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Editorial Opportunities for iTSSe in 2012
The editorial focus for iTSSe in 2012 reflects established applications of thermal spray technology such as power generation and transportation, as well as new applications representing new opportunities for coatings and surface engineering.

November  Emerging Technologies
To contribute an article to one of these issues, please contact the editors c/o Julie Kalista at Julie.Kalista@asminternational.org.
To advertise, please contact Kelly Thomas, Kelly.Thomas@asminternational.org.

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The August issue focuses on thermal spray coatings and engineering surfaces in process and metals industries. These industries range from mining/extraction to refining and processing to coating production and applications. The coatings can be for corrosion control and thin film surfaces in high technology applications.

In corrosion control, corrosion affects a wide range of process industries including oil and gas, petrochemical, power generation, pulp and paper, and metal processing. Engineered surfaces provide a stable interface between the tool or component and the service environment. Thermal spray coatings are used to improve performance, reduce maintenance, and increase service life of a wide variety of processing equipment. Controlling maintenance costs by use of thermal spray in the petrochemical industry is discussed by ExxonMobil Chemical Co. in this edition.

Coating technology is also a key innovation driver for almost all areas of manufacturing, from scratch-proof displays for smart phones to antibacterial coatings on a variety of surfaces. Coatings protect components from corrosion and aging, from solar cell modules to car engine components, without the end user ever noticing their existence.

Continued advancements in process tools (e.g., thermal spray equipment), and processes enable further innovation in engineered surfaces. This ranges from plasma processes providing thin films to thicker films produced using laser-based additive techniques. These processes continue to provide coatings with improved performance, reduced process steps, and reduced costs.

Included in this issue are articles on the advancements in hardware and coatings by the Fraunhofer Institute in Germany and AMT AG in Switzerland. Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) developed a new kind of plasma coating process providing an engineered surface. The key element to their process is a unique plasma device. In the nozzle, an electrical discharge generates small flashes with the plasma exiting from the nozzle in the form of a jet. The process is used in the automotive industry and the energy sector to provide protection against corrosion and aging.

AMT AG discusses progress in high velocity oxy-fuel (HVOF) gun design that enables multiple processes to be conducted with a single thermal spray gun platform. This reduces the number of processes (and guns) required to provide a multicoating system. The hybrid gun design enables development of duplex coatings, and is commercially manufactured for production operations.

You can learn about more advancements in thermal spray technology at ASM Thermal Spray Society’s International Thermal Spray Conference (ITSC). Be sure to join us May 13-15 for ITSC 2013: Innovative Coating Solutions for the Global Economy in Busan, Republic of Korea, to experience premier technical programming from the world’s leading thermal spray experts. The abstract submission deadline has passed but organizers are still considering late submissions. Email Natalie Nemec (natalie.nemec@asminternational.org) by August 13 for consideration.

Robert Gansert, Ph.D., iTSSe co-editor
Advanced Materials & Technology Services Inc.

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ITSC 2012: Air, Land, Water, and the Human Body: Thermal Spray Science and Applications, held May 21-24, in Houston, Tex., was a great success with more than 1100 attendees, 239 presentations, 83 exhibitors with 109 booths, and 39 countries represented. Two keynote presentations kicked off the event: Brian J. Fitzgerald (ExxonMobil Chemical Co.) presented Controlling Maintenance Costs by the Use of Thermal Spray in the Petrochemical Industry (pictured here); Mitchell Dorfman, FASM, Sulzer Metco Fellow, (Sulzer Metco US) presented Global Opportunities and Challenges in the Thermal Spray Industry.

Tucker wins TSS President’s Award for Meritorious Service

During the recent ITSC event in Houston, Dr. Robert C. Tucker, FASM, (left) received the TSS President’s Award for Meritorious Service from TSS president Charles M. Kay for his significant contributions to the revision of the Handbook of Thermal Spray Technology, which will be released in 2013.

Nominations sought for TSS Hall of Fame

The Thermal Spray Hall of Fame, established in 1993 by the Thermal Spray Society of ASM International, is a means of recognizing and honoring outstanding leaders who have made significant contributions to the science, technology, practice, education, management, and advancement of thermal spray. Nominations are now open until September 30, 2012 for the 2013 award. For a copy of the rules, nomination form, and list of previous recipients, visit, http://tss.asminternational.org/portal/site/tss/Networking/Awards/, or contact Sarina Pastoric at Sarina.pastoric@asminternational.org.

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TSS Student Board Members acknowledged

TSS President Charles M. Kay (center) thanked TSS Student Board Members for their contributions while serving on the Board in 2012. Wilson Wong earned his Ph.D. in mining and materials engineering from McGill University (Montreal, Canada). Maya Shinozaki is a graduate student in materials science and metallurgy at the University of Cambridge, UK.

Symposium on thermal spray technology

The Cleveland Chapter sponsored a one day symposium on thermal spray in May, which included six presentations on various aspects of the technology including chromium plate replacement, gun design, cold spray processes, challenges of powder manufacturing, and the influence of spray parameters on coating porosity and properties. Dr. Mark Smith, FASM, ASM immediate past president, gave an overview talk on traditional and emerging thermal spray process technologies, potential advantages and limitations of thermal spray, and examples of how thermal spray has been used to solve challenging materials and design problems. Charles Kay, TSS president, gave an overview of the Thermal Spray Society, emphasizing the new spray operator certification program. Joe Stricker, St. Louis Metallizing, gave a similar presentation on the role of International Thermal Spray Association.

Other technical presenters included Mark Smith, Sandia National Labs; Daryl Cramer, Thermal Spray Technologies; J. Karthikeyan, ASB Industries; Jean Mozolic, Zatorski Coating.

Attendees at Cleveland Chapter’s symposium on thermal spray technology.

Bradley Lerch, FASM, gives a technical presentation at the symposium.

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Co.; Gopal Dwivedi, Stony Brook University; and Bradley A. Lerch, FASM, NASA Glenn Research Center (pictured).

Additional information can be found at: http://www.asmcleveland.com/education/thermal-spray-education-symposium.

Certified Thermal Spray Operator (CTSO) update

The ASM Thermal Spray Society has been delivering certification exams since 2011. The Thermal Spray Certification Committee developed 11 exams including one general knowledge of thermal spray fundamentals, five written process exams, and five practical exams. The five process areas are air plasma, cold spray, flame spray, HVOF, and wire are spray. Each CTSO has taken at least three exams prior to earning the designation.

AeroMat 2013 Call for papers

In 2013, AeroMat promises to deliver a program built around the theme “Building on a Century of Innovation.” Organizers are seeking technical papers on all aspects of materials, processes, and applications for the aerospace industry. Part of the technical program will spotlight design and manufacturing processes of advanced materials for the future. The call for papers is now open. Share your ideas, research, and outcomes to advance the industry. Abstract submission deadline is November 1, 2012. Visit, https://asm.confex.com/asm/aero13/cfp.cgi, to submit your abstract today.

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Advancements in High-Velocity Thermal Spray Gun Design

Ralph Herber
AMT AG
Doetlingen, Switzerland

Advancements in high-velocity gun design enable improvements in coating performance and cost for application to a variety of materials processing industries. AMT AG designed and engineered a high-velocity oxy-fuel (HVOF) gun, HV 200 Hybrid, that enables multiple processes to be conducted with a single thermal spray gun design, reducing the number of processes (and guns) required to provide a duplex-coating system.

Increasing demands of various materials processing industries—from metals processing to aerospace coatings to energy generation—require increasingly sophisticated coatings solutions. In the past, such industries required multiple processes to provide a coating solution to meet the environmental conditions. The solution was often a duplex coating, with each coating layer imparting specific properties to the coating system.

Historically, the development of HVOF as a production tool proceeded primarily in two directions. The use of gas fuel results in higher temperatures, but lower speeds compared to kerosene systems. Thus, the kerosene system with its higher particle velocity was used successfully to produce dense carbide coatings with low surface roughness and minor carbide degradation because of the lower combustion temperature. By comparison, gas fuel systems produce more thermal energy (i.e., higher temperatures), which results in dense alloy coatings with good corrosion resistance.

The positive industrial use of HVOF is seen today in the application of MCrAlY coatings in land-based gas turbines. However, in situations where a dense oxidation protection coating is needed, there is often a need for a rough surface to maintain the adherence of a plasma spray zirconia-based thermal barrier coating (TBC). Thus, a device is needed that can produce a dense MCrAlY with a rough surface.

Development of the HV 200 hybrid HVOF spray gun (Fig. 1) meets this need. The gun was specially developed to produce high-volume coatings with specific coating criteria. It can be operated not only as a conventional HVOF gun running on gas or kerosene, but it can also be used with a liquid-gas fuel combination. This provides the technology to produce a dense MCrAlY coating, then enables producing a rough surface suitable for the TBC layer by switching to gas operation (Figs. 2 and 3).

A single-gun platform offers the potential to reduce coating processing steps in various materials processing industries. Neither gun hardware nor any process changes need to be conducted during the thermal spray process procedure to achieve both coating characteristics in one cycle: a dense coating with a rough surface. A multiple layer coating can be completed in one run, and combined with double powder-material injection, provides high spray rates saving time and production costs.

In addition, various combustion-fuel combinations provide the technology to influence coating structure over a wide range depending on the application. For example, as mentioned previously, it is possible to achieve very dense coating structures together with coatings that have a high surface roughness in one run without any spray process interruption. Together with the kerosene fuel, the HV 200 Hybrid gun can be operated with a wide range of conventional combustion spray gases, such as hydrogen, propane and propylene, or various combinations. Furthermore, nitrogen gas injection directly into the combustion chamber is possible, turning the gun into the cold gas spray mode, producing coatings similar to typical cold gas spray qual-
This flexibility offers a universal HVOF gun for a wide range of thermal spray applications. Features of the gun are shown in the table.

The water-cooled gun can be integrated into a conventional thermal spray control system (HVOF). Multiple hardware combinations are possible to optimize specific needs for individual industry and spray process applications.

For more information: Ralph Herber; AMT AG Switzerland, Badstrasse 34, CH-5312 Doettingen, Switzerland; tel: +41 56 245 90 19; fax: +41 56 245 90 11; ralph.herber@amt-ag.net; www.amt-ag.net.
Coating technology is a key innovation driver for almost all areas of manufacturing, for example, making scratch-proof displays for smart phones or antibacterial surfaces in refrigerators. Other coatings protect components from corrosion or aging, like in a solar cell module or a car engine, without the end user noticing their existence. In industry today, wet chemical processes or vacuum plasma processes are primarily used for coating applications. Both have drawbacks. Vacuum units are expensive, limited to smaller components and applying a coating takes a relatively long time. Wet chemical processes often involve high resource and energy consumption with the corresponding environmental damage and can also cause difficulties in the handling of material combinations for lightweight construction such as plastics/metals or aluminum/steel.

A new kind of plasma coating process that works at ambient pressure was developed. This poses a major challenge because the pressure is more than 10,000 times higher, and the absence of a vacuum reactor means they had to stop unwanted particles from forming and embedding in the coating. That was the key to developing robust, efficient industrial processes using the new plasma system.

One nozzle, various functional coatings

The central element is a plasma nozzle—no bigger than a typical spray can, but containing a highly complex coating system. In the nozzle, an electrical discharge generates small flashes; a plasma that exits from the nozzle in the form of a jet. Materials are systematically fed into the nozzle outlet where they are excited and fragmented in the plasma and deposited out of the plasma jet as a functional nanolayer onto the surface. Extremely high deposition rates were achieved, enabling fast, cost-effective production processes.

The use of a nozzle allows the coating to be applied very precisely and only where needed, conserving resources (Fig. 1). The processes are controlled so the same nozzle can be used to apply coatings with various functionalities; for example, for corrosion protection or for increasing or reducing adhesion. Only very small amounts of coating material are required, and practically all materials and material combinations can be coated (Fig. 2).

The process offers, in addition to the coating qualities and functionalities, even more benefits: it can be easily integrated into an inline production process, requires little space and is easy to automate, meaning it can be controlled via a robot. Other advantages include low investment costs and it is environmentally friendly. Depositing an adhesion-promoting coating on a car window edge before gluing it in replaces environmentally damaging chemicals. It also serves as a substitute for thick protective paint on printed circuit boards, which improves heat dissipation and hence, extends service life. The process is already used in the automotive industry and the energy sector to provide protection against corrosion and aging.

For more information: Dr. Jörg Ihde and Dr. Uwe Lommatzsch; Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM; tel: +49 421 2246-427; fax: +49 421 2246-430; joerg.ihde@ifam.fraunhofer.de; www.ifam.fraunhofer.de.
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Controlling Maintenance Costs in the Petrochemical Industry Using Thermal Spray

Brian J. Fitzgerald
ExxonMobil Chemical Co.
Houston, Tex.

Historical data shows coatings are protective under insulation between 8 and 13 years. Corrosion under insulation (CUI) occurs under all insulation types and is temperature dependent, requiring preventive measures in the 25 to 300°F range. CUI leaks are dependent on equipment age and wall thickness (Fig. 1). Safety, health, and environmental (SHE) risks, and business risks increase with equipment age.

The first wave of CUI leaks occurs after about 16 to 20 years on equipment with thin walls (i.e., small-bore piping). Generally, shutdown can be avoided and SHE and business risks are not high. The second wave of CUI leaks on equipment usually occurs on equipment that is 25+ years old with thicker walls; i.e., vessels. Here, shutdown is required and SHE and business risks increase. CUI maintenance costs are 10% per year of the total maintenance budget. Continuous and cyclic sweating service is a subset of CUI leaks. Probability of failure (POF) is higher, and CUI occurs in nontypical locations. General metal loss can also be severe; increasing the likelihood of rupture (Fig. 2).

Case for Action: Cost of CUI

About 60% of petrochemical industry assets are fixed equipment (FE), and 60% of leaks are from piping. CUI is the number one maintenance cost and SHE risk, and second in frequency. FE accounts for 35% of maintenance cost. Piping drives FE maintenance costs (55% of FE maintenance cost is piping), and CUI drives piping maintenance costs (50% of piping maintenance is CUI). A goal is to reduce repeated loss of containment events (SHE and reliability) because it distracts and disrupts the maintenance organization to work on a reactive basis.

To move toward a maintenance-free, inspection-free operating mode, thermal spray aluminum (TSA) is used. It has competitive total initial costs and lower life-cycle costs. Two application methods for TSA are flame spray and arc spray (Fig. 3), and they can be carried out both in the shop and in the field. TSA is suitable for wide temperature range; from cryogenic to 540˚C (1000˚F). Coating thicknesses from 250-375 µm (10-15 mil) provide barrier properties plus cathodic protection, with an estimated life of 30 to 40 years.

TSA in the petrochemical industry

TSA is recognized as “Best in Class” for CUI prevention by the European Federation of Corrosion (EFC). EFCTSA is included in industry standards including:

- NACE SP 0198-2010 includes TSA from -45˚C to 595˚C
- CINI 7.4.04 includes TSA for CUI protection up to 540˚C (1000˚F)
- EFC publication #55 lists TSA as first choice for CUI prevention
- NORSOK M50 recommends TSA for insulated equipment

ExxonMobil Chemical has widely used TSA for CUI prevention in maintenance and other projects. Equipment coated with TSA has been fabricated around globe, and the TSA experience curve is the primary cost drivers vs. paint costs. The supply chain is responding rapidly to the application of TSA, investing in people and equipment. TSA spray equipment suppliers are available to assist contractors with applicator training and equipment leasing.

To maximize shop application of TSA, shop welds should be coating before field hydrotesting. Vents, drains, and small-bore piping should be fabricated in the

Fig. 1 — CUI leaks are dependent on equipment age and wall thickness.

Fig. 2 — Small bore bleeder valve with severe corrosion.
shop and TSA coated. For field welds, keep the TSA coating 25 mm (1 in.) away from the welds. Quality control testing is important, but do not overspecify. While paint coatings are often damaged in handling, TSA scratches and nicks do not need to be repaired.

**Piping field welds**

Safety procedures with realistic hazard evaluation are essential for safe, efficient TSA on the job site (Fig. 4). Flame spray TSA requires no less attention to safe procedures than field pipe welding. This is best handled by assigning a dedicated TSA field supervisor to coordinate field TSA applications. Using a “dull” chisel test to determine TSA thickness is a useful quality control tool in the field.

**Summary and challenges**

TSA is considered Best in Class for CUI prevention. It is cost competitive after going through a learning curve. Projects have shown that TSA is now widely available; the application and supply chain is growing. Companies spending 10% of their maintenance budget on CUI can reduce costs by using TSA. Challenges include overcoming perceived high initial costs, improving estimating accuracy, paying better attention to productivity, and bidding on the complete job rather than just on one job element. It also is important not to overspecify quality assurance and quality control. Equipment should be tested at least once per shift, and it is imperative to obtain the required surface preparation before coating and achieving the correct thickness.

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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 September issue, as selected by JTST Editor-in-Chief Christian Moreau, are highlighted here. In addition to the print publication, JTST is available online through www.springerlink.com. For more information, please visit www.asminternational.org/tss.

“Cross-Sectional Residual Stresses in Thermal Spray Coatings Measured by Moiré Interferometry and Nanoindentation Technique”  
Jianguo Zhu, Huimin Xie, Zhenxing Hu, Pengwan Chen, and Qingming Zhang

A plasma-spray thermal barrier coating (TBC) was deposited on a stainless steel substrate. Residual stresses were first measured using moiré interferometry combined with a cutting relaxation method. Fringe patterns in the specimen cross section clearly demonstrate deformation caused by residual stress in thermal spray coatings. However, restricted by the sensitivity of moiré interferometry, there are few fringes in the top coat, and large errors may exist in evaluating residual stress in the top coat. The nanoindentation technique was used to estimate residual stresses across the coating thickness. The stress/depth profile shows that process-induced stresses after thermal spray are compressive in the top coat and have a tendency to a more compressive state toward the interface. In addition, the stress gradient in the substrate is nonlinear, and tensile and compressive stresses appear simultaneously for self-equilibrium in the cross section.

“Investigation of Deposition Behavior of Cold-Sprayed Magnesium Coating”  

Two types of magnesium powders with different particle size distributions were deposited by cold spray at different main gas temperatures. The deposition efficiency of particles increased, and the porosity of coatings decreased with increasing gas temperature. The deposition efficiency of particles increased when using the powder with a smaller particle size distribution. Stainless steel and aluminum plates were used as substrates. The commercial finite element software ABAQUS was used to help better understand the deformation behavior of particles and substrates. The mean bonding strength slightly increased when aluminum plates were used as substrates. The bonding mechanism of Mg coatings on stainless steel and aluminum substrates was discussed.

“Improving the Generalization Ability of an Artificial Neural Network in Predicting In-Flight Particle Characteristics of an Atmospheric Plasma Spray Process”  
T.A. Choudhury, N. Hosseinzadeh, and C.C. Berndt

We applied artificial neural network into an atmospheric plasma spray process for predicting in-flight particle characteristics, which have significant influence on the in-service coating properties. One major problem for function-approximating neural network is over-fitting, which reduces the generalization capability of a trained network and its ability to work with sufficient accuracy under a new environment. Two methods are used to analyze the improvement in the network’s generalization ability: (1) cross-validation and early stopping, and (2) Bayesian regularization. Simulations are performed both on the original and expanded database with different training conditions to obtain the variations in performance of the trained networks under various environments. The study further illustrates the design and optimization procedures and analyzes predicted values, with respect to the experimental ones, to evaluate performance and generalization ability of the network. The simulation results show that performance of trained networks with regularization is improved over that with cross-validation and early stopping and, the generalization capa-
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bility of the networks is improved, preventing any phenomenon associated with over-fitting.

“Optimizing Compliance and Thermal Conductivity of Plasma Sprayed Thermal Barrier Coatings via Controlled Powders and Processing Strategies”
Yang Tan, Vasudevan Srinivasan, Toshio Nakamura, Sanjay Sampath, Pierre Bertrand, and Ghislaine Bertrand

The properties and performance of plasma spray thermal barrier coatings (TBCs) are strongly dependent on microstructural defects, which are affected by starting powder morphology and processing conditions. Of particular interest is the use of hollow powders that not only allow for efficient melting of zirconia ceramics, but also produce lower conductivity and more compliant coatings. Typical industrial hollow spray powders have an assortment of densities resulting in masking potential advantages of the hollow morphology. In this study, process mapping strategies were conducted using a novel uniform shell thickness hollow powder to control defect microstructure and properties. Correlations among coating properties, microstructure, and processing reveal feasibility to produce highly compliant, low-conductivity TBC through a combination of optimized feedstock and processing conditions. Results are presented through the framework of process maps establishing correlations among process, microstructure, and properties, and providing opportunities for optimization of TBCs.

“Microstructural Characterization and Strengthening-Toughening Mechanism of Plasma-Sprayed Al2O3-Cr2O3 Composite Coatings”
Kai Yang, Jingwei Feng, Xiaming Zhou, and Shunyan Tao

Al2O3, Cr2O3, and Al2O3-Cr2O3 coatings were fabricated by plasma spray. X-ray diffraction was used to determine the phase composition of powders and coatings. The morphologies and microstructures of the coatings were characterized using electron probe microanalyzer and transmission electron microscopy. Vickers hardness, fracture toughness, and bending strength of the coatings were measured. Al2O3-Cr2O3 composite coatings show better comprehensive mechanical properties than the individual Al2O3 and Cr2O3 coatings, which are attributed to the former’s larger intersplat adhesion or interlamellar cohesion and lower porosity. Solid solution strengthens the phase interfaces and grain boundaries, which is beneficial to improve the mechanical performance of the composite coatings.

Feedstock powder cross-sectional images (left) commercially obtained HOSP powder; (right) hollow powder.

TEM image of as-sprayed Al2O3 coating.

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