Thermal Spray Coatings in the Aerospace Industry/Military

JTST Highlights
Society News

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High Purity Yttria Thermal Spray Powder

- High density yttria coatings with less than 1% porosity
- Improved erosion resistance
- 20% higher productivity = cost savings
- Perfect for dry etch chambers
Nanocoating Provides Superior Corrosion Protection Via Two-Coat System

Accepted Practices to Test Bond Strength of Thermal Spray Coatings

Method Measures Ceramic Coating Stress and Damage on Turbine Blades

Editorial

May
Energy/Power Generation Industries

August
Automotive Industry/Industrial Applications

November
Emerging Technologies

About the cover
The Teslan coating from Tesla NanoCoatings is being tested in a number of field demonstration projects including the fuel tanks seen here. www.teslanano.com.

Editorial Opportunities for iTSSe in 2014
The editorial focus for iTSSe in 2014 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.

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.
Transitioning to 2014

I am happy to report that our final event of 2013, the Reliability, Durability and Performance Assessment of Thermal Spray Coatings conference, was hosted by GE Global Research and turned out to be an unparalleled success with more than 150 attendees, 20 distinguished speakers, and 19 tabletop exhibits. That model, a well known organization hosting a TSS event, is one that we certainly want to revisit in the future, both for the credibility that it brings to the given event (which translates into higher attendance) and for the positive impact on the financials. I actually had preliminary discussions with representatives from OEMs and equipment manufacturers, and they were all enthusiastic about the idea.

ITSC 2014 — Not Fiction: Thermal Spray the Key Technology in Modern Life!

The International Thermal Spray Conference and Exhibition takes place this year May 21-23 in Barcelona. The three-day exposition features a conference, poster session, exhibition, education courses, young professional competition, social events, and much more. At ITSC you will find information about equipment for thermal spraying, research and specialist institutes, applied research, and the latest innovations conveniently located in one big forum. The exposition will be held in the Palau de Congressos de Catalunya, in northwest Barcelona.

ITSC is a golden opportunity for the global thermal spray community to meet, network, exchange key information, and conduct business. The conference officially opens with an awards ceremony and plenary lectures. Look for them on Wednesday, May 21. The exposition and poster session also kickoff on that date.

The ITSC awards banquet takes place on Thursday, May 22. As part of the exhibition, numerous companies from all over the world display their latest developments and related applications. The conference program offers more than 200 presentations from distinguished speakers covering several topics ranging from fundamental science to industrial applications. Whether you are a thermal spray engineer/technician, a TS scientist, a student, or a supplier of TS equipment and materials, you do not want to miss ITSC. Vamos a Barcelona!

North American Cold Spray Conference 2014: Covering the World of Cold Spray

This year the NACSC will be held September 16-17 in Bromont, 40 minutes south of Montreal. Attendees will gain a basic understanding of the cold spray process, follow global R&D programs on cold spray technology, receive first-hand information on industrial applications, and be able to network with international experts. Advancements in cold spray technology are helping to expand the commercial and academic applications of this technically superior metal deposition process.

Aerospace Coatings Conference 2014: Development and Manufacturing Trends for the 21st Century

The third TSS Aerospace Coatings Conference will be held in Hartford, Conn., October 8-9. This symposium brings together thermal spray professionals involved in a wide range of responsibilities. By attending the event, you’ll be able to understand future coating and process requirements, learn about cost reduction improvements related to quality and reliability factors, and gain an appreciation of existing thermal spray coatings for the aerospace industry. Job shop sprayers, engineers, technicians, end-users, suppliers of equipment and material, academicians, researchers, material scientists, marketing companies, and entrepreneurs will all benefit from this event. Gain key perspectives with exciting presentations from invited presenters including Rolls Royce, Sulzer Metco, PWA, Curtiss-Wright Surface Technologies, LLC Surface Technologies, Delta Airlines Inc., Lufthansa Technik AG, Naval Aviation Department, Pratt and Whitney, KLM Engineering and Maintenance, and other leading organizations.

Your regular and active participation in those events is very important and will ensure that we can keep organizing such world-class meetings in the future. I thank you in advance and look forward to seeing you there.

Luc Pouliot, president, Thermal Spray Society
Armelle Vardelle was named lead editor of the Journal of Thermal Spray Technology (JTST) by Christian Moreau, editor-in-chief of JTST, and Robert C. Tucker, Jr., chair of the JTST Editorial Committee. Vardelle succeeds Basil Marple, who retired from the position after holding it since its creation in 2010. As lead editor, Vardelle will be in charge of papers for special issues, including the annual special double issue of JTST that contains a selection of expanded papers originating from the International Thermal Spray Conference (ITSC). Professor Vardelle is co-chair of the doctoral program in science and engineering of materials, mechanics, energy and aeronautics and co-chair of the department of materials science and engineering at the University of Limoges, France.

Moreau and Tucker also announced two new associate editors on the JTST editorial team: Margaret Hyland and Georg Mauer. Hyland is deputy dean, faculty of engineering, and professor, chemical and materials engineering, University of Auckland, New Zealand. Mauer has been head of the thermal spray technology research group at Forschungszentrum Jülich, Germany, Institute of Energy and Climate Research, IEK-1: Material Synthesis and Processing since 2008. Hyland and Mauer join current JTST associate editors, Seiji Kuroda, Kendall Hollis, and Chang-Jiu Li.
Solicitations for Student Members to the TSS Board

The ASM Thermal Spray Society is seeking applications for the two student board member positions. Nominations are due by March 1, 2014. Students must be a registered undergraduate or graduate during the 2014-2015 academic year, studying or involved in research in an area closely related to the field of thermal spray technology. To apply, submit an application package consisting of:

• Current resume/CV
• Two-page essay (typed and double-spaced in English) addressing your interest in participating in the program, including:
  • What experiences led to your interest in the program?
  • What qualities, characteristics, and skills do you possess that will make you a strong candidate to serve as a student representative on the TSS Board?
  • What do you hope to gain from this program?
• Students also must submit two letters of recommendation from faculty.

Applications will be reviewed by the TSS Nominating Committee, and candidates approved by the TSS Board. Selected participants will be notified by June 1, 2014, and they will begin their nonvoting, one-year term as student representatives on the TSS Board of Directors in October 2014. Student representatives must attend one regularly scheduled TSS Board meeting held in the U.S. each year, with expenses for travel, hotels, and meals paid for by ASM-TSS; and must participate in two interim TSS Board teleconferences. Student representatives will receive a one-year complimentary membership (worth $25) in Material Advantage, the program that provides student membership to ASM, TMS, AcerS, and AIST. Submit your application package to sarina.pastoric@asminternational.org.

Education course at ITSC 2014

Thermal Spray Technology, Processing, and Evaluation
May 18-20, 2014
8:00 a.m. – 5:00 p.m.

This course, taking place at the International Thermal Spray Conference and Exhibition in Barcelona, Spain, will be taught by Christopher C. Berndt, FASM, HoF, and Douglas G. Puerta. It provides an understanding of thermal spray processes, presents complex scientific concepts in terms of simple physical models, and integrates this knowledge into practical applications and accepted thermal spray practices. It is not a laboratory course, but provides detailed instruction for the evaluation of thermal spray coatings. Metallographic preparation and the methods used to ensure rigorous and practical evaluation are also covered. Each registrant receives the Handbook of Thermal Spray Technology and a comprehensive set of notes that include the presentation slides. To register, visit www.asminternational.org/education or contact the ASM Member Service Center at memberservicecenter@asminternational.org.
Nanocoating Provides Superior Corrosion Protection Via Two-Coat System

Todd Hawkins
Tesla NanoCoatings Inc.
Massillon, Ohio

One of the many threats the U.S. military must constantly defend against is particularly insidious and advances imperceptibly as it silently erodes the integrity of military, municipal, and global infrastructures—corrosion. It is an ever present and relentless enemy that varies in both intensity and hostility, and combating it requires considerable time and expense.

Based on extensive research, the U.S. Army and Army Corps of Engineers recently coordinated a new front in the war against corrosion by employing potent emerging technologies that promise a more effective, yet lower-cost defense than current protective methods achieve. Considered the military’s center of expertise for corrosion prevention based on its responsibility for structures such as locks, dams, and bridges, the Army Corps of Engineers is presently conducting these procedures under the most rigorous conditions because its interests include a vast infrastructure constructed in some of the world’s most extreme environments.

Challenges

In the past, anti-corrosive approaches used almost exclusively by the military to protect steel structures consisted of a three-part process that was proven to be effective, but costly. This technology, largely unchanged for three decades, begins with a base coat heavily loaded with zinc as the primary defense. However, the density of the zinc results in an inherently unstable and brittle base coat. The second, intermediate coat provides a barrier to moisture and oxygen, reducing the brittleness issue. The third and final coat imparts color and surface finish.

Surface preparation and material application represent the major expenses related to painting large structures. The traditional, three-coat system is both cumbersome and costly. Another drawback is the high lead content, which can create environmental issues during application and often requires extensive precautions when being removed or in preparation for repainting. While not common, issues with adhesion failure related to high zinc levels also can occur. Other problems can arise when inadequate or incorrect surface preparations cause serious and sometimes catastrophic peeling after a relatively short time due to poor bonding between the surface and zinc-rich base layer.

Solutions

As a result of these challenges, the Army and the Army Corps worked with Tesla NanoCoatings to develop an enhanced defense against corrosion. Over the past eight years, this included the testing and documentation of a new carbon nanocoating that provides superior corrosion protection through a two-coat system that is applied like paint, acts like plating, and relies on a much lower zinc content to eliminate an intermediate coat.

Lost conductivity resulting from reduced zinc content is offset by highly conductive carbon nanotubes (CNTs) that self-assemble into rope structures. In addition to enhanced conductivity, nanotechnology also imparts 5-10 x the adhesion strength compared to traditional methods. This builds stability into an inherently unstable primer, making adhesion failure far less likely.

CNTs help create a base layer that is not only highly conductive, but also abrasion-resistant, tough, and flexible. In addition, it is cost effective as it eliminates an entire application step, features a lifecycle that can last twice as long as traditional coating systems, and requires no special training to apply. It is also compatible with conventional paint application equipment and is formulated with a lower lead content to reduce environmental issues in application and removal.

Results and conclusions

Based on the results of initial standardized testing, the Army Corps of Engineers deployed the Teslan coating from Tesla NanoCoatings in a number of field demonstration projects such as fuel tanks, pipelines, water towers, and bridges at military installations throughout North Carolina and Washington. Due to the significance of Tesla’s technology, the U.S. Army identified its corrosion technology as a “technical solution.”

While the Army Corps of Engineers continues to monitor the performance of its present demonstration projects, Teslan has begun test applications in various other industries including petrochemical facilities and oil and gas well sites where corrosion is a common problem.

Accepted Practice to Test Bond Strength of Thermal Spray Coatings

The ASM Thermal Spray Society (TSS) Accepted Practices Committee on Metallography released a new document on the accepted practice to test the bond strength of thermal spray coatings.

A sufficient adhesion bond between the coating and substrate is critical for the functionality of the coated part. Coating integrity and durability directly depends on the cohesion bond strength. ASTM C633 “Standard Test Method for Adhesion or Cohesion Strength of Thermal Spray Coatings” is the baseline and mandatory process to follow for tensile testing of bond strength of thermal spray coatings. The test is required as a condition of approval for new coatings and their suppliers, and is the core qualification test for coatings for aviation, oil and gas, automotive, power, marine, and many other industries. This practice clarifies details of ASTM C633 requirements and provides examples of best practices confirmed by hundreds of tests performed worldwide, adopted by numerous industrial standards, and requested to comply by international technical standardization and certification organizations such as ISO, AS, SAE, and Nadcap.

**Test scope**

The ASTM C633 test applies tensile stresses to coated systems consisting of a coated sample glued to another cylindrical sample as shown in Fig. 1. Alternatively, the coating could be applied on a cylindrical “button,” which is glued between two cylindrical samples as shown in Fig. 2. The load is applied in a perpendicular direction to the interface between the coating and substrate. The amount of tensile load is gradually increased from 0, which results in sample failure—the coating pulled out from the substrate or fractured in two pieces inside the coating. The coated surface is always a flat circle with a diameter of 1 in. + 0/-0.005 in., and sample dimensions are standardized by ASTM 633. Bond strength is calculated as the load at sample failure divided by the coating failure area.

**Coating thickness**

Coating thickness of 0.01 in. (0.25 mm) is recommended if coating porosity is below 2%. If the coating has high porosity, increase coating thickness to 0.015 in. (0.38 mm) and above, as recommended by ASTM C633 to prevent glue penetration through the coating to the substrate, but do not exceed the thickness required for the coated part application. Thicker coatings have lower bond strength due to residual stress accumulation that can lead to nonrepresentative test results.

**Coating thickness variation**

The coating thickness should not vary across the surface by more than 0.001 in. (0.025 mm). The coating surface may be finished by grinding or machining when thickness variation is excessive. Other treatment, such as grit blasting, should not be used to level the coating thickness. Coating tapering increases sample misalignment, which results in failure at a lower load.

**Glue**

Polyamide-epoxy FM 1000 Adhesive Film is recommended (mandatory in many industrial specifications) as a bonding glue for the coating tensile test. Advantages include allowing testing of high-porosity coatings (such as abradable and ceramic coatings) without glue penetration to the substrate. Disadvantages include losing its own strength if stored at temperatures of 85°F (29°C) and above, but can work for years if stored in a refrigerator.

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**Bond test step-by-step**

- Inspect coating quality on bond caps. (Coating chipping, cracks, delamination, separation, or overspray are not allowed.)
- Prepare mating caps; grit blast their flat surface. (Do not grit blast coating surface.)
- Apply a layer of glue on coating surface.
- Place coated samples with applied glue layer into V-groove of curing fixture (see example of V-groove gravity fixture in Fig. 3).
- Add mating cap in the fixture with the grit-blasted surface facing the coating surface.
- Apply compression pressure to assembled samples. Note: Fig. 3 doesn’t show the additional weight on the top of assembled sample to keep them in compression during glue curing (see below under requirements).
- Place fixture with assembled and compressed samples in preheated oven.
- Keep samples under pressure in heated oven until glue cures; cool samples and release pressure.
- Carefully remove excess glue from each assembly with grinding. Recommended abrasive size for grinding paper or wheel is not coarser than 120 mesh; grinding direction is parallel to glued surface; interface damage/removal of sample material(s) not allowed.
- Place assembled samples in grips of tensile machine, gradually apply tensile load, and record failure load.
- Measure diameter (D) of sample failed face, and calculate the failure area as follows: 3.14 × D²/4.
- Bond strength = load of failure/failure area.

To obtain representative results, compare properties of coatings deposited and tested at different facilities; test conditions and processes require consistency and standardization.
Curing cycle
Recommended cycle for FM 1000 film: Heat assembled samples in oven to 340 ±10°F (170 ±6°C), and cure them for 90 min. ±10 min. at the temperatures at bond line of 340 ±10°F (170 ±6°C). Curing conditions may vary based on manufacturer recommendations and for different types of glue. Control the curing temperature with calibrated thermocouple touching (or bonding to) assembled samples. Class 5 furnace (per AMS2750) with temperature uniformity in the working zone of ±25°F is sufficient.

Fixture
Figure 3 shows a V-grooved gravity fixture. Such a design is working with FM1000 adhesive film. To keep assembled samples in compression during glue curing, one solid steel cylinder (1 in. diam. by 2 in. long) must be placed on top of two assembled samples. Fixture could be made from steel or an aluminum alloy, and should support samples at 30° to vertical position. The horizontal groove in the middle of the fixture shown in Fig. 3 protects it from contact with excessive glue during the curing process.

Work in clean and controlled environment
Protect samples from contamination: Do not touch coated surface. Keep coated samples in clean envelopes; plastic is recommended. Use filtered compressed air when removing grit, or dry sample surfaces from liquid degreaser. Protect samples from excessive humidity.

Verify alignment
Sample misalignment always leads to low test results. Verify their alignment in the fixture before curing, and after curing and removing excessive glue from the sample sides. Use tensile machine with universal joints to ensure sample self-alignment when tensile load is applied.

Control load by applying speed
Recommended crosshead speed for tensile load is 0.03–0.05 in./min.

Number of coated samples
It is recommended to test five samples and identify the coating bond strength as an average of the five results. For well-established dense coatings with high adhesion and cohesion strength (such as cermets), sample number can be reduced to three for one data point.

Test reference samples (glue test)
Always test at least one uncoated reference sample with each set of curing samples to verify/confirm that the glue itself has sufficient bond strength (10,000 psi as a minimum for FM1000).

Keep records
Keep records of all test conditions and file test reports. Bond test reports should include as a minimum: glue strength; coating bond strength; percent of each mode of coating failure (see Fig. 2); test date; operator name/signature; reference on applicable standard(s), specifications, and local instructions documenting test conditions and requirements.

This accepted practice is intended to be used as a baseline for your test processes, but does not replace local test/lab instructions. Additional requirements may apply based on available equipment, testing materials, and customer specifications. Acceptance testing should always be performed in accordance with ASTM C633 (latest revision).
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Method Measures Ceramic Coating Stress and Damage on Turbine Blades

Researchers are supplying the aerospace industry with innovative technologies to support the next generation of more efficient and reliable aircraft.

Mike Renfro
Eric Jordan
University of Connecticut, Storrs

As part of a research project funded by the National Science Foundation and Rolls Royce Inc., scientists developed a novel method of measuring stress and damage in the protective ceramic coatings applied to turbine engine blades to prolong their life. Blades are exposed to some of the most intense heat generated by the engine, and their reliability is crucial to extending engine performance. The thermal barrier coatings that provide insulation between the cooled blade and the hot gases in the engine are highly stressed and age over time eventually resulting in failure.

Maintenance crews currently rely on visual blade inspections to judge wear and tear along with a routine maintenance schedule based on engine performance data accumulated over time. If the protective ceramic coating is severely damaged internally, cracked, or chipped, the turbine blades can be damaged and even melt under the engine’s intense temperatures. A more quantitative approach to determine the remaining life of the coating is desired so that good blades can be returned to service while coatings near the end of their life can be replaced.

A process that uses laser technology to measure stress and damage in the ceramic coatings by exciting the bonding material between the coating and metallic blades was recently refined by UConn researchers. A low power laser is focused through the coating and the energy from the laser makes the bonding material fluoresce and that fluorescence is stress-dependent. During the process, the wavelength of light emitted by the fluorescence can be measured to determine how strong the bond is, how much viable coating is left, and whether the blade is damaged and prone to failure.

Previous lab correlation work indicates that when the coating is first made, it is very high stress because the bond between the coating and metal is stronger. As the coating cracks, the stress becomes less and less, and when it becomes too low, it simply flakes off. Determining this stress is key to predicting remaining life. However, applying this technique to actual hardware from an engine exposed new challenges.

Turbine jet engines—because they draw in huge quantities of outside air—are notorious for accumulating a lot of dust and other contaminants during performance, which makes testing the stress of engine blade coatings difficult. The contaminant on the turbine blades is highly irregular and in some places it is very thick and in others very thin. Attempting to sand it off would damage the ceramic coating itself and using chemicals would eat through the coating as well.

To get around this, a technique was developed that uses a pulsing laser to blast off the fine layer of contaminants, without damaging the underlying ceramic coating or blades. The laser is focused to a sufficient energy density to ionize the contaminants, ripping them off the surface and making them glow. Each laser pulse strips away about 1 µ of material at a time. By monitoring the ionization process with a spectrometer, the chemical composition of the removed material can be determined and the point at which all the contaminant is removed can be detected.

After the surface has been cleaned, the stress measurement can be performed. The technique has been developed into an instrument that can automatically clean an area on a blade and perform stress maps across the surface of the blade. It is a unique application of the same technology used by the Mars Rover to determine the chemical composition of rocks, and by art experts to restore valuable paintings to their original condition if they have been touched up or altered over time.

Development of an application for the technology to make it more portable for use while engines are still in service and attached to a plane is underway.

For more information: Mike Renfro is UTC associate professor of engineering innovation and associate department head, University of Connecticut, 860/486-5934, renfro@engr.uconn.edu, www.uconn.edu.
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 October and December issues, as selected by JTST Editor-in-Chief Christian Moreau, are highlighted. The December issue features papers from the 2012 Asian Thermal Spray Conference, organized by guest editor Dr. Seiji Kuroda. The last two articles highlighted below are from this special issue. In addition to the print publication, JTST is available online through www.springerlink.com. For more information, please visit www.asminternational.org/tss.

“Improved Thermal Cycling Durability of Thermal Barrier Coatings Manufactured by PS-PVD”
S. Rezanka, G. Mauer, and R. Vaßen

The plasma spray-physical vapor deposition (PS-PVD) process shows promise for the manufacture of thermal barrier coatings (TBCs). The durability of PS-PVD manufactured columnar TBCs is strongly influenced by the compatibility of the metallic bondcoat (BC) and ceramic TBC. Earlier investigations show that a smooth BC surface is beneficial for durability during thermal cycling. Further bond improvements between BC and TBC could be achieved by optimizing the formation of the thermally grown oxide (TGO) layer. In the present study, parameters of pre-heating and deposition of the first coating layer were investigated in order to adjust TGO growth. The durability of PS-PVD coatings was improved while maintaining a much higher deposition rate in comparison to EB-PVD. Improved thermal cycling lifetimes more than two times higher than conventionally sprayed TBCs were measured in burner rigs at ~1250°C/1050°C surface/substrate exposure temperatures.

“Tribological Characterization of Plasma-Sprayed CoNiCrAlY-BN Abradable Coatings”
E. Irissou, A. Dadouche, and R.S. Lima

Plasma spray torch parameters were varied to produce a set of abradable coatings exhibiting a broad range of porosity levels (34-62%) and superficial Rockwell hardness values (0-78 HR15Y). Abradability tests were performed using an abradable-seal test rig, capable of simulating operational wear at different rotor speeds and seal incursion rates (SIRs). Tests determined rubbing forces and quantified blade and seal wear characteristics for slow and fast SIRs. Erosion wear performance and ASTM C633 coating adhesion strength test results are also reported. For optimal abradability performance, coating hardness needs to be lower than 70.
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and 50 HR15Y for slow and fast blade incursion rate conditions, respectively. Erosion wear performance, as well as coating cohesive strength, was shown to be a function of coating hardness. Current results define coating specifications in terms of hardness and porosity for targeted applications.

“Fundamental Cost Analysis of Cold Spray”
O. Stier

The cost structure of the cold spray (CS) process is analyzed using a generic cost model applicable to all current types of CS systems and applications. The cost model was originally developed at Siemens and is easy to use and sufficiently accurate. Process costs depend on gas stagnation properties and are discussed. Results indicate that high pressure is generally favorable, He-N₂ blends possess economic potential, and He recovery saves costs in high-volume production (even when He-N₂ blends are used). The cost model determines the cost-optimal He concentration of the propellant gas for a given application. CS is, among others, suited to spray bond coatings on gas turbine blades and offers cost-saving potential, as shown.

Dependence of the total costs, $C_{tot}$, of cold-sprayed MCrAlY coatings on the He mass fraction $c$ of the propellant gas and the powder-to-gas mass loading ratio $w$ when He is recovered with 85% capture efficiency.

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