ADVANCED MATERIALS & PROCESSES

AN ASM INTERNATIONAL PUBLICATION

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MATERIALS IN SPORTS & RECREATION

WINNING DESIGNS ASSIST ATHLETES

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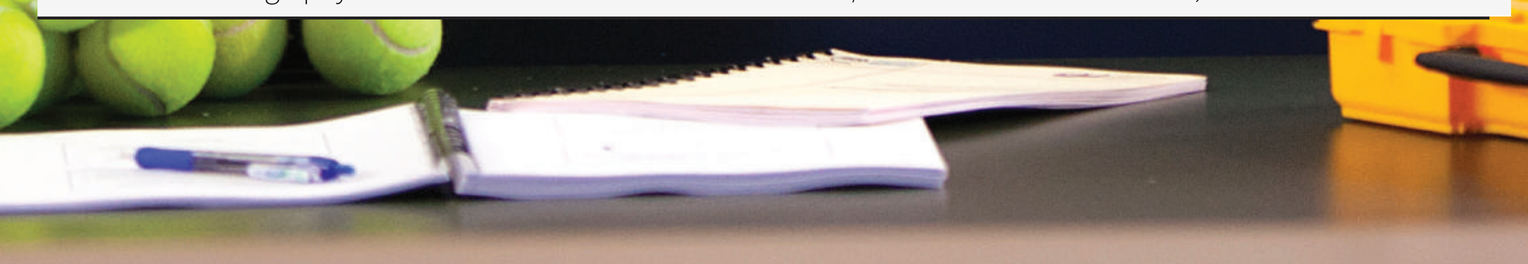
Science and Technology of Materials	8/15-16	ASM World Headquarters
Metallurgy for the Non-Metallurgist™	8/15-18	ASM World Headquarters
Heat Treatment, Microstructures and Performance of Carbon and Steel Alloys	8/8-10	ASM World Headquarters
Steel Metallography	8/15-18	ASM World Headquarters
Corrosion	8/22-25	ASM World Headquarters
Metallographic Techniques - Blended (Lab Session)	9/8-9	ASM World Headquarters
Practical Fracture Mechanics	9/12-13	IMR Test Labs, NY
Oilfield Metallurgy	9/12-14	ASM World Headquarters
Elements of Metallurgy	9/12-15	ASM World Headquarters
Fractography	9/12-15	ASM World Headquarters
Practical Fractography	9/14-15	IMR Test Labs, NY



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On the Cover:

Metallurgy at its finest: The Larry O'Brien NBA Championship Trophy, manufactured by Tiffany & Co., is made of 14.5 pounds of sterling silver and vermeil, and features a 24-karat gold overlay. This year's winner? The Cleveland Cavaliers.

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ADVANCED MATERIALS & PROCESSES

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

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

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

Ed Kubel and Erika Steinberg, *Contributing Editors*

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

Kate Fornadel, *Layout and Design*

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

Press Release Editor
magazines@asminternational.org

WINNING

Are you wondering about the fine example of metallurgy showcased on this month's cover? It's a trophy. In fact, it is none other than the Larry O'Brien NBA Championship Trophy, manufactured by Tiffany & Co. This stunning piece of craftsmanship is made of 14.5 pounds of sterling silver and vermeil, and features a 24-karat gold overlay. We chose this image to represent the thrill of victory in sporting endeavors, a nice fit with our summer issue theme focusing on materials in sports and recreation applications. Of course, with ASM headquarters planted in the Cleveland suburbs, we are also celebrating a long-awaited hometown triumph, a first for our beloved Cleveland Cavaliers. Please forgive our lack of humility—it's not often we experience such conquests and we need to savor it.

Putting together our second annual sports and recreation issue is also a reminder of all the important materials technologies that go into helping both amateur and elite athletes perform at the top of their game. For starters, our cover story discusses the importance of mechanical testing when it comes to apparel and equipment development, injury avoidance, and sports medicine. As one example, design engineers must study the impact performance of different materials used in athletic shoes. Intense activities such as running and basketball can place significant mechanical loads on footwear, resulting in impact forces of more than 10 times an athlete's body weight. By using sophisticated fatigue testing machines, the mechanical performance of complex viscoelastic materials used in shoe soles can be analyzed and improved upon, ultimately leading to reduced wear on ankles, knees, and hips, not to mention better performance.

Sports safety is another critical topic. From protective gear such as shoulder and body padding to helmet shells and cushioning, much research is going into materials that can efficiently distribute impact shock. Besides sports activities, head health issues and protective gear technologies are also important in military environments. For example, we highlight one of the winners of the recent *Head Health Challenge III: Advanced Materials for Impact Mitigation* in this month's 3D PrintShop on page 60. Helmet manufacturer Charles Owen Inc. is working with Cardiff University to further develop a multilayered, elastic material called C3 for use as an energy-absorbing fabric that could be used to protect both athletes and military personnel from brain injury. Funding was awarded by a partnership of the National Football League, Under Armour, GE, and the National Institute of Standards and Technology. Five winning projects are now each using their $250,000 awards as initial funding for their designs. After one year, the best technology will receive another $500,000 toward development.

Beyond injury prevention and safety, our summer issue also highlights some unusual and fascinating developments taking place in the sports performance arena—from 3D-printed running shoes to lightweight skis based on turtle shells. Here in Cleveland, we will simply continue to bask in the glory of our days of wine and gold.

F. Richards
frances.richards@asminternational.org

MARKET SPOTLIGHT

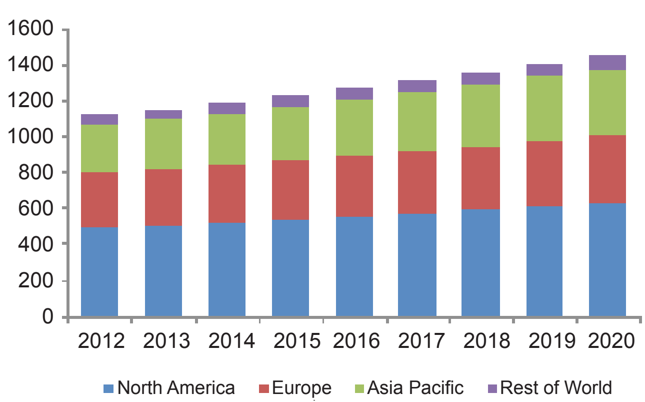
HIGH PERFORMANCE ALLOYS MARKET TO REACH $11.33 BILLION BY 2024

The high performance alloys market is expected to reach $11.33 billion by 2024, according to a new report from Grand View Research Inc., San Francisco. The market is forecast to experience significant growth due to titanium- and aluminum-based high performance alloys replacing steel and other alloys. Platinum group metal alloy advancements have increased their demand. For example, platinum-palladium-copper alloys are used in wrought products, significantly reducing costs. Further, ruthenium-platinum-palladium alloys are increasingly used in industrial applications due to high oxidation resistance and superior strength. Key findings in the report include:

- Non-ferrous high performance alloys are expected to be the fastest growing segment, forecast at a CAGR of over 3% from 2016 to 2024.
- The electrical and electronics segment was valued at over $6 billion in 2015. High performance alloys used in this industry are added to conductive metals to optimize efficiency.
- The Asia Pacific region is expected to exhibit the highest growth due to increasing demand in emerging economies and rapid industrialization in Indonesia, India, and China.
- Europe accounted for a market share of over 26% in 2015 and is forecast to witness strong growth over the next eight years due to growing demand in the automotive and aerospace industries.
- Superalloys are expected to grow by more than 4.5% from 2016 to 2024. Increased use in power plants, chemical and petrochemical processing, and the oil and gas industry is expected to spur demand over the next eight years.

For more information on "High Performance Alloys Market Analysis by Product (Non-Ferrous Alloys, Platinum Group Metal Alloys, Refractory Metal Alloys and Superalloys), by Application (Aerospace, Automotive, Industrial Gas Turbines, Industrial, Oil & Gas, Electronic), by Material (Aluminum, Titanium, Magnesium) and Segment Forecasts to 2024," visit grandviewresearch.com.

High Performance Alloys Market Revenue by Region, 2012-2020 ($ Million)



Courtesy of Grand View Research Inc.

FEEDBACK

BEWARE OF BERYLLIUM

I recently read the article "Beryllium Optics Enable Advanced Space Telescopes" from the September 2015 issue. The article is excellent except for one item: It does not mention the extreme toxicity of beryllium or its horribly long latency period of 20-40 years. I am one of its victims. Of the various satellites I have worked on, the Hubble Space Telescope used virtually no beryllium due to the objections of Michael Krim, the engineer responsible for its basic design.

In my opinion, beryllium should never be used again. Due its terrible effects, I cannot walk 50 steps without sitting down. I was never informed of its use or I would have voiced my opposition. In addition, the Occupational Safety and Health Administration (OSHA) was never notified of our usage for the satellites and they cannot act if it is more than six months since the cause of the complaint occurred. At six months, there is no evidence at all. X-rays are of no use. There is only a blood test for "sensitization to beryllium."

Other materials such as aluminum/silicon carbide can take the place of beryllium, so why use it at all? It is the latency aspect that makes it so dangerous, as well as the incredibly small amount of dust that can be tolerated—less than one milligram per cubic meter per day. It makes arsenic seem like baby candy. So the James Webb Space Telescope is doomed from the start. One cannot ruin the health of one's fellow man and expect no consequences.

Name withheld for privacy

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

OMG!
OUTRAGEOUS MATERIALS GOODNESS

Ultra-light skis from Chomarat feature a multiaxial carbon reinforcement, C-Ply.

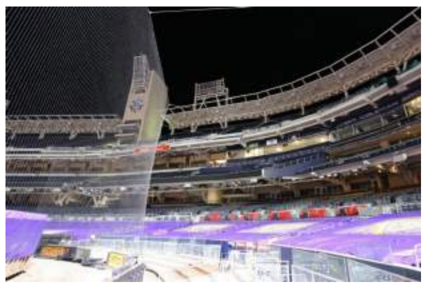
WORLD'S LIGHTEST SKIS FEATURE NEW COMPOSITE

Chomarat, France, has reportedly created the lightest ski on the market using C-Ply—a multiaxial carbon reinforcement produced in its South Carolina facility. Launched in January, the Mythic 87 line of Dynastar's (France) skis uses the new reinforcements. These backcountry skis were first developed for competitive skiing, but are now available for all skiers. C-Ply's structure of carbon reinforcement is optimized in terms of angles, ply weight, and fiber alignment, enabling an effective balance between strength and responsiveness, as well as high performance and weight. *chomarat.com/en.*

BASEBALL FANS PROTECTED WITH NEARLY INVISIBLE NETTING

Fans seated close to the action during Major League Baseball (MLB) games this year will be protected by screens extending further down the foul lines than in past seasons. Fans in 10 MLB ballparks might not readily notice the change thanks to barely visible systems developed and installed by Promats Athletics, using the Ultra Cross netting manufactured by NET Systems made with Black Dyneema material.

Hailed by baseball officials as a positive change to keep spectators safe, some fans and groups initially voiced concern that installing additional screening would have a negative impact on the viewing experience. Ultra Cross is a knotless braided net, resulting in less obstruction than other systems. Other systems also require application of a coating to provide the black color preferred by most sports venues. With Black Dyneema, the color is integrated into the fiber itself. Thus, the black coloration of Promats' system will neither wear away when exposed to natural elements nor abrade should protective screens be repeatedly struck by balls. *dyneema.com.*



Promats Athletics' netting solution uses the unique Ultra Cross system manufactured by NET Systems with Black Dyneema fiber, which incorporates the color into the fabric itself. Ultra Cross is a knotless braided net and is therefore less obstructive than other nets.

IMPROVING TEFLON'S TOUGHNESS

Researchers at the University of Arkansas, Fayetteville, will receive a $450,000 grant from the National Science Foundation to further their study of a novel approach that significantly improves wear resistance of polytetrafluoroethylene (PTFE) coatings. PTFE is better known by its trademarked brand name: Teflon.

"Obviously, PTFE is a great material with many wonderful applications," says Min Zou, professor of mechanical engineering. "But its coatings are easily worn because of their poor adhesion to substrates, and this severely limits its applications."

Researchers work with polytetrafluoroethylene, a wear-resistant coating used on tools and machinery for energy, aerospace, automotive, oil and natural gas, health care, biomedical, and food industries. Courtesy of University of Arkansas.

Zou and Jingyi Chen, assistant professor of chemistry, are incorporating polydopamine as an adhesive underlayer in order to improve wear resistance of PTFE. This approach will allow thin, wear-resistant PTFE coatings to be deposited on any substrate material without changing the underlining surface topography. Achieving this could promote the execution of a wide range of properties—such as self-cleaning, anti-fogging, anti-icing, anti-corrosion, and others—that rely on surface topography and chemistry for proper function.

PTFE is used not only in cooking tools, but also has various applications in the energy, aerospace, automotive, oil and natural gas, health care, and biomedical industries. *For more information: Min Zou, 479.575.6671, mzou@uark.edu, www.uark.edu.*

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

METALS | POLYMERS | CERAMICS

3D-printed scaffold matches the lower jaw of a female patient. Courtesy of Johns Hopkins Medicine.

BRIEFS

A newly formed alliance, **ALTec Industrial R&D Group,** is consolidating research efforts in the Canadian aluminum sector to develop innovative aluminum products for ground transportation vehicles. ALTec already has 23 members and partners that have access to state-of-the-art facilities and advanced expertise in aluminum forming, assembling, corrosion control, and performance validation. A major partner, the **Ministère de l'Économie, de la Science et de l'Innovation du Québec,** has contributed $450,000 through the Advanced Materials Research and Innovation Hub known as PRIMA. *www.nrc.gc.ca.*

3D-PRINTED JAW FEATURES NATURAL BONE AND PLASTIC

Researchers at Johns Hopkins University, Baltimore, found that a good framework for filling in missing bone requires a mix of at least 30% pulverized natural bone and special man-made plastic to create the necessary shape with a 3D printer.

The team incorporated polycaprolactone, or PCL, a biodegradable polyester used in making polyurethane that has been approved by the FDA for other clinical uses. "PCL melts at 80 to 100°C (176 to 212°F)—much lower than most plastics—so it's a good one to mix with biological materials that can be damaged at higher temperatures," says Warren Grayson, associate professor at the Johns Hopkins University School of Medicine. PCL is also strong, but the team knew from previous studies that it does not support new bone formation. So they mixed it with increasing amounts of "bone powder," made by pulverizing the porous bone inside cow knees after stripping it of cells.

To find out whether the scaffolds encourage bone formation, researchers added human fat-derived stem cells taken during a liposuction procedure to scaffolds immersed in a nutritional broth lacking pro-bone ingredients. After three weeks, cells grown on 70% bone powder scaffolds showed gene activity hundreds of times higher in three genes indicative of bone formation, compared to cells grown on pure PCL scaffolds. Cells on 30% bone powder scaffolds showed large but less impressive increases in the same genes. *For more information: Warren Grayson, 410.502.6306, wgrayson@jhmi.edu, www.hopkinsmedicine.org/som.*

NEW MATERIAL AND WELDING TECHNIQUE ENHANCE VEHICLE AESTHETICS

Rear lamp housings for vehicles now look and perform better thanks to material and processing innovations

Carpenter Technology Corp., Wyomissing, Pa., introduced PremoMax, a premium-melted alloy steel, developed for use in multiple downhole drilling applications. Its combination of high strength, impact toughness, and good hardenability in large section sizes provides superior performance in challenging environments. The new alloy is available in both billets and bars. *cartech.com.*

from Ichikoh Japan and INEOS Styrolution, Singapore. Ichikoh was searching for a processing solution that looks good at the weld joints of plastic parts. As conventional welding methods were unable to meet the innovative design parameters, a new laser welding technique was used for the rear lamp housing, which offers more design freedom and better surface appearance. The new laser welding technique also has the potential to generate more stability and higher mechanical strength at welded areas compared to conventional methods.

In addition to the new technique, the right material was needed. The challenge with most black or dark colored polymers is their high sensitivity to laser beams, which results in uneven surfaces at the weld joint when a laser is applied. INEOS Styrolution custom developed Novodur HH-112, a high-heat acrylonitrile butadiene styrene (ABS) specialty styrenic grade that meets Ichikoh's performance and aesthetic requirements. This is the first time an ABS resin has been used for a black laser welded application. *ineos-styrolution.com.*

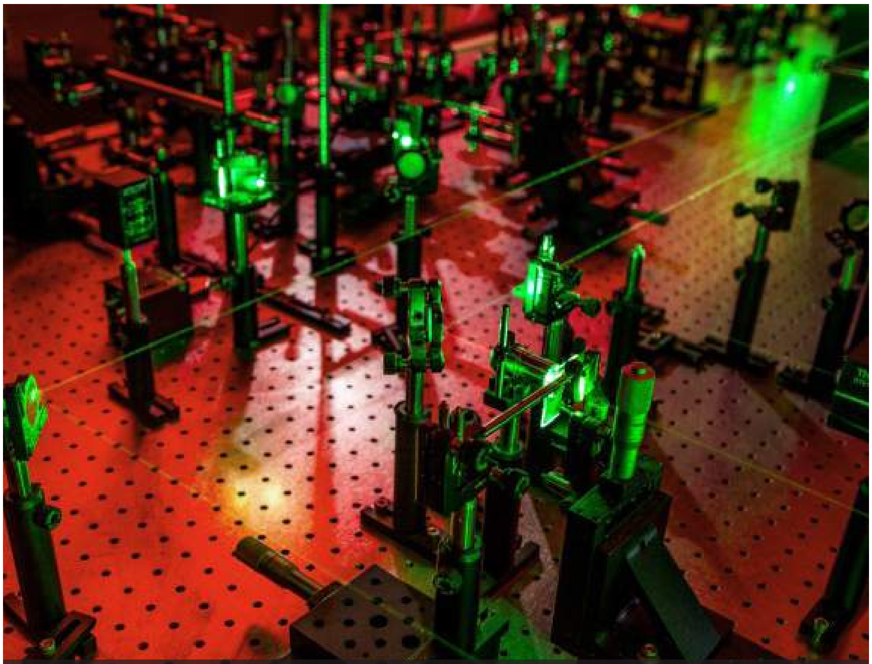
CADILLAC CT6 SHAVES WEIGHT WITH ALUMINUM

The 2016 Cadillac CT6 sports a body made of 62% aluminum from Novelis, Atlanta. By using aluminum and advanced joining techniques, Cadillac achieved significant weight savings, making the full-size luxury sedan comparable in weight to the midsize CTS sedan. When compared to a similar size vehicle using predominantly high-strength steel, the CT6 is approximately 220 lb lighter.

In both North America and Asia, Novelis aluminum is used throughout the vehicle body, including the passenger and rear compartments, roof structure, outer body panels, and door and deck lid structures. The CT6 features one of the most advanced mixed use automotive body structures in the industry, including all-aluminum exterior body panels and rear-drive architecture. GM's advanced joining methods are used to fabricate the vehicle structure, including a proprietary aluminum spot welding technology that reduces weight and increases strength and efficiency. Laser welding, flow drill fasteners, and self-piercing rivets are also used, along with nearly 600 ft of advanced structural adhesives. The CT6 also features a 10% stiffer body than its competitors. *novelis.com, gm.com.*

The Cadillac CT6 features a body made of 62% aluminum.

TESTING | CHARACTERIZATION



This laser ultrasonic setup allows the observation of microscale granular crystal vibrations. Courtesy of Dennis Wise/University of Washington.

MICROSCALE GRANULAR DYNAMICS DESCRIBED

University of Washington mechanical engineers observed and analyzed collective interparticle vibrations in 2D microscale granular crystals. While the dynamics of large-particle granular crystals have been studied, this is the first time such behavior has been described in microscale crystals, which—the team discovered—exhibit significantly different physical phenomena. For example, the microscale particles respond more strongly to adhesive forces, they resonate at higher frequencies, and they interact with each other in more complex patterns—including a combination of horizontal expansion and contraction, rotation, and wave motion.

To conduct their research, the team manufactured a 2D, ordered layer of micron-size glass spheres through self-assembly, then used laser ultrasonic techniques to induce vibration and observe the dynamics between particles. While the researchers used low-amplitude waves, next steps include exploring high-amplitude, nonlinear regimes in 3D crystals. Ultimately, the team hopes to develop new materials. For instance, granular substances are dynamically responsive—when you hit them harder, they react differently.

"If you could design a coating that has unique impact-absorbing capabilities, it could have applications ranging from spacecraft micro-meteorite shielding to improved bulletproof vests," notes Nicholas Boechler, assistant professor of mechanical engineering. *washington.edu.*

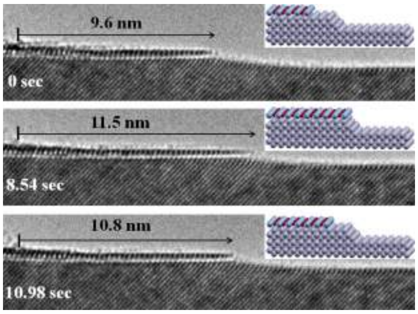
CLOSE-UP OF COPPER CORROSION PROVES EYE-OPENING

Using state-of-the-art in situ microscopy techniques, scientists at Binghamton University, N.Y., observed the oxidation of copper at the atomic level—and were surprised by what they saw. Using atomic resolution electron microscopes, scientists demonstrated that the oxidation of copper occurs via layer-to-island growth of copper oxide on flat copper surfaces, with copper atoms evaporating from the surface. Solid oxide, made of copper and oxygen atoms thermally combining above the original surface, is deposited back on the surface. This contradicts the long-held idea of a solid-solid transformation and demonstrates that—counterintuitively—if a surface can be made more uneven, its oxidation resistance increases.

BRIEFS

Thermo Fisher Scientific Inc., Waltham, Mass., acquired **FEI Co.,** Hillsboro, Ore., for approximately \$4.2 billion. FEI designs, manufactures, and supports high-performance electron microscopy workflows that provide images and information at various scales for both materials science and life sciences. The business will become part of Thermo Fisher's Analytical Instruments Segment. *thermofisher.com.*

Lightweight Innovations for Tomorrow, Detroit, a public-private partnership committed to the development and deployment of advanced lightweight metal manufacturing technologies, is establishing a team to identify new ways to mitigate corrosion in aluminum alloys. **The Ohio State University,** Columbus, and **United Technologies Research Center,** Hartford, Conn., will lead the project, in collaboration with **Lockheed Martin,** Bethesda, Md., **DNV GL,** Norway, and the **University of Michigan,** Ann Arbor. The group will develop computer models to predict aluminum alloy corrosion in components used in airplanes and other modes of transportation. *www.lift.technology.*



In situ atomic scale observation of oxidation process of a copper surface by transmission electron microscopy. Courtesy of Guangwen Zhou.

"Oxidation can lead to the formation of a protective layer against corrosion attack," explains Guangwen Zhou, associate professor of mechanical engineering. "Our results establish the principles of predicting the trend for promoting or suppressing the oxidation of materials." This could allow researchers to tailor a reaction for corrosion resistance in copper water pipes on one hand, or for improved chemical catalysis on the other. *www.binghamton.edu.*

A PALLADIUM PEEK AT GRAPHENE'S INVISIBLE DEFECTS

Researchers at the Zelinsky Institute of Organic Chemistry, Russia, developed a new technique to map carbon reactivity centers on the surface of graphene. While these defects are normally undetectable under an electron microscope, the team used palladium as a contrast agent, rendering them visible. When graphene was added to a solution of palladium complex $Pd_2(dba)_3$ dissolved in chloroform, the palladium clusters selectively attached to the surface of the graphene according to how reactive the carbon centers were: Individual palladium particles stuck to point defects, local accumulations of particles rested on larger defects, and short chains lay along linear defects.

Several types of defects are known to increase the reactivity of graphene's carbon atom, and mapping these reactivity centers is the first step toward manipulating them—removing them when smooth graphene is required, or incorporating them when beneficial, such as in catalysis. Using palladium markers, the team determined that more than 2000 surface defects can be found on each square micrometer of graphene surface area, challenging the current understanding of the electronic and structural properties of carbon materials. *www.zioc.ru.*

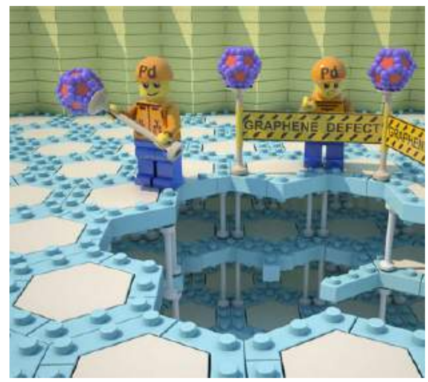
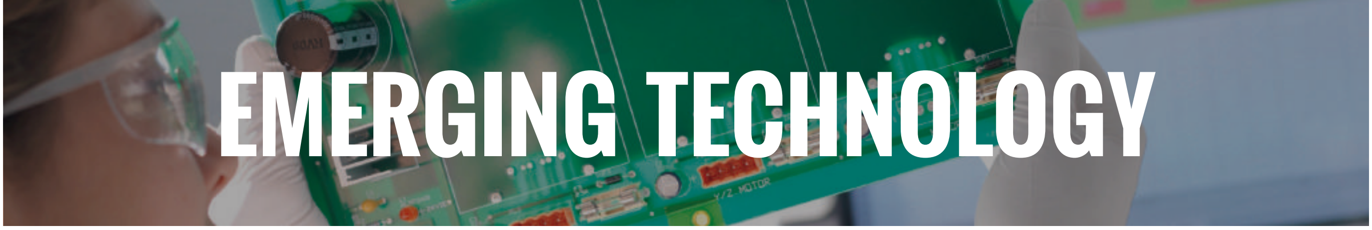
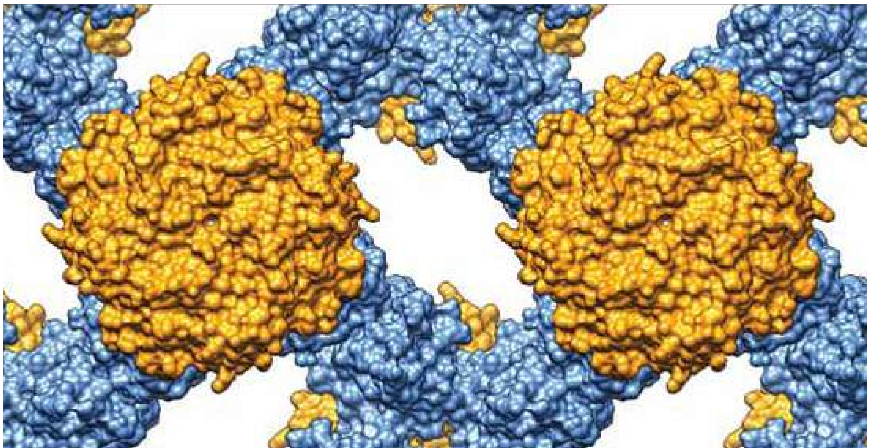


Illustration shows concept of imaging carbon defect areas using palladium markers. Courtesy of Zelinsky Institute of Organic Chemistry.



EMERGING TECHNOLOGY



Strong, flexible bonds in these protein tiles allow them to rotate to open spaces. Courtesy of UC San Diego.

AUXETIC MATERIAL COULD REVOLUTIONIZE RUNNING SHOES

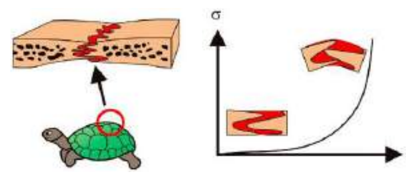
Chemists at the University of California, San Diego created an "adaptive protein crystal" that acts like it is opposite day. When stretched in one direction, the material thickens in the perpendicular direction—rather than thinning, as is typical—and when squeezed in one dimension, it shrinks in the other, becoming denser. This counterintuitive, auxetic behavior could prove useful in the sole of a running shoe that thickens for greater shock absorption as a heel collides with pavement, or in other applications, such as body armor that strengthens when a bullet strikes.

Akif Tezcan, professor of chemistry and biochemistry, and his colleagues created a sheet-like crystal made of square-shaped RhuA proteins arranged like tiles in a repeating pattern. "We found a way to create strong, flexible, reversible bonds to connect the protein tiles at their corners," he says.

The flexibility allows the tiles to rotate to open spaces within the material or to close up in a kind of adaptable sieve. It is the rotation of the protein tiles in unison that creates the auxetic behavior of the material, which has not been previously demonstrated at the molecular level. *ucsd.edu.*

TURTLE-INSPIRED SKIS

Researchers at the École Polytechnique Fédérale de Lausanne (EPFL), in conjunction with the Institute for Snow and Avalanche Research and the ski manufacturer Stöckli—all in Switzerland—developed a new kind of multi-function alpine ski. While downhill experts require rigid skis that withstand the high pressures of turns, intermediate athletes look for the maneuverability that comes with flexibility. The new type of ski delivers both qualities due to inspiration from the morphology of turtle shells.



EPFL researchers helped develop new skis based on a mechanism that mimics turtle scales.

"The scales of a turtle interlock, like a jigsaw puzzle, and are connected by a polymer," explains Véronique Michaud, a researcher at EPFL's Laboratory of Polymer and Composite Technology. "When turtles breathe, the scales separate slightly, and the shell becomes flexible. But when an external shock occurs, the shell tightens and stiffens."

To replicate this quality in the skis, aluminum plates with a snake-shaped fissure are embedded at both ends. When skis take the force of a turn, plates on either side of the gap come together and the ski stiffens, affording the skier stability and precision. As the skier comes out of the turn, the gap reopens, rendering the ski flexible and easier to maneuver. A special type of rubber between the plates functions like the polymer in the turtle shell. *www.epfl.ch.*

BRIEF

The **U.S. Department of Defense** is contributing $75 million toward the establishment of **Advanced Functional Fabrics of America,** a consortium of 89 companies, universities, researchers, and startups. The goal is to use flexible integrated circuits, lights, and sensors to create fabrics that can see, hear, sense, communicate, store energy, monitor health, and more. For example, running shoes using the new fabrics will be able to sense impact load for every step and communicate data about their user's physiological condition, and sensors woven into the nylon of parachutes will be able to catch small tears that otherwise would expand in midair. *defense.gov.*

PROCESS TECHNOLOGY

Adrian Sabau (right) and Jian Chen work with a laser to prepare the surface of carbon fiber composites and aluminum to create bonds that can absorb 200% more energy than conventional joints.

LASERS IMPROVE MULTI-MATERIAL BONDING

Scientists at the DOE's Oak Ridge National Laboratory, Tenn., developed a new approach to join carbon fiber composites and aluminum for use in lightweight cars and other multimaterial high-end products. The method, which uses a laser to prepare surfaces for bonding, improves joint performance and paves the way to automation. The laser not only removes surface contaminants—a critical step prior to bonding—but also penetrates the top resin layer of the composite, leaving individual carbon fibers exposed and increasing the surface area for better adhesion.

Test results for single-lap shear joint specimens that used the laser method show an increase in strength, maximum load, and displacement at maximum load of 15%, 16%, and 10%, respectively, over measurements for baseline joints. Further, joints made with laser-structured surfaces can absorb approximately 200% more energy than conventionally prepared baseline joints, a good sign for crash safety as well as potential use in vehicle and body armor. Unlike conventional methods of preparing surfaces by hand using abrasive pads, grit blasting, and harsh solvents, the laser method can be automated, enabling a more economical production process. *ornl.gov.*

BATTERY RECYCLING, PURE AND SIMPLE

For the first time, researchers at Lappeenranta University of Technology, Finland, extracted lithium, cobalt, and nickel from battery waste, all at nearly 100% purity. The team used a liquid-liquid process on a pilot scale, with a high-flow rate device that simulated the industrial scale. Extraction took place between two liquid phases that do not dissolve in each other, during which impurities were separated from the solution, leaving only the three metals. Ultimately, researchers achieved 99.6% purity for cobalt, 99.7% for nickel, and 99.9% for lithium. "If the purity of lithium is below 99.5%, it is not suitable as raw material for batteries. In other words, the difference between 99.4% and 99.9% purity is very significant," explains postdoctoral researcher Sami Virolainen.

Previous extraction attempts achieved relatively high purity for only two of the three metals. While the global demand for lithium is forecast to quadruple between 2011 and 2025, Europe has few primary resources. Nickel is more widespread, but the metal is always found with cobalt in nature, and separating the two—essential for battery manufacturing—has previously proven difficult. *www.lut.fi.*

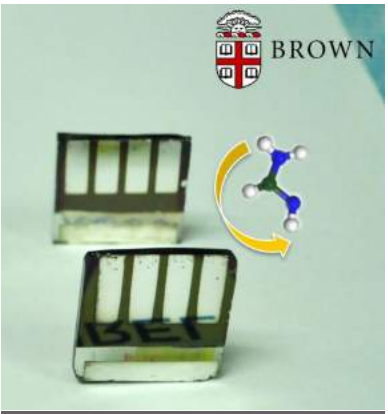
Lithium pellets. To be used as a raw material for batteries, lithium must be at least 99.5% pure.

BRIEFS

Nucor Corp., Charlotte, N.C., is forming a 50-50 joint venture with **JFE Steel Corp.,** Japan, to build and operate a $270 million automotive plant in central Mexico to supply the local market. Estimated capacity is 400,000 tons per year of galvanized sheet steel. Operations will begin in 2019. *nucor.com.*

SolAero Technologies Corp., Albuquerque, N.M., provider of satellite solar power and structural solutions, acquired **Vanguard Space Technologies Inc.,** San Diego, provider of satellite structural components and assemblies for commercial, defense, and civil satellites. Founded in 1994, Vanguard has supplied more than 50 spacecraft with 100% mission success. *solaerotech.com.*

ENERGY TRENDS



An international team of researchers developed a method that flips a chemical switch to convert one type of perovskite into another. Courtesy of Padture Lab/Brown University.

SIMPLE METHOD TRANSFORMS PEROVSKITES

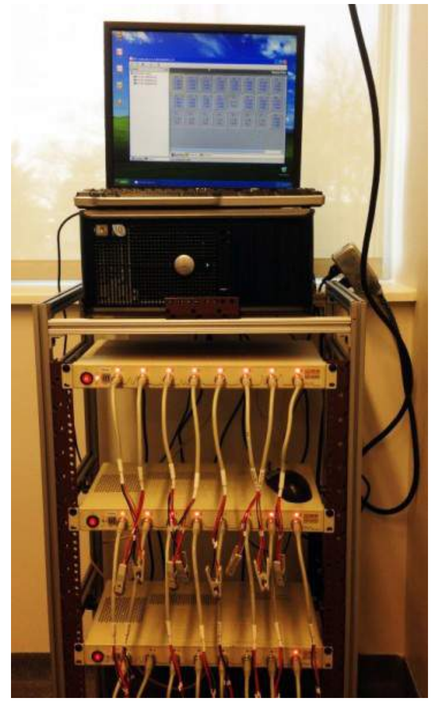
An international team of researchers discovered a way to flip a chemical switch that converts one type of perovskite into another—one with better thermal stability and that is a better light absorber. Most perovskite solar cells produced today are made with a type of perovskite called methylammonium lead triiodide. The problem is that $MAPbI_3$ tends to degrade at moderate temperatures. As a result, there is a growing interest in solar cells that use a type of perovskite called formamidinium lead triiodide instead.

The team, led by Nitin Padture, a professor at Brown University, Providence, R.I., first made high-quality $MAPbI_3$ thin films and then exposed them to formamidine gas at 150°C. The material instantly converted from $MAPbI_3$ to $FAPbI_3$ while preserving the microstructure and morphology of the original thin film. "It's like flipping a switch," says Padture. "The gas pulls out the methylammonium from the crystal structure and stuffs in the formamidinium, and does so without changing the morphology. We're taking advantage of a lot of experience in making excellent quality $MAPbI_3$ thin films and simply converting them to $FAPbI_3$ thin films while maintaining the same quality." *For more information: Nitin Padture, nitin_padture@brown.edu, www.brown.edu.*

BOOSTING LI-ION BATTERY PERFORMANCE

Researchers at Missouri University of Science and Technology, Rolla, are working to improve the short-life of lithium-ion batteries by using atomic layer deposition (ALD). Xinhua Liang, assistant professor of chemical and biochemical engineering, is leading a study that dopes and coats lithium magnesium nickel oxygen (LMNO) with iron oxide—at the same time—through ALD.

"Unlike current research that either covers the particles' surface with insulating film or dopes the particles to improve battery performance," explains Liang, "this ALD process combines the coating and doping processes into one, and applying this technique makes rechargeable lithium-ion batteries last longer." The new process makes lithium-ion batteries that have 93% capacity retention after 1000 cycles of charge and discharge at room temperature and 91% at elevated temperatures. This is equivalent to roughly three years of battery life with nearly the same performance as a new battery, he adds. *For more information: Xinhua Liang, 573.341.7632, liangxin@mst.edu, www.mst.edu.*



Button battery testing in Xinhua Liang's lab.

BRIEF

Researchers at **Stanford University,** Palo Alto, Calif., developed and tested a new material that can cool a solar cell by up to 13°C under the California winter sun. Because heat makes solar cells less efficient, the team predicts their cooling layer could help solar cells turn approximately 1% more sunlight into electricity, a big boost from a simple add-on. Cooler temperatures also mean the solar cells will likely last longer due to greatly reduced efficiency degradation rates. Researchers achieved the combination of cooling plus maintaining sunlight absorption with a wafer made of silica. *stanford.edu.*

SURFACE ENGINEERING

Flake-type nanoparticles of zinc-phosphate increase the gas barrier for corrosion protection in steel. Courtesy of INM/Uwe Bellhäuser.

NEW TECHNIQUE PROTECTS STEEL FROM RUST

Researchers at INM—Leibniz Institute for New Materials, Germany, developed a special type of zinc-phosphate nanoparticles to combat corrosion in steel plates and girders used in architecture, construction, and bridge building. In contrast to conventional, spheroidal zinc-phosphate nanoparticles, the new nanoparticles are flake-like and 10 times as long as they are thick. As a result of this anisotropy, gas molecules cannot penetrate the metal as fast.

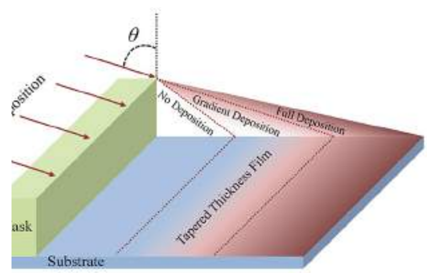
Steel plates were immersed in electrolyte solutions with both spheroidal zinc-phosphate nanoparticles and with flake-type zinc-phosphate nanoparticles in each case. After just half a day, the steel plates in the electrolytes with spheroidal nanoparticles showed signs of corrosion where the steel plates in the electrolytes with flake-type nanoparticles were still in perfect condition and shining—even after three days. Researchers created their particles using standard, commercially available zinc salts, phosphoric acid, and an organic acid as a complexing agent. The more complexing agent they added, the more anisotropic the nanoparticles became. *www.leibniz-inm.de/en.*

CONTROLLED DEPOSITION CREATES COMPLEX STRUCTURES

A team of researchers at Purdue University, Lafayette, Ind., developed an angled vapor-deposition system that allows for more controlled deposition for the creation of complex and novel quasi-3D structures. Physical vapor deposition (PVD) is a common method for creating structures such as perfectly flat thin films. However, the method is fairly static and deposition occurs perpendicular to the vapor source.

In order to deposit complex structures, the team took advantage of the line-of-sight properties of vapor deposition. Unlike a traditional PVD setup, where the deposition angle is perpendicular to the substrate, they used a system where both the deposition angle and substrate angle can be manipulated. This system, known as glancing angle deposition (GLAD), creates shadow regions, where parts of the substrate are blocked from the deposition line of sight. This allows for controlled buildup of material in one area, leaving others untouched.

One of the more straightforward applications of this system is tapered thickness films. GLAD can also create far more complex structures, especially when nonplanar substrates are used. Much like a masked flat surface, a curved surface will receive differing thickness of deposition. A sphere, for example, would receive the largest amount of deposited material at a point perpendicular to the deposition angle, with a gradient along the curve. However, by rotating the substrate, most of the surface region of the sphere will be capped by the evaporation source, leading to an onion-shaped core-shell structure. Alternating deposition between metal and dielectric components creates a multilayered core-shell structure. *For more information: Alexandra Boltasseva, 765.494.0301, aeb@purdue.edu, www.purdue.edu.*



Mask, angled deposition can be used to create thickness gradient thin films. The mask blocks deposition from occurring on the substrate closest to it, with thickness increasing moving away from the mask. Courtesy of Alexandra Boltasseva.

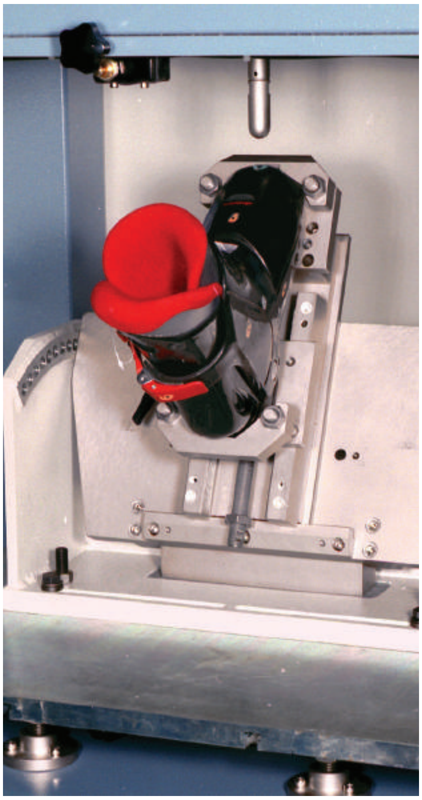
BRIEF

Scientists at the **U.S. Naval Research Laboratory,** Washington, discovered that particle atomic layer deposition (p-ALD) deposits a uniform nanometer-thick shell on core particles regardless of core size. The team grew alumina on nano- and micron-sized particles of tungsten and measured the shell thickness in a transmission electron microscope. Because of the huge mass/density difference of the two materials, this pairing provides maximum contrast in the electron microscope and delineation is easily distinguishable between the particle core and shell. *nrl.navy.mil.*

MECHANICAL TESTING OPTIMIZES ATHLETIC MATERIALS DEVELOPMENT

For sports and recreation equipment manufacturers and sports medicine clinicians, mechanical testing is essential to optimize material performance, minimize injury, and improve recovery outcomes.

Fatigue testing of athletic footwear determines energy absorption.



Impact testing of a ski boot determines fracture properties.

B*iomechanics* applies established mechanical principles to biological structures and functions as they relate to the body in motion. By applying the laws of mechanics to the human body, engineers can analyze professional athletes and develop materials that will enhance performance and help prevent sports-related injuries.

Many sporting goods manufacturers pay close attention to material performance, especially with regard to footwear, clothing, and protective equipment. Even with improvements that help minimize injury risk, damage and wear often still occur. Some of the most common ligament and tendon tears, along with broken bones, occur during sports-related activities. There is a rising demand from both professional and recreational athletes to improve injury-related recovery times and increase therapy options. For sports and recreation equipment manufacturers and sports medicine clinicians, mechanical testing is essential to optimize material performance, minimize injury, and improve recovery outcomes.

ATHLETIC FOOTWEAR TESTING

Footwear is one of the most important aspects of all athletic endeavors, with significant resources invested into the design of high-performance footwear. Therefore, testing plays an important role in athletic shoe research and development efforts. For example, engineers often investigate the impact and rebound performance of different materials and structures. Intense activities such as long-distance running, soccer, and basketball often place excessive mechanical loads on footwear that can result in impact forces of more than 10 times an athlete's body weight.

Today's athletic wear manufacturers are designing and developing shoes with high-performance soles, which often incorporate air cushioning, gel-filled capsules, or both. One type of mechanical test manufacturers use to guide design is *energy return*. Mechanical fatigue testing evaluates the behavior of different parts of the sole and helps identify parameters such as dynamic stiffness and the ability to absorb energy.

Some fatigue testing machines allow users to import complex waveforms to simulate a runner's gait. Determining the mechanical performance of complex viscoelastic materials in shoe soles is critical to improving athletic footwear design. Optimizing this performance helps reduce ankle, knee, and hip stress, and ultimately enables athletes to move faster and avoid injury.

TESTING ENHANCES PROTECTIVE GEAR

Sports safety and sports-related injury are hot topics, especially as they pertain to high-impact activities such as football and hockey. In these sports, the dual objective of equipment suppliers is to both enhance performance and minimize injury. In recent years, hockey and football equipment manufacturers have increased their impact testing and static testing to ensure that protective gear functions correctly.

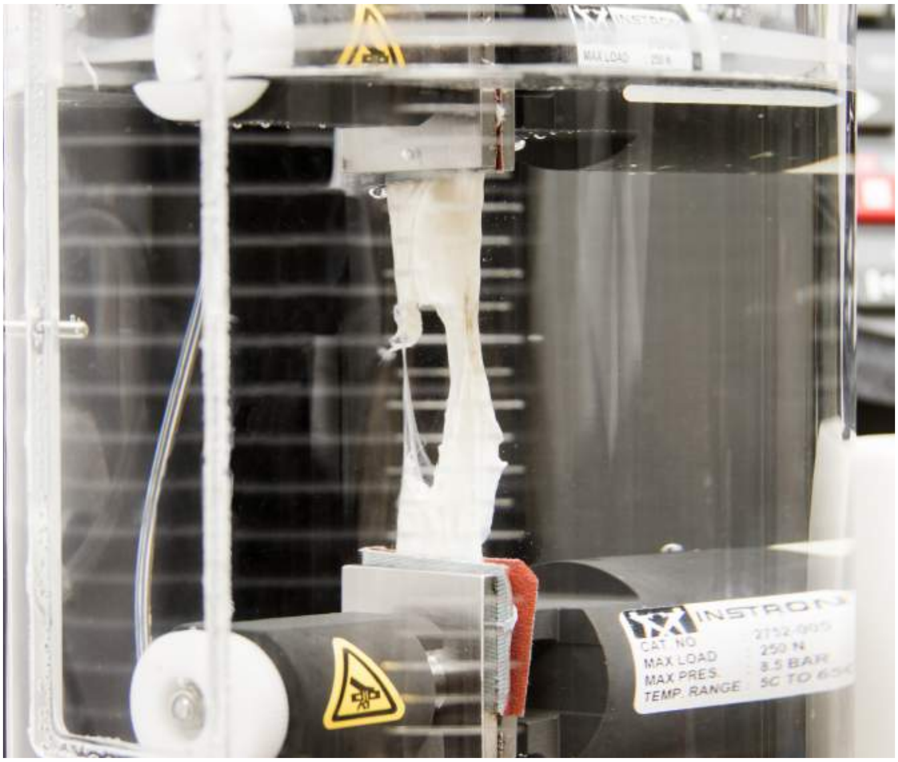
For example, equipment designed to reduce bodily impact, such as shoulder and body padding, is tested to determine the amount of energy absorbed. Also, because protective materials are often bulky and cumbersome for athletes to wear and maneuver in, manufacturers are constantly looking for lighter and more breathable materials that do not sacrifice impact resistance.

Protective gear, such as helmets, is also impact tested to determine the strength of the outer helmet shell, inner cushioning, and strap. One key component of helmet design is the ability to distribute impact shock. The amount of force transmitted through the helmet can be quantified using multiple strain gauges mounted to both a dummy headform and external helmet. Today's helmet design has drastically improved with an abundance of resources continually invested and greater awareness of head health issues. Helmets are now multilayered and combine impact-absorbing pliable materials to reduce concussions and protect athletes from impact-related injuries.

BIOMATERIALS DEVELOPMENT AND TESTING

While impact-related injuries are common in professional football and hockey, some of the most prevalent injuries among other professional athletes and recreational players are muscle pulls and tears, especially in knees and shoulders. A tear to the anterior cruciate ligament (ACL) is one of the most severe sports injuries and requires surgery to restore. Proper repair of an ACL tear may require several months of healing depending on the patient's age and health. Unfortunately, this injury is sometimes serious enough to shorten an athletic career.

Many biomedical companies are focusing on ways to improve musculoskeletal healthcare. Not only are they investing in creating better equipment for surgeons and doctors, but they are also investigating new biomaterials. A major initiative of biomaterials



Tensile testing of a biomaterial determines strength and elasticity properties.

research is to understand and compare the mechanical properties of synthetic materials to native tissues. While ASTM and ISO standards are forming to help guide biomaterials testing, most testing regimens performed in both industry and academia are created internally. As biomaterials exhibit viscoelastic properties, there is often a simple cyclic component to a static tensile test.

Biomaterials testing is often conducted at body temperature and in a saline bath to best mimic physiological conditions. Other knee injuries, such as patellofemoral syndrome, are caused by the knee cap repeatedly moving against the leg bone and wearing out or damaging knee cap tissues. This is often evident in athletes who run, swim, play basketball, and cycle.

Biomaterials, such as hydrogels, may someday help treat wear and damage to knee cap tissues. Hydrogel stiffness can vary by increasing or decreasing the number of crosslinks in the polymer. Many materials scientists perform rheology, compression, tension, and fatigue testing on hydrogels to understand mechanical properties during and after polymerization, as well as long-term properties. Although muscle, ligament, and tendon tears along with cartilage wear are fairly common in both professional and recreational athletes, biomaterial solutions are still in the research and development phase due to the complexity of biocompatibility.

In the clinical setting, materials scientists already have solutions to deal with broken bones—bone screws and fracture fixation plates are widely used and are biocompatible. When a severe bone fracture occurs, sometimes a cast is insufficient to heal the break. Commonly, a titanium plate with bone screws used to hold the plate in place will bridge two or more fractured bone pieces together.

While these are metal implants and not biomaterials, by using a type of metal with mechanical properties similar to bone, scientists have discovered that bone will integrate with these plates. The integration of bone with a fracture fixation plate and bone screws is known as *osseointegration.* Once the metal fixation plate is in the body, it can remain there indefinitely.

Mechanical testing is critical to optimize the performance of sports and recreation equipment and the materials used to heal injuries resulting from these activities. As scientists continue to study the biomechanics of athletes and continue to develop new materials, lighter, stronger, and more flexible sporting equipment will become available to both professional and recreational athletes. **~AM&P**

For more information: Elayne Gordonov is biomedical assistant market manager, Instron, 825 University Ave., Norwood, MA 02062-2643, 800.877.6674, www.instron.us.

TECHNICAL SPOTLIGHT

BIOCOMPOSITE MATERIALS FOR ORTHOPEDIC SPORTS MEDICINE IMPLANTS

The fourth—and most recent—step in the evolutionary ladder of materials for orthopedic sports medicine applications involves composites made of one or more bioabsorbable polymers.

One of the most important aspects of orthopedic sports medicine is attaching soft tissues such as tendons and ligaments to bone. This attachment process is facilitated by a wide variety of implants in the form of anchors, buttons, pins, staples, and screws. Mechanical strength and biocompatibility are important properties of these devices and early generations of implants were made from metal alloys such as Nitinol and stainless steel or plastics such as polyether ether ketone (PEEK). Potential disadvantages of these materials include interference with some imaging modalities, metal sensitivity, and difficulty with device removal[1].

In the 1990s, bioabsorbable homopolymers such as poly-L-lactic acid (PLLA) and polyglycolic acid (PGA) were introduced. Unfortunately, when used in isolation, the former material tends to have a very long degradation rate, while the latter degrades so rapidly that cysts or draining sinuses can form[2]. The patient's conflicting priorities between implant absorption in a reasonably short time and avoiding soft tissue irritation require a delicate balance from designers of new materials for sports medicine implants. Polymer degradation naturally occurs in the human body as these acids are incorporated in the tricarboxylic acid cycle (Krebs cycle) and are ultimately excreted from the body as carbon dioxide and water[3].

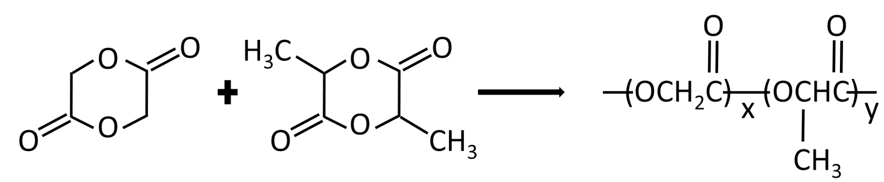


Fig. 1 — Chemical structures of L-lactide and glycolide combine to form poly(lactide-co-glycolide) polymer (PLGA).

A third generation of implants uses copolymers of these and other polymers, as well as stereoisomers of polylactic acid (PLA) such as combinations of dextro and levo monomers. For example, L-lactide and glycolide can be combined to form poly(lactide-co-glycolide) polymer (PLGA) (Figure 1). These implants degrade at a sufficiently fast, but not overly rapid, rate. However, bioabsorption of the implant does not typically fill back in with bone, thus leaving an undesirable area of weakness (i.e., a cavity) in the patient[4].

The fourth—and most recent—step in the evolutionary ladder of materials for orthopedic sports medicine applications uses composites made of one or more bioabsorbable polymers with osteoconductive (bone forming) bioceramics such as β-tricalcium phosphate (β-TCP). Extensive preclinical and clinical data exist for one specific formulation comprising 30% β-TCP by weight and 70% PLGA, called Biocryl Rapide (BR) from DePuy Synthes, Mitek Sports Medicine, Raynham, Mass. A variety of implants manufactured from this material are available including interference screws for use in anterior cruciate ligament (ACL) reconstructions and suture anchors for use in both rotator cuff and labrum repairs in the shoulder. All of these surgical procedures are common in sports medicine.

MANUFACTURING OF BIOCRYL RAPIDE

Powdered β–TCP and PLGA are dried and then mixed together using an extrusion machine: The PLGA is melted and then β–TCP is mixed into the melt using a proprietary microparticle dispersion process. This technique ensures homogenous dispersion of the composite materials (Fig. 2), thereby reducing the incidence of stress risers within the implant itself and ensuring that the osteoconductive β-TCP is in close apposition with the surrounding bone tissues during the entire absorption process. The molten composite exits the machine and is then cut into pellets approximately 3 mm long. Pellets are later fed into injection molding machinery to mold specific implants

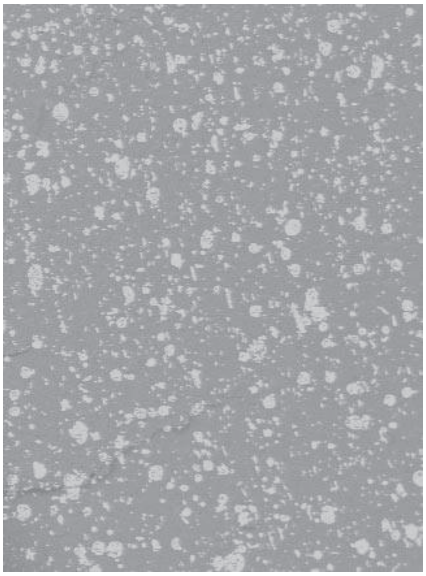


Fig. 2 — Scanning electron micrograph of Biocryl Rapide (270x).

(Fig. 3). Wall thicknesses down to approximately 0.5 mm are possible and implants are typically sterilized with ethylene oxide prior to implantation.

MECHANICAL PROPERTIES

For many orthopedic sports medicine applications, the implant's mechanical properties are critical both immediately after surgery and for the entire healing period. After the patient is fully healed, implants should generally no longer be load bearing. With BR, adding the bioceramic filler compromises the inherent strength of the parent polymer, but not to an unusable degree. For example, suture anchors made from BR are roughly 87% of the strength of the same size suture anchors made from PEEK (Fig. 4). However, in internal tests, the tensile modulus is higher for BR (2.6 GPa) compared to PLLA (2.0 GPa). In addition to decreasing strength and increasing modulus, β–TCP affects ductility, as might be expected. Interestingly, internal testing shows a significant improvement in ductility as the material is brought from room temperature to body temperature. In fact, the engineering strain at fracture nearly doubles to approximately 9% over the course of this 14°C temperature increase. Over the same temperature rise, maximum stress drops from 72.4 to 53.8 MPa (Fig. 5).

Fig. 3 — Suture anchors injection molded from Biocryl Rapide loaded onto stainless steel inserters.

PRECLINICAL STUDY

Despite a long history of clinical use for all three components of BR (β–TCP, PLLA, and PGA), a preclinical study was performed on the specific blend of these components in BR. A femoral transcortical model using Beagle dogs was setup in which cylindrical rods of BR and PLLA (as a control) were implanted into holes drilled in the animals' legs. Bone integration was studied at set time frames up to 24 months after surgery[5].

As expected, PLLA rods exhibited little to no absorption at three and 10 months; at 18 months, absorptive changes were graded as minor to moderate. At 24 months, the absorption profile of all eight implants was still graded as moderate.

The BR rods were also fully intact at three months, but exhibited minor absorption characteristics at 10 months. By 15 months post-op, the rods had significant fissures throughout, although the majority of the BR was still present. At 18 months, the BR rods were mostly absorbed and replaced by a combination of new bone at the periphery and a mixture of macrophages and mesenchymal cells near the center. By 24 months, the BR material was 97-99% absorbed[5]. This volume was completely filled with new bone in four cases and 75-87% filled with new bone in the remaining four cases (Fig. 6). Newly formed bone was visually normal in all respects. This study provided direct in vivo evidence of the biocompatibility and appropriate absorption profile for this material[5].

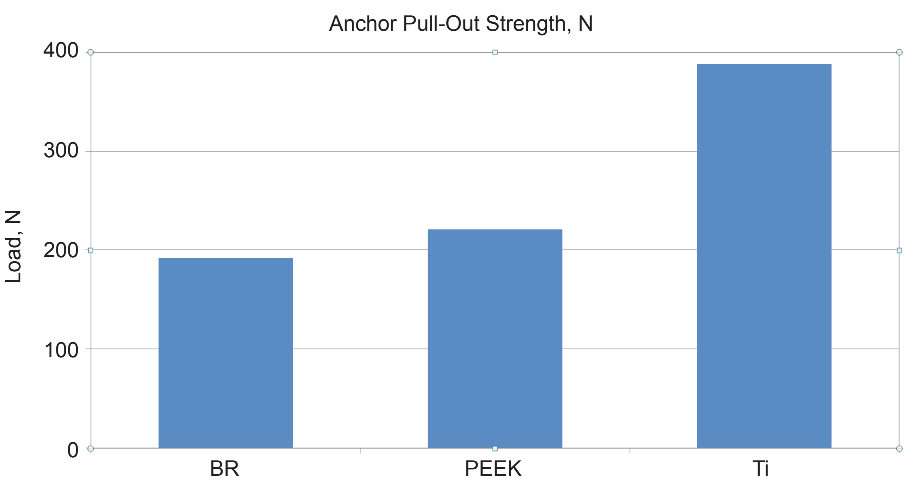


Fig. 4 — Relative pull-out strength of similar suture anchors made of Biocryl Rapide (left), PEEK (middle), and 6Al-4V titanium (right).

SUMMARY OF CLINICAL DATA

Following the launch of the first orthopedic implant made of BR in 2004, multiple clinical series describing the osteoconductivity of this material have been published in the peer-reviewed orthopedic sports medicine literature, including at least four in the past three years[6-9]. In total for these studies, 167 patients were followed for between two and three years after either ACL reconstruction, repair of Bankart lesions following shoulder instability, or rotator cuff repair surgery. Radiographic and magnetic resonance imaging (MRI) evidence suggest that BR is nearly

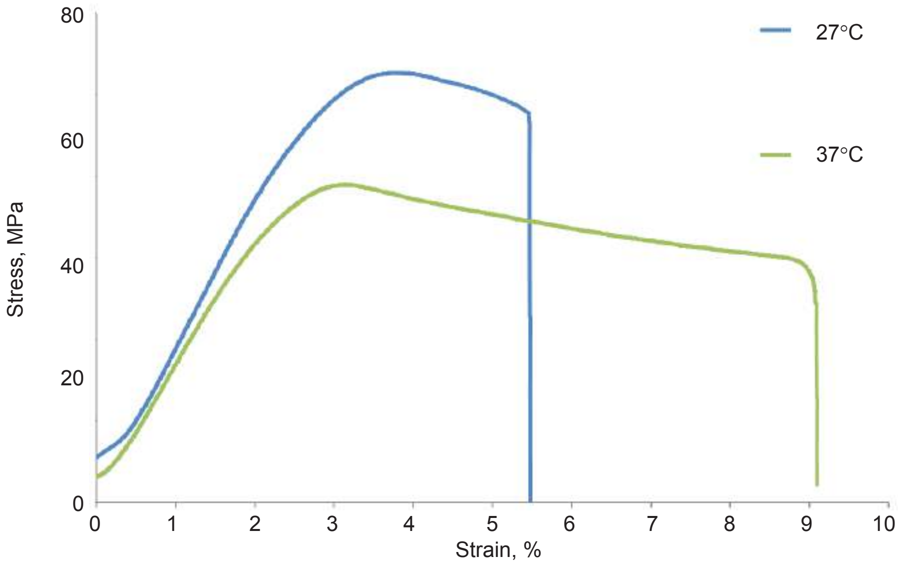


Fig. 5 — Stress vs. strain plots for BR at room temperature (27°C) vs. body temperature (37°C).

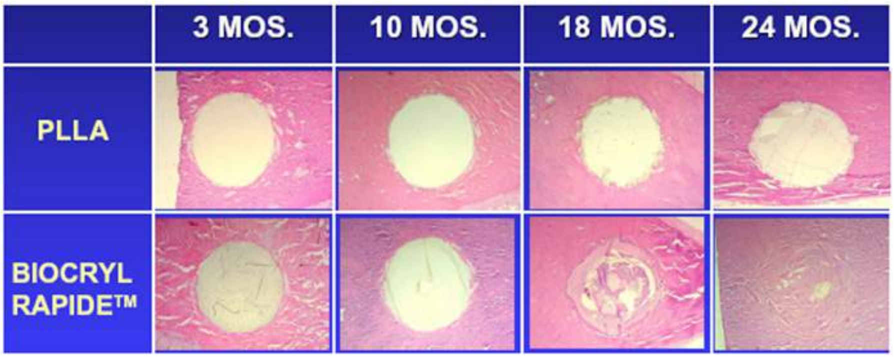


Fig. 6 — Histologic sections of rods (white) in bone (stained red using a hematoxylin and eosin stain) show degradation profiles over 24 months[5].

completely absorbed and in most cases, boney ingrowth follows in the timeframe of approximately 2–3 years.

In addition, implants made of this material do not cause adverse effects such as cyst formation or soft-tissue inflammatory reactions. For example, one prospective clinical study concluded, "Anchors made of 30% β-tricalcium phosphate and 70% PLGA showed excellent biological efficacy, without causing significant cyclic lesions, producing gradual changes in the MR signal that seems to become equivalent to that of the glenoid trabecular bone at a mean of 29 months after implantation."[7] However, not all biocomposite materials were as successful, with one of these clinical studies halted prematurely when the other biocomposite material was pulled from the market by the manufacturer due to "pretibial soft-tissue swelling"[8].

CONCLUSION

With a 12-year history of use in humans, Biocryl Rapide remains state-of-the-art in terms of orthopedic sports medicine applications. Multiple preclinical and clinical studies have shown BR to be sufficiently strong for specific orthopedic applications while almost fully absorbing in an appropriately short timeframe. Further, these studies show that BR promotes formation of new bone to backfill the volume that was previously inhabited by the implant. **~AM&P**

For more information: David Spenciner, FASM, is a research fellow, DePuy Synthes, Mitek Sports Medicine, 325 Paramount Dr., Raynham, MA 02767, 508.828.3721, dspencin@its.jnj.com, depuysynthes.com. Co-authors include Dennis Burke and Samir Bhattacharyya.

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TECHNICAL SPOTLIGHT

DESIGNING THIRD GENERATION ADVANCED HIGH-STRENGTH STEEL FOR DEMANDING AUTOMOTIVE APPLICATIONS

By effectively mitigating the historical paradox between strength and ductility, a new alloy enables an entire family of automotive sheet steel to meet today's lightweight automobile requirements.

There has long been a struggle among materials scientists over the paradoxical relationship between a metal's strength and ductility. The inability of traditional materials to meet the dual demands of both high-strength and easy formability has opened the door for alternative materials in applications such as automotive lightweighting. Existing advanced high strength steels (AHSS) require a tradeoff: High strength parts can either be designed using more limited geometries or produced using more expensive methods such as hot stamping. Both approaches are less than ideal.

The existing pattern of strength and ductility relationships in automotive steel alloys is demonstrated by the well-known *banana plot* from WorldAutoSteel (Fig. 1). Conventional steels (green) represent the backbone of the global economy—they are strong enough for many applications and demonstrate high formability, which allows them to be inexpensively shaped for a wide variety of uses.

The known AHSS (orange) trade much of that formability for increased strength. The one exception is twinning induced plasticity (TWIP) steels, which seemed to solve the problem but are limited in use due to multiple factors including delayed fracture. Austenitic

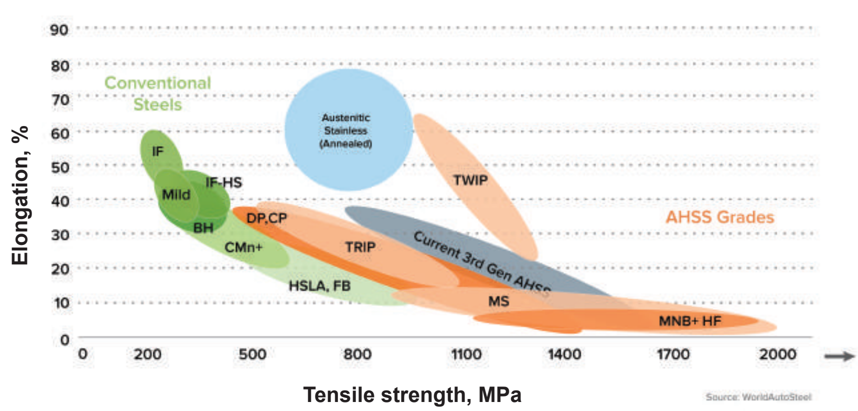

Fig. 1 — WorldAutoSteel banana plot illustrates steel grades used in automobiles.

stainless steels present another option for achieving the desired properties, but their cost is prohibitively expensive for automotive body structures as well as many other applications.

THIRD GENERATION AHSS PROPERTIES

Automakers have established properties for third generation AHSS to meet industry needs (Fig. 2). A number of ways to design new steels to overcome existing challenges are being explored, including variants on quench, partitioning, and tempering. However, these types of steels typically cannot deliver total elongation higher than 20%, which is inadequate for forming advanced automotive parts.

A different approach to overcoming the existing strength and ductility paradox to achieve the desired properties required for third generation AHSS is being taken at NanoSteel, Providence, R.I.[1]. Conventional steel constituents in novel ratios are used while new mechanisms are harnessed for creating the nanoscale structure. This approach results in a targeted formation called a *mixed microconstituent structure*, enabling the sheet to exhibit the desired AHSS properties.

In the new structure, two distinct microconstituents act synergistically on a local level during deformation. By varying the volume fraction of the microconstituents in the final sheet material, many different outcomes for

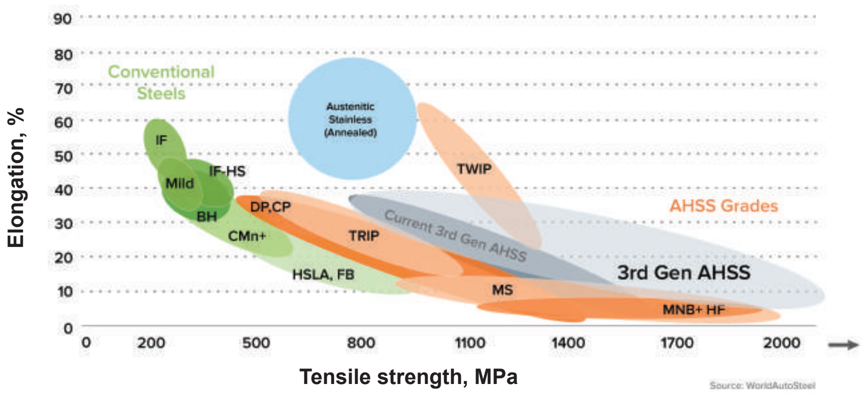

Fig. 2 — WorldAutoSteel banana plot with target properties for third generation AHSS.

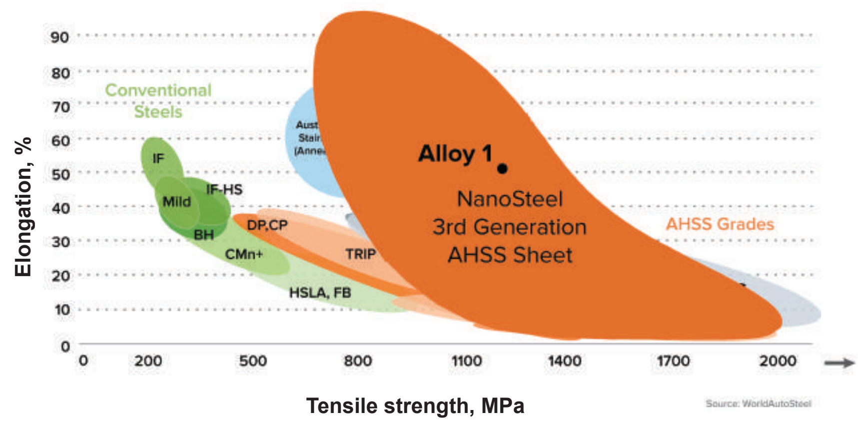

Fig. 3 — Modified WorldAutoSteel banana plot with property ranges achievable through a new approach to developing third generation AHSS.

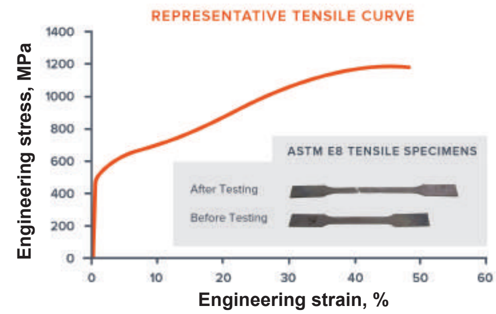

Fig. 4 — Tensile stress-strain curve for Alloy 1 and view of corresponding ASTM E8 tensile specimens before and after deformation.

strength and ductility are possible, as seen in Fig. 3. This article focuses on one sheet steel design produced from example Alloy 1.

TARGETED MICROSTRUCTURE FORMATION

The properties of each alloy depend on the chemistry as well as specific steel mill processing parameters. For example, Alloy 1 has a proprietary iron-based alloy chemistry that, when processed, results in ultimate tensile strength of roughly 1200 MPa with average elongation of 50% (Fig. 3) as seen in the tensile stress-stain curve in Fig. 4.

The two microconstituents that comprise these alloys enhance properties through their ability to act synergistically. *Microconstituent A* consists of micron-sized austenitic grains with dislocation networks and nanoprecipitates. This constituent, with its larger grain sizes, mainly supports high ductility in the final steel with strengthening through nanoprecipitation.

The second component, *microconstituent B,* is comprised of nanoscale ferritic grains with nanoprecipitates that form during deformation. This provides strength due to the combination of nanoscale grain sizes and nanoprecipitation with both the austenite and transformed ferrite contributing to ductility. These two components (~50% each) in the *mixed microconstituent* structure of Alloy 1 can be seen in Fig. 5.

PROCESSING AND FINAL PROPERTIES

The way in which industrial steel is made is a key factor in the mixed microconstituent structure formation in the final sheet. In the steel mill, an alloy is continuously cast into slabs using standard high-throughput mill equipment. The cast alloy then solidifies into dendritic structures with austenite grains and interdendritic pinning phases containing nanoprecipitates (Fig. 6). The properties at this point demonstrate tensile strength of around 600 MPa and elongation below 15%.

In the next stage, slabs are heated in the tunnel furnace to within 50-100°C of the melting point. Hot rolling the slab reduces thickness and forms a hot band, which is then air cooled and spooled into a coil. The hot-band material structure is seen in the second stage of Fig. 6 (the nanomodal structure). The nanomodal structure sees significant structural refinement taking place as grain size is reduced, leading to significant property improvement. At this stage, the hot band material features the required tensile strength of about 1200 MPa and elongation over 40%.

Next comes cold rolling, where material strength is further developed. Cold rolling is done in multiple passes, depending on the starting thickness of the hot band and desired thickness of the cold rolled sheet. The high strength nanomodal structure of the resulting cold rolled sheet occurs due to extensive deformation through dislocation mechanisms with phase transformation. The structure consists of transformed nanoscale ferrite grains, retained austenite, and nanoprecipitates. The effect of this phase transformation is demonstrated by increased strength, in the case of Alloy 1 to over 1600 MPa with an associated reduction in elongation to about 15%.

At this point, the material must be annealed to restore ductility before it can be used in an automotive structural

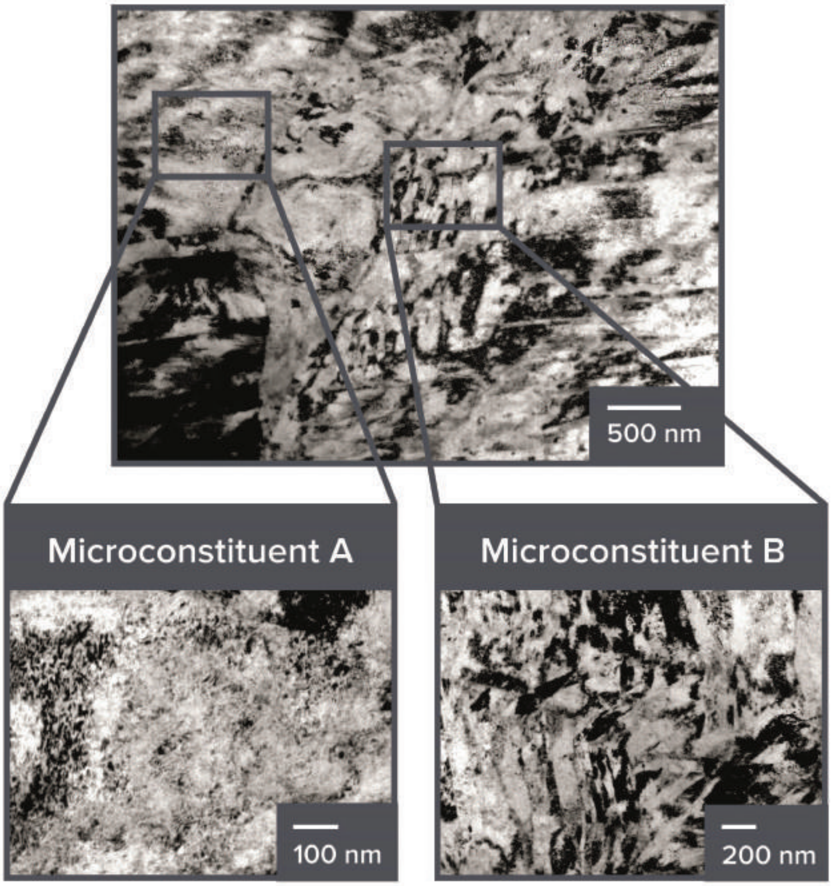

Fig. 5 — Targeted mixed microconstituent structure in Alloy 1, leading to third generation AHSS with novel properties.

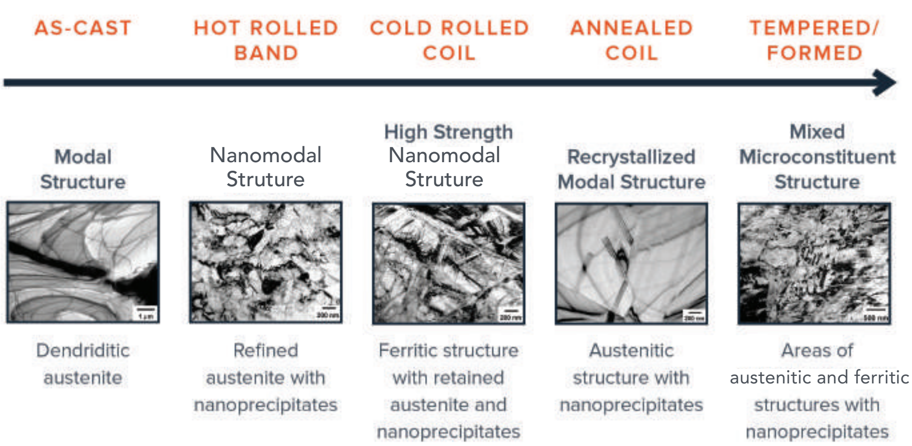

Fig. 6 — Alloy 1 structural development through the major steel processing stages leading to the final third generation AHSS structure.

design. On an industrial scale, annealing can be either continuous or batch. This heat treatment results in alloy recrystallization, which removes cold-work effects and provides a phase transformation of ferrite back to austenite. When the recrystallized sheet structure deforms, the targeted mixed microconstituent structure is formed, resulting in the desired combination of tensile strength at ~1200 MPa with elongation above 45%.

Mixed microconstituent structure formation occurs during steel manufacturing and also during the automotive part manufacturing process—stamping, roll forming, or hydroforming. Microconstituents generated during deformation provide high formability to achieve complex shapes as well as high strength.

The complete microstructural pathway of this new sheet steel alloy—from the as-cast modal structure to the final mixed microconstituent structure—occurs through typical commercial sheet steel processing steps and does not require additional methods such as rapid solidification or quenching.

CONCLUSION

Aggressive fuel economy regulations including U.S. Corporate Average Fuel Economy (CAFE) standards have spurred the automotive market to incorporate alternative materials such as aluminum and composites and create clear targets for third generation AHSS to meet the industry's lightweighting goals. By effectively mitigating the historical paradox between strength and ductility, NanoSteel's alloy design pathway enables a new family of automotive sheet steel to meet these requirements. These new steels are expected to offer automakers affordable structural design options that can substantially reduce vehicle weight for more fuel efficient cars and trucks.

For more information: Daniel J. Branagan is chief technology officer, NanoSteel, 272 W. Exchange St., Suite 300, Providence, RI 02903, 401.270.3549, dbranagan@nanosteelco.com, www.nanosteelco.com.

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METALLURGY LANE

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

THE INTEGRATED STEEL INDUSTRY–PART II

INTEGRATION OF THE STEEL INDUSTRY CONTINUED WITH THE RISE OF BETHLEHEM STEEL CORP.

Bethlehem Steel Corp. debuted as Bethlehem Iron Co. in 1860 with blast furnaces and rolling mills for wrought iron railroad rails. The company hired John Fritz from Cambria Iron Co. in Johnstown, Pa., as general manager. After making iron rails for several years, Bethlehem contracted with Alexander Holley to build one of the first Bessemer plants to convert to steel. They installed four Bessemer converters and new rolling mills for steel rails. The plant went onstream in 1873 with annual capacity of 35,000 tons and a reputation as the finest plant in the U.S.

However, it was a small plant and its eastern location was problematic as rail use was moving west. Under Fritz's leadership, the company built facilities for making large forgings and heavy plate, including armor plate for the Navy. Previously, these products were imported from England and Germany due to a lack of domestic manufacturers. Bethlehem Steel was soon recognized as a producer of ship propeller shafts, large gun barrels, and heavy battleship armor equal to any provided from overseas.

The principals put the company up for sale after the turn of the 19th century. Charles Schwab bought 160,000 shares—giving him controlling interest—while he was still president of U.S. Steel Corp. When he was forced out of "The Corporation," he turned his full attention to developing Bethlehem Steel from a minor steelmaker into a competitor to his former company. The sale included several shipyards that became a large part of Bethlehem's future production and profits.

When World War I started in 1914, the federal government passed a Neutrality Act to keep the U.S. from becoming involved in the conflict. This prevented trade in armaments with England, France, and Russia. Schwab ignored the act, as did many other companies, and received orders for gun barrels, armor plate, and ammunition from all three allies. Bethlehem Steel opened a munition plant to supply this overseas trade and as the war continued over four years, it became the largest manufacturing plant in artillery shells in the world, making 750,000 shells per month. In addition, it produced 60% of all finished guns built for the U.S. market.

GROWTH AND PROFITS DURING WWI

The company shipped 6 million tons of steel during the war period and went from 15,000 to 94,000 employees. The shipyard received orders for freighters and destroyers, significantly adding to profits. Earnings in 1916 were $62 million, with Schwab receiving $2.4 million in dividends and new stock worth $17 million. With these wartime profits, Bethlehem purchased the Pennsylvania Steel Co. for $32 million. They acquired the Steelton plant built by Edgar Thomson and Tom Scott during the age of Bessemer Steel and a newer deep-water plant at Sparrows Point, Md. Bethlehem now had annual capacity of 2.2 million tons, exceeding all competitors except U.S. Steel. In the last two years of the war, Bethlehem's earned income was $111 million.

ACQUISITIONS DURING THE 1920s

Bethlehem used its wartime profits to acquire other steel companies.

Charles M. Schwab, former president of Carnegie Steel, was CEO of Bethlehem Steel from 1904 to 1939. Circa 1918.

In 1922, the company purchased the Lackawanna Steel Co. outside Buffalo, N.Y., for $54 million—raising its annual capacity to 5.5 million tons. A year later, it bought the Midvale Steel Co. for $95 million, which included Cambria Steel where John Fritz had invented the three-high rolling mill and William Kelly had worked on his air blowing process. Bethlehem renamed Cambria Steel the Johnstown Mill. The addition of both Midvale and Johnstown increased Bethlehem's annual capacity to 10 million tons.

Integrating these various steel operations to improve efficiency and lower overhead cost proved to be a greater challenge than expected. This would require a major effort during the following two decades, as Bethlehem had acquired older plants in need of significant maintenance and upgrading. As part of the work, the company modernized and added capacity to the Sparrows Point plant, which became one of the largest in the country.

THE GREAT DEPRESSION

As industry collapsed during the Great Depression, steel shipments reached lows not seen during the previous 20 years. In 1932, Bethlehem operated at just 20% of capacity with a loss of $19 million. When the recovery started

Eugene Grace (hand on face) testifying before Congress in 1955. Grace was president of Bethlehem Steel from 1916-1945 and chairman of the board from 1945-1957.

in 1933 and beyond, the increased business was in lighter flat-rolled products for the automobile and appliance markets in the Midwest. Bethlehem only had one mill that could reach this market—the Lackawanna plant where the company had installed continuous hot rolling mills for sheet in 1937.

CONTRIBUTIONS DURING WWII

With the start of WWII in Europe, Bethlehem received $300 million in orders from England. (Recall that it was production for overseas orders during WWI that allowed Bethlehem to accumulate excessive profits.) This time, orders went through the War Production Board instead of J.P. Morgan in London, therefore limiting profits. During WWII, Bethlehem's greatest contribution was in its shipyards. Shipbuilding employment increased from 7000 to 182,000, accounting for 95% of employment growth for the entire corporation. In four years, Bethlehem built 1127 ships, produced 73 million tons of steel, and furnished the Navy with one-third of its needs for armor plate and gun forgings.

The USS Massachusetts (BB-59) was built at the Bethlehem Fore River Shipyard during WWII.

1950s SEES RENEWED GROWTH

The 1950s were very productive and profitable for the steel industry, as demand for steel exceeded that of WWII. At times, Bethlehem operated at 100% of capacity with an average of 150,000 employees. Total net income for the period 1950-1959 was $1.37 billion. With these reserves, the company added 5 million tons of steel to its annual capacity, bringing the total to 20 million tons. In 1954, Bethlehem attempted to acquire Youngstown Sheet and Tube to gain additional markets in sheet products in the Midwest. However, the merger was prevented by the Justice Department on grounds that it would violate the Clayton Antitrust Act. In 1956, Bethlehem announced a program to expand production to 23 million annual tons. Two million would be at Sparrows Point, increasing that plant to 8 million tons with a 10th blast furnace and a new open hearth shop. When expansion was complete in 1958, Sparrows Point was the largest steel mill in the world. All of this optimism was based on steel consumption continuing well into the next decade or two.

However, in early 1959 the entire steel industry failed to understand that

Bethlehem Steel's corporate headquarters in Bethlehem, Pa.

the high production and profits they had enjoyed for 10 years had come at an unsustainable cost. While the domestic steel industry was busy building new capacity with the open hearth process that had dominated steelmaking for over 50 years, new technology was coming onstream in Europe and Japan. First was the basic oxygen furnace (BOF), which used oxygen blown through the heat of molten metal to convert it to steel. This novel process could convert cast iron from the blast furnaces to steel in 45 minutes compared with 8 hours in the open hearth. The process had been invented in Austria and was installed in other countries as new open hearths were erected at Sparrows Point. One small U.S. producer, McClouth Steel Co., had built a 35-ton unit in 1954 and Jones and Laughlin Steel Co. built several in 1959. This would leave the two biggest steel companies in the U.S. with new open hearth shops that would become obsolete in the 1960s.

The second new technology that was developing overseas was the continuous casting machine. Molten metal from the steelmaking furnaces was ladled into a machine that allowed solidification as it moved through the unit and a semifinished product left the machine. This process eliminated the old system of casting molten metal into large ingots that had to be reheated and reduced to semifinished products either by forging or in a rolling mill. Bethlehem Steel would require many years and billions of dollars to convert its mills to these new processes.

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

Bethlehem Steel supplied the steel and built the Golden Gate Bridge, which opened in 1937. Courtesy of Ryan J. Wilmot/Wikimedia Commons.

Thermal Spray Society
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JULY / AUGUST 2016 | VOL. 11 | ISSUE 3

iTSSe

INTERNATIONAL THERMAL SPRAY & SURFACE ENGINEERING

THE OFFICIAL NEWSLETTER OF THE ASM THERMAL SPRAY SOCIETY

THERMAL SPRAY COATINGS IN INDUSTRIAL APPLICATIONS

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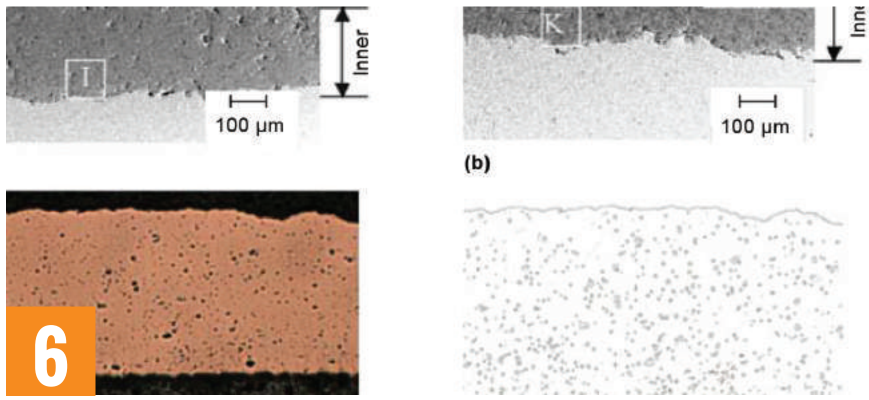
EDITORIAL OPPORTUNITIES FOR *iTSSe* IN 2016

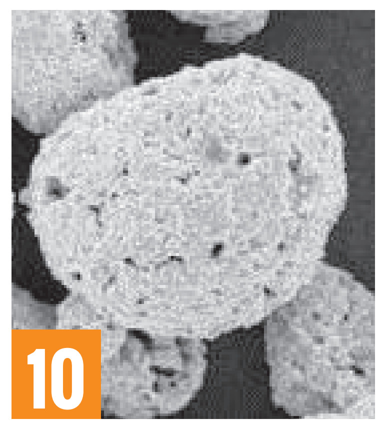
The editorial focus for *iTSSe* in 2016 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing the latest opportunities for coatings and surface engineering.

November Issue:
Emerging Technologies/Applications & Case Studies

To contribute an article, contact Julie Lucko at julie.lucko@asminternational.org.

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





DEPARTMENTS

ABOUT THE COVER

The I7 torch uses high velocity oxide fuel thermal spray processing to coat the interior of a rotary valve. Courtesy of UniqueCoat Technologies. uniquecoat.com.

THERMAL SPRAY SEES AUTOMOTIVE SECTOR GROWTH

The ITSC 2016 conference and exposition took place in May in Shanghai, and featured various sessions on using thermal spray in automotive and industrial applications. The plenary lecture by Andreas Gollwitzer of BMW titled "The Development of the China Auto Market and its Significance for the BMW Group" reflects the importance of increased use of thermal spray in the automotive industry. As Gollwitzer points out, BMW saw a compounded annual growth rate of 28% between 2009 and 2015.


Bamola

Further, ITSC's automotive session included five papers with subjects ranging from new technology to manufacture ball bearings to thermal barriers to cold spray for reactive brazing and the implementation of highly integrated industrial manufacturing lines for spraying of cylinder blocks.

Improving coating density is important for industrial applications in severe service such as pumps and valves operating in highly corrosive and/or erosive environments. Here, technology is evolving based on deposited materials. Cermets, such as cemented carbides, lend particularly well to deposition, using extremely fast velocities such as from high velocity air fuel (HVAF) and newer higher firing rate detonation systems.

Further advantages of higher velocity systems include improved adhesion and generally lower oxidation and dissolution of carbides. Dense, low oxide containing metallic alloys can be applied using HVAF, but at times refractory metallics and alloys such as tantalum or molybdenum are better applied using shrouded or chamber contained plasma systems. This is particularly true when spraying at steep angles where particles deposited using high velocity systems have a tendency to slide.

Plasma spray remains the predominant method of applying ceramics with a move toward systems with improved voltage and current control, such ascascaded guns and pulse width modulated power systems. Here, the lower power fluctuations result in more stable thermal and velocity history for particles, leading to improved coating properties.

I hope that future conferences will emphasize broader application ranges for thermal spray. For example, it would be interesting to see nuclear engineering for both power and medicinal applications covered more thoroughly. Dual fabrication of sensors and packaging, as well as coatings that function as catalytic surfaces, are also hot topics.

Rajan Bamola
iTSSe co-editor
Surface Modification Systems Inc.

NOMINATIONS SOUGHT FOR THERMAL SPRAY HALL OF FAME

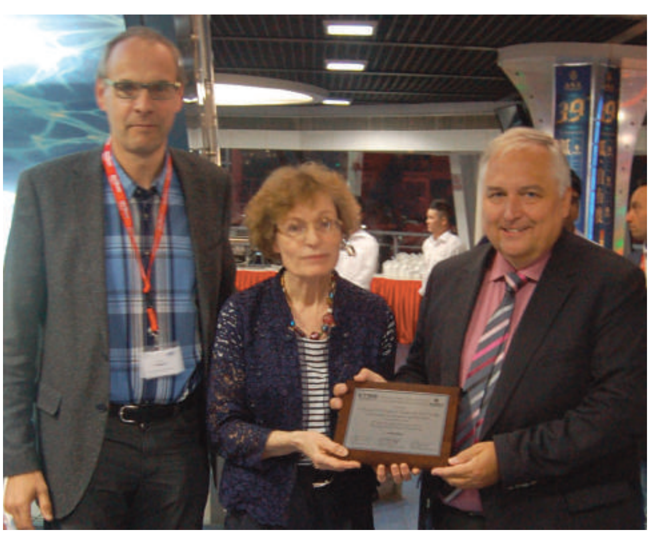
The Thermal Spray Hall of Fame, established in 1993 by the Thermal Spray Society of ASM International, recognizes and honors outstanding leaders who have made significant contributions to the science, technology, practice, education, management, and advancement of thermal spray. For a copy of the rules, nomination form, and list of previous recipients, visit tss.asminternational.org or contact joanne.miller@asminternational.org. **Nominations are due September 30.**

The Journal of Thermal Spray Technology
Volume 24 Best Paper Awards

The *Journal of Thermal Spray Technology* (*JTST*) presented the winners of the *JTST* Volume 24 Best Paper Awards, chosen by an international committee of expert judges, at the International Thermal Spray Conference & Exposition 2016, in Shanghai. Each paper is reviewed and evaluated based on scientific and engineering content, originality, and presentation. The *JTST* Editorial Board and ASM Thermal Spray Society Executive Board of Directors extend their congratulations to the winning authors listed here.

The Journal of Thermal Spray Technology
Volume 24 Best Paper Award:

"Plasma Spraying of Ceramics with Particular Difficulties in Processing" by Georg Mauer, Miss Nadin Schlegel, Stefan Rezanka, and Robert Vassen, Institut für Energie- und Klimaforschung (IEK-1), Forschungszentrum Jülich; Alexandre Guignard, tsd Technik-Sprachendienst GmbH; Maria Ophelia Jarligo, Department of Chemical and Materials Engineering, University of Alberta; and Andreas Hospach, Siemens AG, Corporate Technology, Research & Technology Center.



Journal of Thermal Spray Technology Editor-in-Chief Armelle Vardelle (center) presents the *JTST* Volume 24 Best Paper Award to Robert Vassen (left) and Georg Mauer (right).

The Journal of Thermal Spray Technology
Volume 24 Best Paper Honorable Mention (tie):

"Process-Property Relationship for Air Plasma-Sprayed Gadolinium Zirconate Coatings" by Gopal Dwivedi, Yang Tan, Vaishak Viswanathan, and Sanjay Sampath, Center for Thermal Spray Research, Stony Brook University.

"Microstructural Analysis of Cold-Sprayed Ti-6Al-4V at the Micro- and Nano-Scale" by Aaron Birt, Richard D. Sisson Jr., and

The *JTST* Volume 24 Best Paper Award Honorable Mention was presented by Armelle Vardelle (left) to Wanhuk Brian Choi (right) who accepted on behalf of his Stony Brook University colleagues.

The *JTST* Volume 24 Best Paper Award Honorable Mention was presented by *JTST* Lead Editor André McDonald (left) to Sophia Zhou, VT Technologies (Suzhou) Co., Ltd (right) who accepted on behalf of her colleagues.

Diran Apelian, Metal Processing Institute, Worcester Polytechnic Institute; and Victor K. Champagne Jr., U.S. Army Research Laboratory.

TRIBUTE TO THERMAL SPRAY HALL OF FAMER

Beardsley

M. Brad Beardsley
March 22, 1953 – March 19, 2016

M. Brad Beardsley passed away unexpectedly after a sudden illness. He earned his B.S. and M.S. degrees in metallurgical engineering and a Ph.D. in materials science, all from Iowa State University. During Beardsley's 35-year career at Caterpillar Inc., he pioneered new applications that significantly expanded the use of thermal spray for remanufacturing processes. He was awarded 11 U.S. patents, published 10 external papers, and secured over $25 million in federal funding to develop new thermal spray techniques and materials. He retired from Caterpillar in 2013.

Beardsley was inducted into the Thermal Spray Society Hall of Fame in 2013 to acknowledge "his enduring commitment and success in establishing worldwide utilization of thermal spray processes and materials for sustainable manufacturing processes ranging from remanufacturing to Cr-plate replacement."

2016 NORTH AMERICAN COLD SPRAY CONFERENCE

This biennial event, presented by the ASM Thermal Spray Society and the Canadian Cold Spray Alliance, will take place November 30 to December 1 at Alberta Innovates - Technology Futures, Canada. The latest technical insights from international experts in industry, government, and academia on innovative technology, practical applications, and advanced research will be showcased. New to the conference this year is a young professionals presentation event by student researchers in cold spray. Registration will open in early September.

THERMAL SPRAY SOCIETY EDUCATION COURSES

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

Berndt

Thermal Spray Technology

Date: October 18-19
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Chris Berndt, FASM

This course provides a thorough understanding of thermal spray. It depicts complex scientific concepts in terms of simple physical models and integrates this knowledge into practical engineering applications and commonly accepted thermal spray practices.

Advanced Thermal Spray Technology

Date: October 20
Location: ASM World Headquarters, Materials Park, Ohio
Instructor: Chris Berndt, FASM

This masterclass is customized for professionals keen to enhance their knowledge and thermal spray skills. The course offers deep insights into the latest technologies and solutions.

SUMMER SCHOOL ON SUSPENSION & SOLUTION THERMAL SPRAY

University West, Sweden, will hold "Summer School on Suspension & Solution Thermal Spraying" on September 14-16. The course includes lectures from experts in academia as well as industry, and covers all major aspects of liquid feedstock spray, from fundamentals and process diagnostics to characterization and applications. The program also features a demonstration of state-of-the-art suspension plasma spray equipment available at the university.

COLD SPRAY: ADVANCED CHARACTERIZATION METHODS—OPTICAL MICROSCOPY

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

Optical or light microscopy (OM) uses the visible or near-visible portion of the electromagnetic spectrum and is one of the oldest characterization techniques. With any cold spray coating, it is the first characterization process used to evaluate and optimize process variables.

First, an estimate of the as-sprayed coating thickness and coating porosity is evaluated, and an assessment of the coating-substrate interface integrity is performed. The easiest way to assess coating formation as a function of various coating parameters, such as spray angle, standoff distance, raster speed, deposition efficiency, and powder feed rate, is the optical microscope. Nearly all reports on cold spray coatings begin with this characterization, which is fundamental to assess coating quality.

OM is often used to optimize process parameters for obtaining dense, pore-free coatings. Trials on cold spray coatings have been performed on several pure metals, such as aluminum, copper, titanium, tantalum, nickel, and magnesium, as well as alloys based on aluminum (2052, 6061), magnesium (AZ31B, ZE41A), nickel (IN718, IN625, IN738), and titanium (Ti-64, CP-Ti), with optical micrographs of the as-processed coating. In most cases, coatings become denser when heat treated. However, in certain cases, they become more porous.

A quantitative estimation of porosity, determined by using image analysis attached to an optical microscope, is usually the best way to characterize coating density. The effects of process gas (helium vs. nitrogen vs. air) as well as various process conditions, such as standoff distance, speed, and deposition efficiency, are discerned by using OM.

Figure 1 (a) and (b) show representative optical micrographs comparing a ~0.3 mm (0.01 in.)-thick titanium cold-spray coating, which was sprayed using nitrogen and helium gas in the as-sprayed condition. A clear distinction can be seen between the porous top region and the dense inner region between the two coatings, revealing an important aspect about the tamping effect of the two gases in the densification of the coating.

Figure 1 (c) and (d) illustrate an image analysis of coating porosity measurement of a pure copper coating. The optical micrographs in Fig. 1 (e) and (f) reveal coating interface and surface, respectively, of a WC-Co coating. OM was

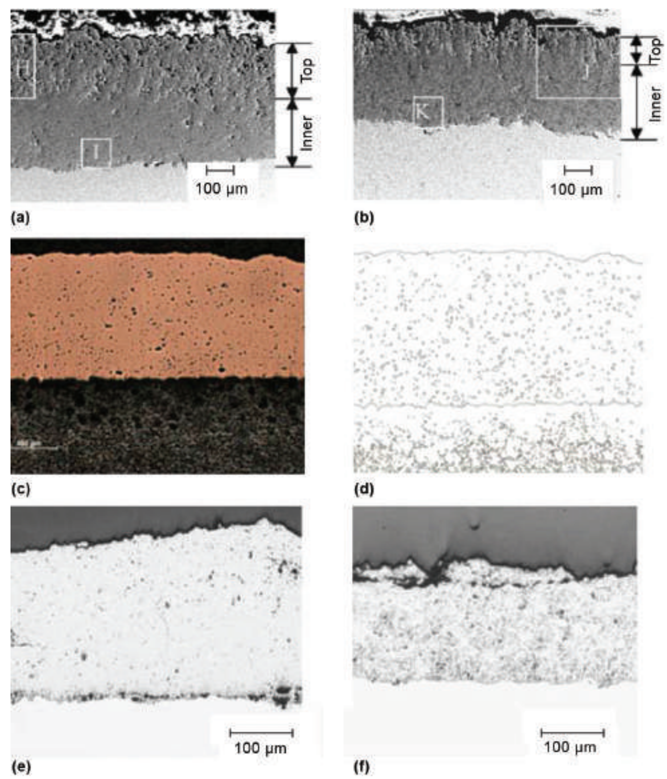


Fig. 1 — Optical micrographs show comparison of overall coating thickness and top layer thickness between a nitrogen-spray and helium-spray copper coating, respectively (a, b); image analysis evaluated porosity in a pure copper coating (c, d); and interface and top surface in a WC-Co cermet coating sprayed using nitrogen gas (e, f).

used to map process variables to obtain dense coatings for an aluminum coating, by etching an aluminum coating and mapping the microstructure evolution as a function of temperature as shown in Fig. 2 (a) and (b).

Observation of the nature of particle deformation and input from optical micrographs enables numerical simulation, as shown in Fig. 3 (a) to (c). Sample preparation for OM is usually straightforward involving metallography, namely cutting the coating either transversely or along the direction of spray, mounting the cross-section using a resin, and

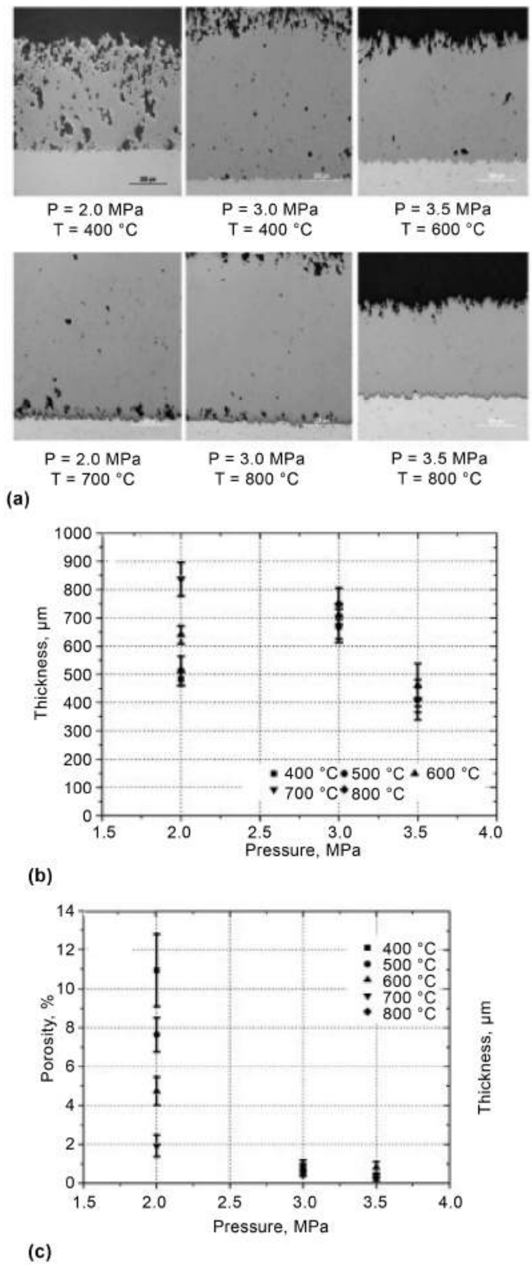


Fig. 2 — Optical micrographs depict variation in porosity with processing parameters for a Ti-64 coating on a SS304 substrate (a). Variation of porosity with thickness and gas pressure as measured from the optical micrograph (b, c).

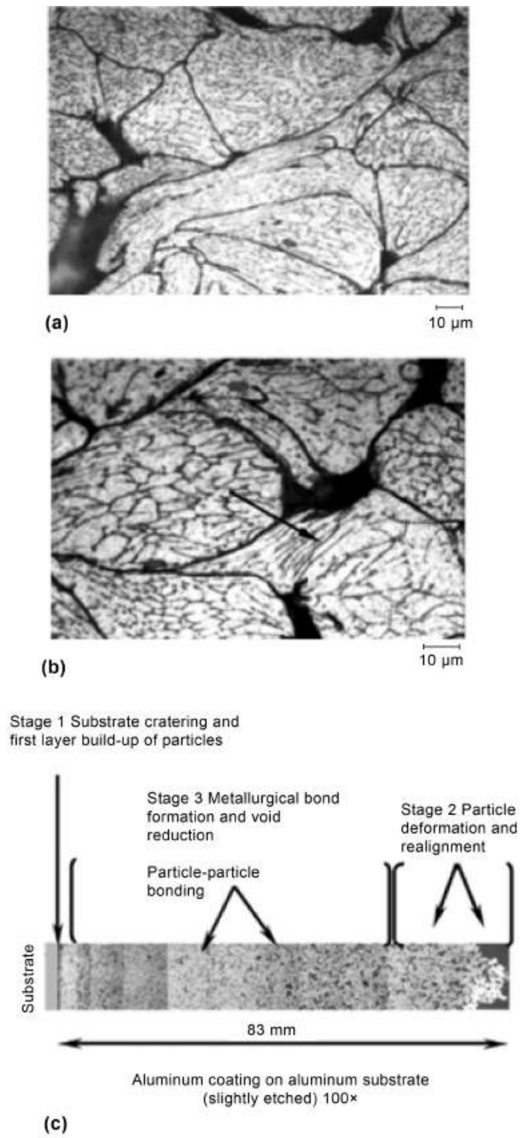


Fig. 3 — Optical micrographs with etched aluminum coatings as a function of gas temperature at 204°C (400°F) (a) and 315°C (600°F) (b) reveal extent of particle deformation. Micrographs determine the nature of the coating bond (c).

grinding and polishing to yield a mirror finish. Because most of the samples are made of metallic or composite materials, mechanical abrasive cutting or electrodischarge machine wire cutting is typically used. However, in some cases, these have been found to result in delamination of the coating from the substrate, and therefore, waterjet cutting is recommended in order not to impart stresses during cutting. Typically, samples are viewed in bright field mode to obtain coating thickness images. However, dark field mode is preferable when a more quantitative assessment of coating pores is desired. **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).

ITSC 2016 IS AN INTERNATIONAL SUCCESS

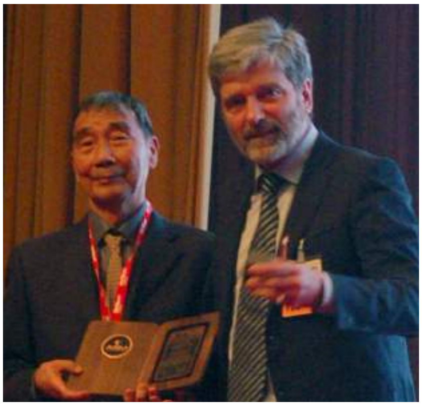
The International Thermal Spray Conference was held May 10-13 at the Shanghai International Convention Center & Oriental Riverside Hotel. More than 1400 thermal spray technologists, researchers, manufacturers, and suppliers from around the globe converged on Shanghai for this year's conference and exposition. The exposition featured 97 booths on the show floor and showcased 60 companies. The technical program was deemed a success with more than 180 oral and poster presentations.

Two plenary sessions were held on Tuesday, May 10: S. Tao from the Chinese Academy of Sciences presented his plenary talk, "Advances in Plasma Sprayed Ceramic Coatings at Shanghai Institute of Ceramics," while A. Gollwitzer presented, "The Development of the China Auto Market and its Significance" for the BMW Group. Both talks were well attended and featured a lively question and answer session.

In addition to the technical program, the three-day exhibition included both an industrial forum and poster session. The show floor offered an unparalleled exposition featuring the world's largest gathering of thermal spray equipment suppliers, consumable and accessory suppliers, vendors, and service providers. (The *JTST* Volume 24 Best Paper Awards photos can be found on page 3.)

Jens Jerzembeck of the DVS German Welding Society gives opening remarks at the awards ceremony on May 10 at the Shanghai International Convention Center.

Seiji Kuroda, FASM (left), a new TSS Hall of Fame inductee, receives his plaque from TSS President Christian Moreau. Kuroda, unit director of the National Institute of Materials Science (NIMS), was recognized for pioneering research on residual stress in thermal spray coatings, development of in-situ beam curvature technique, in-flight particle diagnostics, and warm spray technology.



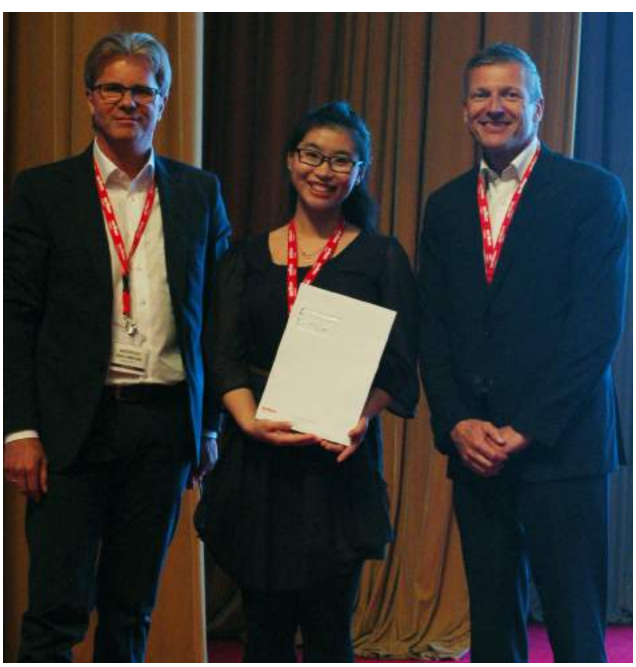
Chuanxian Ding (left), TSS Hall of Fame Inductee, receives his award from TSS President Christian Moreau. Ding, professor at the Shanghai Institute of Ceramics, Chinese Academy of Sciences, and head of the plasma spray coating research group, was recognized for pioneering the science and technology of thermal spray in China especially in the area of emerging applications of coatings and for mentoring students and young professionals.

Thomas A. Taylor, FASM (right), was not present in Shanghai for the awards ceremony so Ann Bolcavage (left), TSS treasurer, presented the award to him at a ceremony at Praxair Surface Technologies in Indianapolis on May 5. Taylor, retired from Praxair, was honored for significant contributions to new and novel thermal barrier coating architectures, and rub tolerant and MCrAlY coatings for gas and engine applications.

Armelle Vardelle, FASM (left), receives her TSS Hall of Fame plaque from TSS President Christian Moreau. Vardelle 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. She was honored for globally recognized contributions to understanding the role of plasma generation and plasma-particle interaction on coatings microstructure.

Kirsten Bobzin, technical chair, presents an ITSC award to Wen Long Chen for his poster presentation, “Microstructure Evolution and Impedance Spectroscopy Characterization of Thermal Barrier Coating Exposed to Gas Thermal-Shock Environment.”

André McDonald makes remarks during the *JTST* Best Paper Awards Ceremony during the networking boat cruise on Wednesday, May 11.



Amanda Wang (center) receives the Oerlikon Metco Young Professionals Award from Oerlikon representatives Andreas Bachmann and Markus Heusser for her presentation, “Three Dimensional Reconstruction of Plasma Sprayed Ni-20Cr on Alumina.”

Presenters of the Young Professional Symposium gathered after the event on May 10.

OPTIMIZING COATING MATERIALS FOR HEAVY DUTY APPLICATIONS

REASON TO CONSIDER SURFACING

Using thermal spray to coat the interiors of pipes and tubes used in heavy duty applications enhances mechanical properties and extends component lifetimes. However, thermal spray processing of internal diameters (IDs) creates a range of processing challenges related to both workpiece diameter and length. The physical size of equipment, hoses, and spray distance boundaries—along with temperature and contamination issues—are considerations for both equipment and material manufacturers.

H.C. Starck GmbH and UniqueCoat Technologies recently conducted a range of trials to optimize coating properties produced with new hardware designed to coat IDs down to less than 5 in., an application area that has traditionally been a challenge for the production of high quality coatings.

VALUE OF COATING

The flame characteristics (thermal and kinetic) had to be matched to a spray material that would provide coating quality comparable to that achieved by larger standard coating equipment. This is especially important for heavy duty industries such as oil and gas, where ID protection in drilling and pumping applications has long been an area requiring improvement. In order to match the spray device to the correct powder consumable, a few simple principles must be taken into account:

1. Can the hardware be sized to allow for consistent energy transfer (both thermal and kinetic) to the powder, in order to reach the desired particle temperature and velocity to produce a high quality coating—dense, hard, and well bonded, at a reasonable efficiency?
2. Can the powder be produced to a very tightly controlled specification on a consistent basis so that optimum coating properties are reliable and reproducible for ID applications?

OPTION

Specially sized materials of very specific morphology were used to run coating trials to find the optimum match between the small ID torch's energy (UniqueCoat's I7 torch) and the size and thermal conductivity of the spray material (Fig. 1). Coating chemistry was WC/Co/Cr (86/10/4)—a coating commonly used in the oil and gas industry due to its mix of wear and corrosion resistance. Trial results appear in Table 1.

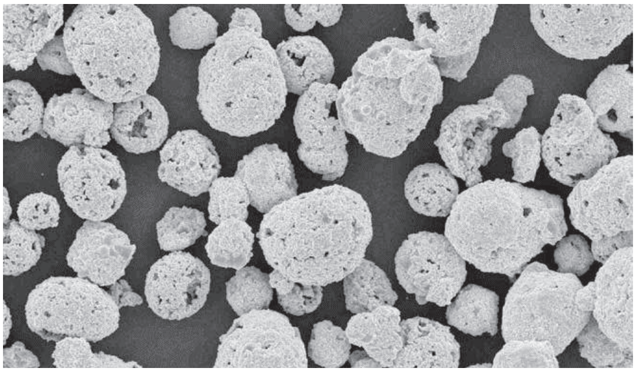


Fig. 1 — Amperit 558—spray dried/agglomerated and sintered. Courtesy of H.C. Starck GmbH.

Fig. 2 — UniqueCoat's I7 torch coating the internals of a rotary valve.

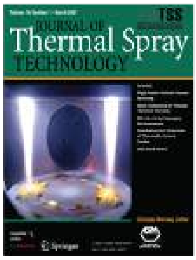
BENEFITS

The I7 torch coating the interior of a rotary valve is shown in Fig. 2, an application that will be run as part of a large scale evaluation of this emerging technology. Further trials will focus on optimizing the performance of specialized coatings for erosion and slurry resistance. iTSSe

TABLE 1—TRIAL RESULTS

Powder designation	Hardness – HV300	Porosity	Powder sizing (µm)	Morphology
Amperit 558.185	1140	<1%	-30 + 5	Agglomerated sintered
Amperit 554.071	1380	<1%	-25 + 5	Sintered crushed
Amperit 554.090	1540	<1%	-20 + 5	Sintered crushed
Amperit 554.067	1502	<1%	-15 + 5	Sintered crushed

For more information: Michael Breitsameter is senior global sales manager, H.C. Starck North American Trading LLC, 45 Industrial Place, Newton, MA 02461, 617.893.7367, michael.breitsameter@hcstarck.com, www.hcstarck.com.



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 June and August 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, please visit asminternational.org/tss.

NANOSTRUCTURED AND CONVENTIONAL CR_2O_3, TIO_2, AND TIO_2-CR_2O_3 THERMAL-SPRAYED COATINGS FOR METAL-SEATED BALL VALVE APPLICATIONS IN HYDROMETALLURGY

Luc Vernhes, Craig Bekins, Nicolas Lourdel, Dominique Poirier, Rogerio S. Lima, Duanjie Li, and Jolanta E. Klemberg-Sapieha

Velan, an international industrial valve designer and manufacturer, in collaboration with the National Research Council of Canada, Boucherville, and Polytechnique Montréal conducted a detailed characterization project to assess the mechanical and tribological resistances of promising ceramic coatings for hydrometallurgy applications, including a novel *n*-TiO_2-Cr_2O_3 blend. Hardness and shear strength were determined using microhardness indentation testers and universal tensile test equipment. Wear resistance of the coatings under sliding wear, abrasion, and galling conditions were measured by standard pin-on-disk tests, abrasion tests, and custom-designed galling tests. The main result is that the synergy between Cr_2O_3 and *n*-TiO_2 produces abrasion performance exceeding that of the materials alone. An optimized balance between the hard and brittle Cr_2O_3 phases and the soft and ductile *n*-TiO_2 phases results in higher abrasion, sliding, and galling resistance. The novel *n*-TiO_2-Cr_2O_3 blend is a promising evolution of the current TiO_2-Cr_2O_3 blend.

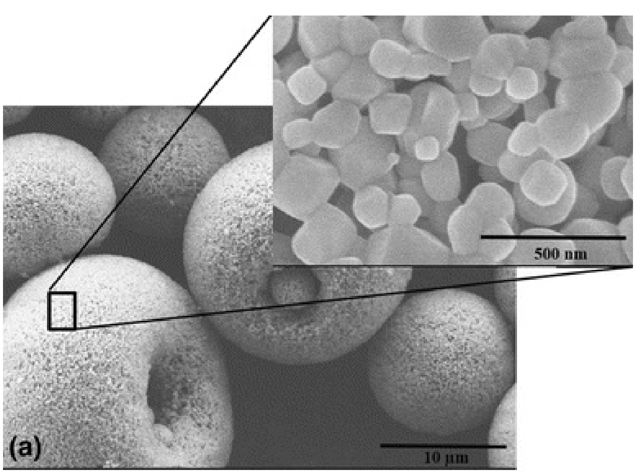


Fig. 1. — *n*-TiO_2 powder characteristics: SEM micrographs.

A REVIEW OF THERMAL SPRAY METALLIZATION OF POLYMER-BASED STRUCTURES

R. Gonzalez, H. Ashrafizadeh, A. Lopera, P. Mertiny, and A. McDonald

A literature review on the thermal spray deposition of metals onto polymer-based structures is presented. Depositing metals onto polymer-based structures enhances the thermal and electrical properties of the resulting metal-polymer material system. Thermal spray metallization processes and the technologies for polymer-based materials are outlined. Polymer surface preparation methods and the deposition of metal bond-coats are also explored. Thermal spray process parameters that affect the properties of metal deposits on polymers are described, followed by studies on temperature distribution within polymer substrates during thermal spray. The objective of this review is devoted to testing and potential applications of thermal-spray metal coatings deposited onto polymer-based substrates. This review aims to summarize the state-of-the-art contributions to research on the thermal spray metallization of polymer-based materials, which has gained recent attention for potential and novel applications.

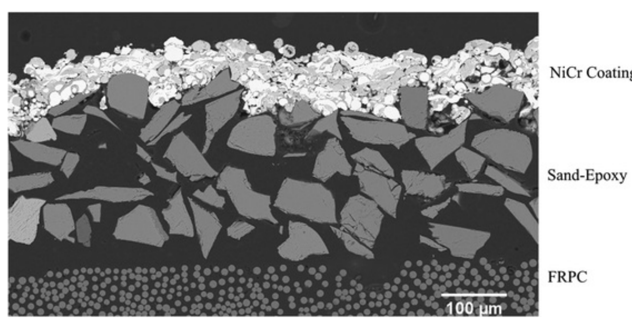


Fig. 2. — Backscattered scanning electron microscope image of the cross section of a flame-sprayed Ni-20Cr coating deposited onto a fiber-reinforced polymer composite substrate.

FABRICATION OF HIGH-TEMPERATURE HEAT EXCHANGERS BY PLASMA SPRAYING EXTERIOR SKINS ON NICKEL FOAMS

P. Hafeez, S. Yugeswaran, S. Chandra, J. Mostaghimi, and T. W. Coyle

Thermal-sprayed heat exchangers were tested at high temperatures (750°C), and their performance compared to foam heat exchangers made by brazing Inconel sheets to their surface. Nickel foil was brazed to the exterior surface of 10-mm-thick layers of 10 and 40 PPI nickel foam. A plasma torch sprayed an Inconel coating on the foil's surface. A burner test rig was built to produce hot combustion gases that flowed over the exposed face of the heat exchanger. Cool air flowed through the foam heat exchanger at rates of up to 200 SLPM. Surface temperature and air inlet/exit temperature were measured. Heat transfer to air flow through the foam was significantly higher for the thermal sprayed heat exchangers than for the brazed heat exchangers. On average, thermal sprayed heat exchangers show 36% higher heat transfer than conventionally brazed foam heat exchangers. At low flow rates, the convective resistance is large (~4×10^{-2} m^2 K/W), and the effect of thermal contact resistance is negligible. At higher flow rates, the convective resistance decreases (~2×10^{-3} m^2 K/W), and the lower contact resistance of the thermally sprayed heat exchanger provides better performance than the brazed heat exchangers.

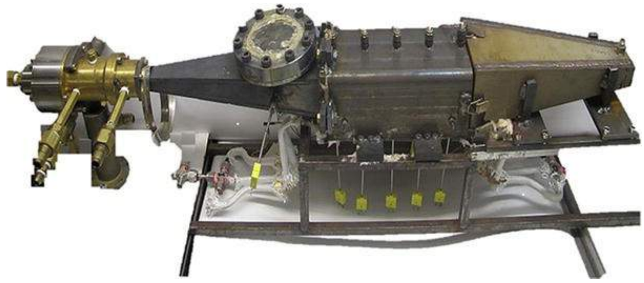


Fig. 3. — Test rig.

PLASMA-SPRAYED HYDROXYLAPATITE-BASED COATINGS: CHEMICAL, MECHANICAL, MICROSTRUCTURAL, AND BIOMEDICAL PROPERTIES

Robert B. Heimann

The salient properties and functions of hydroxylapatite (HA)-based plasma-sprayed coatings, including the effect on biomedical efficacy of coating thickness, phase composition and distribution, amorphicity and crystallinity, porosity and surface roughness, cohesion and adhesion, micro- and nano-structured surface morphology, and residual coating stresses are discussed. In addition, details of the thermal alteration that hydroxylapatite particles undergo in the extremely hot plasma jet that leads to dehydroxylated phases such as oxyhydroxylapatite (OHA) and oxyapatite (OA) are discussed. Thermal decomposition products such as tri-(TCP) and tetracalcium phosphates (TTCP), and quenched phases such as amorphous calcium phosphate (ACP), are also discussed. The article further explains the role of amorphous calcium phosphate during the in vitro interaction of as-deposited coatings with simulated body fluid resembling the composition of extracellular fluid (ECF) as well as the in vivo responses of coatings to the extracellular fluid and the host tissue, respectively.

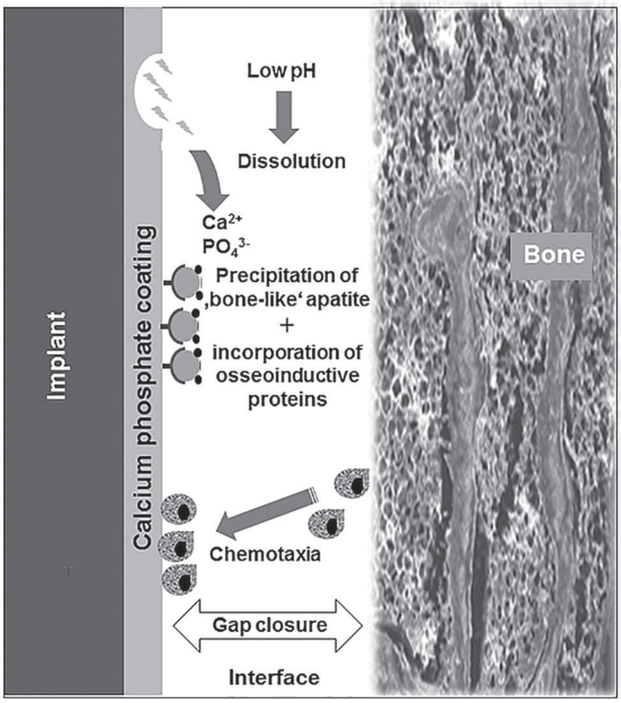


Fig. 4. — Schematic of cell-implant interaction mediated by a thin calcium phosphate coating layer. A local decrease of pH results in partial dissolution of the coatings, triggering the release of chemotaxia from bone. Addition of Ca^{2+} and PO_4^{3-} ions increases supersaturation of the extracellular fluid (ECF) with respect to hydroxylapatite, precipitating bone-like apatite and promoting subsequent incorporation of osseoinductive proteins such as osteocalcin and osteonectin as well as annexins and integrins.

Finally, this article briefly describes performance profiles required to fulfill biological functions of osseoconductive bioceramic coatings designed to improve osseointegration of hip endoprostheses and dental root implants.

PHYSICOCHEMICAL CHARACTERISTICS OF DUST PARTICLES IN HVOF SPRAYING AND OCCUPATIONAL HAZARDS: CASE STUDY IN A CHINESE COMPANY

Haihong Huang, Haijun Li, and Xinyu Li

Dust particles generated during thermal spray pose a serious health risk to operators. Particles generated in the high velocity oxy-fuel (HVOF) spray of WC-Co coatings were characterized in terms of mass concentrations, particle size distribution, micro morphologies, and composition. Results show that the highest instantaneous exposure concentration of dust particles is 140 mg/m³ and the time weighted average concentration is 34.2 mg/m³, which are approximately eight and four times higher than the occupational exposure limits in China, respectively. Large dust particles bigger than 10 μm in size present a unique polygonal morphology or irregular block of crushed powder, and smaller dust particles mainly exist in the form of irregular or flocculent agglomerates. Some heavy metals, such as chromium, cobalt, and nickel, are also present in workshop air with concentrations that exceed exposure limits. Potential occupational hazards are further analyzed based on dust particle characteristics. Exposure to the nanoparticles is assessed using a control banding tool.

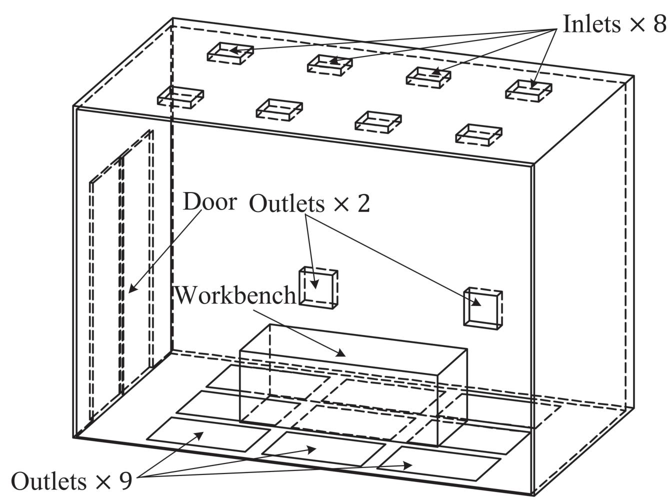


Fig. 5. — Workshop schematic.


The winning coating solution for you and your customers!

ASMNEWS

2016 ASM Award Program Recipients

The ASM International Board of Trustees has named award recipients for 2016. The awards program recognizes achievements of members of the materials science and engineering community. Awards will be presented at ASM's annual Awards Dinner, October 25 in Salt Lake City, during MS&T16. Tickets for the dinner cost $90 each and can be ordered by using the MS&T registration form. Those interested in purchasing a table may contact Christine Hoover at 440.338.5151 ext. 5509; fax 440.338.6614; christine.hoover@asminternational.org.

Honorary Membership

Dr. Alton D. Romig, Jr., FASM, executive officer, National Academy of Engineering, Washington, will receive this year's award "for outstanding contributions to the science and technology of materials and their application to innovative research and development on defense systems." Honorary Membership in the Society was established in 1919 to recognize distinguished service to the materials science and engineering profession, ASM strategic plan and initiatives, and the progress of mankind.

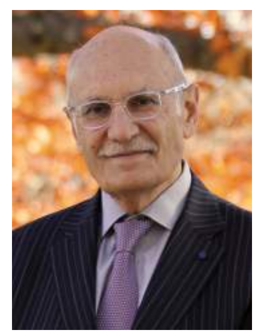
Distinguished Life Membership

Mr. William R. Jones, FASM, owner/CEO, Solar Atmospheres Inc., Souderton, Pa., will receive this year's award "for innovations in the field of vacuum furnace technology and applying this technology to enhance metallurgical thermal processes around the world."

Mr. Albert Kay, **FASM,** president, ASB Industries, Barberton, Ohio, will receive this year's award "in recognition of outstanding innovation and early commercialization of emerging thermal spray technologies including high-velocity oxyfuel and cold spray; exemplary development of a business model that gained worldwide recognition; and for dedication and unselfishness, unstinting personal effort, and leadership on behalf of the Thermal Spray Society and ASM International."

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

Gold Medal



Prof. Diran Apelian, FASM, Alcoa-Howmet professor of mechanical engineering, Worcester Polytechnic Institute, Mass., will receive this year's award "for his leadership and vision for establishing and executing a model for industry-university collaborative research, and for his pioneering work in metal processing." The medal was established in 1943 to recognize outstanding knowledge and great versatility in the application of science to the field of materials science and engineering, as well as exceptional ability in the diagnosis and solution of diversified materials problems.

In This Issue

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

Medal for the Advancement of Research

Dr. Bhakta B. Rath, FASM, associate director of research, head Materials Science & Technology Directorate, Naval Research Laboratory, Washington, will receive this year's award "for leadership in promoting basic research and advanced exploratory developments in multidisciplinary fields of materials science and engineering and promoting technological innovation for the commercial sector and for national security." The award was established in 1943 to honor an executive in an organization that produces, fabricates, or uses metals and other materials. The recipient, over a period of years, will have consistently sponsored research or development, and by foresight and actions, will have helped substantially advance the arts and sciences related to materials science and engineering.

Engineering Materials Achievement Award (EMAA)

Oak Ridge National Laboratory, **Dr. Craig A. Blue, FASM, Mr. Charles Carnal, Mr. Chad Duty, Mr. Vlastimil Junc, Mr. Alan Liby, Mr. Randy Lind, Mr. Peter Lloyd, Mr. Lonnie Love, Ms. Jennifer Palmer, Mr. Brian Post, Mr. John Rowe, Mr. Rick Neff,** and **Mr. Jay Rogers** will receive this year's award. The team is cited "for development of a big area additive manufacturing (BAAM) technology and the materials that enable the technologies that can produce components 10 times larger, 100 times less expensive, and 100 times faster than previous systems." Established In 1969, this award recognizes an outstanding achievement in materials or materials systems related to the application of knowledge of materials to an engineering structure or to the design and manufacture of a product.

Albert Sauveur Achievement Award

Prof. Raj N. Singh, FASM, professor, Oklahoma State University, Tulsa, will receive this year's award "for pioneering and original scientific and technological contributions to the science and technology of materials through innovative processing and in situ studies leading to commercialization for aircraft turbines and energy storage." Established in 1934 in honor of a distinguished teacher, metallographer, and metallurgist, the award recognizes pioneering materials science and engineering achievements that have stimulated organized work along similar lines to such an extent that a marked basic advance was made in the knowledge of materials science and engineering.

William Hunt Eisenman Award

Dr. Paul S. Gilman, FASM, director of technology, deposition materials, Praxair Inc., Orangeburg, N.Y., will receive this year's award "for outstanding technical leadership in industrial research and development of advanced copper metallization, sputtering targets, and mechanical alloyed products for semiconductor, electronics, and aerospace industries." The award was established in 1960, in memory of a founding member of ASM, and its first and only secretary for 40 years. It recognizes unusual achievements in industry in the practical application of materials science and engineering through production or engineering use.

J. Willard Gibbs Phase Equilibria Award

Dr. Ursula R. Kattner, FASM, physical scientist, materials science & engineering division, National Institute of Standards and Technology, Gaithersburg, Md., will receive this year's award "for contributions to the thermodynamic assessment of metallic alloys and application to metallurgical processing." The award was established in 2007 to recognize outstanding contributions to the field of phase equilibria. The award honors J. Willard Gibbs, one of America's greatest theoretical scientists. In addition to many other contributions, Gibbs laid the thermodynamic foundations of phase equilibria theory with his brilliant essay "On the Equilibrium of Heterogeneous Substances," published in 1876 and 1878 in the *Transactions of the Connecticut Academy.*

Allan Ray Putnam Service Award

Mr. Robert J. Gaster, senior staff engineer, Deere & Co. Technology Innovation Center, John Deere, Moline, Ill., will receive this year's award "for continuous and enthusiastic promotion of ASM membership and volunteerism at the local chapter and national society level, as well as his longstanding volunteerism for the Heat Treat Society." Established in

1988, the award recognizes the exemplary efforts of various outstanding members of ASM International on behalf of the Society to further its objectives and goals. The purpose of this award is to recognize those individuals whose contributions have been especially noteworthy and to whom the Society owes a particularly great debt of appreciation.

Albert Easton White Distinguished Teacher Award

Prof. David K. Matlock, FASM, Armco Foundation Fogarty professor, Colorado School of Mines, Golden, will receive this year's award "for his accomplishments in materials education that have positively impacted generations of students and the research and industrial community over several decades." The award was established in 1960 in memory of an outstanding teacher and research engineer, who was a founding member and president of ASM in 1921. It recognizes unusually long and devoted service in teaching, as well as significant accomplishments in materials science and engineering and an unusual ability to inspire and impart enthusiasm to students.

Silver Medal Award

Dr. Mark A. Tschopp, materials engineer, US Army Research Laboratory, Aberdeen Proving Ground, Md., will receive this year's award "for distinguished and sustained contributions in computational materials science, solid mechanics, processing-structure-property relationships, and materials design for integrated computational materials engineering (ICME), and for service to ASM International." Established in 2010, the honor of Silver Medal of the Society recognizes members who are in mid-career positions (typically 5 to 15 years of experience), for distinguished contributions in the field of materials science and engineering, and the Society. The purpose of this award is to recognize leadership at an early stage and encourage individuals to grow, nurture, and further contribute to the growth of the profession, as well as the Society.

Bronze Medal Award

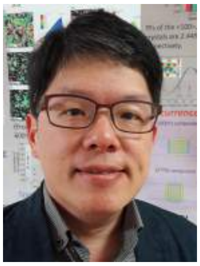
Ms. Margaret Bush Flury, senior materials engineer, Medtronic, PLC, Fridley, Minn., will receive this year's award "for contributions to advancements in medical devices, commitment to the failure analysis community, contributions to students, and selfless participation in ASM." Established in 2014, the honor recognizes ASM members who are in early-career positions, typically 0 to 10 years of experience, for significant contributions in the field of materials science and engineering through technical content and service to ASM and the materials science profession.

Bradley Stoughton Award for Young Teachers

Prof. Jennifer L.W. Carter, assistant professor, materials science and engineering, Case Western Reserve University, Cleveland, will receive this year's award "for dedicated and effective instruction and mentoring of students at various stages of their educational experience in addition to impacting undergraduate engineering education." This award, accompanied by $3000, was established in 1952 in memory of an outstanding teacher in metallurgy and dean of engineering who was president of ASM in 1942. The award recognizes young teachers of materials science, materials engineering, and design and processing, by rewarding them for their ability to impart knowledge and enthusiasm to students. The recipient must be 35 years of age or younger by May 15 of the year in which the award is made.

Henry Marion Howe Medal

Sung Bo Lee, Dong-Ik Kim, Yanghoo Kim, Seung Jo Yoo, Ji Young Byun, Heung Nam Han, and **Dong Nyung Lee** will receive this year's award for their paper entitled "Effects of Film Stress and Geometry on Texture Evolution Before and After the Martensitic Transformation in a Nanocrystalline Co



Lee

Kim

Kim

Yoo

Byun

Han

Lee

Thin Film," *MetTrans* Vol. 46A, 2015. The award was established in 1923 in memory of a distinguished teacher, metallurgist, and consultant, to honor the author(s) whose paper was selected as the best of those published in a specific volume of *Metallurgical and Materials Transactions.*

Marcus A. Grossmann Young Author Award

Ming-Wei Wu will receive this year's award for his paper entitled "The Influences of Carbon and Molybdenum on the Progress of Liquid Phase Sintering and the Microstructure of Boron-Containing Powder Metallurgy Steel," *MetTrans* Vol. 46A, 2015. The award was established in 1960 in recognition of Dr. Grossmann's accomplishments, especially his abiding interest in and encouragement of younger metallurgists and materials engineers whose paper was selected as the best of those published in a specific volume of *Metallurgical and Materials Transactions* for authors under 40 years of age on January 1 of the year in which the paper was published.

ASM Student Paper Contest

Janet L. Gbur, Case Western University, Cleveland, is recognized for her paper entitled "Fatigue and Fracture of Wires and Cables for Biomedical Applications." The contest was established in 1985 as a mechanism for student participation in Society affairs. The award recognizes the best technical paper with a graduate or undergraduate student as first author that is published in an ASM-sponsored publication during the year.

Emerging Professional Achievement Award

Dr. Amit Pandey, Rolls-Royce LG Fuel Cell System, is the 2016 recipient of this award. Established in 2010, the award recognizes extraordinary ASM volunteers with 0-5 years of post-graduation experience who have made a significant impact on ASM International through devoted service and dedication to the future of the Society.

ASM Historical Landmark Designation

Alcoa Inc., Tennessee Operations North Plant, was selected for a 2016 Historical Landmark Award. The citation reads, "For being the primary supplier of aluminum heat treated sheet and structural members for aircraft during World War II, and for playing a significant role in the sustainability and recycling of aluminum can sheet."

Quincy Smelting Works (QSW), Ripley, Franklin Township, Mich., was also selected for a 2016 Historical Landmark Award. The citation reads, "The Quincy Smelting Works is uniquely capable of interpreting the final stage of copper production for one of the few native copper ore mining regions on earth."

The award was estblished in 1969 to permanently identify the many sites and events that have played a prominent part in the discovery, development, and growth of metals and metalworking. In 1987, this award broadened to include all engineered materials.

Alcoa Inc. Tennessee Operations North Plant

Quincy Smelting Works

Official ASM Annual Business Meeting Notice

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

Monday, October 24

4:00–5:00 p.m.

Salt Palace Convention Center,

Salt Lake City

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

MS&T 2016 Lecturers Announced

Continuing the grand tradition of ASM International events, three distinguished lecturers will speak at the 2016 Materials Science & Technology Conference and Exhibition (MS&T16) to be held October 23-26 at the Salt Palace Convention Center in Salt Lake City. MS&T brings together the strengths of four major materials organizations: ASM International, The American Ceramic Society (ACerS), The Association for Iron & Steel Technology (AIST), and The Minerals, Metals & Materials Society (TMS).

2016 Alpha Sigma Mu

Monday, October 24

Dr. Alton D. Romig, Jr., FASM

Executive Officer, National Academy of Engineering

"National Academy of Engineering Grand Challenges for Engineering"

Rarely has an idea captured the imagination of professional practitioners, policymakers, students, and the general public as rapidly and forcefully as the National Academy of Engineering's "Grand Challenges for Engineering" (engineeringchallenges.org). Proposed in 2008 by a committee of 18 distinguished engineers, scientists, entrepreneurs, and visionaries, the Grand Challenges identify 14 goals that will make it possible for people all around the world to thrive. The idea was embraced immediately and has been accelerating ever since.

The NAE Grand Challenges are having an especially powerful inspirational impact on education. The Grand Challenge Scholars Program (GCSP) has been adopted by dozens of colleges and universities across the country, and President Obama recently announced a major initiative that is propelling it onto well over 100 more campuses—including Case Western Reserve University.

Numerous activities are centered on the Grand Challenges at the K-12 level. For example, one high school in North Carolina frames its entire curriculum on the NAE Grand Challenges, and another high school in the state of Washington has incorporated them across its classes. The principal of the Washington school said, "They are the best educational motivator I have found in my career." Other K-12 schools across the country are actively considering these models.

There has also been a series of large international events focused on the NAE Grand Challenges. Global summits were held in London in 2013 and Beijing in 2015, and the next is planned for Washington in 2017. Before these international events, participating universities organized two national and six regional Grand Challenge summits to stimulate conversations on the importance of engineering and science in maintaining and enhancing our quality of life. A *Business Week* story about the first one summarizes the power of the NAE Grand Challenges, "Students may resist geek studies. But they'll flock in for the opportunity to change the world."

2016 ASM/TMS Distinguished Lectureship in Materials and Society

Tuesday, October 25

Prof. Julie A. Christodoulou, FASM

Director, Naval Materials, S&T Division

Sea Warfare and Weapons Department

"Elegant Solutions Exploration and Outcomes that Matter"

New tools and new ways of using existing instruments are made available to us on a near-daily basis. Materials researchers can now explore structure at scales where chemical and physical phenomena occur, allowing more confident identification and control of ultimate properties. In-situ and in-operandi tools provide critical insight into the complicated and rapidly changing environments in which real materials perform, challenging hypotheses and assumptions and forcing the development of more rigorous analysis. Similarly, computational tools are guiding us toward the truly concurrent design of product, material, and manufacturing. This is all great—but it also makes our work harder. More than developing scientific knowledge and engineered goods at an accelerated pace, harnessing the capability of these emerging tools gives scientists and engineers the opportunity and responsibility to change the approach to solving some of society's most urgent challenges. This talk will survey some of these new tools and explore strategies for impactful work.

2016 Edward DeMille Campbell Memorial Lecture

Tuesday, October 25

Prof. A. Lindsay Greer, FIMMM, FRSA
Head of the School of the Physical Sciences and Professor of Materials Science, University of Cambridge

"Extending the Range of the Glassy State: New Insights from the Novel Properties of Metallic Glasses"

Focusing on metallic glasses, we consider developments in understanding and exploiting the glassy state that is formed when a liquid is cooled into a solid state without crystallizing. "The deepest and most interesting unsolved problem in solid state theory is probably the theory of the nature of glass and the glass transition." [P.W. Anderson, *Science*, Vol. 267, p 1615, 1995.] The metallic glasses are of particular interest for several reasons, not least their excellent mechanical properties. These lead to possible applications, but also open up the possibility of using mechanical working to change the structure and properties of glass, something hardly explored for conventional oxide glasses. While plastic deformation can be expected to have structural effects, it is more surprising that there can be significant effects even well within the (nominally) elastic regime. In this talk, we explore the diversity that can be achieved in the metallic glassy state, from very high energy ("rejuvenated") to very low energy ("relaxed" and even "ultrastable") states. In each case, we examine potential applications of the properties (structural and functional) that can be induced.

Student Board Members for 2016-2017 Announced

The ASM Board of Trustees values the insights, ideas, and participation of Material Advantage students. The Student Board Member program provides the opportunity to attend four board meetings where the students will meet and work with leading technical professionals and gain leadership skills that will benefit them throughout their career. The next deadline for submissions is April 15, 2017. Details can be found on the ASM website.

Swetha Barkam

University of Central Florida

Swetha Barkam is a Ph.D. student from the department of materials science and engineering at University of Central Florida. She is involved with a two-fold challenge in her research, in which she is extensively investigating the physiochemical properties of cerium oxide nanoparticles (nanoceria) to understand their interaction with biological entities. Additionally, she is exploring the applications of cerium oxide coatings integrated with polymer nanostructures to develop flexible electronic sensors. One of her major research goals is to investigate sustainable and inexpensive health care and energy solutions for underprivileged populations in developing countries.

Allison Fraser

Lehigh University

Allison Fraser is a junior at Lehigh University pursuing a B.S. in materials science and engineering with a minor in mechanics of materials. She has been conducting research with Professor John DuPont as a recipient of the Clare Boothe Luce Research Scholars Award, studying the microstructural stability of graded transition joints at high temperature. She is currently conducting mechanical tests on graded transition joints at elevated temperatures to understand how strain is partitioned along the joint. Fraser is considering pursuing a Ph.D. in materials science and engineering to further develop her interest in metallurgy. Outside of research, Fraser is involved in the Society of Women Engineers and Women in Science and Engineering, and volunteers as a tour guide for the materials science and engineering department. She has also been riding horses for 15 years.

FROM THE PRESIDENT'S DESK

Many Hands Make Light Work

Supposedly, it was Teddy Roosevelt who said, "Every man owes a portion of his time and his income to the business or industry in which he earns his living." Although Roosevelt scholars have not identified when or where he said this, I believe it is true. As successful professionals, we ought to contribute to the sustainability of our profession across materials science, technology, engineering, and manufacturing. These contributions can be made in ways that are best suited to our available resources including time, money, and talent, either independently or jointly. For some of us, mentoring successors is enough. For others, financial contributions to various foundations is a way to make a difference. Another way of giving back is to serve in leadership roles as a means of framing the future of one's profession. Regardless, like Teddy Roosevelt, I encourage you to give back to your profession. If we ALL give back, we multiply our efforts, an idea amplified by another English proverb, "Many hands make light work."

This basic statement is easy to grasp and use. For the stress analysts among us, this is a simple equation: Stress = load/cross sectional area. For the purpose of this memo, the load is the task at hand and the cross sectional area is the many hands of our volunteers and staff. By increasing the number of hands, we can carry a greater load or do more tasks. Within ASM International we have plenty to do, from developing and deploying content to operating chapters, and from promoting our profession to leading the Society. There is no shortage of tasks, but if we all work together and lend a hand, we can make a difference in our profession. Additionally, and you might not tell your boss this, by collaborating you might also have some fun. In my next memo, the message will probably focus on yet another quote, "Talk does not cook rice!" Until then, thank you for serving ASM.

Jon D. Tirpak, PE, FASM
Chief Volunteer of ASM International
jon.tirpak@scra.org

Rachael Stewart

Colorado School of Mines

Rachael Stewart obtained a B.S. in materials engineering at the University of Alberta. After working in the Canadian oil and gas sector, she moved to Colorado where she is currently pursuing a Master of Science degree in materials engineering at the Colorado School of Mines. Her master's thesis is focused on achieving quenched and partitioned microstructures in thick plate steels. Stewart's professional interests include failure analysis and oilfield metallurgy. She has been involved with ASM for nine years.

Zeiss and ASM Announce Collaboration

Zeiss, Germany, has formed a close collaboration with ASM International, in which ASM is adding a combination of electron and light microscopes, including Zeiss EVO scanning electron microscopes and Zeiss Smartzoom 5 automated digital microscopes. ASM will use the new instruments in advanced metallography training courses designed to instruct members on high precision manufacturing and materials testing techniques. Zeiss is also collaborating with ASM to develop correlative work flows between light and electron microscopy. "Zeiss and ASM both place a focus on education as an enabler for materials science and materials testing and advancement in industry, which makes this new expanded collaboration such a great fit," says Alex Soell, vice president of marketing at Carl Zeiss Microscopy LLC.

John Cerne, senior manager of education at ASM, looks to the collaboration as a way of enriching its educational program with the expertise of Zeiss. "We are always looking for the most effective ways to provide training and were

ASM's recently renovated teaching laboratories now include scanning electron microscopes.

really struck by the enthusiasm Zeiss shows for our educational mission and focus on bringing solutions tailored to our industrial customer base," says Cerne. "Zeiss brought us an integrated solution that no one else could offer—an optical microscope and correlation to macro images—which greatly adds to our capabilities. The Zeiss solution will help us better educate users on finding images optically, conducting failure analysis, and performing metallographic interpretations."

VOLUNTEERISM COMMITTEE

Profile of a Volunteer

James Callahan, Laboratory Technician, Takata Corp.

Some of us learn by doing—and thrive by giving back. James Callahan does both. After graduating from high school in the Florida panhandle, he moved to San Antonio to work for Chromalloy, an international powerhouse in gas turbine engines for the aerospace industry. Callahan worked his way up from a simple role as plating operator into the chemical and metallurgy lab where he learned how to test chemicals and work with the R&D team on analysis and reports. With his thirst for learning, he decided to explore metallurgy—all part of his 23 years of hands-on experience at Chromalloy. Callahan recently began a new position with Takata, a leader in seat belt technology.

At a training seminar in 2010, he learned about ASM and joined the Alamo Chapter. He was soon invited to become membership chair and jumped right in. Callahan has made a noticeable difference by improving communication with members and attracting new ones as he added a Chapter Facebook page, maintaining the website, and working with college interns to get the ASM message out. "I really enjoy seeing an issue or problem and finding a better way," says Callahan. He finds that being on the Board gives him more of a say in the Chapter so he can make a greater impact.

He believes ASM's greatest value is through its outreach to the community, especially to college students at schools like University of Texas at San Antonio and St. Mary's University. "I can be there to answer questions and help students become part of our community," says Callahan, "so they can use the ASM member knowledge base to help with their careers." Encouragement from ASM members helped him through a year-and-a-half of unemployment after Chromalloy reduced its workforce. Deeply devoted to God and family, Callahan is also grateful for support from his wife of 28 years and three children.

WOMEN IN ENGINEERING

*This new profile series introduces leading materials scientists from around the world who happen to be females. Here we speak with **Amber N. Black,** an applications engineer for PTR – Precision Technologies Inc.*

What does your typical workday look like?

No two days are the same, which is part of what I love about my job. Some of the things I do on a daily or weekly basis include: Check on projects currently being welded in our contract welding shop; discuss new projects with potential customers; answer questions from engineers who call me to ask about electron beam welding because it is not a common process; work with my operators to develop welds for any new parts; work to improve longstanding welded parts; and provide documentation that our welds are sound and developed to specification.

What's been your biggest technical challenge?

Welding the "unweldable" metals continues to be a challenge we attempt to solve. I've done extensive research and testing on gamma-prime strengthened superalloys in an effort to weld without microcracking. Hardened, carburized, or nitrided alloys can also cause issues. I've been working with local heat treatments to try to overcome the weak welds and cracking issues that often occur.

What part of your job do you like most?

I enjoy hands-on work on the floor to bring a part from conception to reality. We need to figure out tooling to hold it together, any issues with weld geometry during development, and how to overcome issues stemming from the original design.

What do you least like to do?

Paperwork! A lot of engineering involves appropriate documentation and as a critical element of many engineered parts, the welding process has a lot of necessary paperwork. But that doesn't mean I like to do it.

What is your engineering background?

I have a bachelor's in materials science and mechanical engineering from UConn and a Ph.D. in engineering science from Penn State.

What attracted you to engineering?

I did a project on metallurgy during chemistry in high school. When I found out that you could have an entire career based on that, I was hooked.

Did you ever consider doing something else with your life besides engineering?

Yes, I started college as a double major in chemistry and social sciences. Since switching majors, I have not seriously considered a different career.

What are you working on now?

I'm working on bringing about six different parts to fruition for small companies, very large companies, and national labs. We're also doing research on welding additively manufactured parts and how the additional processing affects mechanical properties.

How many people do you work with?

My company employs 43 people and I'm in a unique position to work with all of them on a weekly basis. I also work with perhaps 75 to 100 customers at a time—mainly engineers—to ensure they receive all the information they need and a quality product.

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

The most important part of engineering is finding your passion. Before I found lasers, I had worked with composites, photovoltaics, and shape memory alloys. Once you figure out what you like, talk to people in that field and figure out what you can do with it. It's a flexible, constantly changing career choice.

Hobbies?

Weightlifting and reading.

Last book read?

"The Round House" by Louise Erdrich.

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

CHAPTERS IN THE NEWS

Chennai Organizes Heat Treatment, Automotive Conference

In May, the 2nd International Conference and Expo on Heat Treatment and Surface Engineering concurrent with Automotive Materials and Manufacturing was held in India. Organized by the Chennai Chapter, the event received an overwhelming response from across the country and abroad, with more than 250 attendees. The event featured 12 plenary lectures and 44 invited presentations in the technical sessions, including speakers from the U.S., Brazil, Belgium, France, UK, Germany, Singapore, Korea, and Australia. More than 50 exhibitors were featured in the exhibition. The meeting was opened on May 12 by Mr. Sivanesan of Ashok Leyland, and T.S. Sudarshan, FASM, of Materials Modifications Inc. delivered the Guest of Honor Lecture. Many technical topics were covered such as surface modifications using lasers, properties of additively manufactured materials, low pressure carburizing for energy savings, and development of ultra-high strength steels.

More than 250 attendees visited a May conference on heat treatment and automotive materials organized by the Chennai Chapter.

University of Maryland Materials Science Students Win Alumni Cup

In April, the University of Maryland's materials science and engineering department won the famous "Alumni Cup" for the first time. Since 2012, this annual engineering competition challenges each department in the engineering school during a one-week contest to develop a machine that will perform a specific task within certain parameters. This year, the challenge was to design a Rube Goldberg machine that would successfully complete, in a minimum of 20 steps, moving a pencil 2 ft into a sharpener and then removing it after 10 seconds. The pencil must then be capa-

Alumni Cup winners from the University of Maryland's materials science and engineering department.

ble of writing. Luke Bittner, president of the school's Material Advantage Chapter, said, "This win grants us bragging rights as the 'best engineers' at the University of Maryland, and we've certainly earned that distinction." Team members include Luke Bittner, Omar Abdullah, Drew Stasak, Sabrina Curtis, Josh Eng-Morris, Patrick Ayerle, Alan Kaplan, and Kailey Stracka.

Carolina Southern Piedmont Chapter Enjoys Brewery Tour

On April 19, the Carolina Southern Piedmont Chapter toured the Wooden Robot Brewery in Charlotte, N.C., based on inspiration from the Milwaukee Chapter at Leadership Days. The monthly meeting also included officer elections for 2017, in which the executive board gained three new members.

Carolina Southern Piedmont Chapter members visit Wooden Robot Brewery.

Frazier Visits Orange Coast, Los Angeles

In April, ASM President-Elect William Frazier, FASM, visited the Orange Coast Chapter for a talk, and the Los Angeles Chapter for a student poster session.

Student poster winners from the Los Angeles Chapter and Bill Frazier, far right.

Ravindran Visits Santa Clara Valley

ASM Past President Ravi Ravindran, FASM, visited the ASM Santa Clara Valley Chapter on May 11. He discussed opportunities for students as eventual professional members of ASM International by illustrating his own career. His invited talk, "Lightweighting : A Revolution in the Automotive Industry," was well received by the 70+ attendees.

From left, Geoff Egan, Al Kwong, Dave Himmelblau, Paul Flowers, Shawn Hussey, Ravi Ravindran, Jason James, Brock Hinzmann, and Jack Jew.

Tirpak Visits Oak Ridge

ASM President Jon Tirpak, FASM, visited the Oak Ridge Chapter in May.

Jon Tirpak next to the ASM plaque at Oak Ridge National Laboratory's X-10 Graphite Reactor, the second ASM National Historical Landmark, dedicated in June 1973.

MEMBERS IN THE NEWS

Colorado School of Mines Establishes Rath Research Award

Colorado School of Mines (CSM), Golden, recently established the Rath Research Award, consisting of a certificate and cash prize. The new award is endowed by ASM Past President **Bhakta Rath, FASM,** and his wife, **Sushama,** to recognize a Ph.D. graduate and their advisor for the thesis that has the greatest potential to impact U.S. society and industry. The recipient is selected by CSM's Rath Dissertation Fellowship Committee. This year's award recognizes **Laura Condon** and her thesis advisor R.M. Maxwell for seminal research in the field of hydrology and understanding of water management.

From left, CSM president Paul Johnson, Bhakta Rath, and award recipient Laura Condon.

Vander Voort, Sunday Honored by Drexel University

George Vander Voort, FASM, and doctoral student **Katie Jo Sunday** were recognized for exceptional achievements at Drexel University's Alumni Association Awards, held in May. Vander Voort received the Service to the Profession Award for his work as a physical metallurgist and expertise in process metallurgy and mechanical metallurgy. Sunday received the Outstanding Student Award, given to an exceptional student who excels in studies and exhibits outstanding leadership skills. In addition to her research on coating iron powders with oxide particles and producing soft magnetic composites for use in electromagnetic devices, she was recognized for her work as a teaching assistant. In addition, for the past two years, Sunday has organized ASM's Materials Camp at Drexel, a one-week free camp for high school juniors and seniors to introduce them to materials science and engineering.

From left, George Vander Voort, Katie Jo Sunday, and Fred Schmidt, FASM, at Drexel University's 2016 Alumni Association Awards.

Karthikeyan Receives TSS President's Award

Jeganathan Karthikeyan, FASM, director of research & development, ASB Industries, (center) is surrounded by his family after receiving the 2016 TSS President's Award for Meritorious Service at a company picnic held in his honor on June 20. Look for the full story in the *iTSSe* November issue. Karthikeyan holds an advance copy of the new ASM publication, *High Pressure Cold Spray,* he co-edited with Charlie Kay, vice president of marketing at ASB.

Jeganathan Karthikeyan (center) and family at an ASB company picnic held in his honor.

IN MEMORIAM

Karl A. Gschneidner Jr., FASM, known internationally as Mr. Rare Earth, passed away on April 27 at age 85. He began work on his Ph.D. at Iowa State University in 1955 and was hired as an Ames Laboratory graduate researcher in metallurgy. After receiving his doctorate in 1957, Gschneidner took a job in the chemistry and metallurgy division of Los Alamos National Laboratory in New Mexico and was promoted to section leader in 1961. An opening at Iowa State and Ames Laboratory gave him the chance to return to Ames in 1963. Gschneidner formally retired from Ames in January after a 60-year career dedicated to the study of rare-earth metals. He was a distinguished professor of materials science and engineering at Iowa State University, senior metallurgist at Ames Laboratory, and chief scientist of the Critical Materials Institute (CMI), a U.S. Department of Energy Innovation Hub located at Ames Laboratory. He was also a member of the National Academy of Engineering and earned a lengthy list of awards for his research. A prolific writer, he published more than 544 articles in scientific journals and more than 170 chapters in books and conference proceedings. As testament of the quality of his research, his published works have been cited 19,013 times. "Our work on the giant magnetocaloric effect of gadolinium-silicon-germanium has been cited more than 2100 times," Gschneidner said at his retirement, "so you could say we really hit the jackpot with that one. Finding something new or unexpected is what makes it worthwhile. It's kind of like hitting a great drive in golf; it keeps you coming back."

Richard (Dick) Ryan, FASM, passed away in May at age 78. Born in Springfield, Illinois, in 1937, Ryan attended Loyola University, Chicago, and Illinois Institute of Technology, studying chemistry and metallurgical engineering. He also received an M.B.A. with high honors from Lake Forest School of Management. After working summers as a metallographic technician while in school, Ryan joined Buehler Ltd. as a metallographer in 1957 and worked at the company for 45 years. Part of his career involved an 11-year stay in Los Angeles, where he became involved in ASM International and served as chair of the San Fernando Valley Chapter. During his career, Ryan became responsible for managing sales in the U.S., Canada, and eventually worldwide. Over a 20-year period, sales increased tenfold. A charter member of the International Metallographic Society (IMS) in 1967, Ryan served in several leadership roles for the Society, including IMS President from 2001-2003. He was also an active member of ASM, serving on the Heat Treat Committee, Publications Council, *AM&P* Editorial Committee, Nominating Committee, and many others. He was a true world traveler as well, having visited all 50 states, most Canadian provinces, and more than 50 foreign countries.

ADVANCED MATERIALS & PROCESSES

EDITORIAL PREVIEW

SEPTEMBER 2016

Nondestructive Testing & Failure Analysis

Highlighting:

- Advanced NDE Methods
- Corrosion Prevention & Analysis
- Analyzing Electronics Failures

Special Supplement:

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

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- HT Mexico
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  October 5-6, Nashville, Tenn.

Advertising closes August 4

OCTOBER 2016

2035: Metals of the Future

Highlighting:

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- Liquid Metal Engineering
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- MS&T16 Conference & Exposition
  October 24-27, Salt Lake City

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AD INDEX

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STRESS RELIEF

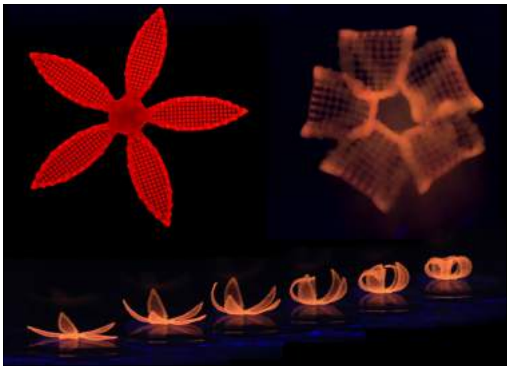
BONBONS PREDICT THIN SHELL THICKNESS

A simple fabrication technique derived by engineers at Massachusetts Institute of Technology, Cambridge, may help chocolate artisans create uniformly smooth shells and precisely tailor their thickness. The research could also have uses far beyond the chocolate shop. By knowing just a few key variables, engineers could predict the mechanical response of many other types of shells, from small pharmaceutical capsules to large airplane and rocket bodies.

The fabrication technique quickly creates thin, rubbery shells, in which a liquid polymer is drizzled over dome-shaped molds and spheres such as ping pong balls. Each mold was coated with liquid and cured over 15 minutes. The resulting shell was peeled off the mold and was smooth—virtually free of noticeable defects—with nearly uniform thickness throughout. Combining this simple technique with the theory they derived, the team created shells of various thicknesses by changing certain variables, such as mold size and polymer density. *web.mit.edu.*

Inspired by videos of chocolatiers making bonbons and other chocolate shells, Pedro Reis and his team wondered if there is a way to precisely predict the final thickness of chocolate and other shells that start as a liquid film.

4D-PRINTED HYDROGELS TRANSFORM UNDER WATER



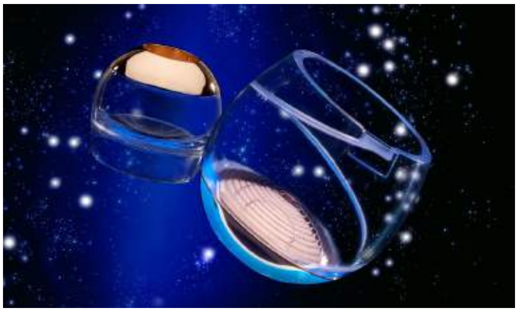
A series of images shows the transformation of a 4D-printed hydrogel composite structure after being submerged in water. Courtesy of Wyss Institute at Harvard University.

A team of scientists at Harvard University, Cambridge, Mass., unveiled 4D-printed hydrogel composite structures that change shape upon immersion in water. The team was inspired by natural structures such as certain plants that change their form over time according to environmental stimuli. The new hydrogel composites are programmed to perform precise, localized swelling behaviors. The composites contain cellulose fibrils that are derived from wood and are similar to the microstructures that enable shape changes in plants.

By aligning cellulose fibrils during printing, the hydrogel composite ink is encoded with anisotropic swelling and stiffness that can be patterned to produce intricate shape changes. The anisotropic nature of the cellulose fibrils gives rise to various directional properties that can be predicted and controlled. The new method opens up many potential applications for 4D-printing technology including smart textiles, soft electronics, biomedical devices, and tissue engineering. *wyss.harvard.edu.*

SHOW ME THE WAY TO THE NEXT WHISKEY BAR

Ogle, UK, created a whiskey glass model able to withstand rigorous testing that proves its suitability for use beyond earth's atmosphere. The company's stereolithography (SLA) machines were used to create the precise specifications needed for the microgravity-friendly object. To ensure the prototype is visually realistic and durable, a resin called ClearVue was selected for production due to its moisture resistance.



This 3D-printed whiskey glass is designed for microgravity happy hour.

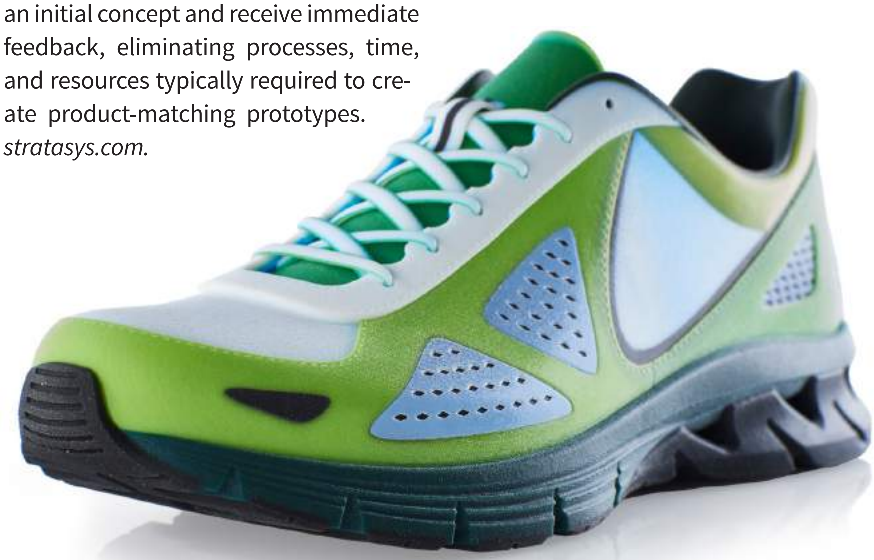
The model was eventually hand-finished inside and out using 800 wet grade paper to remove any layering and provide a smooth texture. To create a glasslike appearance, it was masked and clear lacquered on both sides. The glass, made of six component parts, was subject to many pre- and post-production checks by the team. This included applying a rose gold-plated base to ensure that the thread, which brings liquid to the top of the glass and prevents spills, fits correctly and with enough clearance for the paint team. The prototype was tested in microgravity at the ZARM Drop Tower in Germany where it was approved for space flight. *oglemodels.com.*

3D PRINTSHOP

ONE-STOP PRINTER BUILDS COMPLETE ATHLETIC SHOE

Stratasys Ltd., Minneapolis, introduced the J750 3D printer that produces finished models with colors, textures, and multiple materials, eliminating the need for post-processing. For example, the J750 can print a complete athletic shoe with full color, smooth surfaces, and a rubberlike sole in a single operation. Built-in PolyJet Studio software is newly designed and allows users to mix and match more than 360,000 different colors plus multiple materials and material properties—from rigid to flexible and opaque to transparent. Color textures can be loaded intact via VRML files imported from CAD tools.

The machine also offers increased efficiency over previous models. Its six-material capacity keeps the most used resins loaded and ready for printing, while newly designed print heads allow simulated production plastics such as Digital ABS to be printed in half the time of other Stratasys PolyJet systems. Finally, the J750 is expected to improve total cost of ownership. Designers and engineers can handle product prototypes within hours of developing an initial concept and receive immediate feedback, eliminating processes, time, and resources typically required to create product-matching prototypes. *stratasys.com.*

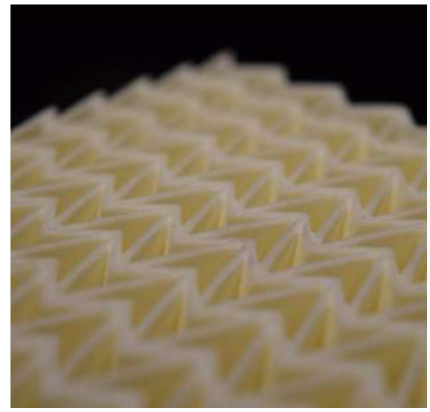


Prototype produced with full color, smooth surfaces, and a rubberlike sole, all in a single print operation. Courtesy of Business Wire and Stratasys Ltd.

NOVEL MATERIAL BOOSTS BRAIN PROTECTION

Helmet manufacturer Charles Owen Inc., Lincolnton, Ga., was awarded $250,000 to develop a new, energy absorbing material that could protect athletes and military personnel, among others, from brain injury. The prize will support a collaboration between the company, which produces equestrian, motorcycle, and military helmets, and Cardiff University, UK, creator of the multilayered, elastic material called C3. The project will further develop the material, which can be precisely designed using mathematical modeling, and then computer test it for specific impact scenarios prior to fabrication with a 3D printer. During C3 production, a polymer-based powder is fused into a specific shape by a laser, which solidifies the material to form a strong, flexible structure.

Funding was awarded by a partnership of the National Football League, Under Armour, GE, and the National Institute of Standards and Technology as part of *Head Health Challenge III: Advanced Materials for Impact Mitigation.* The team is among four winners to secure initial funding; after a year, the most promising technology will receive another $500,000 to support further development. *charlesowen.com, www.cardiff.ac.uk.*



C3 material can be designed using mathematical modeling and tailored for specific impact scenarios. Courtesy of Cardiff University.

POWDER PROCESS POWERS UP FOR AM

H.C. Starck, Germany, launched a new process to produce specialized refractory metal powders for additive manufacturing (AM). The company will apply the new process to its existing products—molybdenum, tantalum, niobium, and tungsten in pure and alloyed powder forms—offering spheroidized refractory metal powders with tailored chemistry and particle size distribution. The new powders are engineered for enhanced processability and performance when used with standard AM techniques such as binder jet, directed energy deposition, and powder bed fusion. *hcstarck.com.*