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

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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.

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. Cermet, 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 metals 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 as cascaded 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
iTSS 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 Klimatechnik (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.

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 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 Sophia Zhou, VT Technologies (Suzhou) Co., Ltd (right) who accepted on behalf of her 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.
TRIBUTE TO THERMAL SPRAY HALL OF FAMER

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.

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 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. 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).
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.

**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).

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 WRAP-UP**

**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.)
ITSC WRAP-UP

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.

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.

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.
Case Study

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.

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.

Table 1—Trial Results

<table>
<thead>
<tr>
<th>Powder designation</th>
<th>Hardness – HV300</th>
<th>Porosity</th>
<th>Powder sizing (µm)</th>
<th>Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amperit 558.185</td>
<td>1140</td>
<td>&lt;1%</td>
<td>-30 + 5</td>
<td>Agglomerated sintered</td>
</tr>
<tr>
<td>Amperit 554.071</td>
<td>1380</td>
<td>&lt;1%</td>
<td>-25 + 5</td>
<td>Sintered crushed</td>
</tr>
<tr>
<td>Amperit 554.090</td>
<td>1540</td>
<td>&lt;1%</td>
<td>-20 + 5</td>
<td>Sintered crushed</td>
</tr>
<tr>
<td>Amperit 554.067</td>
<td>1502</td>
<td>&lt;1%</td>
<td>-15 + 5</td>
<td>Sintered crushed</td>
</tr>
</tbody>
</table>

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 synthesize 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$_2$O$_3$, TIO$_2$, AND TIO$_2$-CR$_2$O$_3$ 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$_2$O$_3$ 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$_2$O$_3$ and $n$-TiO$_2$ produces abrasion performance exceeding that of the materials alone. An optimized balance between the hard and brittle Cr$_2$O$_3$ phases and the soft and ductile $n$-TiO$_2$ phases results in higher abrasion, sliding, and galling resistance. The novel $n$-TiO$_2$-Cr$_2$O$_3$ blend is a promising evolution of the current TiO$_2$-Cr$_2$O$_3$ blend.

**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.

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

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

Thermal-sprayed heat exchangers were tested at high temperatures ($750^\circ$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 m² K/W), and the effect of thermal contact resistance is negligible. At higher flow rates, the convective resistance decreases (~2 × 10⁻³ m² K/W), and the lower contact resistance of the thermally sprayed heat exchanger provides better performance than the brazed heat exchangers.

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Finally, this article briefly describes performance profiles required to fulfill biological functions of osseoconductive bio-ceramic 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/m$^3$ and the time weighted average concentration is 34.2 mg/m$^3$, 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.
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