examples include the turbine blades and discs used in aircraft engines, together with stationary turbines for power generation, plus items such as exhaust gas turbochargers, exhaust manifolds, and other similar components.

In these components, strain-induced plastic cyclic deformation occurs at designed-in notches such as the blade-disc joint. Sooner or later this results in crack nucleation. In a low-cycle fatigue (LCF) test, these forces or strains are simulated on a specimen and the number of cycles to crack initiation is determined. The elastic field around the crack also has a supporting effect after crack initiation. Further crack growth then occurs in accordance with fracture mechanics criteria. Results are used directly in the calculation of the anticipated service life. Tests are performed at constant amplitude and hold times can additionally be interspersed to investigate creep or relaxation processes. A triangular waveform is used as a set value, or a trapezoidal wave for hold times.

If specific operating loads are to be simulated, other strain-time sequences are also possible. Thus LCF tests are also performed with a superimposed higher-frequency oscillation. The test

The HB100 servohydraulic testing machine has a load range of up to 100 kN.

The HB3500 servohydraulic testing machine is applicable for testing large components used in construction applications.

frequency is usually lower than or equal to 1 Hz, although this limit is constantly shifting upward with the result that LCF tests are regularly performed at up to 10 Hz. Strain control is used for these tests. Only in special cases is there a change to force-control in the stabilized hysteresis region or for hold times in order to investigate creep effects. Tests for materials characterization are usually performed with an R ratio of -1. Historically, most attention has focused on situations that require more than 10^4 cycles to failure where stress is low and deformation is primarily elastic.

High-cycle fatigue (HCF) refers to the effect of low-amplitude, high-frequency vibration within the elastic strain region for a number of load cycles N, where typically $N > 10^5$. High-cycle fatigue tests typically occur over 10^7 cycles with some materials requiring up to 5×10^8 cycles. While the applied stress is within the material's elastic region, plastic deformation can still take place on a microscopic level as the part ages, eventually leading to component failure. A component or material's fatigue characteristics can be quantified by generating the graph of stress versus cycles at a given load, known as the Wöhler curve, where fatigue strength is determined from the maximum stress the specimen or component can withstand for a specified number of cycles. The endurance limit of the material or part is then defined as the stress level below which failure does not occur, meaning it has theoretically infinite life. Because fatigue failures can occur quickly if the endurance limit is exceeded, performance must be guaranteed by demonstrating adequate fatigue strengths through cyclical testing that simulates installed conditions.

S-N curves are derived from tests on samples of the material to be characterized, often called coupons, where a regular sinusoidal stress is applied by a testing machine, which also counts the number of cycles to failure. This process is sometimes known as coupon testing. Each coupon test generates a point on the plot, although in some cases there is a run-out where the time to failure exceeds that available for the test. The progression of the S-N curve can be influenced by many factors such as corrosion, temperature, residual stresses, and the presence of notches.

The remote-controlled Vibrophore 100 system provides ergonomic testing in a compact footprint.

The wide test area of this Vibrophore system accommodates HCF testing at non-ambient temperatures.

Analysis of fatigue data requires techniques from statistics, especially survival analysis and linear regression. The Goodman relation, an equation used to quantify the interaction of mean and alternating stresses on the fatigue life of a material, lends support for fatigue data analysis. The general trend presented by the Goodman relation is one of decreasing fatigue life with increasing mean stress for a given level of alternating stress. A Goodman diagram is a graph of mean stress versus alternating stress, demonstrating when the material fails at a given number of cycles.

VIBROPHORES FOR HIGH CYCLE FATIGUE TESTING

Magnetic resonance testing machines, also known as high-frequency pulsators or Vibrophores, are advanced systems for HCF testing. Zwick Vibrophores are specifically designed for rigid metal or ceramic specimens and can induce low-amplitude stress cycles at loads similar to those experienced in aircraft applications.

Operating at high test frequencies, Vibrophores can perform a fatigue test in a short period of time, enabling increased specimen throughput. For example, a Vibrophore requires 20-40% of the time a servohydraulic machine requires to run the same number of cycles. This fast testing capability is essential in a production environment where several specimens from each lot must be successfully tested before the lot can be released for use.

The Vibrophore functions like a driven oscillator, where a large mass on the end of a spring is subjected to an external, time-dependent force. When installed in the testing machine, the specimen functions as the spring, and is oscillated by the excitation mass via the resonance drive. The greatest force amplification occurs when the oscillation amplitude matches the natural frequency of the specimen, as installed in the test machine. A PID controller provides a feedback loop based on mean force (or stress), frequency, and displacement, and tunes the force exerted by the resonance drive to the natural frequency of the testing system.

From a cost-of-ownership perspective, magnetic resonance systems can be installed in most labs without infrastructure modifications and consume only 2% of the power of a comparable servohydraulic test system. Operation of the Vibrophore is straightforward, requiring minimal training. Furthermore, with few parts subject to mechanical wear and tear, Vibrophores are reliable and low-maintenance machines. As an example of these machines, Zwick recently introduced a new generation of Vibrophore systems available in 50-1000 kN capacities and offering a frequency range of 30-300 Hz. These products are the result of decades of HCF testing experience with the company's Amsler line of high-frequency pulsators.

The new Vibrophores use an electric drive for controlled static loading similar to a static materials testing machine, and a magnetic resonance drive for controlled dynamic loading. This design enables both dynamic HCF evaluations and pure static testing. With up to eight frequency steps achievable through the activation of top-mounted weights, tests can simulate changes such as partial loss of torque due to thermal effects, or provide additional system damping if component heating during the test is a problem. In addition to testing by force or strain control, true crosshead position is available as a control parameter.

Strain measurement is only relevant when Vibrophore systems are used for static tests. Operating in static mode, Zwick's systems are often configured with makroXtens extensometers. The geometry of the knife edges in these extensometers enables testing of both round and flat specimens, making them suitable for static testing of critical components such as aerospace fasteners. **~AM&P**

For more information: Markus Semrau is product manager, Vibrophore systems, Zwick/Roell, August-Nagel-Str. 11, D-89079 Ulm, Germany, +49.7305.100, info@zwick.de, www.zwick.com.

RECENT ADVANCES IN EBSD DEFORMATION ANALYSIS

High-speed, high-fidelity techniques used to analyze texture and dislocation content enable greater understanding of the influence of texture on deformation of titanium alloys than previously possible.

John Foltz, ATI Specialty Alloys and Components, Albany, Ore.

Rick Hugo, RC Imaging & Analysis, Portland, Ore.

Titanium alloys are increasingly used in many value-added applications due to their low density, high strength, and compatibility with various biological and composite systems. Most titanium alloys are composed of hexagonally close-packed (hcp) alpha (α) phase and body-centered cubic (bcc) beta (β) phase. The length scale and morphology of these phases, including their preferred orientations in a product form (texture), influences quasistatic and dynamic material properties. The importance of many microstructural features is now recognized and routinely quantified. However, the presence and degree of texture and grain-level deformation mechanisms have proven to be a more difficult challenge to analyze until recently.

Over the past two decades, commercialization of electron backscattered diffraction (EBSD) and electron backscattered pattern (EBSP) analysis has improved in terms of speed and ease of use. Scans with millions of points can now be collected quickly due to automated data reduction at the EBSD detector, while still maintaining adequate angular resolution (≈0.5°) for generic textural studies.

In contrast, dislocation level deformation studies have been limited primarily to two families of techniques—transmission electron microscopy (TEM), and electron channeling contrast imaging (ECCI) in the scanning electron microscope (SEM). TEM analysis is limited by sample preparation to small volumes, as well as free-surface effects from the thin foil. ECCI, in turn, is based on theory similar to dark-field TEM, and is conducted in specialized SEMs with limited sample preparation[1].

These two techniques can resolve individual dislocations, but the greater pattern of dislocation generation or motion is often worth studying. Three bulk techniques used for this work include conventional misorientation maps generated from Hough-transform based EBSD, graphical slip band analysis combined with conventional EBSD, and an emerging technique called high resolution EBSD (HR-EBSD). The latter two techniques are applied in this work to elucidate the deformation mechanisms in three titanium alloys in different microstructural conditions.

In graphical slip band analysis, a sample is polished for EBSD followed by subsequent deformation to induce slip band traces at the sample surface. Surface deformation is visible in the SEM using conventional secondary, backscattered, and forward-scattering electron detectors, and is also cross referenced with EBSD data collected while imaging[2]. For hcp and other low-symmetry deformable materials, this can often identify the slip plane upon which dislocations moved in response to the applied deformation.

In high resolution EBSD (HR-EBSD) analysis, EBSPs from a crystal are compared via image cross correlation to a reference pattern, yielding a misorientation resolution of 0.006°, ≈80× more accurate than Hough transform EBSD analysis. This allows the software to accurately deconvolute the misorientation into separate slip systems and directly quantify the full deformation state of the material[3].

In this study, specimens were examined using graphical slip band analysis to understand the influence of microstructure, alloy content, and loading orientation on the surface deformation response of titanium. In addition, one sample was subsequently analyzed using HR-EBSD to compare results with bulk deformation of titanium.

SPECIMEN PREPARATION AND DATA ACQUISITION

Wire and plate made of ATI 6-4, ATI 3-2.5, and ATI 425 alloys were used in the study. Two heat treated microstructures analyzed were $\alpha+\beta$ mill-annealed structure and $\alpha+\beta$ solution quenched and aged (Q + A) microstructure (see Table 1).

Heat treated specimens were metallographically polished to create a flat on the circumferential surface of the material. Polishing titanium is typically performed using silicon-carbide papers through 1200 fine grit and subsequent polishing using colloidal silica. After polishing, materials were strained

TABLE 1—TEST MATERIALS AND CONDITIONS

Sample number	Material	Max. O_2 content, %	Product form	Condition	Loading direction
1	ATI 6-4	0.20	Wire	Q + A (a)	Longitudinal
2	ATI 6-4	0.20	Wire	Annealed (b)	Longitudinal
3	ATI 6-4	0.20	Wire	Annealed	Radial
4	ATI 6-4	0.20	Wire	Annealed	Double shear
5	ATI 6-4 ELI	0.13	Wire	Annealed	Longitudinal
6	ATI 3-2.5	0.12	Wire	Q + A	Longitudinal
7	ATI 3-2.5	0.12	Wire	Annealed	Longitudinal
8	ATI 425	0.30	Wire	Q + A	Longitudinal
9	ATI 425	0.30	Plate	Annealed	Longitudinal

(a) Q+A = α/β solution treated, quenched, and aged. (b) $\alpha + \beta$ annealed structure.

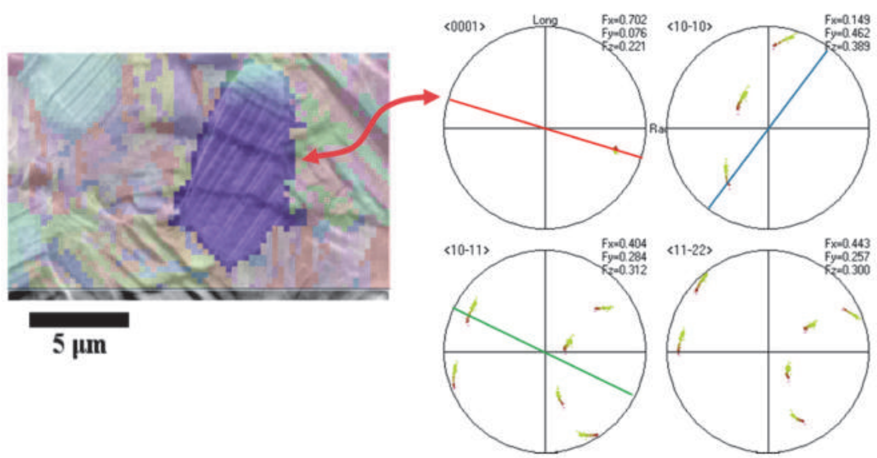


Fig. 1 — Slip line traces translated from the forward-scattered electron image onto the crystallographic pole figures of the purple grain (red arrow). Each colored line corresponds to a family of slip lines in the image and with a single family of crystals.

at room temperature in either uniaxial compression or using a double-shear test fixture to approximately 5-8% engineering strain.

SEM data were acquired using a Carl Zeiss Sigma-VP FEG-SEM. Channeling contrast images were taken at 10 kV and 0° specimen tilt with a solid-state backscattered electron detector, yielding both channeling and atomic number contrast for visualization of slip lines and α/β phase distribution. Subsequently, EBSD maps were acquired at 20 kV accelerating voltage and 70° specimen tilt using an Oxford Instruments NordlysNano EBSD detector. During EBSD mapping, secondary electron and forward-scattered electron detectors captured images of the EBSD scan areas. Images and EBSD data were collected from two locations for each sample at a magnification sufficient to examine approximately 50 grains.

After acquiring EBSD scans for slip-trace analysis, the ATI 6-4 (condition 4) specimen was re-polished and rescanned, saving EBSPs at 1344 x 1044 pixels for subsequent processing with CrossCourt software (BLG Vantage Software).

POST-ACQUISITION DATA ANALYSIS

EBSD data from slip band analysis was correlated with images using a method described by T.R. Bieler, et al.[2]. The trace of the slip line produced on the polished surface was graphed onto the $\{0002\}$, $\{10\bar{1}0\}$, $\{10\bar{1}1\}$, or $\{11\bar{2}2\}$ pole figures for the specific grain, and visually matched to intersections with the plane normal, the intersection of which identifies the slip system (basal, prism, 1st pyramidal, and 2nd pyramidal, respectively) responsible for the deformation. Between the two EBSD scans per sample, 20 grains were analyzed for each material and condition (Fig. 1).

In the HR-EBSD technique used by CrossCourt 3 software[3,4], the EBSP of each pixel in a grain is compared with a reference EBSP via two types of cross-correlation analysis; one measures the unit cell distortion, and therefore, elastic strain at each pixel; and one measures whole-body rotations, and, therefore, plastic strains. The strains are mapped onto the possible slip systems in the analyzed material[4-6] using the configuration that yields the minimum dislocation line energy[7]. This yields the lower bound of the geometrically necessary dislocations (GND) required to produce the observed misorientation, with a detection threshold as low as 10^{12} lines/m^2.

RESULTS

Multiple slip bands from each family of slip systems were observed in nearly all grains, conditions, and alloys. The frequency of each slip system within a given material and condition is shown in Table 2. Basal slip occurred infrequently among all samples, and loading orientation appeared inconsequential when comparing samples 2, 3, and 4. Conversely, activation of prism slip bands was significantly different between samples 2, 3, and 4, demonstrating that prism slip activation is texture dependent based on the texture shown in Fig. 2. It also appeared that $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$ slip bands formed more frequently in annealed microstructures.

Figure 3 shows the results of reconstructing dislocation content using HR-EBSD analysis. Relevant Burgers vector and line direction components were calculated using the CrossCourt software for each slip system, indicating that the $[11\bar{2}0]$ dislocations of both edge and screw character were in greater number density than other directions. However, no maps show clear signs of slip band formation, suggesting a difference in activation energy or interaction of slip bands within the bulk of the specimens.

DISCUSSION

The HR-EBSD technique is a good fit for analyzing dislocations in bulk

TABLE 2—FREQUENCY OF GRAINS WITH SLIP SYSTEM ACTIVATION WITHIN MATERIAL AND CONDITION

Sample number	Condition	Loading direction	% with {0001}	% with $\{10\bar{1}0\}$	% with $\{10\bar{1}1\}$	% with $\{11\bar{2}2\}$
1	Q + A (a)	Longitudinal	10	30	30	50
2	Annealed (b)	Longitudinal	10	55	60	45
3	Annealed	Radial	20	20	55	40
4	Annealed	Shear	15	10	50	60
5	Annealed	Longitudinal	15	55	55	70
6	Q + A	Longitudinal	10	15	60	55
7	Annealed	Longitudinal	20	20	70	75
8	Q + A	Longitudinal	15	40	60	50
9	Annealed	Longitudinal	10	50	75	35

(a) Q+A = α/β solution treated, quenched, and aged. (b) $\alpha + \beta$ annealed structure.

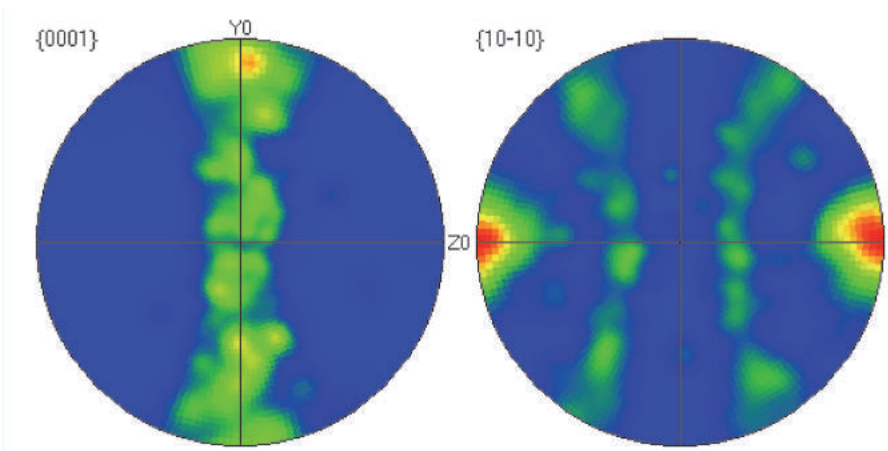


Fig. 2 — Pole figures generated from Sample 4. Wire longitudinal axis is aligned with Z0.

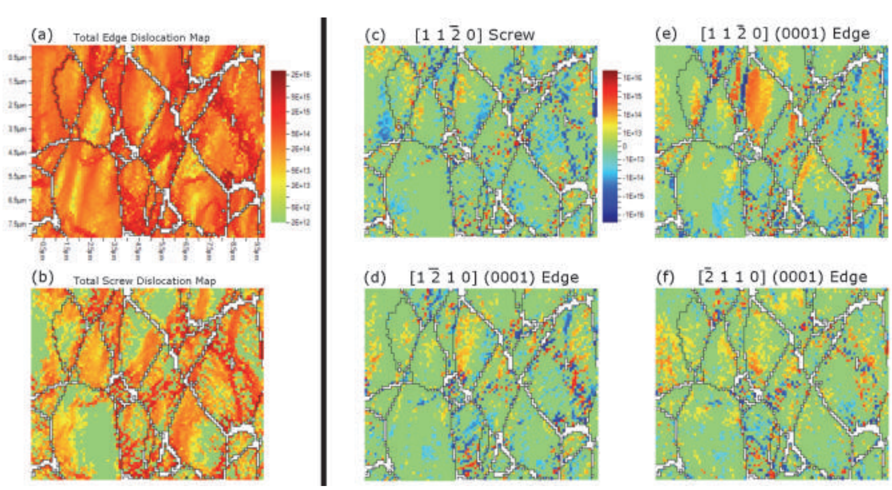


Fig. 3 — Dislocation density analysis from HR-EBSD technique for Sample 4. Direction of wire longitudinal axis in maps is vertical. (a) Calculated edge dislocation content is larger than (b) total screw dislocation content from all slip systems. (c) Screw dislocation content of $[11\bar{2}0]$ character. (d-f) Basal edge dislocation content from different vectors of basal dislocations.

materials, such as within the subsurface of a fatigue sample[8]. The technique requires preparation of only one polished surface rather than two surfaces closely spaced together like in TEM. Having only one surface reduces the effect of strain relaxation, which can occur during soft-materials TEM analysis. By comparison, graphical slip band analysis is a surface technique to study a surface exposed to deformation. As such, graphical slip band analysis might not show the same results due to the nature of the free surface during deformation.

Based on data in Table 2, quenched and aged microstructures demonstrate a higher number of grains with $\{11\bar{2}2\}$ slip bands. Similarly, radial and shear loading appears to decrease the number of grains demonstrating $\{10\bar{1}0\}$ slip bands. Finally, there is a significantly greater number density of slip bands and twinning in samples 6 and 7, which had both lower aluminum content than all other samples, and lower nominal oxygen content than all samples except sample 5. This confirms the general trend that higher strength alloys tend to have fewer activated slip bands, with a greater overall intensity of deformation on the remaining slip bands.

HR-EBSD results differ both from that reported in the literature on dislocation content visible in TEM and from slip band EBSD mapping. The latter could be explained by the differences of stress state due to the free surface during deformation, while the former may be due to image forces acting upon more mobile edge dislocations in TEM foils during analysis. The same trend with edge versus screw dislocation content in HR-EBSD and TEM analysis has been observed in other materials using CrossCourt software. Further investigations could be undertaken to prove the enhanced mobility of edge dislocations in TEM foils using ECCI on a TEM foil and a bulk sample to compare the dislocation content.

HR-EBSD results show significantly more basal slip than measurement by slip trace analysis, and less $\{10\bar{1}1\}$ and $\{11\bar{2}2\}$ slip bands. This disparity might be due to differences in the accuracy of each technique, differences in EBSD acquisition variables, or stress state at the free surface; and could be further explored by analyzing smaller strain levels using both techniques. A difference in slip banding near surfaces could be an important consideration for fracture initiation mechanisms, such as in fatigue, where cracks may originate at either surface or subsurface sites.

CONCLUSIONS

The loading direction for α+β titanium alloy wire affects the activation of prism slip bands, presumably due to the titanium wire having preferred crystallographic texture. Similarly, solution quenched and aged microstructures are more resistant to $\{10\bar{1}1\}$ slip band formation. The interplay of these mechanisms is likely important in dictating inherent material strength, and therefore, in the material selection and optimization process for a given application.

These high speed, high fidelity techniques for analyzing texture and dislocation content enable greater understanding of the influence of texture on deformation of complex titanium engineering alloys than previously possible. This information can be used to validate meso-scale microstructure modeling such as crystal plasticity and finite element models that track anisotropic grain behavior. These models can work in conjunction with other models to predict macroscopic physical properties such as strength, fatigue life, and creep behavior. **~AM&P**

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DISTRIBUTED, CONNECTED EVERYTHING: IT'S ALREADY HAPPENING

The Materials Genome Initiative aims to enable discovery, manufacture, and deployment of advanced materials twice as fast as using traditional development methodologies, at a fraction of the cost.

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Clare Paul, Air Force Research Laboratory, Dayton, Ohio

Technological advances are continually made through innovative processing, characterization, and modeling techniques. Yet, efforts to develop and deploy new materials are hampered due to constraints in discovering and accessing materials data and a lack of interoperability among advanced analytic tools and techniques. What could scientists accomplish without these constraints? This is the goal of the federal government's Materials Genome Initiative (MGI) launched in 2011—to develop an infrastructure that eliminates these constraints, accelerating advanced materials discovery and deployment. This article explores how semantic technologies address three of the four key challenges outlined in the MGI Strategic Plan[1], namely:

1. Lead a culture shift in materials research by establishing mechanisms that facilitate the flow of knowledge across the materials-development continuum through deeper community collaboration.
2. Integrate experimental, computational, and theoretical knowledge by developing advanced simulation tools that are validated through experimental data with networks to share useful modeling and analysis code and access to quantitative synthesis and characterization tools.
3. Make digital data accessible through broad, open access to validated data and tools generated by the materials community across the materials development continuum. This allows both reuse of individual data sets and application of data analytics techniques to examine the aggregation of large volumes of data from many disparate sources.

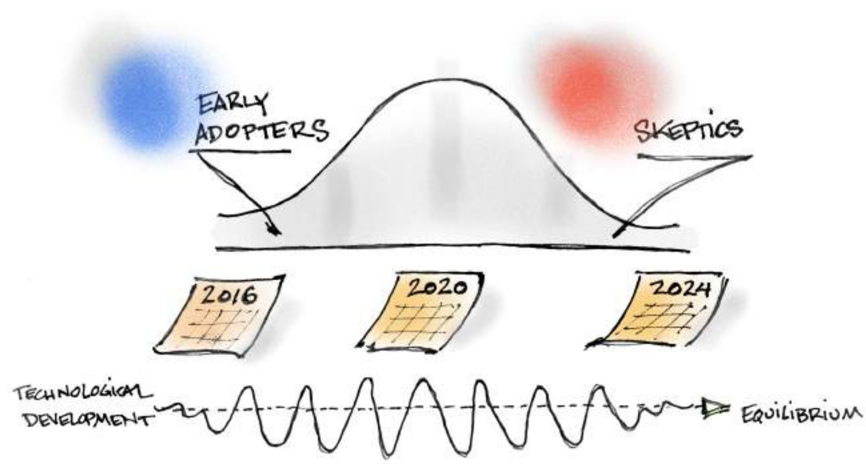

Fig. 1 — Adoption curve for transformative technologies follows a path similar to Tuckman's group development model of form-storm-norm-perform.

A CULTURE SHIFT

Web 1.0 gained traction in ways that its creators did not expect. The initial attempt to link documents via a global network was motivated in large part by the scientific community. Web 1.0 creators built a framework for global connectivity. As this framework grew through incremental gains in global adoption, commercial interests became involved, and it created a symbiotic relationship—driving sustainable growth well beyond initial expectations.

The adoption curve for transformative technologies extends well beyond typical technology curves, and barriers to adoption are many. Extending this concept beyond the enterprise and across an entire community of enterprises increases the challenges exponentially. The adoption curve follows a path similar to Tuckman's group development model of *form-storm-norm-perform* (Fig. 1). Early-stage innovators collaborate to form core consensus and capability. Subsequently, waves of adopters find it more difficult (due in large part to the sheer size of the group) to reach or obtain consensus and might question earlier decisions (a chaotic period—the storm). Then, declining numbers of adopters (converted skeptics) are more likely to accept the work of earlier adopters as the norm. After reaching this stage, efforts of the community focus on performance.

As Web 1.0 demonstrated, the key to success is establishing a flexible framework that enables the entire community to adopt and grow the technology organically over time through development of symbiotic relationships. Web 2.0 brought the advent of social media along with community driven content, transforming publishing into an ongoing and interactive process of micropublishing and tagging (folksonomy)[2]. This accelerated the culture shift, prompting the explosion of commerce that dominates the World Wide Web today—a symbiotic relationship between publishers, retailers, and consumers.

The Semantic Web[3], sometimes referred to as Web 3.0, extends Web 2.0 through standards developed by the World Wide Web Consortium (W3C). These standards outline a flexible framework for sharing data as opposed to sharing documents, i.e., linking data and tools across application, enterprise, and community boundaries. By defining a flexible framework for the interoperability of data and tools, W3C Semantic Web standards enable large-scale integration of, and reasoning over, data and analytics on the web. This framework sets the stage for a cultural transformation of the way materials scientists work.

INTEGRATED TOOLS

In the current state of technology, applications query sets of predefined data sources. Each data source has its own schema and format, which requires custom interfaces to connect and extract content. When a new data source is introduced or a data schema changes, application logic (e.g., business rules), presentation logic, and interfaces must change. This brittle, point-to-point architecture constrains analytic and modeling capabilities, and greatly increases IT costs. Further, queries are written to specific databases. Therefore, the entire set of available databases and other content repositories is not considered, so although the answer to a basic question may reside in the "system," the query will never know.

To highlight the challenge of integrating tools over the web, a generic approach of using application programming interfaces (API) is used to make structured data available on the web. Web APIs provide simple query access to structured data over the http protocol. High-profile examples of these APIs include Amazon Product Advertising API[4] and the Flickr API[5]. The advent of web APIs led to an explosion in small, specialized applications (or "mashups") that combine data from several sources, each of which is accessed through an API specific to the data provider. While the benefits of programmatic access to structured data are indisputable, the existence of a specialized API for each data set creates a landscape where significant effort is required to integrate each novel data set into an application. That is, every programmer must understand the methods available to retrieve data from each API, and then write custom code to access data from each data source.

"Materials research is emphasizing the need for integrated computational tools and high throughput experiments, and at the same time, product development is striving to more effectively integrate materials, manufacturing, and design," explains Daniel Miracle, senior scientist in the Materials and Manufacturing Directorate at the Air Force Research Laboratory. "Integration of heterogeneous, distributed data is moving away from 'wouldn't it be nice' to 'we have to do it.'" This is where semantic technology comes in. Since it was designed for machine-to-machine interchange on the web and is based on open, mature standards, it is a perfect fit for this community.

Semantically linked data is schemaless. Humans and software applications correlate and interpret information unambiguously, using one standard. Linkage between multiple datasets, files, and their respective metadata is established without having to adhere to specific database table structures. As such, data changes to not "break" applications. Conversely, application changes do not break the information fabric. Data operations are greatly simplified, enabling scientists to focus on critical research as opposed to continual data extract, transform, and load (ETL) functions. Linked data's graph structure is machine understandable, i.e., applications can infer meaning in the data, making them "smarter."

Where are all these semantic applications? Because applications operate on data, the question regresses to a more fundamental one: Where is all the linked data? The symbiotic relationship required for global adoption of Web 3.0 begins with data, and that leads to the final MGI challenge.

ACCESSIBLE DIGITAL DATA

Scientists generally agree that sharing data is a worthwhile goal. The Data Sharing Policy of the National Science Foundation states, "Investigators are expected to share with other researchers, at no more than incremental cost and within a reasonable time, the primary data, samples, physical collections and other supporting materials created or gathered in the course of work under NSF grants[6]."

The MGI suggests that to benefit from broadly accessible materials data, a culture of data sharing must be supported by constructing a modern materials-data infrastructure that includes the software, hardware, and

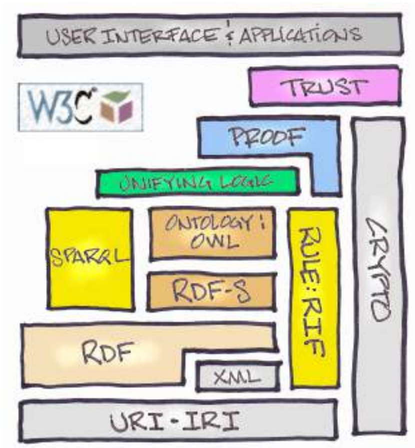

Fig. 2 — W3C's Resource Description Framework (RDF) specification is built on Universal/Internationalized Resource Identifiers that uniquely identify data resources.

data standards necessary to enable discovery, access, and use of materials science and engineering data. It advocates the development of highly distributed repositories because data sharing is optimized in a many-to-many, net-centric data environment that manages data across a community of interest (COI) rather than connecting disparate data sources with brittle, point-to-point interfaces throughout the research ecosystem.

MGI also recommends community developed standards that provide "…the format, metadata, data types, criteria for data inclusion and retirement, and protocols necessary for interoperability and seamless data transfer." The MGI website lists 10 partners working on such standards[7], and there are many others. But these standards already exist in the W3C Semantic Web, proven and in use in other research industries such as the life sciences[8], and by big-data giants including Google[9]. The W3C Linking Open Drug Data[10] effort links pharmaceutical companies Eli Lilly, AstraZeneca, and Johnson & Johnson together in a cooperative effort to interlink openly licensed data about drugs and clinical trials to aid drug discovery and development.

How do W3C standards establish the infrastructure to meet MGI goals? Distributing data across the web requires a standard mechanism to specify the existence and meaning of connections between items described in the data. The mechanism is provided by the W3C's Resource Description Framework (RDF) specification.

The RDF specification is built on Universal/Internationalized Resource Identifiers that uniquely identify data resources (Fig. 2). RDF provides the baseline for "linking data" to form the web of data—a graph structure for representing machine-understandable information. XML provides one means to connect data to the RDF. The RDF query language SPARQL enables users to write unambiguous queries, which can be distributed to multiple SPARQL endpoints, computed, and results gathered.

Together, OWL and RDF-S combine to provide publication tools for semantics of schemas. OWL provides the abstract syntax to develop expressive ontologies that describe content relative to other described entities/concepts within a domain of interest, and assign a URI to uniquely identify data components. Together these establish semantic meaning. RDF-S provides basic logic primitives for writing lightweight ontologies that define classes of resources, organize their hierarchies, and add more intelligence to the data. The Rule Interchange Format provides the framework to encode knowledge as first-order logic used to implement inference engines that process conditions and draw conclusions. The Unifying Logic layer applies higher order reasoning over result sets.

The Proof and Trust components use provenance models, such as W3C PROV Ontology (PROV-O), to provide explanations about results and their sources, including information about entities, activities, and people involved. The provenance ontology supports assessments about quality, reliability, and trustworthiness of data and results. Crypto security may be applied throughout the stack using industry standards to protect data and services. The W3C Semantic Web framework supports a host of user interfaces and applications to analyze, visualize, and share enriched, semantically linked data.

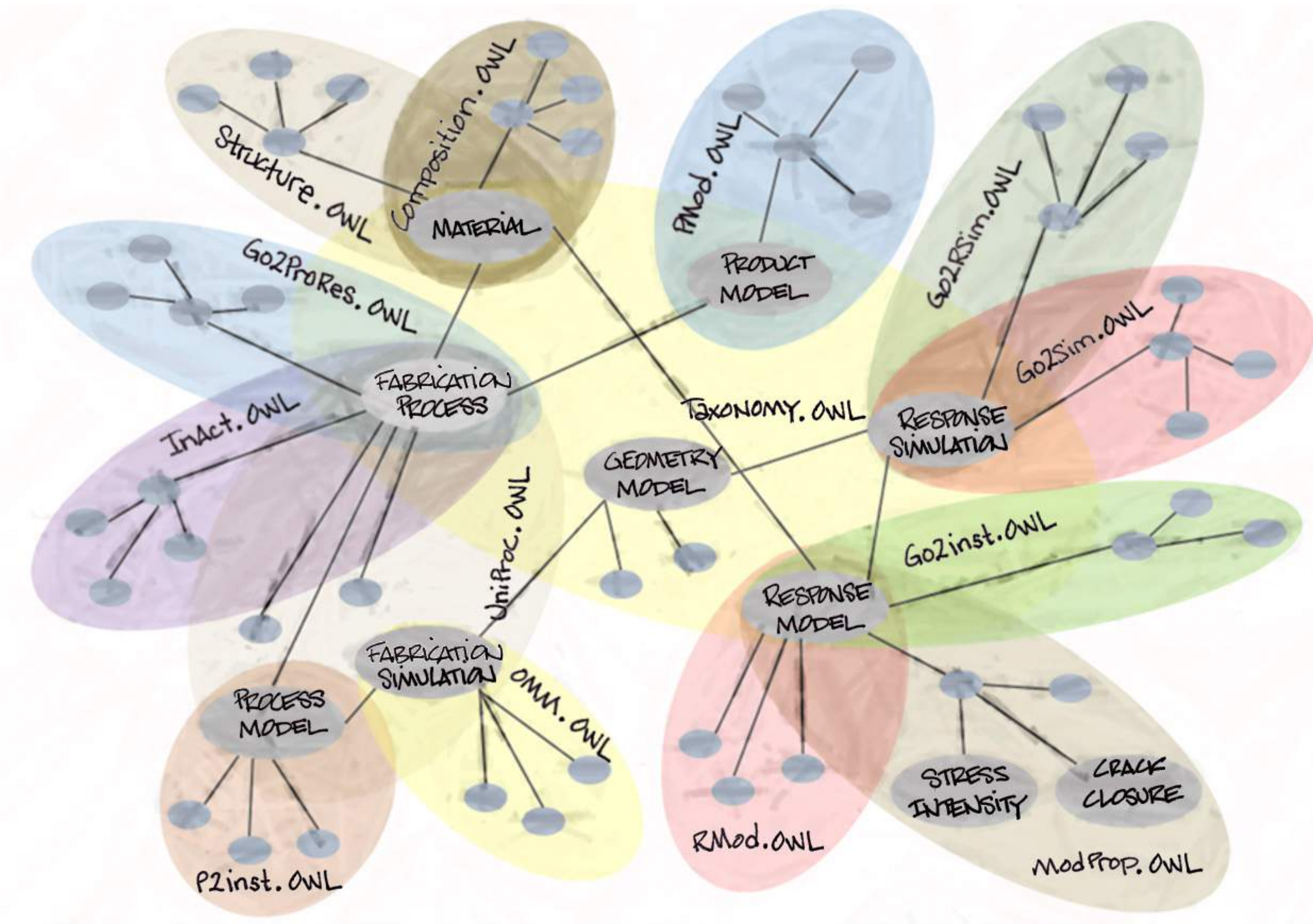

Fig. 3 — Depiction of connecting/merging of RDF graphs via ontology, making the web appear as one giant global graph.

RDF expresses linked data on the web as data triples—a directed, labeled graph where discreet data elements comprise “Subject, Predicate, and Object.” This syntax provides a machine-interpretable “sentence.” Given the pervasive use of the relational database model (RDB), the W3C standard includes recommendations to map relational data to RDF. One recommendation is called “RDB to RDF Mapping Language (R2RML)”[11]. Such mappings provide the ability to view existing relational data in the RDF data model.

Figure 3 depicts connecting (merging) of RDF graphs via ontology. Data in RDF that are linked to other RDF data represent linked data, which makes the web appear as one “giant global graph.” Materials scientists and engineers use the interplay between composition, process, and structure to create or modify materials to achieve desired characteristics. Domain models are created and implemented in software to create simulations. Data from characterization and simulation are assessed to measure model performance or further inform model development. Elements that constitute the system to achieve this are naturally linked, and the linkage can be echoed using semantic technologies.

Domain-specific linked data requires common vocabularies. A common vocabulary is Dublin Core (DC) ontology, a set of universally accepted metadata used to describe a resource (e.g., document). Developing and publishing common vocabulary using the W3C RDFS/OWL specification is one of the initial steps required to link relevant materials information across disparate (federated) sources. Development of common vocabularies for materials has been jumpstarted by several organizations including the National Institute for Standards and Technologies (NIST)[12] and University of Queensland in Australia[13]. Collaborative efforts with professional societies and other organizations (e.g., ASM International and ASTM terminology standards) could accelerate vocabulary/ontology development. Over time, Tuckman’s group development model would channel multiple vocabularies into key sets of generally accepted terms and mappings between terms having the same meaning.

In information retrieval, keyword searches generally return masses of “hits,” requiring a method to assess the usefulness of results, that is, how accurate they are. Precision and recall are two methods of measuring the relevance of search results. Precision is the qualitative fraction of retrieved instances considered relevant (i.e., of all results returned, what portion is relevant?). Recall is the quantitative fraction of relevant instances that are retrieved (i.e., of all possible relevant results, how many were returned?).

Precision and recall could exhibit an inverse relationship where increasing the value of one term reduces the value of the other. For example, a query that maximizes recall (positive impact) will likely decrease precision by returning more irrelevant results (negative impact). Conversely, a query constructed in a way that maximizes precision will likely decrease recall by missing highly relevant content.

Query-based applications (e.g., Internet search engines) offer an effective tradeoff where recall is maximized at the expense of precision. These applications compensate by presenting results in order of perceived precision (relevance). The tradeoff is optimal for traditional browsing where search results do not have to be very good. Recall is not important as long as you get some highly relevant hits, and precision is not important as long as the most relevant hits are presented first. However, such a tradeoff does not support effective scientific research, where recall and precision are equally important.

W3C linked data do not require such a tradeoff. Just as SQL is used to query a relational database, SPARQL provides the standard mechanism to query linked data. Linked data enhances a user's ability to discover new information and also maximizes both precision and recall by providing more informed/complete answers. Linked data query responses are more complete by definition, because all data is inherently linked. When an analytic is applied over the complete set of data retrieved from the Semantic Web (recall), more informed input is returned (precision).

GETTING THERE FROM HERE

The MGI has spurred a variety of approaches to promote data sharing and interoperability throughout academia, government, and private industry. A Semantic Web framework was established to achieve three of the four goals outlined in the MGI Strategic Plan, as noted previously. There is also work aimed at creating a world-class materials workforce—the fourth goal of the MGI plan. For example, ASM International's Computational Materials Data Network (CMD Network) partnered with Northwestern University, the University of Chicago, and private technology firms to develop the Center for Hierarchical Materials Design (CHiMaD). The focus of this group is to develop the next generation of computational tools, databases, and experimental techniques to enable the design of novel materials and establish a new center of excellence for advanced materials research. Efforts like these facilitate distribution of modeling resources to selected universities, helping to prepare the future workforce for materials design.

This work has not yet reached the tipping point in terms of building a Semantic Web framework as the foundation for achieving the first three goals of the MGI Strategic Plan to begin widespread adoption.

The Metadata Research Center at Drexel University is gaining momentum with its open-source project called HIVE (helping interdisciplinary vocabulary engineering)[14]. HIVE presents an automatic linked open data (LOD) technology that integrates interdisciplinary semantic ontologies encoded with the Simple Knowledge Organization System (SKOS), a W3C standard. Researchers initially focused on metals, and are currently “training” HIVE across materials science by working with a group of selected articles and keywords assigned by domain experts (the gold standard), and enhancing HIVE’s ontology indexing via machine learning algorithms.

OTHER ACTIVITIES

A semantic framework is being developed though the U.S. Department of Defense Small Business Innovative Research (SBIR) program. The Materials and Manufacturing Directorate of the U.S. Air Force Research Lab (AFRL) at Wright-Patterson Air Force Base, Dayton, is managing a project to develop the foundational elements of a semantic technology for materials design and development. A robust mid-level materials ontology is being developed, ready for crowdsourcing and initial experimental research use. The project aims to significantly expand integration across data stores, demonstrating computational approaches for establishing provenance and processing restricted linked materials data and information.

AFRL awarded a contract to a private firm to build MatOnto, a comprehensive semantic platform that links data, processes, and applications together into a domain-specific conceptual view for materials. MatOnto’s Stephen Kahmann explains their distributed architecture and open-license approach. “A semantic web behaves like an ecosystem that supports long-term organic growth through adoption and emergent use patterns. It is not realistic to apply commercial concepts such as licensing and transaction-based fees. We are simply creating a framework where the community can share data securely and privately, and make their own decisions about licensing content,” says Kahmann. With the first release of the platform targeted for Q1 2016, MatOnto provides a decentralized, federated, and distributed framework to publish and discover data, services, and computational functions (analytics) that are instantly consumable. This enables the materials-design community to organize, relate, digest, and synthesize the vast amount of materials data. For more information, visit matonto.org.

To realize the benefits envisioned by the Materials Genome Initiative, scientists should work through their corporate channels and with industry organizations such as ASM International to pursue and fund semantic data solutions. With a proper semantic foundation, the MGI can achieve its goal to discover, manufacture, and deploy advanced materials twice as fast, at a fraction of the cost. **~AM&P**

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AEROMAT 2016 SCHEDULE-AT-A-GLANCE

The preliminary schedule included here is subject to change.

Date/Time	Event
Sunday, May 22	
5:00–8:00 p.m.	Registration Open (Hyatt Regency Bellevue Lobby)* *Preregistered attendees only
Monday, May 23	
6:45 a.m.–6:00 p.m.	Registration Open (Meydenbauer Center)
8:00–10:00 a.m.	Technical Programming
10:00–10:30 a.m.	Refreshment Break
10:30 a.m.–12:00 p.m.	Technical Programming
12:00–1:00 p.m.	Lunch (on own)
1:00–3:00 p.m.	Technical Programming
3:00–6:00 p.m.	Exhibits Open
3:00–3:30 p.m.	Refreshment Break
3:30–4:30 p.m.	Plenary Speaker: Chris Lewicki
4:30–6:00 p.m.	Expo Welcome Reception
Tuesday, May 24	
7:00 a.m.–5:00 p.m.	Registration Open (Meydenbauer Center)
8:00–10:00 a.m.	Technical Programming
10:00 a.m.–3:30 p.m.	Exhibits Open
10:00–10:30 a.m.	Refreshment Break
10:30 a.m.–12:00 p.m.	Plenary Speakers: Stefano Bianchi & Mike Lombardi
12:00–1:00 p.m.	Lunch on Exhibit Floor
1:00–3:00 p.m.	Technical Programming
3:00–3:30 p.m.	Refreshment Break
3:30–5:30 p.m.	Technical Programming
7:00–9:30 p.m.	Social Event–Seattle Space Needle (Transportation included)
Wednesday, May 25	
7:00–11:30 a.m.	Registration Open (Meydenbauer Center)
8:00–10:30 a.m.	Technical Programming
9:00 a.m.–1:00 p.m.	Exhibits Open
10:30–11:00 a.m.	Refreshment Break
11:00–11:45 a.m.	Plenary Speaker: Dan Miracle
11:45 a.m.–1:00 p.m.	Lunch on Exhibit Floor
1:00–5:00 p.m.	Optional VIP Tour of Boeing Everett Factory (Limited space and preregistration required)
Thursday, May 26	
8:30 a.m.–12:00 p.m.	Additive Manufacturing Education Short Course
8:30 a.m.–12:00 p.m.	Corrosion Education Short Course

PLENARY SPEAKERS

Monday, May 23

Chris Lewicki

President and Chief Engineer, Planetary Resources Inc.

Redefining Natural Resources

3:30–4:30 p.m.

Stefano Bianchi

Head of ESA Launchers Development Department, European Space Agency—ESA/ESTEC

European Launchers Developments and Technologies: Perspectives and Challenges

10:30–11:15 a.m.

Mike Lombardi

Corporate Historian, The Boeing Company

Making Dreams Into Reality: The Epochal Stories That Define The Boeing Company

11:15 a.m.–12:00 p.m.

Wednesday, May 25

Daniel Miracle

Senior Scientist, Materials and Manufacturing Directorate, Air Force Research Laboratory

The Future of Aerospace Metals

11:00–11:45 a.m.

EDUCATION SHORT COURSES

Two education short courses will be offered on Thursday, May 26.

Additive Manufacturing
Instructor: Frank Medina
8:30 a.m.–12:00 p.m.

This course deals with various aspects of additive, subtractive, and joining processes to form 3D parts with applications ranging from prototyping to production. Students will learn about a variety of additive and other manufacturing technologies, their advantages and disadvantages for producing both prototypes and functional production quality parts, and some of the important research challenges associated with using these technologies.

Corrosion
Instructor: Alain Adjorlolo
8:30 a.m.–12:00 p.m.

Corrosion of metals and alloys affects all industries and has been a threat to basic human creations since metal implements first appeared. Its principles are simple despite the complexity of application to real-world situations. The course is designed for engineers who have minimal to intermediate corrosion background and are seeking to increase their understanding of the phenomenon and methods for testing and protection in specific environments.

EXHIBITOR LIST

Advanced Composite Materials LLC
Ambrell Induction Heating Solutions
American Stress Technologies Inc.
AMT AG
Balazs Nanoanalysis
The Boeing Company
Bruker Nano Analytics
CMI Industry Metals
Curtiss Wright Surface Technologies
Ensinger
GeoCorp Inc.
HORIBA Scientific
Houghton International
Kamatics RWG

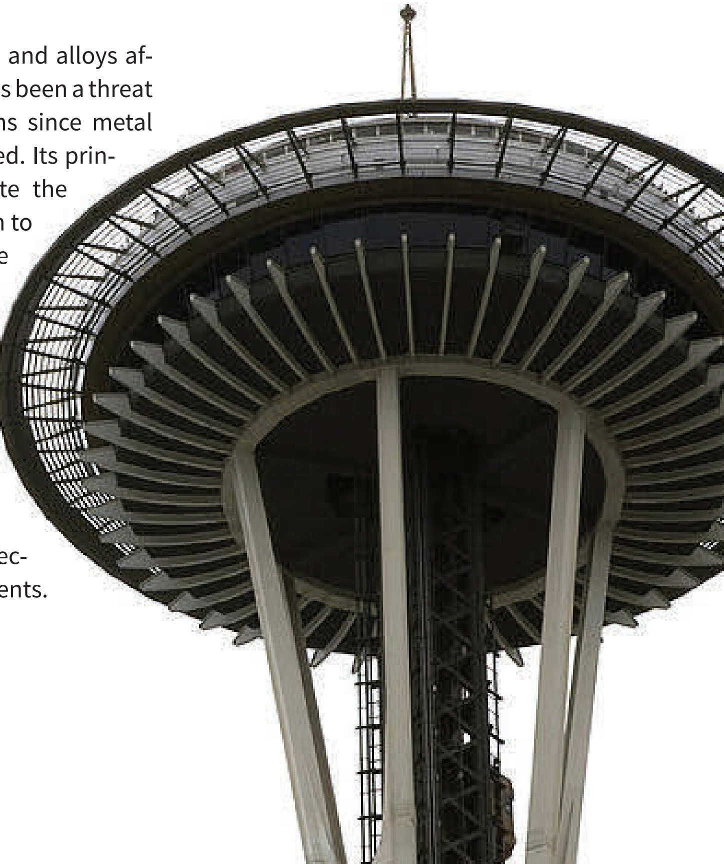
Kittyhawk Products
Olympus
Paulo
Proto Manufacturing Inc.
Renishaw Inc.
Rex Heat Treat
Scientific Forming Technologies Corp.
Solar Atmospheres of California
Solar Manufacturing
TA Instruments
TEC
Thermo-Calc Software Inc.
Westmoreland Mechanical Testing & Research Inc.

Note: Exhibitor list current as of March 15.

NETWORKING EVENT

Tuesday, May 24
7:00–9:30 p.m.

Attendees will enjoy dinner, entertainment, and a one-of-a-kind view atop the Space Needle, Seattle's "must see" destination. Transportation is included.



METALLURGY LANE

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

THE INTEGRATED STEEL INDUSTRY–PART I

THE BEGINNING OF THE BIG INTEGRATED STEEL INDUSTRY BEGAN WITH THE FORMATION OF THE UNITED STATES STEEL CORPORATION IN 1901.

United States Steel Corporation, known simply as "The Corporation" for the century that followed its debut, was initially composed of the Carnegie Steel Co. as its biggest producer and the Federal Steel Co. as number two. Carnegie Steel was well known as the leading steel company in the Bessemer steel age from 1875 to 1900. Federal Steel was an unknown company assembled by a lawyer and judge named Elbert H. Gary from Illinois who had combined nearly 40 plants making wire. This group was financed by J.P. Morgan who would eventually lead the financing of General Electric Co., International Harvester, and United States Steel (USS). Judge Gary was the first chairman of USS in 1902 and Charles Schwab of Carnegie Steel was the first president.

The new USS owned plants and facilities of iron ore, coke, wire, plate, and tube, in addition to the American Bridge Co. They had 213 steel mills, 41 iron mines, 112 ore boats, and 57,000 acres of coal mines. The company was capitalized at $1.4 billion and shares were offered for sale to the public. In the first full year of operations, revenues were $560 million and earnings were $34 million. After a year as president, Schwab was forced out of the company over differences with Gary. Schwab was used to having free rein at Carnegie Steel and did not fit in with the corporate image under Gary. Schwab would later become president of Bethlehem Steel, which he would lead to be a major competitor of USS.

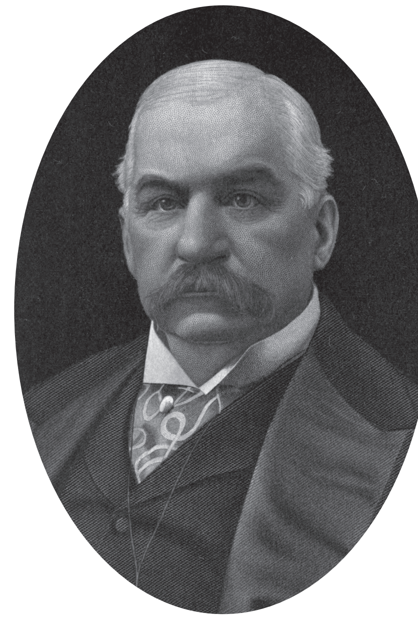
EARLY 1900s

In the early 1900s, most steel mills were still located in the east. In 1906, Judge Gary decided that The Corporation would build a big new mill in Indiana, bordering on Lake Michigan. This isolated location required building all the infrastructure needed for an integrated steel mill with railroads, a harbor for receiving raw materials, and a new town for workers and service personnel. The project was enormous for the time and this steel mill would be among the largest in the world. By 1911, the city—named Gary in honor of the chairman—had a hotel, hospital, churches, and homes for a population of nearly 20,000. The steel plant housed eight blast furnaces, 47 open hearth furnaces, hundreds of coke ovens, and rolling mills to produce railroad rails, axles, and bars. Later, sheet and plate mills would be installed for the new auto and home appliance industries.

As The Corporation grew, it relied on immigrants for labor, just as Andrew Carnegie had in the 1880s and 90s. In 1910, half the workers were from Poland or the Slavic countries. This kept labor costs to a minimum, but would lead to problems in the future. In WWI, the new supply of immigrants was closed and recruits of African Americans from the south filled the labor needs. There were 3000 in Gary and 4000 in Pittsburgh by 1919. With the war over, wages and working conditions led to strikes in many plants. At Gary, the Indiana State Guard was called to restore order.

ROARING TWENTIES AND THE GREAT DEPRESSION

The Corporation enjoyed successful years during the 1920s. With the booming auto industry's need for steel, they built sheet mills in Gary, as well as Pennsylvania, Ohio, and Alabama. They also built pipe mills to supply the ever increasing oil production. During this 10-year period, total earnings reached $1 billion with two-thirds of that paid in dividends. All of this success was accomplished under Judge Gary who continued to work until he was 80 years old.



John Pierpont (J.P.) Morgan, the financier who assembled many companies to form United States Steel Corp. Circa 1918.

With the depression of the 1930s, steel demand plummeted. The Corporation produced 14 million tons of steel during the peak year of 1929. In 1933, they only produced 3.8 million. The loss that year was $91 million with 80,000 workers compared with 240,000 during the 1920s. At the lowest point in 1933, plants were operating at 9% capacity. Production increased as government programs began construction under the Works Progress Administration (WPA) and auto sales increased during the 1930s. USS appointed Myron Taylor as its new chairman in 1932 to replace Judge Gary. Taylor would lead the company through the difficult times and build five million tons of new capacity while eliminating the same amount of obsolete production.

United Nations Headquarters, the first high-rise built after the Great Depression.

WARTIME EFFORTS

By 1940, the defense effort increased to rebuild the U.S. armed forces, in addition to helping England and France through the lend-lease program. During the five years leading up to Japan's surrender, the U.S. produced \$190 billion in armament with a third of all steel made by USS. For example, a USS mill in Lorain, Ohio, produced over 1200 miles of 24-inch-diameter pipe for the big pipeline carrying oil from Texas to New Jersey. The Corporation built a new government funded steel mill at Geneva, Utah, to supply steel for the West Coast shipbuilding industry. Throughout the war, the USS American Bridge Division erected several government funded factories and buildings.

The post war era saw the cancellation of nearly all government contracts with severe unemployment. With the conversion back to consumer goods and the introduction of new technologies developed during the war, the economy soon revived with demand for steel exceeding wartime levels. The 1950s was the most prosperous decade since the 1920s beginning with the Korean conflict, which again increased demand for armament. This resulted in the Cold War and the continued need for a strong defense industry. New technologies such as the nuclear powered navy and the beginning of the nuclear power energy industry increased demand for steel. The auto industry was building more and heavier cars and appliances became household necessities. In addition—for the first time since construction of the Empire State Building in 1931—a new high-rise was erected, the United Nations headquarters in New York. The 1950s would see the beginning of a boom in such buildings, and the Federal-Aid Highway Act of 1956 (to build the interstate highway system) added to the steel demand as well.

Judge Elbert Henry Gary, the first chairman of USS. Circa 1915.

STEEL INDUSTRY BOOMS

With the increasing use of steel, USS started a program of modernizing its older mills and adding equipment for new products. The most ambitious project was a new steel works at a rural site on the Delaware River in Pennsylvania at the New Jersey border. This works required all the infrastructure of rail lines, a harbor for unloading ore ships, blast furnaces, open hearth furnaces, coke ovens, and rolling mills for various products. The iron ore for this mill would be imported from a deposit owned by USS in Venezuela. This plant was the largest ever built in the United States on a new site. Also, a new town was built several miles away to house workers and all the related services. The plant was named The Fairless Works and the town named Fairless Hills after the new chairman, Benjamin Fairless.

The Corporation built a new headquarters in Pittsburgh in 1953—a 41-story building using steel and stone. In 1956, they built a new research and development campus at Monroeville near Pittsburgh. USS had first established a central research laboratory in 1928 at Kearny, N.J., in an unused building in the Federal Shipbuilding and Drydock Co., a division of the company. One of the first research employees was Edgar Bain who would become world famous for his studies on the transformation of austenite to pearlite at constant subcritical temperatures. A fundamental research laboratory on the new campus was named in his honor.

Myron Charles Taylor, the second chairman of USS who led the company through the Great Depression.

The 1950s would end with the understanding that there was a great future for steel and it would be led by The Corporation. However, in the last months of 1959, negotiations between the major integrated steel industry and the United Steel Workers Union ended with a four-month strike that eventually changed the industry beyond recognition.

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

Headquarters of The Corporation, erected in Pittsburgh, 1953.

TSS
Thermal Spray Society
ASM INTERNATIONAL

APRIL 2016 | VOL. 11 | ISSUE 2

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

THERMAL SPRAY COATINGS FOR ENERGY AND TURBINE APPLICATIONS

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EDITORIAL OPPORTUNITIES FOR iTSSe IN 2016

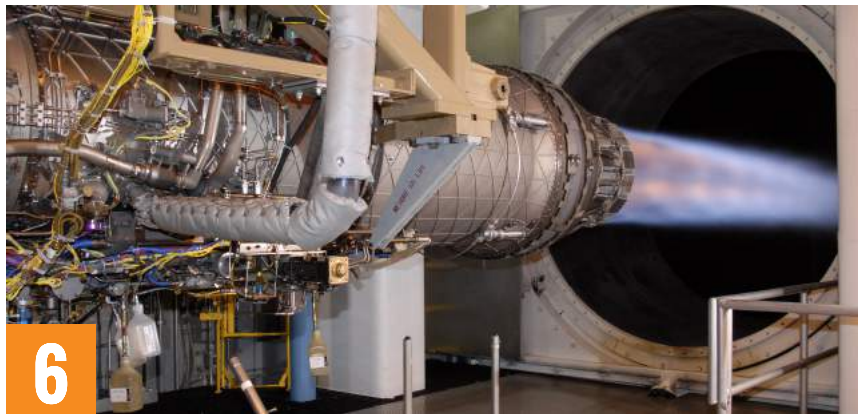
The editorial focus for *iTSSe* in 2016 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

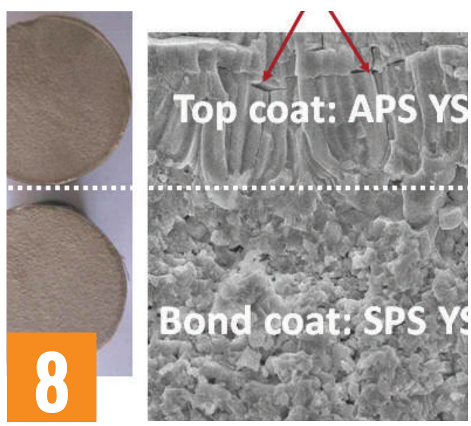
August:
Automotive & Industrial Applications

November:
Emerging Technologies/Applications & Case Studies

To contribute an article to one of these issues, contact the editors c/o Julie Lucko at julie.lucko@asminternational.org.

To advertise, contact Kelly Thomas, at kelly.thomas@asminternational.org.





DEPARTMENTS

ABOUT THE COVER

Thermal barrier coatings are used throughout the hot section of modern aero gas turbine engines on heat shields, nozzle guide vanes, blades, augmenters, and other parts. Augmenters are used almost exclusively on military aircraft turbine engines including the F100 engine that powers F15 and F16 military aircraft. Shown here is an F100 engine in a test cell. Courtesy of Arnold AFB AEDC.

A WORLD OF THERMAL SPRAY

Puerta

As we approach what promises to be a truly fabulous event in Shanghai, I have enjoyed looking back over the past decade at what has transpired within our thermal spray community and at my place in this community. I joined ASM's Thermal Spray Society (TSS) in 2003. Coming from the services industry, I found a fascinating niche working with other experts to establish best practices for the metallographic characterization of thermal spray coatings. Being a part of TSS has been an outstanding experience and I look forward to assuming the role of president of this society later this year.

I made my first trip to China in 2007 to be a part of the ITSC event held in Beijing that year. I had many wonderful experiences ranging from walking the Great Wall to witnessing the construction of the various Olympic venues to teaching a thermal spray characterization class, which included students from Europe, Asia, and North America. Of course, the ITSC event itself was a tremendous success and served as a fantastic venue to bring together thermal spray experts in this rapidly emerging market.

Much like China, thermal spray has evolved from being viewed as "emerging" to now being considered quite well established. Thermal spray continues to find new applications not only in traditional markets such as aerospace and industrial, but also in areas such as medical, oil & gas, and power generation. Thermal spray derivatives, such as cold spray and suspension thermal spray, are now being used in remarkable new applications including additive manufacturing of highly complex components. Suppliers to the thermal spray industry continue to develop new, highly engineered coatings, spray equipment, monitoring solutions, and characterization tools.

As we return to China this year, I not only look forward to enjoying the contrast in the development of this country, but also in the developments within the thermal spray industry. ITSC continues to provide the ideal venue for professional networking and exchange as well as for demonstration of the latest technologies that will fuel the continued growth of this industry. Looking back over the past decade, I'm excited to see which developments will be driving our growth over the next 10 years.

I hope to see you all in Shanghai!

Sincerely,
Doug Puerta
Director, Aerospace Product Qualification Testing
Element Materials Technology

THERMAL SPRAY SOCIETY INDUCTS FOUR INTO THERMAL SPRAY HALL OF FAME

Four leaders and innovators in thermal spray technology will be inducted into the Thermal Spray Hall of Fame at ITSC in Shanghai, taking place in May. The 2016 inductees include:

Chuanxian Ding is being recognized "for pioneering the science and technology of thermal spraying in China especially in the area of emerging applications of coatings and for mentoring students and young professionals." Ding has been a professor at the Shanghai Institute of Ceramics, Chinese Academy of Sciences, and head of plasma spraying coating research group since 1990. He has conducted fundamental research and technological developments in the field of oxide, carbide, and graded, metal-oxide coatings with applications in many industries in China. He is a member of the Chinese Academy of Engineering and serves as a technical chair of ITSC 2016.

Ding

Seiji Kuroda, FASM, is cited for "for pioneering research on residual stress in thermal spray coatings, development of in-situ beam curvature techniques, in-flight particle diagnostics, and warm spray technology." His research has been widely published and earned international awards. He is unit director of the National Institute of Materials Science, Japan, where he has worked since 2001. Kuroda has held academic positions in the UK, France, Tokyo, and Poland and acts as a technical bridge between Japan/Asia and the ASM Thermal Spray Community. He served as programming chair of ITSC 2004 and is in his seventh year as associate editor of the *Journal of Thermal Spray Technology*.

Kuroda

Thomas A. Taylor, FASM, is being recognized "for significant contributions to new and novel thermal barrier coating architectures, and rub tolerant and MCrAlY coatings for gas and turbine engine applications." Taylor is retired from Praxair Surface Technology of Indianapolis. He previously worked for Union Carbide Coatings Services, later acquired by Praxair. He holds more than 20 patents in the field of thermal spray and is credited for development of ZirCoat, vertically segmented thermal barrier coatings. He authored more than 50 papers related to ceramic, cermet, and high temperature coatings and sponsored doctoral projects on coatings for Purdue University students. Taylor is a past chair of the ASM Indianapolis Chapter.

Taylor

Armelle Vardelle, FASM, is cited "for globally recognized contributions to understanding the role of plasma generation and plasma-particle interaction on coatings microstructure." She is distinguished professor and co-chair of the Department of Materials, Surface Treatments, and Environment at the Engineering School of Limoges, University of Limoges, France. Her research focuses on plasma spray and thermal spray plasma processes. She has supervised over 30 Ph.D. theses and has been published in 110 peer reviewed journals and 145 proceedings. Vardelle is a Fellow of the International Plasma Chemistry Society, has served on the TSS Board, and is currently Editor in Chief of the *Journal of Thermal Spray Technology*.

Vardelle

KARTHIKEYAN RECEIVES TSS PRESIDENT'S AWARD

Jeganathan Karthikeyan, FASM, Director of Research & Development, ASB Industries, is the 2016 recipient of the TSS President's Award for Meritorious Service. He will be recognized at a future TSS event.

Karthikeyan

THERMAL SPRAY SOCIETY EDUCATION COURSES

Visit asminternational.org/learning to find out more about these valuable courses.

Advanced Diagnostics of Thermal Spray
Date: July 14
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Christian Moreau, FASM, Thermal Spray Society president

This course provides a historical perspective of diagnostic techniques development as well as a detailed description of the basic principles of sensor operation. An extensive series of examples of the use of sensors in research and production environments is also included.

Moreau

Thermal Spray Technology
Date: July 26-27
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Chris Berndt, FASM

Coating reliability and effectiveness requires overlay coatings to be selected, engineered, and applied correctly. This course provides a thorough grounding and understanding of thermal spray processes, depicts complex scientific concepts in terms of simple physical models, and integrates this knowledge into practical engineering applications and commonly accepted thermal spray practices.

Berndt

Advanced Thermal Spray Technology
Date: July 28
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Chris Berndt, FASM

Thermal spray is increasingly used to manufacture net shapes, advanced sensors, and materials for the biomedical and energy/environmental industries. These and a vast array of emerging applications take advantage of the rapid and cost-effective capabilities of thermal spray technology in the OEM and repair industries.

TRIBUTE TO A THERMAL SPRAY PIONEER: EMIL PFENDER

MAY 25, 1925—JANUARY 28, 2016

Maher Boulos, University of Sherbrooke, Québec, Canada, and Pierre Fauchais, University of Limoges, France

Pfender

The Thermal Spray Society mourns the passing of Emil Pfender, Professor Emeritus at the University of Minnesota. Pfender was a leading member of the thermal spray community and contributed immensely to our understanding of the scientific foundations of this rapidly developing field. He was a Fellow of the ASME (1981) and member of the National Academy of Engineering (1986). Pfender was also the recipient of many honors by leading scientific societies including the Alexander von Humboldt Award of the German Government (1978), the Gold Honorary F. Krizik Medal for Merit in the Field of Technical Sciences of the Czech Academy of Sciences, an Honorary Doctor's degree from the Technical University of Ilmenau, Germany, and the prestigious Plasma Chemistry Award, then given by the International Union of Pure and Applied Chemistry (1995) for lifetime achievement in plasma chemistry.

Pfender was born on May 25, 1925, in Dietershausen, a small farming village in southern Germany. He earned his diploma in physics in 1953, and Dr. Ing. in electrical engineering in 1959, both from the Technical University of Stuttgart, where he became chief assistant and lecturer at the Institute for Gaseous Electronics. In 1961, he spent a year as a visiting scientist at the Plasma Physics Branch of the Air Force Research Laboratories at Wright Patterson Air Force Base near Dayton, Ohio. In 1964, Pfender was recruited to direct the High Temperature Laboratory, now the High Temperature and Plasma Laboratory (HTL/HTPL), in the department of mechanical engineering at the University of Minnesota. He joined the department as an associate professor and became professor in 1967. Under his leadership the HTL/HTPL grew to become one of the world's leading centers in the field of plasma science and technology with four faculty members and over 20 graduate students, research assistants, and several postdocs and visiting scientists.

As colleagues and friends who had the privilege of working closely with Pfender for more than four decades since the 1970s, we would like to share with the thermal spray community our thoughts and fond memories of this period and point out the importance of his contribution to thermal spraying and thermal plasmas in general. His contributions can be found in three distinct areas:

- Fundamental research of fluid dynamics and heat transfer under plasma conditions using direct current (DC) and radio frequency inductively coupled plasma sources. The topics studied by Pfender varied widely from electrode phenomena and DC torch design for plasma spraying and cutting, modeling, and diagnostics to thermal spray coating applications, chemical vapor deposition, and nanopowder synthesis.
- Training of young scientists who completed their master's and Ph.D. degrees in this field under his supervision. He was also an active participant in a large number of continuing education courses, which we jointly offered together for many years (1981-2001) in conjunction with the international conferences of the Thermal Spray Society and the biannual International Summer School and Symposium on Plasma Chemistry.
- Consulting and engineering services offered to the industrial community on an international scale contributing to their advancement in the integration of thermal plasmas in their process technology. These were offered either individually or through our joint International Thermal Plasma Engineering Corp., which was active in this field over the period of 1983-1995.

In terms of specific technical achievements, it is a challenging task to attempt to point out a single or specific accomplishment because Pfender devoted his research career to a vast number of diverse topics to which he made significant contributions. In terms of relevance to thermal spray technology, it has been widely recognized that his study and proposed model for the entrainment of cold gas into thermal plasma jets by Pfender, et al., (1991) had a significant impact on this field.

Few university professors have had the influence of Emil Pfender on the fundamental science of thermal plasmas, torch optimization, and their applications—especially on plasma sprayed coatings. All of us who had the chance to know him will always cherish the memory of these moments. Through his publications, students, and colleagues, his works on thermal plasmas will continue to guide us in this field.

iTSSe | TSS

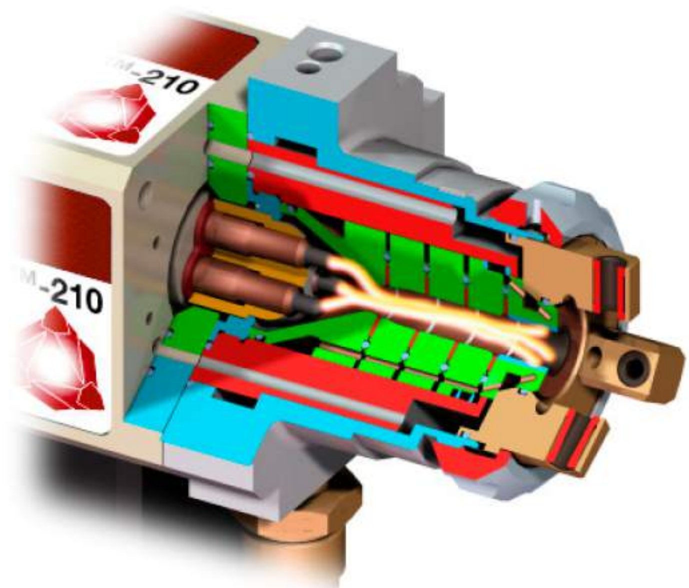
CASE STUDY

FASTER THERMAL BARRIER COATING APPLICATION ON MILITARY AIRCRAFT AUGMENTERS

REASON TO CONSIDER SURFACING

Today's aero gas turbine engines employ higher-pressure ratios and higher turbine inlet temperatures to improve efficiencies. Thermal barrier coating (TBC) systems consist of a heat-insulating ceramic coating such as a yttrium-stabilized zirconium oxide applied over an oxidation-resistant metallic bond coat, usually an MCrAlY, that results in reduced heat transfer to the base material. Benefits include improved mechanical properties and additional life expectancy. TBCs are widely specified and their use abounds throughout the hot section of modern turbines on transition ducts, combustors, heat shields, nozzle guide vanes, blades, and augmenters (afterburners).

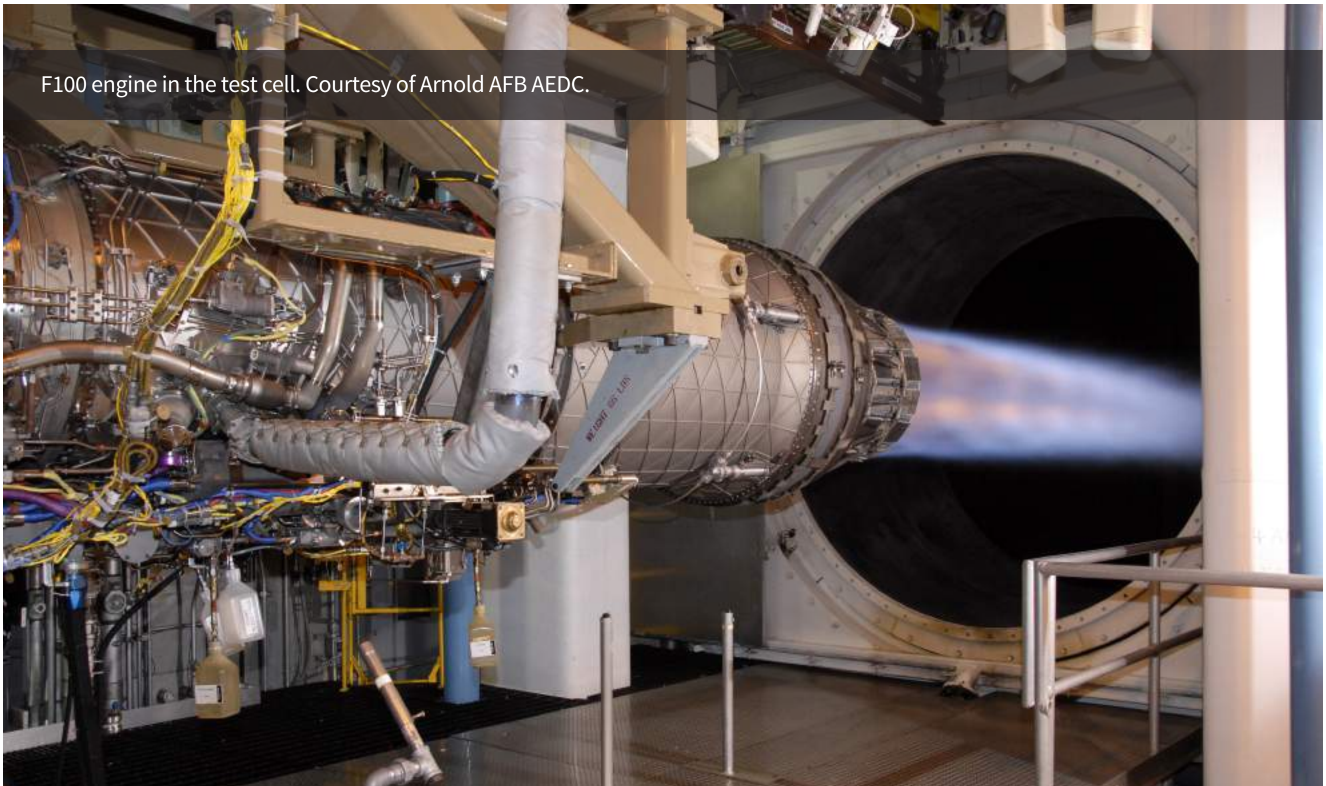
Augmenters are used almost exclusively on military aircraft turbine engines, an example of which is the F100 engine that powers F-15 and F-16 military aircraft. Here, already hot exhaust gases are reignited to burn residual fuel, giving the aircraft additional thrust when needed. The TBC system ensures the service life and mission-readiness of the augmenter, both of which would be severely degraded without it.



Cascading arc technology.

VALUE OF COATING

The F100 augmenter is a large part with an interior surface area (depending on the engine model) of approximately 6.3 m² (68 ft²). The MCrAlY bond coat (Amdry 9622) is applied to a thickness of 0.075 to 0.125 mm (0.003 to 0.005 in.) and the top coat (Metco 204NS) is applied 0.2 to 0.3 mm (0.008 to 0.010 in.) thick. Although the overall coating thickness is relatively thin for a TBC coating, spray process times are quite long as a result of the large part size. Using conventional plasma



F100 engine in the test cell. Courtesy of Arnold AFB AEDC.

TriplexPro-210 cascading arc plasma spray gun.

spray, 4.5 hours are required to apply the TBC system and the spray gun must be maintained after 15 hours of spray time, causing a work stoppage after every three augmenters.

OPTION

Cascading arc technology for plasma spray guns is now a proven method for reducing the application costs of TBC systems. For example, the Oerlikon Metco TriplexPro-210 spray gun applies coatings as much as 300% more efficiently than traditional plasma spray guns and the part-to-part reliability of the coating is much improved. In the case of the F100 augmenter, the entire TBC system is applied in only 1.5 hours. Rebuild of the gun need only occur every 150 to 200 spray hours.

BENEFITS

- Faster processing time reduces labor and utility costs.
- Part turn time is reduced and thermal spray cell production throughput is increased.
- Improved coating consistency reduces the likelihood of rework.
- Improved part-to-part consistency improves mission reliability.

iTSSe

For more information: Mitch Dorfman, FASM, is Metco Fellow/Product Portfolio Manager-High Temperature Materials, Oerlikon Metco, 1101 Prospect Ave., Westbury, NY 11590, 516.334.1300, mitch.dorfman@oerlikon.com, www.oerlikon.com/metco.

THERMAL SPRAY COATINGS FOR NUCLEAR PLANTS

Armelle Vardelle, FASM, is a professor at the University of Limoges, France. She is co-chair of the Department of Materials (Surface Treatments and Environment), which trains roughly 120 engineering students in surface and coating technologies with an emphasis on saving energy and raw materials. Her research interests include thermal spray and thermal plasma processes; modeling of plasma processes and torch operation; transport and chemical rate phenomena at high temperature; thermal spray coatings; and green manufacturing. Vardelle has been a member of TSS for more than 10 years and served on the TSS board from 2009-2015. She was the lead editor of the *Journal of Thermal Spray Technology* from 2009-2015 and is now the chief editor. In addition, she is a Fellow of both ASM International and the International Plasma Chemistry Society.

As part of Vardelle's research interests, she and her team in the Laboratory of Science of Ceramic Processing and Surface Treatments are developing thermal spray coatings for application in fourth generation nuclear plants. This work is carried out with CEA, the French Alternative Energies and Atomic Energy Commission. France is involved in development of two reactors, while six reactor concepts have been chosen by the Generation IV Forum. France has decided to focus on two concepts—sodium-cooled fast reactors (SFRs, reference system) and gas-cooled fast reactors (GFRs, longer-term option). The work with the SFR reactor is not yet finished, while the coating system developed for the GFR has resulted in a patent with CEA.

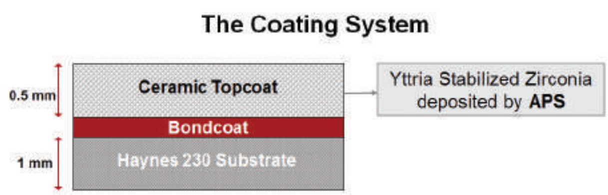
GAS-COOLED FAST REACTORS

The Generation IV gas-cooled fast reactor (GFR) nuclear system features a fast-neutron-spectrum and helium-cooled reactor. It maximizes the usefulness of uranium resources by breeding plutonium and can contribute to minimizing both the quantity and radiotoxicity of nuclear waste by actinide transmutation in a closed fuel cycle. The helium-cooled reactor operates with an outlet temperature of 850°C and uses a direct-cycle, helium turbine for electricity (42% efficiency at 850°C) and process heat for the thermochemical production of hydrogen[1,2]. Challenging issues for the GFR design include development of in-core and out-of-core materials capable of resisting fast-neutron damage and high temperatures in accident situations. Protective coatings are visualized to protect various parts of the system and also protect the system in extreme cases where the functional temperature can increase up to 1250°C and there is depressurization from 70 bars to atmospheric pressure.

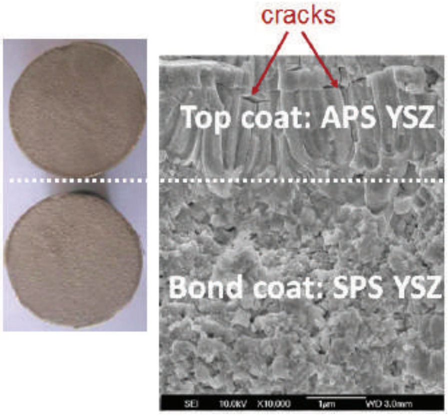
Such coatings must withstand high temperature, depressurization, and specific conditions of wear linked to erosion by high-speed (about 280 m/s) helium gas flow. They would be deposited on materials 1 mm thick that are resistant to heat and erosion and exhibit stable mechanical properties at high temperatures, e.g., Haynes 230, a solid solution-strengthened nickel-base alloy. This work involves a double-layer plasma-sprayed zirconia coating for protecting the out-of-core metal alloy structures against depressurization events. The coating system consists of a thin nanostructure layer and a thick microstructure layer. The first layer deposited by suspension plasma spraying provides adhesion of the coating on the smooth and thin (1-mm thick) metal (Haynes) substrate while the top layer, deposited by conventional plasma spraying, acts as a thermal barrier coating.

CERAMIC COATINGS

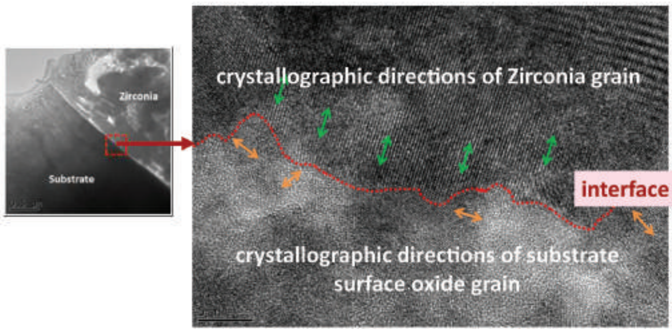
Ceramic coatings deposited by plasma spraying are potential candidates for use as protective coatings. However, both the procedures used to prepare the substrate before deposition and the spray process itself must be adapted to the thinness of the substrate and its low surface roughness (average roughness, Ra, of 0.4 μm). The principal objective of surface preparation is to achieve proper adhesion of the thermal spray coating to the substrate. The procedure generally combines abrasive blasting with other surface preparation techniques to create the appropriate degree of surface cleanliness and roughness. However, roughening of the surface by grit-blasting induces compressive stresses that bring about a



Coating system deposits yttria stabilized zirconia (YSZ) using atmospheric plasma spraying (APS).



ASTM C633 tensile testing shows that the point of failure occurs close to the interface between the ceramic layers.



High-resolution TEM image of the ceramic/metal interface.

deformation of thin substrates, e.g., compressive stresses of 400 MPa were measured in 1-mm-thick 304L substrate after grit-blasting[3]. Thus, the technique could not be used for this application if the shape of the parts to be covered cannot be altered. Three plasma technologies could be used to deposit the ceramic coating—conventional atmospheric plasma spraying (APS) using powder, suspension plasma spraying (SPS), and solution plasma spraying.

APS spraying of the 0.5-mm-thick ceramic coating on the as-received substrate after solvent cleaning to remove potential surface contaminants made it impossible to form a coating with good adhesion to the substrate, regardless of the spraying conditions and temperature of the substrate. Also, deposition of a 0.5-mm-thick ceramic coating by suspension spraying took too long. Therefore, to circumvent this adhesion problem, a specific procedure had to be developed. This method consists of deposition of a duplex thermal barrier coating made of (i) a thin layer of yttria-stabilized zirconia (YSZ) by SPS on the as-received and cleaned alloy and (ii) a thick layer of YSZ by conventional APS. The SPS layer creates an increased surface area for mechanical bonding of the APS coating and provides the adhesion of the duplex coating to the Haynes 230 alloy. **iTSSe**

For more information: Armelle Vardelle is a professor at the University of Limoges, France, armelle.vardelle@unilim.fr. Portions of this article have been adapted from a full length feature in the *Journal of Thermal Spray Technology* 21 (2012): 1128-1134, DOI 10.1007/s11666-012-9798-2. © ASM International.

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Booth #100

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Booth #141

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Booth #142

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—PART I

This new article series explores the indispensable role of characterization in the development of cold spray coatings and illustrates some of the common processes used during coatings development.

***Dheepa Srinivasan,** GE Power, GE India Technology Center, Bangalore*

Materials characterization is an inherent aspect of the cold spray coating evaluation process. Characterization of as-sprayed microstructures enables development of an understanding of the thermomechanical evolution of the coating and elucidates the bonding mechanisms both within the coating and at the coating-substrate interface. Evaluating coating residual stress and coating relaxation behavior after thermal treatments is imperative to establish the reliable functionality of the coating for the proposed application. Microstructural characterization methods including optical microscopy, scanning electron microscopy, transmission electron microscopy, electron backscatter diffraction, and electron probe microanalysis are integral to understanding the highly nonequilibrium process that enables formation of thick adherent coatings via severe plastic deformation of metal powders. Microhardness, nanoindentation, and residual stress analysis add to a more complete understanding of the formed coating.

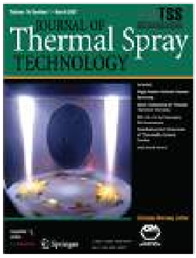
This article series will explore the indispensable role of characterization in the development of cold spray coatings and will illustrate some of the common processes used during coatings development. As an overview, Table 1 provides an exhaustive list of all the characterization techniques that can be used for cold spray coating characterization. The table also lists the key aspect of each technique and its relevance to cold spray coating characterization. Not all of the techniques listed have been used to their optimum level in developing a complete understanding of the complex nature of a cold spray coating.

This new series will emphasize the advanced microstructural characterization techniques that are used in high-pressure cold spray coating characterization, including residual stress characterization. Future article installments will also discuss the preliminary screening tool of hardness and bond adhesion strength, as well as a distinction between surface and bulk characterization techniques and their importance for cold spray coatings. Further, each article will explore a different characterization method, including a note on sample preparation for characterization, which is critical and must be followed for accurate results without any artifacts. iTSSe

For more information: Dheepa Srinivasan is a principal engineer at GE Power, GE India Technology Center, Bangalore, dheepa.srinivasan@ge.com, www.ge.com. This article series is adapted from *Chapter 5, Cold Spray—Advanced Characterization*, in High Pressure Cold Spray—Principles and Applications, edited by Charles M. Kay and J. Karthikeyan (ASM, 2016).

TABLE 1—CHARACTERIZATION TECHNIQUES USED FOR COLD SPRAY COATINGS AND THEIR KEY ATTRIBUTES

No.	Characterization technique	Key aspect for cold-sprayed coating
1	Optical microscopy	Coating thickness, coating porosity, substrate-coating interface integrity, coating porosity after heat treatment
2	X-ray diffraction	Feedstock powder phase evolution, as-sprayed and heat treated coating phase formation, coating macro- and microstrain, coating relaxation behavior, presence of any coating texture
3	Scanning electron microscopy	Intersplat interactions in the sprayed coating before and after heat treatment, microcracks and micropores, coating fracture surface, inclusions and other phases in the coating or substrate-coating interface
4	Focused ion beam	Preparation-specific sections for examination in the scanning and transmission electron microscopes, coating splat interface or coating-substrate interface
5	Electron probe microanalysis	Precise chemistry, diffusion layers in a cold-sprayed coating, coating-substrate interface chemistry
6	Transmission electron microscopy	Phase identification, dislocation structure, recovery processes and recrystallization, coating chemistry
7	Electron backscattered diffraction	Coating texture, extent of recrystallization, deformation map in the substrate, nature of bonding in the coating and coating substrate, grain size and orientation
8	Electron channeling contrast	Dislocation structure, deformation characteristics
9	Residual stress	Residual stress in the as-sprayed coating, coating relaxation process monitoring
10	X-ray photoelectron spectroscopy	Chemical bonding, presence of oxides
11	X-ray fluorescence	Presence of oxide and nature of chemistry on coating surface
12	Auger electron spectroscopy	Surface chemistry of the coating
13	Raman spectroscopy	Phase transitions in the coating
14	Oxygen analysis	Feedstock powder characterization
15	Surface roughness	As-sprayed coating, distinguishing between process parameters, gas type
16	Microhardness	Screening tool for coating
17	Nanoindentation	Coating characterization, deformation
18	Bond adhesion test	Evaluating the adhesion and cohesion strength of the coatings

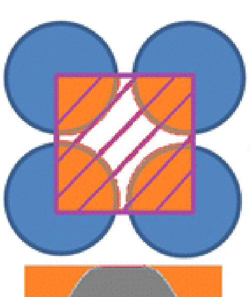


The *Journal of Thermal Spray Technology (JTST),* the official journal of the ASM Thermal Spray Society, publishes contributions on all aspects—fundamental and practical—of thermal spray science, including processes, feedstock manufacture, testing, and characterization. As the primary vehicle for thermal spray information transfer, its mission is to synergize the rapidly advancing thermal spray industry and related industries by presenting research and development efforts leading to advancements in implementable engineering applications of the technology. Articles from the February and April issues, as selected by *JTST* Editor-in-Chief Armelle Vardelle, are highlighted here. In addition to the print publication, *JTST* is available online through springerlink.com. For more information, visit asminternational.org/tss.

"LASER PATTERNING PRETREATMENT BEFORE THERMAL SPRAYING: A TECHNIQUE TO ADAPT AND CONTROL THE SURFACE TOPOGRAPHY TO THERMOMECHANICAL LOADING AND MATERIALS"

Robin Kromer, Sophie Costil, Jonathan Cormier, Laurent Berthe, Patrice Peyre, and Damien Courapied

Coating characteristics are highly dependent on substrate preparation and spray parameters. Hence, the surface must be adapted mechanically and physicochemically to favor coating-substrate adhesion. Conventional surface preparation methods such as grit blasting are limited by surface embrittlement and produce large plastic deformations throughout the surface, resulting in compressive stress and potential cracks. Among all such methods, laser patterning is suitable to prepare the surface of sensitive materials. No embedded grit particles can be observed, and high-quality coatings are obtained. Finally, laser surface patterning adapts the impacted surface, creating large anchoring area. Optimized surface topographies can then be elaborated according to the material as well as the application. The objective of this study is to compare the adhesive bond strength between two surface preparation methods, namely grit blasting and laser surface patterning, for two material couples used in aerospace applications: 2017 aluminum alloy and AISI 304L stainless steel coated with NiAl and YSZ, respectively. Laser patterning significantly increases adherence values for similar contact area due to mixed-mode (cohesive and adhesive) failure. The coating is locked in the pattern (Fig. 1).



$$CZR = \frac{\text{Cohesive zone}}{\text{Plane Area}}$$

Fig. 1 — Cohesive zone ratio computation.

"THERMOELECTRIC DEVICE FABRICATION USING THERMAL SPRAY AND LASER MICROMACHINING"

Mahder Tewolde, Gaosheng Fu, David J. Hwang, Lei Zuo, Sanjay Sampath, and Jon P. Longtin

Thermoelectric generators (TEGs) are solid-state devices that convert heat directly into electricity. They are used in many engineering applications such as vehicle and industrial waste-heat recovery systems to provide electrical power, improve operating efficiency, and reduce costs. State-of-the-art TEG manufacturing is based on prefabricated materials and a labor-intensive process involving soldering, epoxy bonding, and mechanical clamping for assembly. This reduces their durability and raises costs. Additive manufacturing technologies, such as thermal spray, present opportunities to overcome these challenges. In this work, TEGs have been fabricated for the first time using thermal spray technology and laser micromachining. The TEGs are fabricated directly onto engineering component surfaces. First, current fabrication techniques of TEGs are presented. Next, the steps required to fabricate a thermal spray-based TEG module, including the formation of the metallic interconnect layers and the thermoelectric legs, are presented. A technique for bridging the air gap between two adjacent thermoelectric elements for the top layer using a sacrificial filler material is also demonstrated. A flat 50.8 mm × 50.8 mm TEG module is fabricated using this method, and its performance is experimentally characterized and found to be in agreement with expected values of open-circuit voltage based on the materials used (Fig. 2).

Fig. 2 — Measurement of top-side temperature with an infrared camera.

"HOT CORROSION BEHAVIOR OF LOW-PRESSURE COLD-SPRAYED CoNiCrAlY COATINGS"

L.W. Zhang, X.J. Ning, L. Lu, Q.S. Wang, and L. Wang

CoNiCrAlY coatings were deposited by low-pressure cold spraying and pre-oxidized in a vacuum environment, and its hot corrosion behavior in pure Na_2SO_4 and 75 wt% Na_2SO_4 + 25 wt% NaCl salts was investigated. The pre-oxidation treatment resulted in the formation of a dense and continuous α-Al_2O_3 scale on the coating surface. After being corroded for 150 h at 900°C, the pre-oxidized coating exhibited better corrosion resistance to both salts than the as-sprayed coating. The presence of preformed Al_2O_3 scale reduced the consumption rate of aluminum by delaying the formation of internal oxides and sulfides and promoting the formation of a denser and more adherent Al_2O_3 scale. Moreover, we investigated the corrosion mechanism of cold-sprayed CoNiCrAlY coatings in the two salts and discussed the effect of the pre-oxidation treatment (Fig. 3).

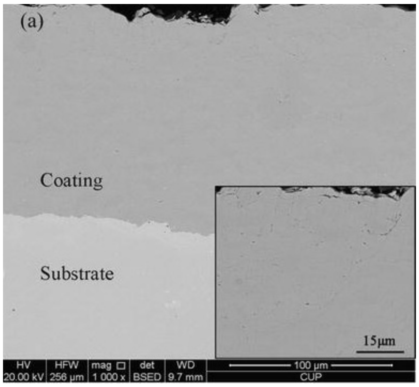


Fig. 3 — Cross-sectional BSE images of as-sprayed coating.

"THORIUM-FREE VERSUS THORIATED PLASMA GUN ELECTRODES: STATISTICAL EVALUATION OF COATING PROPERTIES"

Jose Colmenares-Angulo, Ronald Molz, David Hawley, and Ramachandran Chidambaram Seshadri

Industries throughout the world today have an increased awareness of environmental, health, and safety issues. This, together with recent Nuclear Regulatory Commission changes concerning source material (e.g., thorium) has added complexity in the supply chain of thoriated tungsten commonly used in plasma spray gun spares. In the interest of a safer and more sustainable work environment, Oerlikon Metco has developed thorium-free material solutions proven to have longer service life than conventional thoriated spares. This work reports on the effect, if any, caused by tungsten compositional changes and extended service life in coating properties. Microstructure, coating efficiency parameters, hardness, particle state, in situ coating stress, and ex situ modulus are evaluated over the service life duration of the nozzle, comparing coatings with thoriated and non-thoriated nozzles and electrodes with the same spray parameters (Fig. 4).

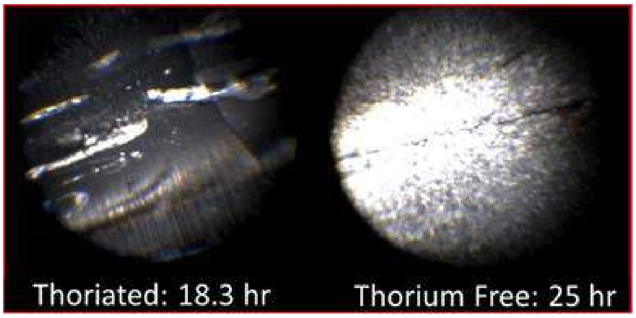


Fig. 4 — Borescope image comparison of thoriated and thorium-free nozzles after testing.

"MICROSTRUCTURE AND MECHANICAL PROPERTIES OF WARM-SPRAYED TITANIUM COATING ON CARBON FIBER REINFORCED PLASTIC"

Amirthan Ganesan, Okada Takuma, Motohiro Yamada, and Masahiro Fukumoto

Polymer materials are increasingly dominating various engineering fields. Recently, polymer-based composite materials' surface performances—in particular, surfaces in relative motion—have been improved markedly by thermal spray coating. Despite this recent progress, the deposition of high-strength materials—producing a coating thickness on the order of more than 500 μm—remains highly challenging. In the present work, a highly dense and thick titanium coating was successfully deposited onto the carbon fiber reinforced plastic (CFRP) substrate using a newly developed high-pressure warm spray (WS) system. The coating properties, such as hardness (300 ± 20 HV) and adhesion strength (8.1 ± 0.5 MPa), were evaluated and correlated with the microstructures of the coating. In addition, a wipe-test and in situ particle velocity and temperature measurement were performed to validate the particle deposition behavior as a function of the nitrogen flow rate in a warm spray system. It was found that the microstructures, deposition efficiency (DE), and mechanical properties of the coatings were highly sensitive to nitrogen flow rates. The coating porosity increased with increasing nitrogen flow rates; however, the highest density was observed for nitrogen flow rate of 1000 standard liters per minute samples (SLM) samples due to the high fraction of semi-molten particles in the spray stream (Fig. 5).

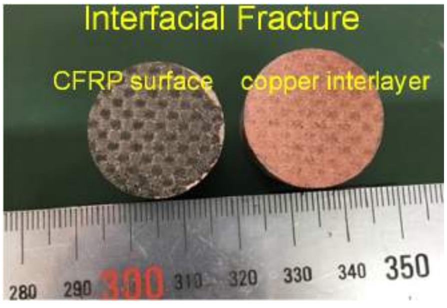


Fig. 5 — Fracture surface of adhesion strength samples.

ASMNEWS

ASM LAUNCHES FAILURE ANALYSIS SOCIETY

ASM International is proud to welcome its latest affiliate society, the Failure Analysis Society (FAS). The newly launched society is dedicated to advancing the important role failure analysis plays in the materials science industry. FAS emerged from an existing ASM committee that has long offered failure analysis programming and content. The new affiliate will continue to provide collaboration, networking, and educational opportunities for materials science professionals. It will also continue to present its own technical programming at the annual Materials Science & Technology conference. Look for a longer article about the new society in our May issue!

The Dome Makes Headlines

ASM International's famous geodesic dome is the subject of a short travel article recently included in the March issue of *Ohio Magazine.* A portion of the text reads, "The honeycomb-like dome seems out of place in rural Geauga County. In fact, the 13 miles of connected metal tubing would look at home on the cover of an Isaac Asimov novel. Although it appears otherworldly, the dome over ASM International's headquarters is a tribute to what's possible here on Earth…the 103-foot-high and 274-foot-wide dome is built entirely of aluminum and weighs 80 tons. It hangs over a public garden that features more than 60 types of mineral ores used in materials engineering. The interior of the 50,000-square-foot headquarters also boasts custom details in copper and brass that further the society's mission to share the potential for various metals. The organization even welcomes curious visitors to stop by its public garden during business hours." To read the full article, visit ohiomagazine.com/Main/Articles/5291.aspx.

ASM and Zeiss Announce Partnership

ASM is proud to announce a new partnership with Carl Zeiss as part of the ongoing enhancement of its education laboratories. The collaboration will facilitate sharing of resources while bringing state-of-the-art classroom equipment to ASM's headquarters. More details will be announced soon, but one new piece of equipment is a Zeiss scanning electron microscope (SEM). This acquisition will significantly improve hands-on learning for ASM students across a wide range of course offerings. Zeiss and ASM will continue to leverage the new partnership, bringing both organizations' expertise to students through cooperative instruction. A detailed article about the recent ASM lab renovation will appear in the May issue.

Zeiss scanning electron microscope.

IMC: Fewer Classes, Larger Prize Money

Deadline: July 9

The International Metallographic Contest (IMC), an annual event cosponsored by the International Metallographic Society (IMS) and ASM International to advance the science of microstructural analysis, continues to offer fewer classes and larger prize money. These updates, initiated two years ago, were designed to encourage participation and to simplify the process for participants to submit

In This Issue

Submit news of ASM and its members, chapters, and affiliate societies to Frances Richards, editor, ASM News | ASM International
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entries. There are now just five different classes of competition covering all fields of optical and electron microscopy:

- **Class 1:** Optical Microscopy—All Materials
- **Class 2:** Electron Microscopy—All Materials
- **Class 3:** Student Entries—All Materials (Undergraduate or Graduate Students Only)
- **Class 4:** Artistic Microscopy (Color)—All Materials
- **Class 5:** Artistic Microscopy (Black & White)—All Materials

All classes offer increased prize money. Best-In-Show receives the most prestigious award available in the field of metallography, the Jacquet-Lucas Award, which includes a cash prize of $3000. For a complete description of the rules, tips for creating a winning entry, and judging guidelines, visit metallography.net.

Canada Council Award Nominations due April 30

ASM's Canada Council seeks nominations for its 2016 awards program. These prestigious awards include:

The G. MacDonald Young Award–The ASM Canada Council established this award in 1988 to recognize distinguished and significant contributions by an ASM member in Canada. This award consists of a plaque and a piece of Canadian native soapstone sculpture. The 2015 recipient was John Wolodko, Alberta Innovates, Edmonton.

M. Brian Ives Lectureship–This award was established in 1971 by the ASM Canada Council to identify a distinguished lecturer who will present a technical talk at a regular monthly meeting of each Canadian ASM Chapter who elects to participate. The winner receives a $1000 honorarium and travels to each ASM Canada Chapter throughout the year to give their presentation with expenses covered by the ASM Canada Council. The 2015 recipient was Linruo Zhao, National Research Council of Canada, Ottawa.

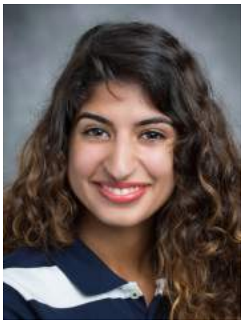
John Convey Innovation Awards–In 1977, the Canada Council created a new award to recognize contributions of sustaining member companies for further development of the materials engineering industry in Canada. The award considers a new product and/or service directed at the Canadian or international marketplace. Two awards are presented each year, one to a company with annual sales in excess of $5 million, and one to a company with annual sales below $5 million. The 2015 recipient was CanmetMATERIALS, Hamilton.

Nomination forms and complete rules can be found at asminternational.org/membership/awards/nominate. Contact christine.hoover@asminternational.org for a unique nomination link or more information.

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

Merna Salama, Materials Process & Physics Engineer, The Boeing Company



Salama

At 23, Merna Salama has accomplished much. She earned her bachelor's degree in chemistry and her master's in materials science and engineering from the University of California, Irvine, and had internships with Boeing's Next Gen Extreme Environment Materials and 737MAX Propulsion commercial aircraft team. In 2015, Salama was hired by the Boeing Research and Technology group in Huntington Beach, Calif., to develop materials for thermal protection systems.

Beyond academics and career, she decided to step out of her comfort zone and volunteer with ASM's Orange Coast (OC) Chapter. Salama first got involved with ASM as an undergraduate when a professor invited her to enter a poster contest hosted by the Los Angeles Chapter. "I met the OC chapter guys there," she recalls, "They asked me to join their team and I said yes."

Salama helps plan meetings, find speakers, and run the website and emails. "We all help out and even though we're all busy, we do a good job with it." She especially likes the Chapter's outreach program, which was set up to share demos with middle school students. "Little kids have an innocence when approaching science," says Salama. "It's nice to see their wonder about the world because we lose that as adults."

ASM gives Salama a place to network and grow personally. "I was always a little quiet. ASM really opened me up more," she says. "In college, I wasn't that involved and would say 'no' a lot. But in my internships at Boeing, I met more people and decided to say 'yes' to trying new things. At work, you can get in a routine and forget about the world outside. Through ASM, I meet people doing different things in materials science. I keep learning something new from both younger and older members with so much experience. It inspires me to keep my eyes open for what's out there and to try new things to learn and grow."

EMERGING PROFESSIONALS

Getting through Grad School

Rachael Stewart, Colorado School of Mines

Stewart

Choose grad school. Choose a high-ranking program with a credo of hard work. Choose knowledge doses in neat 50-minute lecture packets. Choose weekend TA duties and grim homeworks. Choose reading papers and studying for qualifying exams until 4:00 a.m. Choose stress, caffeine, and alcohol. Choose an eccentric adviser with a high *h*-index and mismatched socks. Choose student loans and $2 burrito Wednesdays. Choose a novel thesis and discover why no one has published on the topic. Choose unexpected delays, broken equipment, and funding battles. Choose corrections and figure formatting. Choose graduating and returning to work.

But why choose grad school at all? I chose it for the same reasons I chose engineering—to understand how and why things work. Hard things are what I like best, but grad school caught me off guard.

At first, the stress was crippling. The unexpected mental challenge was humbling. Constant evaluation made it difficult to separate my grades from my self-worth. In industry, communication rather than technical skills were primarily required. I had operated in third gear. Grad school pushed me into sixth gear. I slept six hours a night, forwent all exercise, ceased all social interaction, and spent every available minute studying. Finally, lonely, exhausted, and ready to quit, I sought help. I turned to classmates and found they shared my struggles. We helped each other, creating new ideas and avoiding mistakes. And I found a mentor who helped me set realistic expectations. What is good practice in industry may not equally apply in school.

Coursework is one degree component; a successful thesis is another. The third does not appear on transcripts. Grad school is more than just advanced technical training—it grew me in many unexpected ways. I discovered a sixth gear and acquired the skills to perform effectively. Prioritization, discipline, and stress management allied with peer support and mentorship were keys to success, while physical activity provided balance.

A year ago, I quit my job, left my country, and returned to school. Were I to retake my decision, I would make it the same, and choose grad school.

CHAPTERS IN THE NEWS

Los Angeles, Orange Coast Host Chong

The Los Angeles and Orange Coast Chapters held a joint meeting in January featuring Dianne Chong, FASM, retired vice president of Boeing and ASM past president, who spoke about the history of materials in aerospace.

Dianne Chong and Amirhossein Khalajhedayati, Orange Coast Chair.

Students from the UC Riverside Materials Advantage Chapter.

Northwestern PA Holds Student Night

The Northwestern Pennsylvania Chapter recently held a successful student night at Penn State Behrend. The event featured Yustianto Tjiptowidojojo, a lecturer in the mechanical engineering department, giving a talk titled, "Predicting Damage in Mechanical Components."

From left, Chetan Nikhare and William Bennett present an ASM gift set to Yustianto Tjiptowidojojo.

On the Road with Vander Voort

George Vander Voort, FASM, gave talks at three ASM Chapters this winter. In January, he spoke about "The Measurement of Decarburization" to the Akron Chapter. In February, he presented "Failure Analysis—Materials and Manufacturing Problems" to the Southern Connecticut Chapter, and then spoke on "Determination of the Degree of Thermal Exposure to the Lower Head of the Three Mile Island Unit 2 Nuclear Reactor Using Metallography" to the Philadelphia Liberty Bell Chapter.

From left, Jamie Jones presents George Vander Voort with a Liberty Bell memento.

Los Angeles Hosts Hawkins

Gary Hawkins (left), formerly of Aerospace Corp. and co-founder and CTO of Radian Labs, is thanked by Jeff Goldstein, Los Angeles Chapter webmaster, after speaking on "Machine Augmented Composites—From Invention to Application" at the February Chapter meeting.

MEMBERS IN THE NEWS

Frazier, Halbig Honored by The Engineers' Council

Bill Frazier, FASM, VP of ASM International and Chief Scientist, Air Vehicle Eng. Dept., Naval Air Systems Command, received the Distinguished Engineering Achievement Award of The Engineers' Council on February 19 in Palm Beach Gardens, Fla. Frazier was recognized "for pioneering work as the technical architect and driving force behind several cross-disciplinary, multi-organizational, public-private RDT&E programs in materials engineering, additive manufacturing, nanomaterials and metamaterials, and structural health management." He received his award from Cris Vigil, senior vice president of BRPH, an international architecture and engineering firm.

From left, Bill Frazier and Cris Vigil.

Michael C. Halbig, materials research engineer, NASA Glenn Research Center, received the William B. Johnson International Inter-professional Founders Award of The Engineers' Council at the 61st Annual Honors & Awards Banquet celebrating National Engineers Week, held on February 27 in Universal City, Calif. Halbig was cited for "for dedicated organizational leadership in professional societies and technical contributions to advance the field of engineered ceramics." He received his award from Sharlene Katz, who serves on the Council's board of directors and is a professor at California State University, Northridge.

From left, Michael Halbig and Sharlene Katz.

Rajiv Asthana, FASM, editor of the *Journal of Materials Engineering and Performance,* nominated Frazier and Halbig for the awards. Asthana received the Distinguished Engineering Educator Award from The Engineers' Council in 2015.

Jandeska to Receive PM Lifetime Achievement Award

William F. Jandeska, Jr., FASM, president of Midwest Metallurgical Ltd. and project manager for the Center for Powder Metallurgy Technology, will receive the Kempton H. Roll PM Lifetime Achievement Award by the Metal Powder Industries Federation (MPIF). The award will be presented during Powdermet 2016, taking place June 5-7 in Boston. The award is named in honor of Kempton H. Roll, founding executive director of MPIF. It was established in 2007 to recognize individuals with outstanding accomplishments and a lifetime of involvement in the PM field and related technologies. This is only the third time the award has been given since its inception.


Jandeska

Connor Named VP of Technology for AFS

The American Foundry Society (AFS) named **Zayna Connor** vice president of technology in March. Most recently, she was a senior engineering specialist at Caterpillar Inc. and led the corporate casting team, where she was responsible for all casting and aluminum specifications and also performed failure analysis. Connor earned her B.S. degree in metallurgical engineering from the University of Missouri-Rolla and her Ph.D. in materials science and engineering from Northwestern University, where she received a National Science Foundation fellowship and an Amelia Earhart fellowship.


Connor

Anderson Elected to National Academy of Engineering

In February, the National Academy of Engineering (NAE) elected 80 new members and 22 foreign members. Among the new members is **Kevin Anderson, FASM,** Mercury Fellow, corporate research and development, Mercury Marine. He is cited "for advances in metals recycling through invention of innovative aluminum alloys." Election to NAE is among the highest professional distinctions accorded to an engineer. Academy membership honors those who have made outstanding contributions to engineering research, practice, or education. An induction ceremony will be held on October 9 at NAE's annual meeting in Washington.


Anderson

Howard Named TMS President

The Minerals, Metals & Materials Society (TMS) installed **Stanley M. Howard** as its 2016 president in February at the TMS 2016 Annual Meeting & Exhibition in Nashville, Tenn. He is a professor of materials and metallurgical engineering at the South Dakota School of Mines and Technology. Howard received his B.S. and Ph.D. in metallurgical engineering from the Colorado School of Mines and is a licensed professional engineer.


Howard

IN MEMORIAM


John Cahn. Courtesy of NIST.

John W. Cahn, FASM, passed away on March 14 at age 88. He was born in a Jewish family as Hans Werner Cahn in Cologne, Germany, in 1928. In 1933, his immediate family fled to the Black Forest, later moving throughout Europe and eventually living in Amsterdam. In 1939, the family came to the United States. Most of his relatives who stayed in Germany and Holland died in the Holocaust. The Cahn family settled in New York City and John became a U.S. citizen in 1945, serving in the Army in Japan after World War II. He earned a bachelor's degree in chemistry from the University of Michigan and a Ph.D. in physical chemistry from the University of California, Berkeley, in the early 1950s.

Cahn worked for General Electric in Schenectady, N.Y., and taught at the Massachusetts Institute of Technology before joining the National Institute of Standards and Technology (NIST) in 1977, where he worked for decades. In 1998, he received a National Medal of Science from President Bill Clinton and also the Kyoto Prize for advanced technology in 2011, among other awards and honors. Cahn is perhaps most widely known for the Cahn-Hilliard equation, which he developed with British metallurgist John E. Hilliard. The equation describes how dissimilar materials move away from each other during phase separation. Beyond metallurgy, the equation has also been applied in areas from population studies to the formation of galaxies. During the 1980s, Cahn assisted his colleague Dan Shechtman with discovery of quasicrystals, which feature non-repeating patterns, a form thought to be impossible in nature. Cahn moved to Seattle in 2007 and served as an affiliate professor at the University of Washington.

Bob Balow passed away unexpectedly on February 24 at age 69. He earned his degree in metallurgical engineering from the University of Wisconsin and later started Accu-Temp Heat Treating in the Racine area. Accu-Temp also housed three other of Balow's companies—Ferroxy-Aled, RCP Products, and Neat Ideas.

He developed at least five patents, including his famous Pasta Fork. Holding the twisted fork and pressing down makes the fork spin, wrapping noodles around it. A 2011 YouTube video in which Balow demonstrates the fork has achieved more than 1 million views. Balow also developed a coating process for cast iron cookware that prevents rust and is very tough. The process requires a specialized $1 million furnace, so he built one at Accu-Temp. Balow also worked as an international metallurgical consultant for companies such as SC Johnson, General Motors, and MillerCoors.


Bob Balow and his famous Pasta Fork. Courtesy of RCP Products.

ASM INTERNATIONAL

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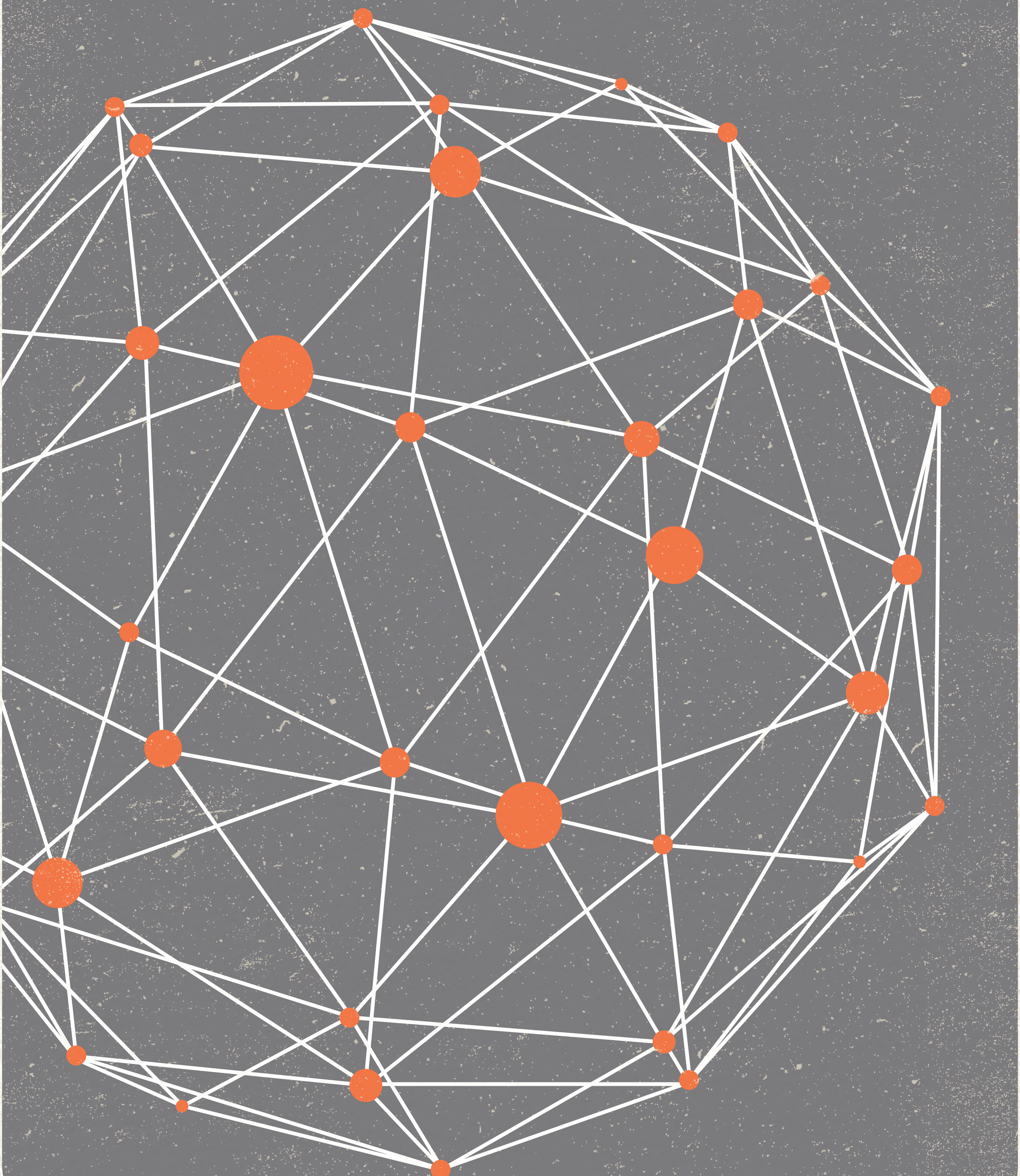

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Edited by Jon L. Dossett and George E. Totten
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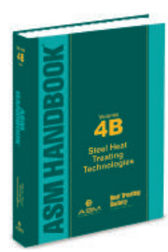
This volume addresses the basics of steel heat treating and thoroughly covers the many steel heat treating processes. Major topics include: the physical metallurgy of steel heat treatment, fundamentals and practical aspects of steel hardness and hardenability, quenching, annealing, tempering, austempering,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



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ISBN: 978-1-62708-025-5
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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.

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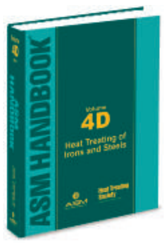
This *all new* ASM Handbook gives design, manufacturing, and materials engineers an important new reference. Written by internationally recognized experts, Volume 4C provides in-depth and comprehensive coverage on one of the most significant technologies in the metals processing industries. Covering 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.



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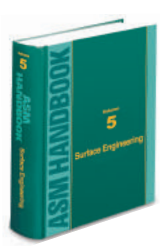

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Product Code: 05348G

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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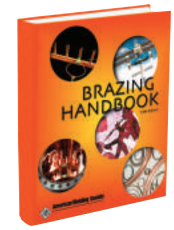

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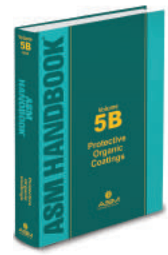

Volume 5B: Protective Organic Coatings

Edited by Kenneth B. Tator

2015 • 545 pages

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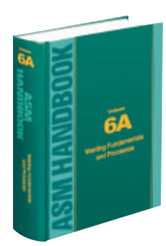

Volume 6A: Welding Fundamentals and Processes

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

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

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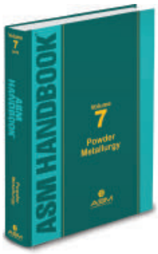

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Edited by G.F. Vander Voort

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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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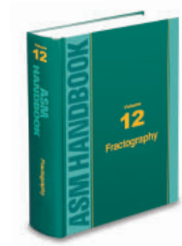

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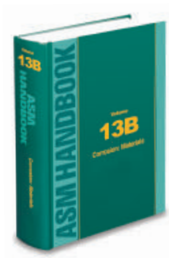

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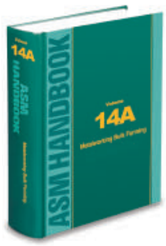

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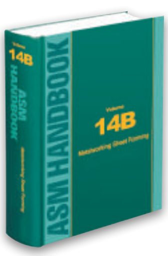

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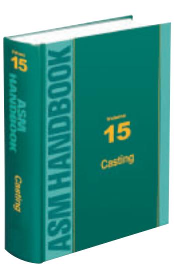

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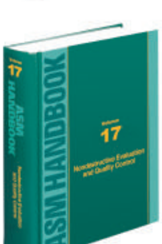

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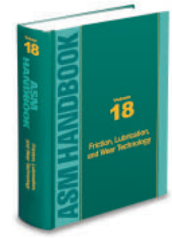

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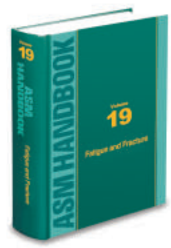

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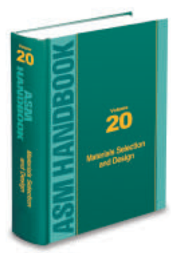

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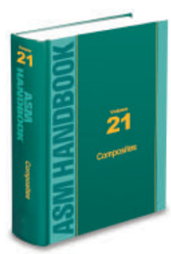

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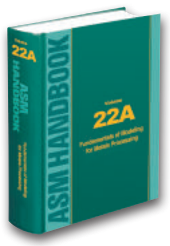

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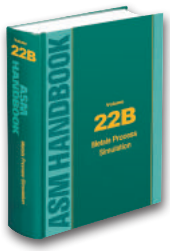

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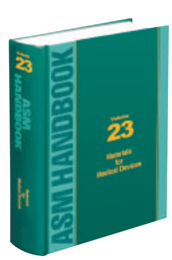

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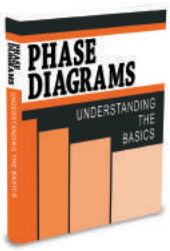

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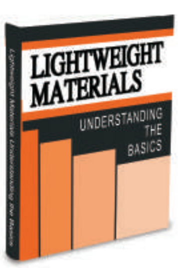

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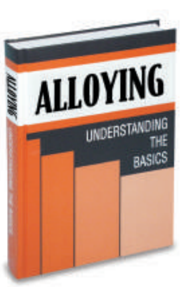

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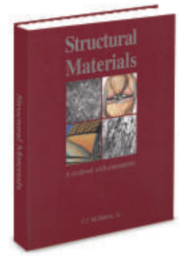

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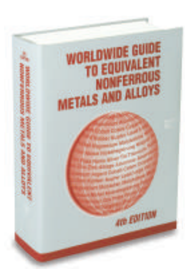

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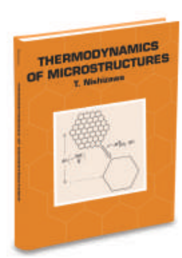

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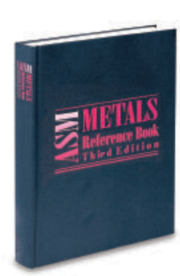

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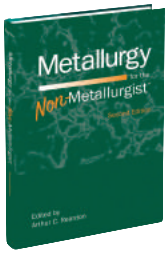

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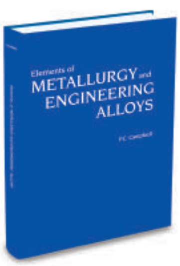

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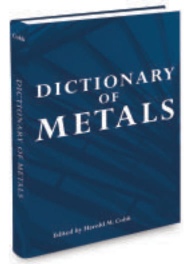

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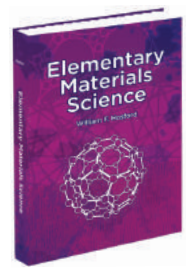

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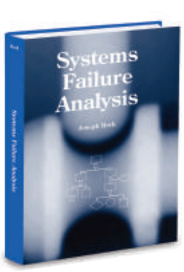

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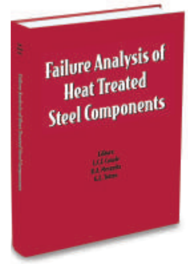

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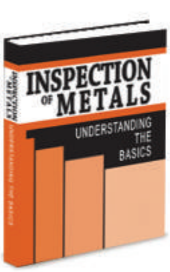

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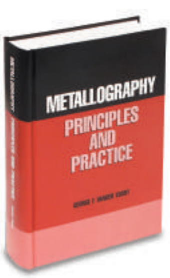

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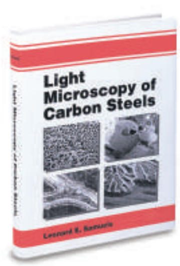

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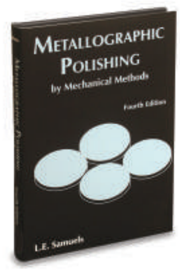

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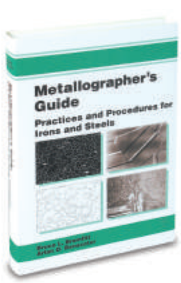

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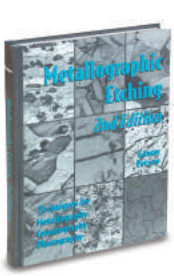

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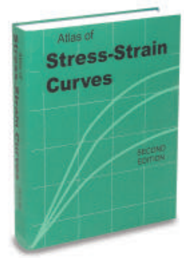

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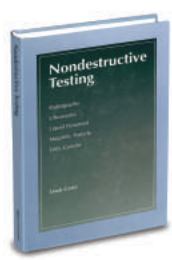

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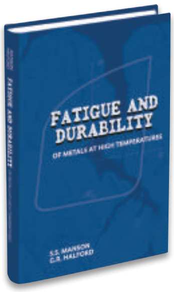

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ISBN: 978-0-87170-718-5
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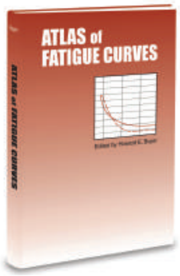
Price: $257 / ASM Member: $185

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



Atlas of Fatigue Curves

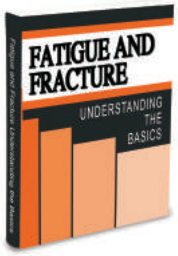
Edited by H.E. Boyer

1986 • 518 pages • Illustrated

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

Price: $307 / ASM Member: $231

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



Fatigue and Fracture: Understanding the Basics

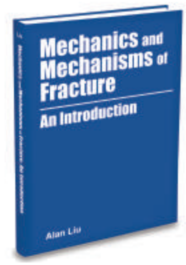
Edited by F.C. Campbell

2012 • 698 pages

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

Price: $187 / ASM Member: $135

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



Mechanics and Mechanisms of Fracture: An Introduction

By A.F. Liu

2005 • 458 pages

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

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

Price: $167 / ASM Member: $125

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

Fatigue and Fracture Reference Library DVD 2012 Edition

2012 • ASM International

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

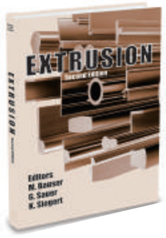
Price: $703 / ASM Member: $601

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

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

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

MANUFACTURING & DESIGN



Extrusion, 2nd Edition

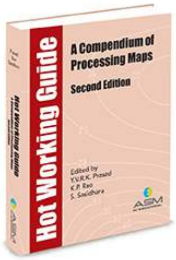
Edited by M. Bauser, G. Sauer, and K. Siegert

2006 • 608 pages

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

Price: $257 / ASM Member: $185

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



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

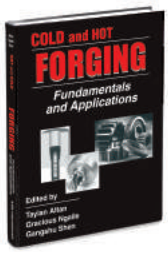
Edited by Y.V.R.K. Prasad, K.P. Rao, and S. Sasidhara

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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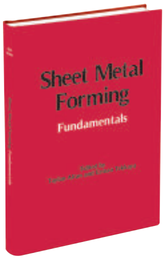
Product Code: 05351G
Price: $327 / ASM Member: $245



Sheet Metal Forming: Fundamentals

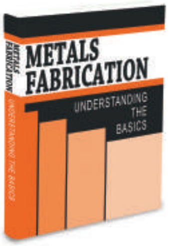
Edited by Taylan Altan and A. Erman Tekkaya
2012 • 314 pages
ISBN: 978-1-61503-842-8
Product Code: 05340G
Price: $207 / ASM Member $155

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

Sheet Metal Forming: Processes and Applications

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

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



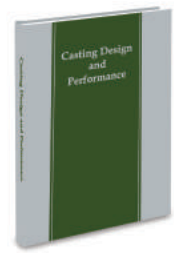
Metals Fabrication: Understanding the Basics

By F.C. Campbell
2013 • 439 pages
IBSN: 978-1-62708-018-7
Product Code: 05374G
Price: $187 / ASM Member: $135

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

ASM Specialty Handbook® Tool Materials

Edited by J.R. Davis
1995 • 501 pages
ISBN: 978-0-87170-545-7
Product Code: 06506G
Price: $307 / ASM Member: $231



Casting Design and Performance

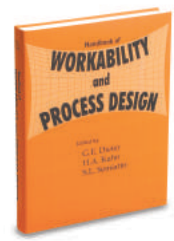
2009 • 272 pages
ISBN: 978-0-87170-724-6
Product Code: 05263G
Price: $197 / ASM Member: $145

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

Gear Materials, Properties, and Manufacture

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

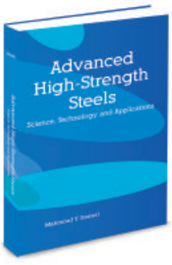
Overview of gears, lubrication and wear; in-depth treatment of metallic alloys (ferrous and nonferrous) and plastic gear materials; gear manufacturing methods (including metal removal, casting, forming, and forging); heat treatment; and failure analysis, fatigue life prediction and mechanical testing.



Handbook of Workability and Process Design

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

STEELS



Advanced High-Strength Steels: Science, Technology and Applications

By Mahmoud Y. Demeri
2013 • 312 pages
IBSN: 978-1-62708-005-7
Product Code: 05370G
Price: $167 / ASM Member: $125

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

Stainless Steels Reference Library DVD, 2011 Edition

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

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

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

Engineering Properties of Steel

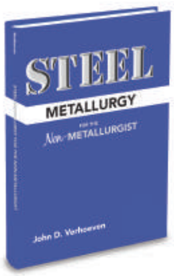
Edited by Philip Harvey

1982 • 509 pages

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

Price: $157 / ASM Member: $115

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



Steel Metallurgy for the Non-Metallurgist

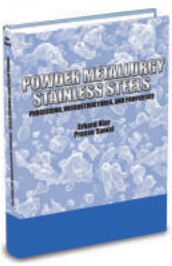
By John D. Verhoeven

2007 • 225 pages

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

Price: $107 / ASM Member: $75

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



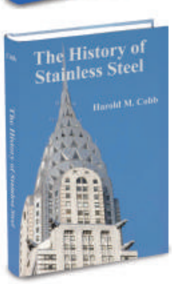
Powder Metallurgy Stainless Steels: Processing, Microstructures, and Properties

By E. Klar and P. Samal

2007 • 256 pages

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

Price: $107 / ASM Member: $75



The History of Stainless Steel

By Harold M. Cobb

2010 • 384 pages • Illustrated

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

Price: $43 / ASM Member: $32

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

Price: $83 / ASM Member: $65

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

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

ASM Specialty Handbook® Stainless Steels

Edited by J.R. Davis

1994 • 576 pages

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

Price: $307 / ASM Member: $231

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

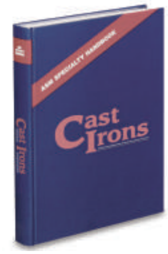
ASM Specialty Handbook® Carbon and Alloy Steels

Edited by J.R. Davis

1996 • 731 pages

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

Price: $307 / ASM Member: $231



ASM Specialty Handbook® Cast Irons

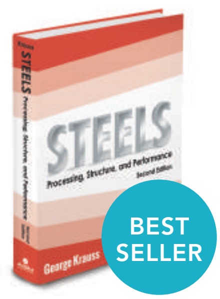
Edited by J.R. Davis

1996 • 494 pages

ISBN: 978-0-87170-564-8
Product Code: 06613G

Price: $307 / ASM Member: $231

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



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

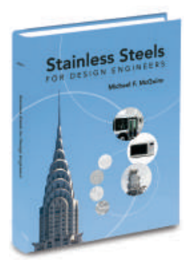
By George Krauss

2015 • 682 pages

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

Price: $207 / ASM Member: $155

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



Stainless Steels for Design Engineers

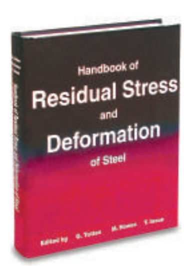
By Michael F. McGuire

2008 • 312 pages

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

Price: $187 / ASM Member: $135

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



Handbook of Residual Stress and Deformation of Steel

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

2002 • 499 pages

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

Price: $167 / ASM Member: $125

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

Introduction to Stainless Steels, 3rd Edition

By J. Beddoes and J.G. Parr

1999 • 315 pages

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

Price: $53 / ASM Member: $42

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Stahlschlüssel (Key To Steel) 2016 Edition

By Verlag Stahlschlüssel Wegst GmbH

2016 • Approximately 880 pages

ISBN: 978-3-922599-32-6
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Price: $249 / ASM Member: $215

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

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Stahlschlüssel (Key To Steel) CD-ROM 2016 Edition

By Verlag Stahlschlüssel Wegst GmbH

2016

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Product Code: 05512C

Price: $689 / ASM Member: $605

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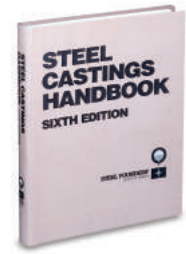
The CD version offers flexible and powerful capabilities, including the ability to search for steels by designation, chemical composition, and mechanical/physical properties.



Steel Castings Handbook, 6th Edition

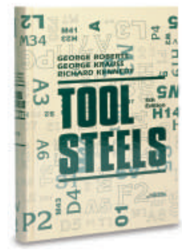
Co-published by Steel Founders' Society of America and ASM International

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

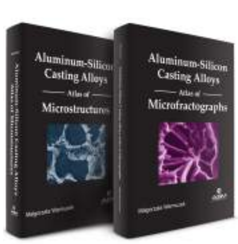
By Małgorzata Warmuzek

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.

Price: ~~$199~~ / ASM Member: ~~$149~~
Prepublication Price: $179 / ASM Member: $129
Prepublication price good through June 30, 2016!



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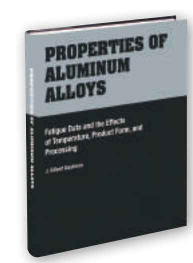
Properties of Aluminum 2-Volume Set
Product Code: 05250G
Price: $457 / ASM Member: $335



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

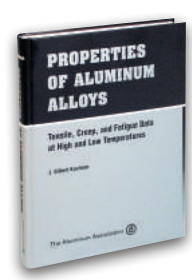
Edited by J.G. Kaufman

2008 • 574 pages

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

Price: $257 / ASM Member: $195

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



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

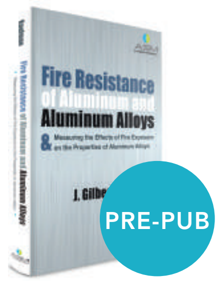
Edited by J.G. Kaufman

1999 • 311 pages

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

Price: $257 / ASM Member: $195

Co-published by the Aluminum Association and ASM International.



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!

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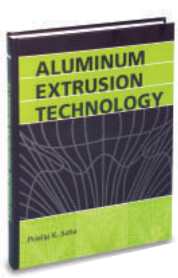
ISBN: 978-1-61503-723-0
Product Code: 05322V

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

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

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



Aluminum Extrusion Technology

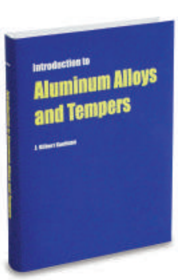
By P.K. Saha

2000 • 259 pages

ISBN: 978-0-87170-644-7
Product Code: 06826G

Price: $207 / ASM Member: $165

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



Introduction to Aluminum Alloys and Tempers

By J.G. Kaufman

2000 • 258 pages

ISBN: 978-0-87170-689-8
Product Code: 06180G

Price: $43 / ASM Member: $32

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

Beryllium Chemistry and Processing

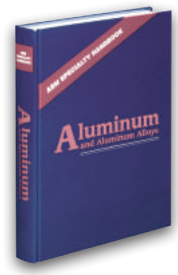
By K.A. Walsh • Edited by E.E. Vidal, A. Goldberg, E. Dalder, D.L. Olson, and B. Mishra

2009 • 680 pages

ISBN: 978-0-87170-721-5
Product Code: 05223G

Price: $257 / ASM Member: $191

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



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

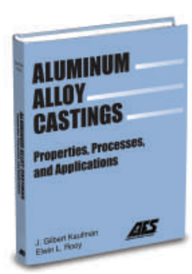
Price: $307 / ASM Member: $231

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.

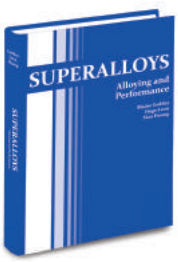
Superalloys Reference Library DVD, 2011 Edition

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.



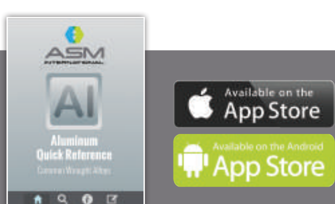
Superalloys: Alloying and Performance

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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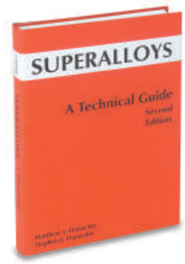
Aluminum Quick Reference App

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



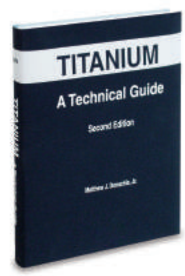
Superalloys: A Technical Guide, 2nd Edition

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

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

Price: $703 / ASM Member: $601

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

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

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Price: $167 / ASM Member: $125

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

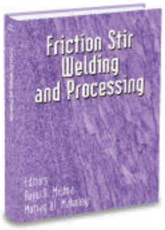
Principles of Soldering

By Giles Humpston and David M. Jacobson

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

Price: $167 / ASM Member: $125

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



Friction Stir Welding and Processing

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

2007 • 368 pages

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

Price: $157 / ASM Member: $115

Weld Integrity and Performance

1997 • 417 pages

ISBN: 978-0-87170-600-3
Product Code: 06593G

Price: $207 / ASM Member: $155

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

Joining: Understanding the Basics

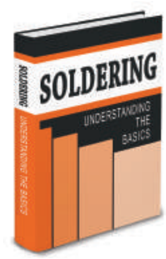
Edited by F.C. Campbell

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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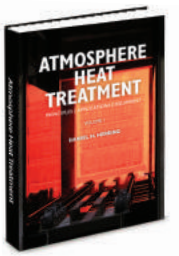


Atmosphere Heat Treatment: Principles, Applications, Equipment, Volume 1

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

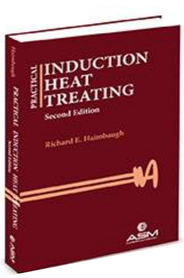
By Daniel H. Herring • Publisher: BNP Media

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

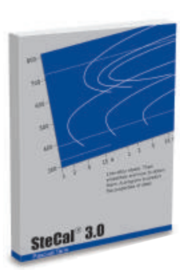
By A.K. Rakhit

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

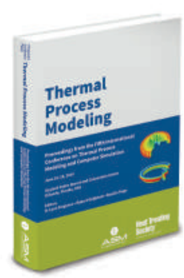
ISBN: 978-1-61503-840-4

Product Code: 05347V

Price: $703 / ASM Member: $601

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

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



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

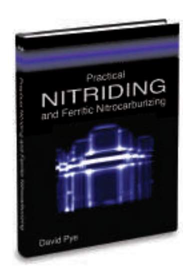
Edited by B.L. Ferguson, R. Goldstein, and R. Papp

2014 • 329 pages

ISBN: 978-1-62708-068-2
Product Code: 05447G

Price: $168 / ASM Member: $139

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



Practical Nitriding and Ferritic Nitrocarburizing

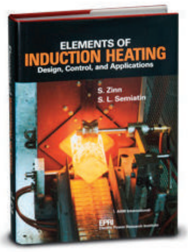
By David Pye

2003 • 256 pages

ISBN: 978-0-87170-791-8
Product Code: 06950G

Price: $207 / ASM Member: $155

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



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.

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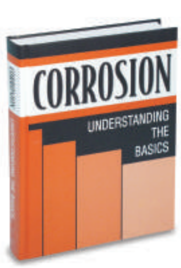
CORROSION



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

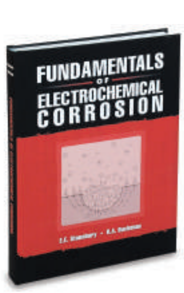
Edited by B. Craig and D. Anderson

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.



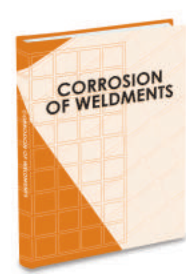
Fundamentals of Electrochemical Corrosion

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

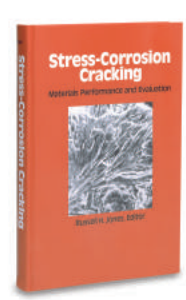
Edited by J.R. Davis

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.



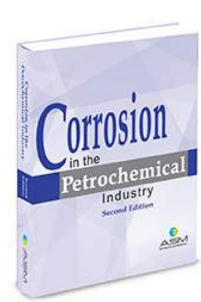
Stress-Corrosion Cracking: Materials Performance and Evaluation

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

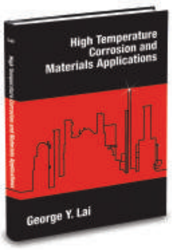
Edited by Victoria Burt

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

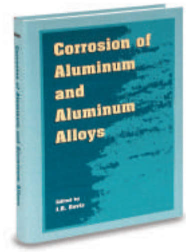
By George Y. Lai

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.

Surface Engineering for Corrosion and Wear Resistance

Edited by J.R. Davis

2001 • 279 pages

Co-published by IOM Communications and ASM International

ISBN: 978-0-87170-700-0
Product Code: 06835G

Price: $107 / ASM Member: $75

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

High Pressure Cold Spray: Principles and Applications

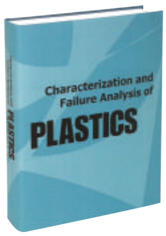
Edited by C.M. Kay and J. Karthikeyan

2016 • 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!

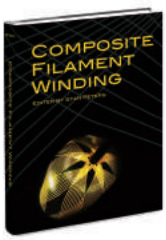


Characterization and Failure Analysis of Plastics

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
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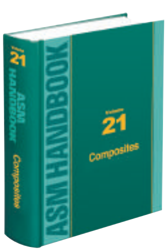

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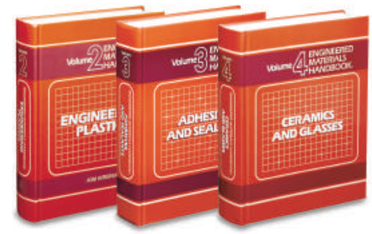

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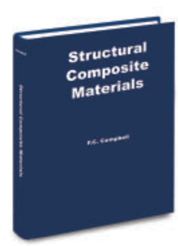

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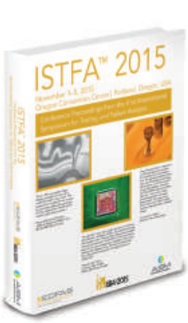

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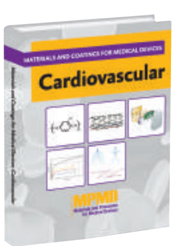

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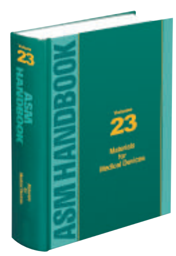

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Edited by Roger Narayan
2012 • 396 pages
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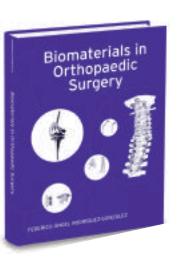
Product Code: 05285G

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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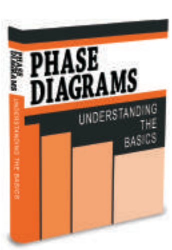

Phase Diagrams: Understanding the Basics

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

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Edited by Pierre Villars • 1997

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Product Code: 57763G

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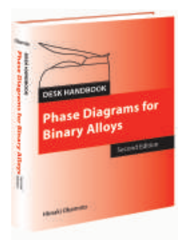
27,686 entries of the highest quality crystal data, representing 27,686 different compounds.



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

By Hiroaki Okamoto

2010 • 855 pages

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

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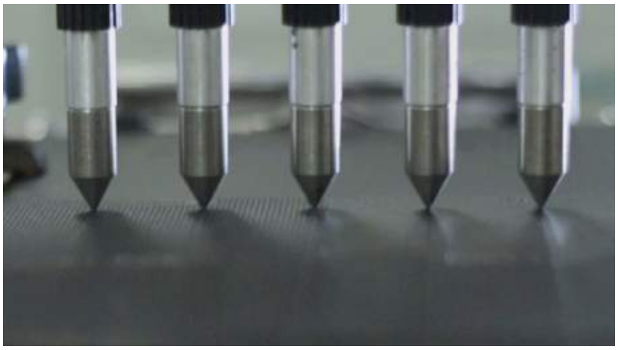
STRESS RELIEF

SCRATCH AND SNIFF



The five-finger scratch test is used to scratch plastics to see how much abuse they can take. Courtesy of Business Wire.

What makes a vehicle rough and tough? A powerful engine or hardy suspension might come to mind, but the interior of an automobile also needs to withstand a variety of stresses and strains. To determine the durability of fabrics, leathers, and plastics used inside vehicle cabins, engineers at Ford Motor Co., Detroit, subject these materials to a series of tests where they are stretched, scratched, snagged, sniffed, and stained to see how they will stand up to wear and tear. As part of this gauntlet, Ford plastics undergo ordeals like the "five-finger scratch test," where samples are scraped with a claw of pointed metal rods at different levels of force. In the "soil and cleanability test," substances like coffee, grease, and mud are splashed onto seat fabrics to evaluate stain resistance. And in the medieval style "mace snagging test," seat fabric strength is evaluated by spinning samples on rollers 600 times while striking them repeatedly with a spikey iron ball. Material samples are also sealed in hot, humid jars and then sniffed by a team of "approved odor assessors" to help the engineers achieve interiors free of disturbing smells. *youtu.be/J9gyq9dGnUE.*

Toto's Neorest 750h intelligent toilet.

TECH-SAVVY TOILET CLEANS UP

The Neorest 750H intelligent toilet from Toto, Japan, might be smarter than you are. It sports sensors that decide when it should open, close, and flush, plus a heated seat at an ergonomic 17 in. from the floor. The bowl washes itself with a dual-jet, tornado flush action and a catalytic deodorizer, and washes its user with a spritz of warm, aerated water followed by a puff of toasty air. The toilet stays tidy with a pre-use mist that prevents waste adherence and a post-flush mist of slightly acidic, electrolyzed water that keeps things cleaner longer. The bowl's coating of titanium dioxide and zirconium not only imparts a pearly sheen, but also accelerates decomposition of organic substances when a UV light turns on inside the closed lid, triggering a photocatalytic reaction. The 750H consumes a single gallon of water per flush (gpf) at full force and 0.8 gpf in light mode. *totousa.com.*

CLIMB LIKE A GECKO

Glass wall climbing test. Courtesy of Eric Eason.

Researchers at Stanford University, Calif., developed a handheld device covered with 24 adhesive tiles that let humans scale glass walls like Spider-Man. This handheld "gecko pad" is connected to special degressive springs that become less stiff the further they are stretched, allowing large loads to be shared evenly across every adhesive patch. Like natural gecko adhesive, the device's synthetic adhesive can be turned on and off as you climb—release the load tension, and the pad loses its stickiness. A team at the University of Cambridge, UK, recently lamented that under normal biological conditions, geckos are the largest animals that can climb walls—40% of a human body would need to be covered in adhesive to support its own weight. The Stanford team says that with a little human engineering, wall climbing can be scaled up. *stanford.edu.*