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Zirconium Diffusion Barrier Coatings for Uranium Fuel used in Nuclear Reactors

Application Note: Thermal Spray Applications in the Energy Industry

Case Study of Low-Pressure Cold Spray Conductive Coating

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About the cover
Coating of thermal spray aluminum applied to a petrochemical vessel. Accelerated corrosion under wet insulation is an issue for new pipes and vessels. Coating with TSA (thermal spray aluminum) is a cost-effective solution compared with other systems over the life of the facility. Photo courtesy of Metallisation Ltd., Dudley, West Midlands, UK. www.metallisation.com.

Editorial Opportunities for iTSSe in 2011
The editorial focus for iTSSe in 2011 reflects established applications of thermal spray technology such as corrosion and transportation, as well as new applications representing new opportunities for coatings and surface engineering.

- February: Corrosion Prevention
- May: Applications in the Transportation Industry
- August: Emerging Technologies
- November: Energy Production Applications

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.
Volunteers: the Driving Force Behind TSS Growth

Another successful Thermal Spray Society event—Cold Spray 2010—was held September 27-28 in Akron, Ohio, with over 160 attendees. The discussions and exchange of information covered everything from the technological advancements of this surface enhancement process and its solid state particle compaction/feature capabilities to its successful and growing applications. In November, TSS is teaming up with NACE for a symposium in Sao Paulo, Brazil, on Practical Solutions for Wear and Corrosion Problems.

The TSS volunteers, the professional staff of ASM International, and most importantly, the event attendees, drive the success of these special events aimed at meeting the information needs of the thermal spray community. For example, for the event in Brazil, industrial companies have sponsored their own customers to attend the event.

A TSS Board meeting was held in conjunction with the Cold Spray event. During the meeting, TSS immediate past president Mitch Dorfman thanked outgoing Board members Peter Hanneforth, Roland Seals, Peter Heinrich, and Bill Lenling and the two student Board members, Viktor Drescher (Technical University of Berlin) and M. Lorena Bejarano (Stony Brook University), for their valuable contributions.

The new TSS Board is truly an international board with the addition of Luc Pouliot (Tecnar Automation), Masahiro Fukumoto (Toyohashi University of Technology), Dongming Zhu (NASA-Glenn Research Center), Ann Bolcavage (Rolls-Royce), and our young and vibrant Student Board Members, Maya Shinozaki (University of Cambridge) and Wilson Wong (McGill University).

The TSS leadership shows a bold, open initiative to work with the international community. Many new and long-term volunteers are engaged in Thermal Spray Society activities. As incoming TSS president, it is quite an honor and challenge to live up to the high expectations of this group and the entire Thermal Spray Society membership.

No conversation can go on without mentioning volunteer opportunities. The driving forces of using surface enhancements affect every one of us both personally and professionally. When you visit the TSS Web site (tss.asminternational.org), your “mouse clicks” will take you into your own personalized journey. If your path takes you to the inspiration of volunteering, then please contact me. The process is very easy, and we look forward to your volunteerism in areas that will benefit you, as well as the Thermal Spray Society. Contact me at Charlie.kay@asminternational.org.

Charles M. Kay, president, Thermal Spray Society
TSS announces new officers and board members

In accordance with TSS rules of governance, TSS elected officers and board members for 2010-2011. Mr. Charles M. Kay, vice president, marketing, ASB Industries, becomes the president of TSS, while Mr. Mitchell R. Dorfman, FASM, Sulzer Metco fellow, Sulzer Metco (U.S.) Inc., remains on the board as immediate past president. Mr. Luc Pouliot, vice president of operations, Tecnar Automation Ltd., is elected vice president. Officers serve a two-year term. In addition, Mr. Douglas G. Puerta, laboratory director, IMR KHA - Portland, is appointed secretary/treasurer for a one-year term.

Elected to the Board for a three-year term is Dr. Ann Bolcavage, senior engineering specialist, Rolls-Royce Corp., Prof. Masahiro Fukumoto, Toyohashi University of Technology, and Dr. Dongming Zhu, materials engineer, NASA-Glenn Research Center.

Two student members were also appointed to the board for a one year term: Ms. Maya Shinozaki, first year Ph.D. student in Materials Science and Metallurgy at the University of Cambridge, and Mr. Wilson Wong, second year Ph.D. student in Mining & Materials Engineering at McGill University.

Solicitations for student members to the TSS Board

The ASM Thermal Spray Society (TSS) is seeking applications for the two student board member positions. Nominations are due by March 1, 2011.

Young people are the future of the Society. TSS values the input and participation of these young people at all levels of activity. Participation already exists at the technical program level and the TSS Board wants to hear more of what you have to say and contribute.

Students must be a registered undergraduate or graduate during the 2010-2011 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 learn/gain from this program?

Students also must submit two letters of recommendation from faculty.

Applications will be reviewed by the TSS Nominating Committee, which will forward recommendations to the TSS Board for approval. Selected participants will be notified by June 1, 2011, and they will begin their non-renewable and non-voting, one-year term as Student Representatives on the TSS Board of Directors in October 2011.

The 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 of ASM, TMS, ACSR, and AIST.

This is a tremendous opportunity for leadership training. It also is a unique, first-hand way to experience how a Board of Directors functions and makes decisions.

Please send your application package to Sarina.pastoric@asminternational.org.

Cold Spray 2010 event a huge success!

The ASM Thermal Spray Society hosted a two-day meeting on Cold Spray Technology, September 27-28, at the Hilton Akron/Fairlawn Hotel, in Akron, Ohio. More than 150...
persons attended the event that showcased Vic Champagne, supervisor and scientist from the Army Research Laboratory, Aberdeen, Md., as keynote speaker delivering his address on “Cold Spray: From Laboratory Curiosity to Production.” The event featured 12 thermal spray exhibitor companies from the U.S., Germany, and Japan; as well as 26 technical presentations throughout the two-day conference. The conference included a panel discussion with Mitch Dorfman, Sulzer Metco (US) Inc.; a tabletop expo and networking; and concluded with an industrial tour/demonstration sponsored by ASB Technologies, Barberton, Ohio.

Panel discussion. Left to right: Mr. Vic Champagne, Army Research Laboratory; Dr. Julio Villafuerte, Centerline Windsor Ltd.; Dr. Joachim Merkmanns, Linde Glass; Dr. Tim Eden, Penn State University; and Mr. Jim Ryan, Advanced Materials Service.

Dr. Seiji Kuroda, National Institute of Materials Science, Japan.

Cold-spray exhibits and poster session.
ITSC 2011
in Hanseatic City of Hamburg

The International Thermal Spray Conference 2011 will be held September 27-29, 2011, at the Congress Center Hamburg, Germany. The event will be part of the DVS Congress and Expo 2011, an interdisciplinary event addressing the areas of joining, cutting, and coating technology. ITSC 2011 is cosponsored by the German Welding Society (DVS), the ASM Thermal Spray Society (TSS), and the International Institute of Welding (IIW), and offers the opportunity for exchange of expertise and knowledge in thermal spray research, equipment, and applications. The event theme of “Different Days, Different Markets,” fits nicely with the strategic goal of the thermal spray community to identify and address novel applications and new users of thermal spray coatings. To reinforce the position of thermal spray in its existing and future markets, ITSC 2011 offers a very practically oriented “application highlights,” as part of its technical program. Papers are invited in the areas of: Thermal Spray Processes; Properties; Equipment and Consumables; Applications; Economic, Regulatory, and Other Business Issues; and Young Scientists.

The deadline for the Call for Papers is December 1, 2010.

Mr. Jeff Haynes, program manager, Pratt & Whitney Rocketdyne.

Dr. Dennis Helfritch, Army Research Laboratory.

Dr. Motohiro Yamada, Toyohashi University of Technology, Japan (left) and Mr. Charles Kay, ASB Industries and president, Thermal Spray Society.

Mr. Charles Kay, ASB Industries and president, Thermal Spray Society.

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Test taking tips and advice

Last month we talked about how the exams are created; this month we’ll talk about taking multiple-choice exams. We all take tests. Most of us dislike them. Many of us are unaware of ways we can prime ourselves for success. Here are a few hints to help you maximize your next testing opportunity. The same rules apply to driving license tests or certification tests.

**Psych yourself up.** Read the questions and answer only those that you really know, flag the others for later review. If you read ahead, you may sometimes find the answer to a question that you’ve already read and didn’t know the answer.

**Read carefully.** Read every single word of the question. Do not skip over words, as you may not notice that the question is asking for the exception.

If the right answer does not pop right up, read the question and answer “A,” read the question and answer “B,” etc. That way, you might notice that the correct answer is the only one that is grammatically correct or that makes sense to you.

**Focus on the question in front of you.** Read only that question. Answer only that question. Do not try to out-think the question and decipher the exact meaning behind it and the possible exceptions to it. Take the question as it is; one question at a time and answer it, and only it, accordingly.

**Watch the time.** Know how many questions are on the exam and how many minutes you can devote to each one or to each section of multiple questions. Stick to your time limit. This way you have a good shot at finishing the entire exam instead of getting stuck somewhere in the middle.

**Change your answers.** If you think you answered incorrectly the first time, don’t hesitate to change your answer to the one you now feel is correct. Your first choice isn’t always the best one; most often if you think of a good reason to change your answer, you should change it. But don’t change it unless you have a reason to do so.

Check out the following links to other web sites that have more information on test taking; www.socialpsychology.org/testtips.htm; academic.udayton.edu/legaled/barpass/MultipleChoice/mc00.htm.

Don’t panic – you can always retake a test. Pretend the first time was a reconnaissance mission and use your knowledge to help prepare for the real testing mission.

For more information on the pilot testing program for the CTSO and to take advantage of the limited time, money saving offer, visit the certification section of the TSS web site at http://asmcommunity.asminternational.org/portal/site/tss/Certification/, or contact Louise Wehrle, Ph.D., CAE at certification@asminternational.org, or 440/338-5151, ext. 5894.
Zirconium Diffusion Barrier Coatings for Uranium Fuel used in Nuclear Reactors

Kendall J. Hollis
Los Alamos National Laboratory
Los Alamos, N.M.

The U.S. National Nuclear Security Administration (NNSA) Global Threat Reduction Initiative (GTRI), Los Alamos, N.M., has the mission to reduce and protect vulnerable nuclear and radiological material located at civilian sites worldwide. The GTRI scope includes more than 130 countries working to reduce the threat of radiological materials within their borders. Within the GTRI, the Reactor Conversion Program supports the minimization and, to the extent possible, elimination of the use of highly enriched uranium (HEU) in worldwide civil nuclear applications by working to convert research and test reactors to the use of low enriched uranium (LEU) fuel with a U-235 enrichment of less than 20%.

To convert high neutron flux HEU test reactors such as the one shown in Fig. 1, development of a replacement LEU fuel with higher uranium packing density than the previously used HEU powder dispersion in an aluminum matrix is required. The fuel under development consists of a monolithic U-10% Mo foil (178-508 μm thick × 43.3-103 mm wide × 289-1219 mm long) encased in 6061 aluminum alloy[1]. A fuel bundle comprising several such clad foils is shown in Fig. 2. One of the primary challenges in developing the fuel is the insertion of a thin (25 to 100 μm) diffusion barrier to prevent the interaction of the U-10Mo fuel with the Al cladding. Such interaction can lead to fuel plate swelling and possible rupture during reactor operation. The diffusion barrier must be of high density to prevent fission gas accumulation, must be well bonded to the underlying U-Mo fuel foil, and must have a top surface that promotes strong adhesion to the Al cladding, which is hot isostatic press (HIP) bonded to the coated fuel foil. The diffusion barrier material of primary interest is zirconium metal.

Among other alternatives, plasma spraying and electrospark deposition (ESD) are being considered as coating methods for the application of the Zr diffusion barrier to the LEU fuel. Plasma spraying is expected to have process time and cost advantages over Zr foil lay-up techniques while affording the possibility of gradient composition within the coating. ESD is a promising technique for spot repair of Zr coatings or for the coating of the thin (μm) edges of the U-Mo fuel.

Plasma Sprayed Coatings

Plasma spraying was conducted in a vacuum chamber to minimize the reaction of the zirconium with the environment. The substrates used for plasma spraying were U-Mo with dimensions 0.3 mm thick × 19 mm wide × 32 mm long. Prior to deposition, the substrates were transferred arc (TA) cleaned in reverse polarity (substrate neg-
Zirconium Diffusion Barrier Coatings, continued

To explore a range of coating structures, reverse polarity TA current during deposition was also used as a source of continuous surface cleaning and substrate heating. A chamber pressure of 59.8 kPa (450 torr) was found to support sufficient melting of the powder particles while still retaining some of the beneficial aspects of reduced pressure deposition such as high coating density. An example coating structure for Zr plasma sprayed on U-Mo is shown in Fig. 3.

The structure in Fig. 3 shows that the interface between the coating and substrate is highly conformal indicating good flow of the impacting Zr particles. Spray conditions were chosen to give high density (<2% porosity) while also producing a high-roughness coating surface to promote mechanical bonding with the aluminum cladding layer to be HIP bonded to the outer surface of the coating. The U-Mo substrate material cannot be highly roughened since a very precise spatial distribution of the uranium is required to ensure proper reactor functioning. Therefore, it is necessary to have a low amplitude interface height variation between the U-Mo and the Zr while it is desirable to have a higher amplitude surface height variation of the Zr to provide a larger surface area and modulating interface with the Al cladding. The rough outer coating surface is accomplished by choosing spray parameters that allow some degree of particle splashing on impact. The splashed material collects on small protrusions and causes the more rapid growth of these protrusions compared to the other areas of the coating resulting in a rougher top surface of the coating than the substrate beneath it. As observed in Fig. 3, many of the coating surface protrusions have an undercut shape. When the soft Al is HIP bonded to the Zr, the Al is expected to flow to fill in the interface making intimate contact with the Zr and is expected to be mechanically locked to the Zr by the undercut features.

Electrospark Deposited Coatings

Electrospark deposition, also known as electrospark alloying, is an arc discharge process between the material source electrode (anode) and the substrate that receives the coating (cathode) both of which must be electrically conductive. The discharge is of short duration followed by a quiescent period much longer than the discharge period to minimize substrate heating. The arc melts portions...
of both the electrode and substrate and the electrode material is transferred to the surface of the substrate. The primary adjustable parameters are the spark voltage, capacitance, and discharge frequency. Zr coatings were deposited on 0.3 mm thick U-Mo samples using a 3 mm diameter Zr rod as the anode. Deposition was conducted in a glove bag filled with argon. An example of ESD Zr on U-Mo is shown in Fig. 4.

Due to the molten zone on the substrate during deposition of the molten coating, the interface between coating and substrate is intimate with some intermixing as is observed in Fig. 4. The mutual melting and mixing causes the bonding of the coating to the substrate to be metallurgical in nature for ESD coatings. The surface roughness of the ESD coating is smoother than for the plasma sprayed coating shown in Fig. 3. Surface morphology enhancements on the 10 to 50 μm scale to improve mechanical bonding of the ESD Zr to the Al cladding may be possible by varying the deposition thickness of the coating from point to point. This is possible with the ESD process since the spot size for deposition is on the order of 10 μm.

Summary
To transition high neutron-flux research reactors from the currently used highly enriched uranium fuel to the more proliferation-resistant low enriched uranium fuel, a new monolithic type uranium fuel must be developed. A zirconium diffusion barrier between the U-Mo and the aluminum cladding is required to maintain the integrity of the fuel plates during reactor service. Plasma spraying and electrospar deposition have been investigated as possible techniques for depositing Zr on the U-Mo fuel. Both techniques have shown promise for this application and research is continuing to fully prove their suitability.

References

For more information: Kendall Hollis is an R&D scientist in the Materials Science and Technology Division of Los Alamos National Laboratory, P.O. Box 1663, MS G-770, Los Alamos, NM 87545; email: kjhollis@lanl.gov.
Corrosion has always been a major problem for the energy industry, regardless of whether in the emerging renewable energy sector or the more traditional fossil fuel industries. In this instance, we are looking at two specific areas of concern: wind turbine towers, due to their extreme locations; and the aggressive corrosion under insulation (CUI) experienced in the petrochemical industry.

Wind-turbine Systems
The wind turbine industry is growing rapidly. In the UK alone there are in excess of 3,000 wind turbines in operation, over 800 under construction, and several thousand more expected to be erected by the year 2020. Many manufacturers of wind turbines specify thermal spray zinc (Zn) or zinc-aluminum (Zn-Al) alloy coatings as a method of corrosion protection. Thermal spray coatings offer a resilient finish, which is less susceptible to damage than many paint coatings. When the size of this growing industry is taken into account, protecting against corrosion is crucial.

Onshore wind turbine towers are commonly manufactured in three or four sections. Each section often is given a metal sprayed coating around the flanged joints and up to 0.5 m (~1.5 ft) on either side of these joints, both inside and out. Many offshore towers are specified to have the entire external surface coated. In addition, areas around the internal bolting fixtures and access hatches are also metal sprayed to provide added protection against assembly damage, as well as protection against general wear and tear. Some wind tower sections can be in excess of 30 m (nearly 100 ft) long, making any corrosion protection process very challenging.

Metal spraying using the Metallisation Arc140 system (Metallisation Ltd., Dudley, West Midlands, UK) makes the entire process much simpler than more traditional metal spray systems. The 20 m (65.5 ft) push/pull supplies package also allows the energizer, wire, and wire-dispensing system to be located outside the tower section, while the operator moves along the inside, spraying where required. This flexibility is also beneficial when spraying the outside of the tower sections, allowing the energizer and wire feed to be kept away from the dusty spray area. The coated sections are then painted to the manufacturer’s specification.

One of Metallisation’s Spanish customers uses automated thermal spray to spray components within the assembly that supports the turbine blades. The actual coating with pure zinc is only one part of the process. In common with all metal spray coatings, the surface of the turbine part is first grit blasted to a profile of around 75 mm and a cleanliness of Swedish Standard SA3 (Surface Preparation - Cast Iron Parts). A robot-mounted arc spray system applies an even 120 mm of zinc at a spray rate of up to 36 kg/h. A final coating of epoxy paint is then applied. This is an excellent way to protect wind turbines from corrosion and offers up to 20 years protection.

Petrochemical Applications
In the petrochemical industry, corrosion under insulation (CUI) in piping systems consumes a significant percentage of the maintenance budget. A large portion of this money is spent on expensive items such as external piping inspection, insulation removal and reinstallation, painting, and pipe replacements. CUI prevention strategies provide long-term, reliable pre-
vention of CUI that move toward inspection-free and maintenance-free piping systems and significant maintenance cost reductions.

CUI, where accelerated corrosion can occur under wet insulation, will always be an issue for new pipes and vessels. Coating with TSA (thermal spray aluminum) is an ideal and cost-effective solution compared with other systems when reviewed over the lifetime of the facility. One of Metallisation’s customers, Iris NV, based in Belgium, has embraced the process of thermal spray to protect against CUI with many of its own customers. Iris NV applies thermal spray coatings to new vessels and pipework prior to installation. The preparation of the steelwork surfaces is critical to the success of the thermal spray process. Prior to spraying the distillation columns, the surface needs to be prepared by grit blasting with steel grit to Swedish Standard SA 2.5 (Surface Preparation - Cast Iron Parts), with a surface roughness between 75 and 110 µm. The surface is then arc sprayed with aluminum Grade 1350 to a thickness of 250 µm. Finally, a seal coat is applied to the columns.

As well as new installations, existing insulated pipe and vessels are often protected against CUI as part of an ongoing maintenance and safety regime. It is hoped that maintenance inspection programs can be reduced in years to come through the implementation of a CUI prevention strategy. Pipes are stripped of insulation to enable engineers to inspect the pipework for potential damage and excessive corrosion. A series of nondestructive tests are carried out before the surfaces are grit blasted to SA 3 where possible. In normal circumstances, it is at this stage that TSA will be applied using flame spray equipment, and in some cases, the surfaces are sealed. The final stage is to reapply the insulation to the pipework. This coating solution is increasing in volume, with a number of global oil companies adopting this process within many plants around the world. Confidence in the application process and technique has grown to such an extent that coating of live plant is commonly undertaken.

These few application examples provide some insight into the use of coatings that offer a safe future for the oil and gas industry, as well as supporting renewable energies for a greener long term future.

For more information, contact Stuart Milton, Metallisation Ltd.; tel: +44 (0) 1384 252 464, or visit www.metallisation.com.
Cold spray is a coating deposition method that uses a moderately heated supersonic velocity gas stream to propel relatively cold (i.e., below melting point) particles at a substrate. Upon impact, particles undergo plastic deformation and bonding to form a uniform coating surface. The deposited coatings have a high density (e.g., very low porosity) and residual compressive stresses. In addition, the equipment does not require combustible gases or fuels.

Among the many applications of cold spray coating is incorporating electromagnetic interference shielding onto a part. Metallic powders are most often used as the coating material, but ceramic particles can be used if combined with more ductile particles. Cold spray coatings can be used to tailor the properties of components for specific applications. This article discusses designing a cold spray coating to serve as a protective coating for improved corrosion resistance while meeting electrical property requirements.

**Spraying Magnesium Housings**

Magnesium housings are prone to corrosion, and while some coatings provide enhanced corrosion protection, they also can degrade electrical properties. In this case study, it was necessary to provide corrosion protection for a magnesium alloy housing while leaving specific areas of the housing electrically conductive to electrically ground components to the housing, and the entire housing to a larger assembly.

**Deficiency of Anodized Coatings**

An anodized magnesium component was not meeting the requirements of MIL-STD-461F (Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment) due to the poor electrical conductivity of the anodized coating. The conductivity of a component is measured using a bolt through a plate of a particular material in accordance with MIL-STD-461F.

**Cold Spray Coating Provides Improved Electrical Properties**

A cold spray coating was designed that protected the magnesium alloy while maintaining the conductivity. To test the conductivity, three 10 cm × 15 cm EV31 magnesium test plates were machined with slightly larger holes than required in MIL-STD-461F and with a specific geometry to aid in the deposition of cold sprayed material (Fig. 1). Commercially pure aluminum (CP-Al) powder was deposited on the interior surface of the hole and the plate surface of the plate (Fig. 2). The cold spray coating was machined flat and the hole was drilled to the required diameter. The Tagnite anodizing process was then applied to two of the plates, and the third plate was also coated with Rockhard over the Tagnite coating. The plates are shown in Fig. 3. All plates passed the conductivity testing.

**Initial Cold Spray Deposition**

Commercially pure aluminum was chosen for this application because of its superior conductivity compared to aluminum alloys or an aluminum/alumina matrix. However, attempts to spray CP-Al at the optimal settings resulted in nozzle clogging before a practical amount of material could be deposited. Further work was carried out to find the optimal nozzle design and operating parameters. The use of a shorter length ceramic nozzle gave significantly better performance, but nozzle clogging still occurred after prolonged spraying.

Further development of the commercial pure aluminum coating focused on increasing the adhesion strength of the
Coating on an AZ91 magnesium substrate by varying powder feed rates and robot travel speed. Results of adhesion tests of aluminum deposited on ASTM C633-01 adhesion test coupons showed that the best adhesion strength using the optimized setting was 17.2 MPa (2,490 psi); average adhesion strength of multiple tests was 13.4 MPa (1,940 psi).

Conductive Coating Application on Housings

The effectiveness of the cold spray conductive coating was evaluated on nine housings prepared using two conductive features. The first step was to deposit a cold spray coating of pure aluminum on the conductive areas. A corner location on the interior of the housing (Fig. 4a) was coated with four to five layers of cold spray aluminum to a thickness of about 2.5 mm (Fig. 4b), and a location on the housing exterior about 35 mm in diameter with a small and large hole in the surface was also sprayed. The feature was machined two different ways: 1.5 mm lower than the final dimension (Fig. 5) and 1.5 mm lower than the final dimension plus a 2 mm deep step added on the outside 5 mm of the circle (Fig. 6).

For the feature without the step, 4 to 5 layers of cold spray aluminum were deposited crisscross pattern to a
thickness of about 3 mm. For the feature with the step, the step was sanded to roughly a 60° angle and 2 mm of cold spray aluminum was deposited on the lower side of the step in a circular pattern leaving the entire surface relatively even. This was followed with 2 mm of cold spray aluminum deposited in a crisscross pattern over the entire circular area. Both styles of the coated feature with the step are shown in Figures 7 and 8.

Machining and Magnesium Protection

The housings were machined to final dimensions, and the surface of the coatings did not have voids or edge effects. Tagnite (an anodized coating) and Rockhard sealant were applied to the housing, and the cold sprayed surfaces were masked off to protect the electrical grounds. The housing successfully passed conductive and prototype testing. Future work will be aimed at developing methods to increase the strength, efficiency, and reliability of the cold spray coating on these housings.

Further work demonstrated that it was possible to make the cold spray areas more suitable for commercial cold spray application. A more uniform coating was achieved by machining the holes after cold spray. Also, a smoother spray path transition was made by adding a chamfer to the corner feature. These changes also increased the deposition efficiency of the process. A second batch of prototype housings was made using these specifications.

Further work also will be conducted to optimize the cold spray process including whether using high purity aluminum powder would increase coating adhesion strength and hardness. High-purity aluminum (HP-Al) powder is more spherical and uniform in size compared to CP-Al powder. HP-Al powder was deposited on magnesium using the same process parameters optimized for the CP-Al powder. A full design of experiment was then conducted based on the results from the first coupons.

The HP-Al coating was dense and without cracking. Coating adhesion strength ranged from 27.2 to 32.1 MPa (3,940 to 4,650 psi), with a four-sample average adhesion strength of 28.6 MPa (4,150 psi). SEM images of coatings at optimized settings (Figures 9 and 10) show low porosity and no evidence of cracking at the interface; porosity is <4%. It was determined that the optimized high purity aluminum cold spray would be used for future components.

The authors acknowledge Technology Applications Group, Grand Forks, N.D., and Rockwell Automation, Mequon, Wis., for their support of the project.

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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.

JTST editor Christian Moreau has chosen several articles 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.

“Numerical Study on the Effect of Substrate Angle on Particle Impact Velocity and Normal Velocity Component in Cold Gas Dynamic Spraying Based on CFD”
Shuo Yin, Xiao-fang Wang, Wen-ya Li, and Bao-peng Xu

A numerical study was conducted to investigate the effect of substrate angle on particle impact velocity and normal velocity component in cold gas dynamic spraying by using 3D models based on computational fluid dynamics. The substrate angle has significant effect on particle impact velocity and normal velocity component. With increasing substrate angle, the bow shock strength becomes increasingly weak, resulting in a gradual rise in particle impact velocity. The distribution of the impact velocity presents a linear increase along the substrate centerline due to the existence of the substrate angle, and the growth rate increases gradually with increasing substrate angle. Furthermore, the normal velocity component significantly decreases with increasing substrate angle, which may result in a sharp decrease in deposition efficiency. In addition, gas pressure, temperature, type, and particle size also play an important role in particle acceleration.

Continued on next page
“Mechanical Properties of LaTi$_2$Al$_9$O$_{19}$ and Thermal Cycling Behaviors of Plasma-Sprayed LaTi$_2$Al$_9$O$_{19}$/YSZ Thermal Barrier Coatings”
X.Y. Xie, H.B. Guo, and S.K. Gong

A LaTi$_2$Al$_9$O$_{19}$ (LTA) thermal barrier coating (TBC) was synthesized by solid-state reaction at 1773 K, and the mechanical properties of the LTA bulk were evaluated. The microhardness is about 14 GPa, comparable to that of YSZ bulk, whereas the Young’s modulus is about 44 GPa, lower than the value of YSZ. However, the fracture toughness of 0.8-1 MPa m$^{1/2}$ is much lower than that of bulk YSZ. A double-ceramic-layer LTA/YSZ TBC structure was proposed and the TBC was deposited via plasma spray. Thermal cycling tests of the TBC specimens were performed at 1373 K with a dwell time of 10 min. The LTA maintained good stability with ZrO$_2$ and Al$_2$O$_3$. However, the single layer LTA TBC was cracked at the LTA/bond coat interface after about 300 cycles due to its poor thermal shock resistance, while the YSZ TBC yielded a life of about 1,000 cycles. The LTA/YSZ TBC remained intact even after 3,000 cycles, exhibiting a promising potential as new TBC materials.

Y.-Y. Wang, Y. Liu, G.-J. Yang, J.-J. Feng, and K. Kusumoto

TiN coatings on Al$_2$O$_3$ substrates were fabricated by a vacuum cold spray (VCS) process using ultrafine (20 nm) starting ceramic powders at room temperature. The effects of microstructure on the electrical properties of the coatings were investigated. The sheet resistance of TiN coatings was related to spray distance, nozzle traversal speed, and deposition chamber pressure. A minimum sheet resistance of 127 Ω was achieved. The microstructural changes can be correlated to the electrical resistivity of TiN coatings.

“Cold Spraying of TiO$_2$ Photocatalyst Coating With Nitrogen Process Gas”
Motohiro Yamada, Hiroaki Isago, Hiromi Nakano, and Masahiro Fukumoto

Titanium dioxide (TiO$_2$) is a promising material for photocatalyst coatings. Anatase TiO$_2$ coatings were fabricated by the cold spray process. It was possible to fabricate TiO$_2$ coatings with an anatase
phase in all spraying conditions. The process gas used is not an important factor in fabricating TiO₂ coatings. The thickness of the coatings increased with increasing gas temperature, indicating that the deposition efficiency of the sprayed particles can be enhanced by controlling spray conditions. The photocatalytic activity of the coatings is similar or better than that of the feedstock powder due to the formation of a large reaction area. Cold spray is an ideal process to fabricate a TiO₂ photocatalyst coating.

“Microstructural Development and Deposition Behavior of Titanium Powder Particles in Warm Spraying Process: From Single Splat to Coating”
KeeHyun Kim, Seiji Kuroda, and Makoto Watanabe

Warm spraying was developed by NIMS, in which powder particles are accelerated and simultaneously heated and deposited onto a suitable substrate in a thermally softened solid state. In this study, commercially available titanium powder was sprayed onto steel substrate. Microstructural developments and deposition behaviors from a deposited single particle to a thick coating layer were observed by high resolution electron microscopes. A single titanium particle sprayed onto the substrate was severely deformed and grain-refined mainly along the interfacial boundary of particle/substrate by the impact of the sprayed particle. A successive impact by another particle further deformed the previously deposited particle and induced additional grain refinement of the remaining part. In a thick coating layer, severe deformation and grain refinement were also observed.

JTST Special Issue Planned on Emerging and Innovative Processes in Thermal Spraying

A special issue of the Journal of Thermal Spray Technology highlighting the most recent advances in thermal spray technology is coming soon. JTST associate editor Prof. Armelle Vardelle, University of Limoges, and JTST Committee vice chair Prof. Robert Vassen, Forschungszentrum Jülich GmbH, are serving as guest editors for the special issue.

Topics that will be covered include plasma spray PVD, reactive spray, suspension and solution precursor thermal spray, cold spray, pre- and post-processing, emerging applications, and much more. All papers will be peer-reviewed.

The planned publication date is June 2011. To subscribe to JTST and receive this special issue, contact the ASM Member Service Center at memberservicecenter@asminternational.org; tel: 800/336-5152, ext. 0 or 440/338-5151, ext. 0.
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