THIRD QUARTER 2016 / VOLUME 23

SPRAYTIME

PUBLISHED BY THE INTERNATIONAL THERMAL SPRAY ASSOCIATION, A STANDING COMMITTEE OF THE AMERICAN WELDING SOCIETY

- Joining Dissimilar Metals
- Simulation for HVOF Optimization

Where is your article? We encourage you to send articles, news, announcements and information to ***spraytime@thermalspray.org***

On the cover: An arcbeam spray for dense coatings is in use. (Photo courtesy of Metallisation)

Published by International Thermal Spray Association
A Standing Committee of the American Welding Society

Mission: To be the flagship thermal spray industry publication providing company, event, people, product, research, and membership news of interest to industrial leaders, engineers, researchers, scholars, policy-makers, and the public thermal spray community.

SPRAYTIME® (ISSN 1532-9585) is a quarterly publication of the International Thermal Spray Association. Printed on Recycled Paper.

Article submissions (subject to acceptance and edit), advertising insertions, address correspondence, subscription request, back issue copies, and changes of address should be sent to:

American Welding Society
Att: SPRAYTIME
8669 NW 36 Street, #130, Miami, Florida 33166-6672
Phone: 800-443-9353 or 305-443-9353 | *www.spraytime.org*

A subscription to SPRAYTIME® is free for individuals interested in the thermal spray and coatings industry. Visit ***www.spraytime.org*** to subscribe.

NORSK TITANIUM TO BUILD AEROSPACE ADDITIVE MANUFACTURING PLANT

Norsk Titanium AS, Norway, recently announced the State of New York, in partnership with SUNY Polytechnic Institute, has placed an order for an initial lot containing 20 of the company's patented MERKE IV™ Rapid Plasma Deposition™ machines. This is in accordance with an approved state budget allocation to facilitate Norsk Titanium's U.S. subsidiary building and operating what's claimed to be the world's first industrial-scale metal additive manufacturing plant in New York.

The factory will be in Plattsburgh, N.Y., and is expected to be operational by the end of 2017. The first 20 machines will establish a baseline production level of 400 metric tons/year of aerospace-grade, structural titanium components. The New York program also envisions a capacity ramp-up to a total of 40 machines capable of up to 800 metric tons/year. New York has released an additional $4 million in planning funds for the company's U.S. factory.

"Today marks the beginning of a new era in the way aircraft, marine vessels, automobiles, spacecraft, and many industrial products are designed and built," said Norsk Titanium President and CEO Warren M. Boley Jr.

Norsk Titanium US will provide additional investment into the Plattsburgh operation that is expected to bring the total program commitment to the $1 billion level over the initial ten-year period of operations. The company is also partnering with the North County Chamber of Commerce in Plattsburgh to support the launch and growth of its factory, including workforce training.

For 50 years, Holster Engineering has been in business. Its staff is shown on the newly installed Berthiez vertical lathe.

HOLSTER ENGINEERING CELEBRATES 50-YEAR ANNIVERSARY

Holster Engineering Co., Ltd., celebrated 50 years in engineering and 46 years in the thermal spray field this last October. Located in Tokoroa, New Zealand, it is a medium-to-heavy precision engineering repair service company that offers specialized services in thermal spray and machinery repair. Operating under the guidance of Directors Marty Camenzind (director/operations manager) and Bruce Martin (director/works manager/senior thermal spray engineer) is a staff of 27, many of whom have had a long period of service with the company. Martin and Camenzind have a combined 70 years' experience in the industry.

The thermal spray division was set up in 1969 and today is at the forefront using equipment such as plasma, flame spray, arc spray, high-velocity oxyfuel (HVOF), and high-velocity air fuel (HVAF) along with robotic automated traverses. It is the only thermal spray company to currently hold Lloyds Register approval for flame, arc, plasma, and HVOF spraying of engineering components in New Zealand.

Holster was the first New Zealand engineering company to realize the benefits of thermal spray technologies reclaiming damaged parts at a fraction of the cost of new replacements and as an alternative to traditional welding process repairs.

Holster has worked on some of the largest and most challenging thermal spray coating projects in the country. In 1984, one such project dealt with corrosion inside a local kraft pulp digester. A nickel-based alloy powder was plasma sprayed to approximately 800 sq ft of the digester with a fully automated system believed to be the first in the world at that time. The company now has equipment that gives the flexibility to apply coatings in-house as well as in-situ. The company also purchased the first HVAF aero-spray (by Browning) in the world.

In 1996, Holster Engineering acquired the franchise to be the sole applicators in New Zealand to apply the full range of release coatings developed by Plasma Coatings, Inc., based in Connecticut, which is now a subsidiary company of American Roller. This agreement is still in place. The company has a wide customer base and has assisted with more than 90 hydro and 20 thermal station overhauls, most having metallized coatings designed by Holster Engineering to help with erosion, corrosion, and cavitation.

More than 200 past and present employees, suppliers, and friends enjoyed the festivities of the special event held to celebrate the 50th anniversary.

STATE OF THE POWDER METALLURGY INDUSTRY IN NORTH AMERICA GETS ANALYZED

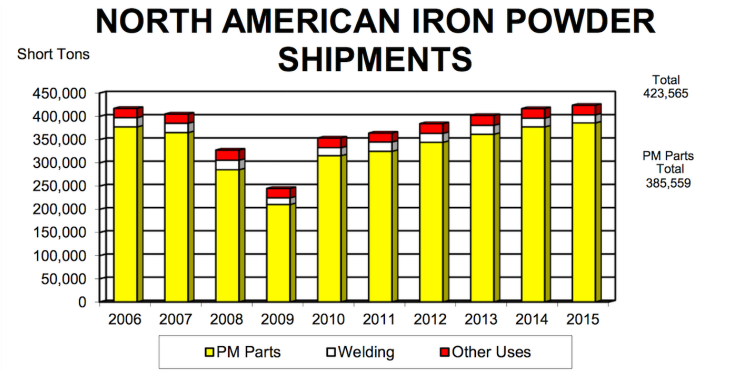
The State of the PM Industry in North America — 2016 was recently presented at POWDERMET2016. This study showed that the entrepreneurial spirit still rings true in the powder metallurgy industry, and confidence remains strong in the majority of powder metallurgy industry companies. Following a prosperous 2015, the year opened on a positive trend with a modest growth forecast by most observers. Press-and-sinter companies and metal powder producers report good business levels as well as companies involved with metal injection molding, metal additive manufacturing, and hot isostatic pressing. However, demand for refractory metals has continued to decline.

The total North American iron powder shipments increased by 1.73% to 423,565 short tons with the powder metallurgy sector reflecting 91% and growing by 2.3% to 385,559 short tons (see graph). Other sectors representing welding, cutting, scarfing, and lancing dropped off. Developing metal powders for metal additive manufacturing via gas atomization is a new trend set for acceleration by most leading powder makers.

Overall, powder metallurgy parts makers fared well in 2015, especially firms selling heavily into the automotive market. Western Pennsylvania powder metallurgy parts makers saw moderately busy production levels, yet continued facing skilled-labor shortages.

Highlights for specialty powder metallurgy products were as follows: Slower growth impacted the U.S. metal injection molding industry in 2015, mainly due to a decline in the domestic firearms market; all powder-related applications account for an estimated 20–25% of hot isostatic pressing business; an estimated 50 to less than 100 companies and organizations are actively pursuing metal additive manufacturing and development programs using metal powders; and while the tungsten market continues to experience difficult times, nonmining and energy-related demand continues at a steady pace.

Most Metal Powder Industries Federation members also forecast sales increases this year. The powder metallurgy parts makers, depending upon what markets they serve, see business increasing in the mid- to upper-single digits.



This graph, reflecting North American iron powder shipments, not only shows short tons and years but is also color coded for powder metallurgy parts, welding, and other uses

The company has launched its 3D printing metal powder production facility at the Alcoa Technology Center (shown here from an aerial perspective).

ALCOA OPENS 3D PRINTING METAL POWDER PLANT

Alcoa has opened its 3D printing metal powder production facility. Located at the Alcoa Technology Center in Pennsylvania, the company will produce proprietary titanium, nickel, and aluminum powders optimized for 3D printed aerospace parts. The lightweight metals provider has also invested in technologies to further develop additive processes, product design, and qualification.

"Alcoa is forging a leadership path in additive manufacturing with a sharp focus on the critical input material — metal powders," said Chairman and CEO Klaus Kleinfeld.

Metal powders used for 3D printing durable aerospace parts are available in limited quantities. Through this expansion, announced in September 2015, Alcoa will develop materials with the specific properties needed to 3D print high-performance components.

In addition, the facility will form part of Arconic following separation from Alcoa's traditional commodity business in the second half of 2016. The plant is part of a $60-million investment in advanced 3D printing materials and processes that builds on the company's 3D printing capabilities in California, Georgia, Michigan, Pennsylvania, and Texas.

H.C. STARCK POWDER DIVISIONS ADOPT NEW CORPORATE LEGAL STRUCTURE

H.C. Starck, Munich, Germany, a manufacturer of customer-specific powders and components made from technology metals and advanced ceramics, is optimizing the corporate legal structure of its powder divisions (tungsten, tantalum/niobium, plus surface technology and ceramic powders).

Employees assigned to the three powder divisions were transferred to the new companies as of August 1. Employees who work in technical/administrative services and group functions will remain at H.C. Starck GmbH. H.C. Starck Infrastructure GmbH & Co. KG will have no staff for the time being. The new companies began operating as independent enterprises on August 1.

The new structure will allow the business segments to operate with greater autonomy and individual responsibility.

"We are giving the new companies the capabilities and leeway they need in order to position themselves optimally on the market," said Dr. Engelbert Heimes, chairman of the executive board of H.C. Starck.

WATSON VALVE UPGRADES OXYGEN CLEAN ROOM

Watson Valve Services, Inc., has upgraded its O2 clean room at its Houston, Tex., facility to ensure proper cleaning procedures are performed on valves for oxygen service.

Operated by trained technicians, the room has been constructed with positive pressure ventilation to limit airborne particles and environmental contamination. Mechanical and solvent cleaning methods are used. The company also maintains separate tools, benches, and equipment.

Procedures are followed to maintain and keep all O2 clean room equipment clean and free of contaminants. After each valve is thoroughly cleaned and reassembled, it is given a seat and shell test; once inspected, all cleaned valves are labeled and sealed to protect them during storage and shipment.

INNOVNANO LAUNCHES NEW WEBSITE

Innovnano, Coimbra, Portugal, has launched a new website at innovnano-materials.com to highlight its zirconia powder range. These powders have applications across many industries, such as structural ceramics, refractories, energy materials, and thermal barrier coatings.

The website has been designed so technical content and product/application information is accessible via tablets and smartphones. The resource area includes articles and technical papers written by company scientists to explain its proprietary manufacturing technology, Emulsion Detonation Synthesis.

"To celebrate the launch, we are offering new customers the chance to receive a trial sample of the powder of their choice," added Paul Newbatt, sales and marketing director at Innovnano.

Upcoming Presentations

What Is Thermal Spray?

INTERNATIONAL THERMAL SPRAY ASSOCIATION

STANDING COMMITTEE AWS American Welding Society

To increase awareness of thermal spray coating technology and how it works, the following presentations will take place at the following key industry events. All ITSA-sponsored thermal spray presentations are free to attendees. ITSA Company Members will be recognized as part of the presentations. Not an ITSA Company Member? For an ITSA Membership Application, visit www.thermalspray.org.

2016 Events:

- FABTECH: Las Vegas, NV, November 16-18, 2016
- Power-Gen: Orlando, FL, December 13-15, 2016

2017 Events:

- AISC – 2017 NASCC/NSBA Steel Conference: San Antonio, TX, March 22-24, 2017
- NACE Corrosion: New Orleans, LA, March 26-30, 2017

Presented by: James Weber, James K. Weber Consulting

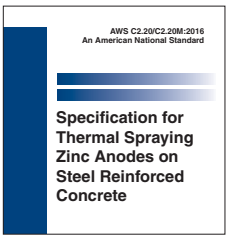
For dates & times of the thermal spray presentations, visit the sponsor websites and look under education programs.

THERMAL SPRAY SYSTEMS CAPABLE OF REMOTE DIAGNOSTICS

The 25 Series single-process thermal spray systems have been introduced. The AP-25 plasma and HV-25 HVOF products utilize stainless steel plumbing and fittings throughout, a Siemens 12-in. color touch screen, and Horizon-S software. They are capable of remote diagnostics through eWon technology. This series, capable of interfacing with most plasma and HVOF systems, is also manufactured to CE and UL standards. Additional features include ergonomically comfortable process control knobs and being compact with a small footprint.

Flame Spray Technologies
fst.nl / +31 [0]26 3190140

AWS RELEASES NEW SPECIFICATION FOR THERMAL SPRAYING ZINC ANODES ON STEEL REINFORCED CONCRETE



The American Welding Society (AWS) has released C2.20/C2.20M:2016, *Specification for Thermal Spraying Zinc Anodes on Steel Reinforced Concrete*. This technical standard covers the application of zinc thermal spray coatings to steel-reinforced concrete using arc and flame spray equipment. It is formatted for industrial process instructions and includes information on job descriptions, safety, equipment, surface preparation, thermal spraying, and quality control. The publication is $68 for non AWS members and $51 for AWS members.

AWS Book Store
pubs.aws.org / (888) 935-3464

FEEDER FEATURES TWO POWDER HOPPERS

The Twin 150, a multiprocess powder feeder, can be integrated into a thermal spray, laser cladding, or powder additive manufacturing system. The unit can be operated in full remote mode, where its functions are controlled by the user's external control system, such as a robot or process controller, using UDP/IP or PROFIBUS protocols. The product can be used in stand-alone (manual operation) or remote on/off mode, where an external mechanism turns powder feeding on or off. In addition, this model has two powder hoppers.

Oerlikon Metco
oerlikon.com / +41 58 274 20 00

BOOK ON HIGH-PRESSURE COLD SPRAY DESCRIBES APPLICATIONS IN MANY INDUSTRIES

High Pressure Cold Spray: Principles and Applications presents baseline information on design and modeling, materials science of engineered coatings, and specific applications in various high-tech industries. Published by ASM International, the 300-page book is authored by a group of global cold spray experts, and edited by Charles M. Kay and J. Karthikeyan of ASB Industries, Barberton, Ohio, with an introduction by Dr. Mark Smith of Sandia National Labs. Various applications of cold spray processes, including protective coating production, development of performance-enhancing layers, repair and refurbishing of parts, plus NNS fabrication, are elaborated in each industry with illustrative case studies by cold sprayers actively involved in the field. The price is $199, but for ASM members, it is $149.

ASM International
asminternational.org / (440) 338-5151

REPORTS DETAIL GLOBAL THERMAL SPRAY MATERIALS AND EQUIPMENT MARKETS

Two thermal spray reports have recently been released by Research and Markets. *The Global Thermal Spray Materials Market – Trends and Forecasts (2015–2020)* valued this market at $1.40 million in 2015, but that's expected to grow over the forecast period. This division is driven by growing thermal spray applications in the aerospace and automotive sectors, increased use of thermal spray in medical devices, and reduced technology transfer time. In terms of consumption last year, North America led the market. Additionally, the *Global Thermal Spray Equipment Market – Segmented by Product Type*, by *End-User Industry*, by *Thermal Spray Process, and Geography – Trends and Forecasts (2015–2020)* indicates this market size includes only the revenues being generated through the sales and repair of equipment being used in thermal spray. Key deliverables consist of region-specific assessments and competition analysis on global and regional scales, plus macro and micro factors that affect this market on global and regional scales.

Research and Markets
researchandmarkets.com / (800) 526-8630

SCHOLARSHIP OPPORTUNITIES

International Thermal Spray Association

Up to three (3) Graduate scholarships worth $2,000.00 each to be awarded each calendar year.

Since 1991, the ITSA Scholarship Program has contributed to the growth of the Thermal Spray Community, especially the development of new technologists and engineers. The International Thermal Spray Association is very proud of this education partnership and encourages all eligible participants to apply.

NEW APPLICATION DATES: Scholarship applications are now accepted annually April 15 through July 15 ONLY for the Graduate scholarships.

Please visit the Scholarship area at
WWW.THERMALSPRAY.ORG

ITSA MEMBERS... DID YOU KNOW?

ITSA company members are also Supporting Company Members of the American Welding Society (AWS). All AWS Supporting Company Members can have up to 5 individuals (employees, customers, colleagues, etc.) on their company roster who will each enjoy:

- 12-month *Welding Journal* magazine subscription
- 25% discount on 200+ publications, including nearly a dozen related to thermal spray
- Access to the online AWS Member Network
- Networking at AWS Section Meetings
- Complimentary attendance at FABTECH

(800) 443-9353, ext. 480

Take full advantage of your AWS Supporting Company Membership.
Add up to 5 individual members today by calling AWS Member Services at:
(800) 443-9353, ext. 480.

JOB SHOP MEMBER COMPANIES

- **ACCUWRIGHT INDUSTRIES, INC.**
  Gilbert, AZ
  Mr. David Wright
  dave@accuwright.com / 480.892.9595
  www.accuwright.com

- **ATLAS MACHINE & SUPPLY, INC.**
  Louisville, KY
  Mr. Richie Gimmel
  richie@atlasmachine.com / 502.584.7262
  www.atlasmachine.com

- **BENDER US**
  Vernon, CA
  Mr. Doug Martin
  dmartin@benderus.com / 323.232.2371
  www.benderus.com

- **BYRON PRODUCTS**
  Fairfield, OH
  Mr. Keith King
  kking@byronproducts.com / 513.870.9111
  www.byronproducts.com

- **CASTOLIN EUTECTIC**
  Lausanne, Switzerland
  Ms. Patricia Frund
  pfrund@castolin.com / 0041.21.694.1132
  www.castolin.com

- **CINCINNATI THERMAL SPRAY, INC.**
  Cincinnati, OH
  Mr. Bill Menth
  bmenth@cts-inc.net / 513.699.3992
  www.cts-inc.net

- **CURTISS-WRIGHT SURFACE TECHNOLOGIES**
  Windsor, CT
  Mr. Peter Ruggiero
  peter.ruggiero@cwst.com
  860.623.9901 / *www.cwst.com*

- **ELLISON SURFACE TECHNOLOGIES, INC.**
  Mason, OH
  Mr. Eric Dolby
  info@ellisonsurfacetech.com / 513.770.4928
  www.ellisonsurfacetech.com

- **EXLINE, INC.**
  Salina, KS
  Mr. Doug Porter
  d.porter@exline-inc.com / 785.825.4683
  www.exline-inc.com

- **F.W. GARTNER THERMAL SPRAYING**
  Houston, TX
  Richard McCullough
  rmccullough@fwgts.com / 713.225.0010
  www.fwgts.com

- **FUSION, INC.**
  Houston, TX
  Mr. Jeff Fenner
  jfenner@fusionhouston.com / 713.691.6547
  www.fusionhouston.com

- **HAYDEN CORP.**
  West Springfield, MA
  Mr. Dan Hayden
  daniel.hayden@haydencorp.com
  413.734.4981 / *www.haydencorp.com*

- **KERMETICO, INC.**
  Benicia, CA
  Mr. Andrew Verstak
  averstak@kermetico.com / 707.745.3862
  www.kermetico.com

- **NATION COATING SYSTEMS**
  Franklin, OH
  Mr. Larry Grimenstein
  ncslgrimen@aol.com / 937.746.7632
  www.nationcoatingsystems.com

- **PLASMA COATINGS**
  Union Grove, WI
  Mr. Daniel Cahalane
  info@plasmacoatings.com / 262.878.2445
  www.plasmacoatings.com

- **PLASMA TECHNOLOGY, INC.**
  Torrance, CA
  Mr. Robert D. Dowell
  salespti@ptise.com / 310.320.3373
  www.ptise.com

- **SPRAYMETAL, INC.**
  Houston, TX
  Mr. Andrew Schumacher
  ars@schumachercoinc.com / 713.924.4200
  www.schumachercoinc.com

- **SUPERIOR SHOT PEENING, INC.**
  Houston, TX
  Ms. Mollie Blasingame
  mmb@superiorshotpeening.com
  281.449.6559 / *www.superiorshotpeening.com*

- **UNITED SURFACE TECHNOLOGIES**
  Altona, Melbourne Australia
  Mr. Hugo Howse
  hhowse@ust.com.au / 61.393.98.5925
  www.ust.com.au

SUPPLIER MEMBER COMPANIES

- **AMETEK, INC.**
  Eighty-Four, PA
  Ms. Cindy Freeby
  cindy.freeby@ametek.com / 724-225-8400
  www.ametekmetals.com

- **ARDLEIGH MINERALS, INC.**
  Beachwood, OH 44122
  Mr. Ernie Petrey
  epetrey@ardleigh.net / 216.464.2300
  www.ardleigh.net

- **CAMFIL APC**
  Jonesboro, AR
  Mr. Matt Caulfield
  matt.caulfield@camfil.com / 800.479.6801
  www.farrapc.com

- **CARPENTER POWDER PRODUCTS**
  Pittsburgh, PA
  Mr. Chip Arata
  warata@cartech.com / 412.257.5102
  www.carpenterpowder.com

- **CENTERLINE WINDSOR LTD.**
  Windsor, ON Canada
  Mr. Julio Villafuerte
  julio.villafuerte@cntrline.com / 519.734.8464
  www.supersonicspray.com

- **DEWAL INDUSTRIES, INC.**
  Narragansett, RI
  Ms. Susan Dunn
  sdunn@dewal.com / 401.789.9736
  www.dewal.com

- **DONALDSON TORIT**
  Minneapolis, MN
  Mr. Jeff Abelson
  jeff.abelson@mail.donaldson.com / 800.365.1331
  www.donaldsontorit.com

- **FLAME SPRAY TECHNOLOGIES, INC.**
  Grand Rapids, MI
  Mr. Terry Wilmert
  t.wilmert@fstincusa.com / 616.988.2622
  www.fst.nl

- **FUJIMI INC.**
  Arlington Heights, IL
  Mr. Michael Akiyoshi
  makiyoshi@fujimico.com / 847.398.6544
  www.fujimico.com

- **GLOBAL TUNGSTEN AND POWDERS CORP.**
  Towanda, PA
  Ms.Laura Morelli
  Laura.morelli@globaltungsten.com
  570.268.5182 / *www.globaltungsten.com*

- **GLOBE METAL, INC.**
  Sainte-Catherine, QC Canada
  Mr. Adam Rubin
  adam@globemetal.com / 450.645.9397
  www.globemetal.com

- **GREEN BELTING INDUSTRIES LT**
  Mississauga, ON, Canada
  Mr. Tim Connelly
  tconnelly@greenbelting.com / 905.564.6712
  www.greenbelting.com

- **H.C. STARCK NORTH AMERICAN TRADING LLC**
  Newton, MA
  Ms. Ana Duminie
  ana.duminie@hcstarck.com / 617.407.9960
  www.hcstarck.com

- **HAI ADVANCED MATERIAL SPECIALIST**
  Placentia, CA
  Mr. Daren Gansert
  dgansert@haiams.com / 877.411.8971
  www.hardfacealloys.com

- **HAYNES INTERNATIONAL**
  Mountain Home, NC
  Mr. Brandon Furr
  BFurr@haynesintl.com / 713.937.7597
  www.haynesintl.com

- **IMPERIAL SYSTEMS**
  Jackson Center, PA
  Mr. Jeremiah Wann
  jwann@isystemsweb.com / 724.992.1721
  www.isystemsweb.com

- **KENNAMETAL STELLITE COMPANY, INC.**
  Goshen, IN
  Mr. David A. Lee
  David.A.Lee@Kennametal.com
  574.534.8631 / *www.stellite.com*

- **LINCOLN ELECTRIC**
  Cleveland, OH
  Mr. Thomas Brown
  thomas_brown@lincolnelectric.com
  216.383.2951 / *www.lincolnelectric.com*

- **LINEAGE ALLOYS**
  Baytown, TX
  Mr. Adel Djam
  adjam@lineagealloysllc.com / 281.426.5535
  www.lineagealloys.com

- **METALLISATION LTD.**
  Dudley West Midlands, United Kingdom
  Stuart Milton
  sales@metallisation.com / +44.1384.252464
  www.metallisation.com

- **METALLIZING EQUIPMENT CO. PVT.**
  Jodhpur, India
  Mr. SC Modi
  scmodi@mecpl.com / 91.291.2747601
  www.www.mecpl.com

- **NORTH AMERICAN HÖGANÄS**
  Hollsopple, PA
  Mr. Andy Hoffman
  andy.hoffman@nah.com / 814.361.6875
  www.hoganas.com

- **OERLIKON METCO (US) INC.**
  Westbury, NY
  Mr. Steven Ort
  steven.ort@oerlikon.com / 516.334.1300
  www.oerlikon.com/metco

- **POLYMET CORP.**
  Cincinnati, OH
  Mr. Bob Unger
  runger@polymet.us / 513.874.3586
  www.polymet.us

- **PRAXAIR SURFACE TECHNOLOGIES**
  Concord, NH
  Mr. Richard Thorpe
  richard_thorpe@praxair.com / 603.224.9585
  www.praxair.com/thermalspray

- **PROGRESSIVE SURFACE**
  Grand Rapids, MI
  Mr. Bill Barker
  wnb@progressivesurface.com / 800.968.0871
  www.progressivesurface.com

- **SAINT-GOBAIN CERAMIC MATERIALS**
  Worcester, MA
  Mr. Howard Wallar
  howard.wallar@saint-gobain.com
  508.795.2351
  www.coatingsolutions.saint-gobain.com

- **THERMACH, INC.**
  Appleton, WI
  Mr. David Lewisen
  davelewisen@thermach.com / 920.779.4299
  www.thermach.com

- **THERMION**
  Silverdale, WA
  Mr. Dean Hooks
  dhooks@thermioninc.com / 360.692.6469
  www.thermioninc.com

ASSOCIATE MEMBER ORGANIZATIONS

- **ADVANCED MATERIALS AND TECHNOLOGY SERVICES, INC.**
  Simi Valley, CA
  Dr. Robert Gansert
  rgansert@adv-mts.com / 805.433.5251
  www.adv-mts.com

- **ASM THERMAL SPRAY SOCIETY**
  Materials Park, OH
  Ms. Sarina Pastoric
  sarina.pastoric@asminternational.org
  440.338.5151 / *http://tss.asminternational.or*

- **MASON GLOBAL MANAGEMENT LLC**
  Killingworth, CT
  Mr. Richard P. Mason
  rmason@masonglobalmanagementllc.com
  724-554-9439
  www.masonglobalmanagementllc.com

- **STATE UNIVERSITY OF NEW YORK AT STONY BROOK**
  Stony Brook, NY
  Prof. Sanjay Sampath
  ssampath@ms.cc.sunysb.edu
  631.632.8480
  www.ctsr-sunysb.org

- **WHITE ENGINEERING SURFACE CORP.**
  Newtown,PA
  info@whiteengineering.com / 800.220.2097
  www.whiteengineering.com

SUPPORTING MEMBER SOCIETIES

- **DVS, THE GERMAN WELDING SOCIETY**
  Mr. Jens Jerzembeck
  jens.jerzembeck@dvs-hg.de
  www.die-verbindungs-spezialisten.de

- **GTS E.V., THE ASSOCIATION OF THERMAL SPRAYERS**
  Mr. Werner Kroemmer
  werner.kroemmer@gts-ev.de
  +49.89.31001.5203 / *www.gts-ev.de*

- **IMM, INSTITUTE OF MATERIALS MALAYSIA**
  Mr. Johar Juhari
  johar_juhari@petronas.com.my
  603.5882.3584 / *www.iomm.org.my*

- **JTSS, JAPAN THERMAL SPRAY SOCIETY**
  Mr. Nick Yumiba
  jtss@mb8.seikyou.ne.jp / +81.6.6722.0096
  www.jtss.or.jp

- **MPIF, METAL POWDER INDUSTRIES FEDERATION**
  Mr. James R. Dale
  jdale@mpif.org / 609.452.7700
  www.mpif.org

- **TSCC - THERMAL SPRAYING COMMITTEE OF CHINA SURFACE ENGINEERING ASSOCIATION**
  Prof. Huang Xiao
  xiaoou@chinathermalspray.org
  +86.10.64882554
  www.chinathermalspray.org

PRINT OR ONLINE OR BOTH? YOUR CHOICE.

If you would rather receive **SPRAYTIME** online or receive both the print and online version, please send an email to spraytime@thermalspray.org with your preference and you will receive an email automatically when the next issue is available at ***spraytime.org***.


Chairman Ryan

You may notice a different feel with this issue of *SPRAYTIME*. It is the result of the publications' staff at AWS taking on the responsibility of producing Spraytime with Cindy Weihl becoming the editor. Cindy is Senior Editor of the *Welding Journal* and a seasoned veteran in the field of communication with seven years' experience at AWS and 12 years overall. In the coming issues, we envision *SPRAYTIME* reporting more on the news of the thermal spray industry and also becoming more technical in nature, but we also want to hear from you on what you would like to see in the publication. We welcome your ideas. Our goal is to make this publication a reflection of your interests and a valuable benefit of your membership in ITSA.

ITSA MISSION STATEMENT

The International Thermal Spray Association, a Standing Committee of The American Welding Society, is a professional industrial organization dedicated to expanding the use of thermal spray technologies for the benefit of industry and society. ITSA invites all interested companies to talk with our officers, and company representatives to better understand member benefits.

OFFICERS

Chairman: Jim Ryan, *Carpenter Powder Products*
Vice-Chairman: David Lee, *Kennametal Stellite Company*

EXECUTIVE COMMITTEE (above officers plus the following)

Dan Hayden, *Hayden Corporation*
Bill Mosier, *Polymet Corporation*
Peter Ruggiero, *Curtiss-Wright Surface Technologies*
David Wright, *Accuwright Industries, Inc.*

ITSA MEMBER NEWS

Tradeshow Assessment for ITSA Member Eliminated

Earlier this year, ITSA Members were invited to participate in an ITSA Member Satisfaction Survey, in which they were asked to rate the value of various member benefits. Based on feedback received on the value of ITSA Booth participation at industry tradeshows, at its April 20, 2016, meeting, the ITSA Executive Committee unanimously decided to discontinue ITSA booth activity at tradeshows effective July 2016. As ITSA Members subsidized the cost of ITSA booth activity via annual assessments, this move will result in the elimination of these costly annual ITSA Member assessments going forward.

In lieu of booth representation at tradeshows, ITSA will proactively participate in alternative ways at key industry events. For example, a series of educational presentations promoting thermal spray are being scheduled as free, half-day sessions at tradeshows like FABTECH, POWER-GEN International, and CORROSION.

ITSA SCHOLARSHIP OPPORTUNITIES

The International Thermal Spray Association offers annual Graduate Scholarships. Since 1992, the ITSA scholarship program has contributed to the growth of the thermal spray community, especially in the development of new technologists and engineers. ITSA is very proud of this education partnership and encourages all eligible participants to apply. Please visit *www.thermalspray.org* for criteria information and a printable application form.

ITSA THERMAL SPRAY HISTORICAL COLLECTION

In April 2000, the International Thermal Spray Association announced the establishment of a Thermal Spray Historical Collection that is now on display at the State University of New York at Stony Brook in the Thermal Spray Research Center, USA.

Growing in size and value, there are now over 30 different spray guns and miscellaneous equipment, a variety of spray gun manuals, hundreds of photographs, and several historic thermal spray publications and reference books.

Future plans include a virtual tour of the collection on the ITSA website for the entire global community to visit. This is a worldwide industry collection and we welcome donations from the entire thermal spray community.

ITSA SPRAYTIME

Since 1992, the International Thermal Spray Association has been publishing *SPRAYTIME* for the thermal spray industry. The mission is to be the flagship thermal spray industry publication providing company, event, people, product, research, and membership news of interest to the thermal spray community.

JOIN THE INTERNATIONAL THERMAL SPRAY ASSOCIATION

ITSA is a professional, industrial association dedicated to expanding the use of thermal spray technologies for the benefit of industry and society. ITSA Membership is open to companies involved in all facets of the industry – equipment and materials suppliers, job shops, in-house facilities, educational institutions, industry consultants, and others.

Engage with dozens of like-minded industry professionals at the Annual ITSA Membership Meeting, where there's ample time for business and personal discussions. Learn about industry advancements through the one-day technical program, participate in the half-day business meeting, and enjoy your peers in a relaxed atmosphere complete with fun social events.

Build awareness of your company and its products and services through valuable promotional opportunities – a centerfold listing in the SPRAYTIME Newsletter, exposure on the ITSA Website, and recognition at industry trade shows.

PLUS, ITSA Membership comes with an American Welding Society (AWS) Supporting Company Membership and up to five AWS Individual Memberships to give to your best employees, colleagues or customers. Visit *www.aws.org/membership/supportingcompany* for a complete listing of additional AWS benefits.

For more information, contact Cassie Burrell at 800.443.9353 Ext 253, or itsa@thermalspray.org. For an ITSA Membership Application, visit the membership section at *www.thermalspray.org*.

By Andrew Cullison

ITSA ANNUAL CONFERENCE UPDATE

Bill Mosier, executive officer, International Thermal Spray Association (ITSA), welcomed attendees (Fig. 1) from 33 member companies to its annual technical conference and business meeting, April 20–22. The conference, held at the Opryland Hotel, Nashville, Tenn., had a full day of technical presentations. Below is a brief review of some.

Fig. 1 — Attendees listened intently to presentations at the International Thermal Spray Association's annual technical conference.

ADDITIVE MANUFACTURING ADVANCES

The day was started with a presentation from Mark Smith, deputy director for Additive Manufacturing, Sandia National Laboratories, on the challenges and world of opportunities of additive manufacturing (AM). Additive manufacturing (aka, 3D printing) is basically making parts using data from a 3D model that directs a layer-upon-layer deposition of material in the form of the object. There are various processing technologies for depositing plastics, metals, ceramics, and multimaterials. The commercialization of 3D printing plastic parts is relatively mature, while metal material is relatively immature but growing. At present, ceramic use is limited and multimaterial shows potential, but requires further development.

He noted the potential advantages of AM include the production of shapes that previously might have been impractical or unachievable, reduction of waste or material cost, and weight and energy savings. It also is a process that can produce engineered materials that may have need for special properties, as well as inexpensive prototype objects, jigs, and fixtures.

Smith spoke of its commercial use in aerospace with an example of a part that was redesigned with an internal geometry that could only be built with AM. The part was 84% lighter than the previous part produced with traditional manufacturing, and performed well in load testing.

Another example is a unique product designed at Sandia. It is a robotic hand operated remotely for bomb disablement. The fingers can be quickly configured to handle many different shapes. Half of the construction of the hand was additive manufactured. Because of the many iterations allowed in the design process by AM, it was estimated the design phase cost only $10,000, whereas normally it would have cost in the area of $250,000.

Although new applications for AM are growing, the process does have limitations. It is still an evolving manufacturing field, and there is a lack of engineering data to establish design standards. There are software limitations, and material properties, tolerances, and residual stresses are still issues that have to be defined. Postfinishing equipment is needed, adding another stage of production. There are also inspection and metrology challenges, and depending on the application, AM is not always faster and less costly than traditional manufacturing.

Still in its formative stages, there are possibilities for thermal spray in AM. In the medical field, thermal spraying might be the final stage of a custom 3D-printed body implant. Additive manufactured plastic parts that require conductivity and wear properties can rely on thermal spraying to provide them. There is development being done on spray forming rocket nozzles, and most interesting, research is being conducted on direct writing of thermocouples, strain gauges, integrated wiring, and sensors using thermal spray.

C2 THERMAL SPRAY COMMITTEE UPDATE

David Lee, proxy committee chair, gave the audience an update on the American Welding Society's C2 Committee on Thermal Spray. This committee establishes standards on thermal spray design, manufacture, inspection, and test methods, as well as develops guides. It also works on standardizing thermal spray symbols and definitions.

Presently, AWS has seven publications that offer guides and specifications for thermal spraying, with three new guides in the works on powders, masking, and equipment selection. The committee is composed of 20 members and 10 advisors representing producers, end users, educators, and consultants.

Also in the planning stages by AWS Learning is an online learning module that will present the fundamentals of thermal spraying, which will include its science, equipment, materials, variables, and safety.

DAMAGE-TOLERANT THERMAL SPRAY COATINGS

Greg Smith (Fig. 2), an ITSA scholarship recipient, spoke of the research being conducted at Stony Brook University on damage-tolerant thermal spray coatings.

Understanding how to stop a crack from happening or progressing requires an extensive study of failure modes and experiments in arresting cracks. With thermal spraying, the real challenge is trying to measure an inherently unstable process. Torch, operating parameters, kinetic energy, surface preparation, cooling, and plume character are just some of the factors that enter into reproducibility.

One approach for the design of tolerant coatings being researched at the university was to take a lesson from nature, specifically the mollusk shell. Many shells are composed of two layers: a nacreous layer that is damage tolerant, and above it, a hard, thick layer that blunts stresses from outside forces. Using a rod flame spray process, a layer was deposited followed by a polymer infiltration. Then a dense ceramic layer was deposited with the high-velocity oxygen fuel (HVOF) process. Subsequent bending tests showed the outer layer provided good strength. On its fracture, the load was redistributed to the more flexible under layer. Experiments are continuing with this concept.

Fig. 2 — Greg Smith talked about research being conducted at the State University of New York at Stony Brook on nature-inspired, damage-tolerant thermal spray coatings.

Where is your article?
We encourage you to send articles, news, announcements and information to
spraytime@thermalspray.org

THE HISTORY OF THERMAL SPRAY

James Weber, Sulzer Chemtech Tower Field Service, gave an interesting historical perspective on thermal spraying.

He claimed thermal spraying got its start from a method patented by Oerlikon in 1882 of spraying lead powders against a fixed surface. The process was developed to make lead plates for batteries. As this process was refined, more patents followed, and lead was the material for early coatings.

Thermal spraying really got its boost from the work of Ulrich Schoop, who is considered the "Father" of thermal spraying. In 1909, he patented the first commercially viable thermal spray plant for delivering metal coatings. In 1912, he developed the first practical flame spray wire gun (or pistol, as it was called then), and in 1914, he patented a twin wire arc spray gun. He continued his research into materials and methods of thermal spraying, including plasma spraying, and by the 1930s thermal spraying was considered an accepted process for applying coatings, especially in corrosion prevention.

THERMAL SPRAY: RULES OF THUMB

Daryl Crawmer, Fisher Barton Technology Center, made an interesting presentation on rules of thumb for thermal spraying.

He started with his first law, "The only absolute in thermal spray is that there are no absolutes." Then went on to his second law, "There are no small carrier gas leaks," and "All carrier gas leaks are bad." He explained any leak can lead to contamination, significant drops in control pressure, and plasma gun restrike instability, making leaks a condition not to be ignored.

On the equipment side, he noted power supplies for plasma and electric arc spraying only pretend to be DC. Actually they are really "noisy" AC superimposed on really "dirty" DC. On arc starting, he commented most high-frequency starters are essentially a spark-gap transmitter, similar to what was used in the early days of Morse Code transmission.

If your arc start takes more than 100 ms, you have a problem. It could be any number of things, including water-cooled cables, bad gas, moisture, high-frequency components, point gap, or dirt and oil.

With surface preparation, he noted that to increase surface roughness, it is more effective to increase grit size rather than increasing pressure or dwell times.

Wires for electric arc spraying should not have a cast of more than 30 in. Powder size and mass affect splat cooling rate the most. His presentation closed with the statement, "Handles do not belong on high-energy devices such as plasma guns, HVOF guns, and cold spray guns. They just encourage people to grab them and create an unsafe situation."

Four new member companies, DeWal, Kermetico, Lincoln Electric, and Mason Global Management, were also given a chance to speak about their products and services.

UPCOMING EVENTS

At FABTECH 2016 in Las Vegas, Nev., Nov. 16–18, there will be a free half-day class on "Thermal Spray Basics: Putting Coatings to Work." Next year, the annual ITSA conference is scheduled to be in Albuquerque, N. Mex. If you are interested in becoming an ITSA member company or want to find out more about the organization, go to *thermalspray.org*.

ANDREW CULLISON (cullison@aws.org) is publisher, *Welding Journal*.

See pages 10 – 11

ITSA WELCOMES NEW MEMBER

White Engineering Surfaces Corp. (*whiteengineering.com*), Newtown, Pa., is a woman-owned, world-class supplier in the application of all types of thermal spray coatings. Coupled with the ability to be a one stop shop, it offers single-source responsibility that produces a complete part coated to specification, allowing the company to keep its main focus on customer service.

White Engineering specializes in tungsten carbide, ceramic, pure metal, and alloy coatings using high-velocity oxyfuel (HVOF), plasma, and wire arc processes. The choice of process depends on the application's requirements, such as hardness and density for wear resistance, as-coated surface roughness, electrical insulating value, and corrosion protection. As an industry leader for 54 years, White Engineering has had the opportunity to produce many parts for various military branches of the U.S. government, including parts that meet Pratt & Whitney and GE specifications. White Engineering is a certified FAA Part 145 repair station and approved supplier for many Fortune 500 companies. Its customer base has groomed White to excel in all necessary thermal spray scenarios, low-volume R&D work, and high-volume original equipment manufacturer (OEM) production.

Fig. 1 — An example of White Engineering's military-engineered components

WALL COLMONOY APPOINTS PRESIDENT

Wall Colmonoy, Madison Heights, Mich., has appointed Nicholas W. Clark to president. All company business units will now report to Clark, including Alloy Products, Aerobraze Engineered Technologies, and Franklin Bronze Precision Components, LLC. Clark joined Wall Colmonoy Limited (UK) in 2012 as a process engineer before rising to deputy managing director. In 2014, he returned to the United States as a director and assumed responsibility for the Alloy Products and Aerobraze Engineered Technologies – Cincinnati business units, and later the finance and accounting units.

FRANKLIN BRONZE PRECISION NAMES GENERAL MANAGER

Franklin Bronze Precision Components, LLC., Franklin, Pa., recently announced that John Nichols has been named general manager. In his new position, he will lead the Franklin Bronze team to develop and grow the business with a strong focus on continuous improvement, quality, innovation, and customer service. Nichols has more than 30 years of experience in castings, with a concentration in investment castings. He has held several leadership roles in general management, sales, operations, and technical engineering.

WATSON VALVE ANNOUNCES NEW PRESIDENT

Watson Valve Services, Inc., Houston, Tex., has named Robert "Bob" White as company president. White has served as executive vice president and owner of Watson Valve Services since its inception in 2002. Prior to his executive vice presidency, White spent more than 39 years in executive management for Watson Grinding and Manufacturing, a sister company of Watson Valve Services. He continues to hold that position. Former Watson Valve Services President, John M. Watson, will remain as the company's chief executive officer.

POWDER METALLURGY LEADER RECOGNIZED FOR LIFETIME ACHIEVEMENTS

William F. Jandeska, Jr., FAPMI, president, Midwest Metallurgical, Ltd., and project manager for the Center for Powder Metallurgy Technology, has received the Kempton H. Roll PM Lifetime Achievement Award from the Metal Powder Industries Federation. Jandeska has distinguished himself as an expert in the field of powder metallurgy (PM) through developing innovative components and relationships between suppliers and vendors. He has also promoted the continued growth of PM for more than 44 years through the joint involvement of part fabricators and the end-user community.

OBITUARY
ANTHONY J. ROTOLICO

Anthony "Tony" Rotolico of Hauppauge, N.Y., passed away on July 3. Rotolico was an innovator in the thermal spray industry. He held 40 patents covering the development of proprietary high-technology coating systems, including combustion, nontransferred arc and transfer arc plasma, twin arc, and high-velocity oxygen fuel thermal devices. Rotolico retired in 2001. In 2004, he was inducted into the Thermal Spray Hall of Fame as an outstanding leader who has made significant contributions to the science, practice, education, management, and advancement of thermal spray. Rotolico was also a lifelong fisherman, an avid golfer, and active in his church and community. He is survived by his wife of 58 years, Maria, four children, and eight grandchildren.

METAL POWDER SOCIETY NAMES FELLOWS

Hideshi Miura

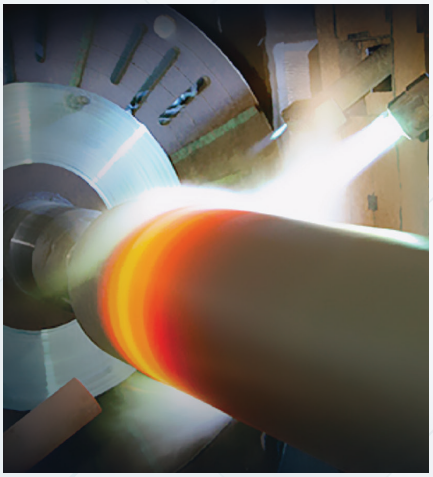
César Molins Jr.

APMI International, Princeton, N.J., the professional society for powder metallurgy, recently elevated Hideshi Miura, professor, Kyushu University, Fukuoka, Japan, and César Molins Jr., director general, AMES S.A. Barcelona, Spain, as APMI Fellows. Miura is considered one of the leading Japanese academics in powder metallurgy (PM). He has been widely recognized with significant awards, including the Japan Institute of Metals Distinguished Achievement Award. For more than 25 years, he has been a member of APMI, and currently serves on the APMI International Liaison Committee. Molins has actively promoted the powder metallurgy industry for more than three decades. His deep understanding of the technology, and how to best utilize the advantages of PM vs. other manufacturing technologies, has contributed substantially to market growth for PM manufacturers globally. Molins has been a member of APMI for more than 30 years and also serves on the APMI International Liaison Committee.

SAVE THE DATE

March 7–8, 2017 / Greenville, SC

COATINGS & ADVANCED INNOVATIONS FOR INDUSTRIAL GAS TURBINES SYMPOSIUM



Featuring Keynote Speaker

David Bucci of GE Power,

this symposium will cover the latest technology in Advanced Thermal Spray Coatings, Advanced Materials and Additive Manufacturing.

Registration Information Coming Soon.

Sponsored by: International Thermal Spray Association; AWS Standing Committee American Welding Society

COLD SPRAY JOINING OF DISSIMILAR METALS

by Victor Champagne III, Michael K. West, Todd Curtis, Victor Champagne Jr., and Baillie McNally

The transition of the Cold Spray (CS) process has been accelerating over the past few years and has sparked much discussion and debate concerning its advantages and limitations. The U.S. Army Research Laboratory (ARL) has been an international leader in CS, furthering the development of sophisticated predictive modeling tools, advanced CS materials, optimized processes, and more capable hardware through research programs in collaboration with private industry and academia. These accomplishments have been reported in open literature and in depth at the Cold Spray Action Team (CSAT, coldsprayteam.com). Dr. Anatolii Papyrin, a specialist in gas dynamics and one of the inventors of CS, is credited with its introduction into the United States more than 20 years ago. Various reference books and dozens of scientific journal papers have been written on the subject.

Initially, the research being conducted in CS could be viewed by some as primarily academic in nature, concerning itself with theoretical predictions about particle impact phenomena, gas dynamics, particle flow, and bonding mechanisms, without a lot of down-to-earth materials characterization. This is what many designers and engineers require when determining the structural integrity associated with CS bulk materials and/or coatings when contemplating its utility. Duplication of data was also a challenge for many, as well as knowing the differences between the CS systems offered by the commercial sector and consistent feedstock powders. This proved to be the crux of some disparity in test results.

TURNING POINT FOR COLD SPRAY

It wasn't until research funded through the Environmental Security Technology Certification Program (ESTCP, serdp-estcp.org/About-SERDP-and-ESTCP/About-ESTCP) in 2005 and executed by ARL, that extensive materials characterization was accomplished toward a specific objective, "To investigate and validate CS as a viable means of providing dimensional restoration of magnesium aerospace parts" (Refs. 1, 2). ESTCP is DoD's environmental technology demonstration and validation program that resulted in the first widespread implementation of cold spray as a repair technology for aerospace components. The groundwork for this paper was laid by ARL to facilitate the adaptation of the ESTCP research for other novel uses. Cold spray offers such a solution. It has been tested and approved for aerospace applications through the U.S. Army Research Laboratory in conjunction with the U.S. Army Aviation and Missile Research Development and Engineering Center (AMRDEC), the South Dakota School of Mines R3 Center, and Original Equipment Manufacturers (OEMs), including Sikorsky Aircraft Co., United Technologies Research Center, and Boeing, as reported at various CSAT Conferences.

PREMISE OF THE CONCEPT

The joining of dissimilar materials by the use of cold spray has been demonstrated and is practical for certain combinations of engineering materials, including magnesium and aluminum alloys. (Refs. 3, 4). The premise of this research is a joint invention disclosure with the U.S. Army Research Laboratory and subsequent patent application, "Process for Joining Dissimilar Materials" by Champagne et al., submitted more than three years ago. This collaborative idea and subsequent research proved it is possible to capitalize on the exceptional bond strength achieved between various materials when cold, and to incorporate its use for various joint designs, allowing cold spray to be used alone or in conjunction with other techniques to join dissimilar materials. The joining of magnesium to aluminum illustrates the potential of cold spray.

PROBLEM STATEMENT

The ability to join Al and Mg represents a significant challenge for many industries, including the automotive and aerospace industries, and success would enable significant weight savings to be realized and subsequent energy efficiency (Refs. 5, 6). The military has numerous applications in aerospace, munitions, and tactical vehicles that require the joining of dissimilar materials. The U.S. Army has an interest in Mg armor, which holds significant promise in its ability to become part, if not a whole, of an ultra-lightweight armor solution for future military weapon systems and platforms (Ref. 7). Reduction in weight and improvement of performance are important in the design and manufacture of armored military vehicles, and therefore, a solution to this problem is important to enable the use of dissimilar material joints. Dissimilar welding of aluminum (Al) and magnesium (Mg) alloys in addition to achieving significant weight reduction would also attain high efficiency of production by a substitution of Mg alloys for Al alloys (Refs. 8 ,9). Magnesium is also an engineering material of choice for such applications as transmission housings because of its low density, high stiffness, and high specific strength. It is also widely used for DoD and commercial rotorcraft (Ref. 10).

The ability to join magnesium and aluminum has been attempted using various welding processes to a limited degree, and there are dozens of reputable research papers that have reported a certain degree of success. However, the resultant joints have lacked sufficient structural integrity to be considered for applications demanding high loads and have failed to satisfy the basic definition of a dissimilar weld, which is "a weld between dissimilar metals must have the strength of the weaker of the two metals being joined" (Ref. 11). Conventional technologies fall short because of limitations regarding thermal input and the formation of a deleterious intermetallic layer or compounds at the dissimilar metal interface that adversely affect the mechanical properties of the resultant joint. Additionally, other competing methods have restrictions on the types of materials that can be joined (i.e., metals, ceramics, polymers, etc.) and/or extensive fixturing requirements, are economically prohibitive or are impractical in production or field use.

COLD SPRAY CONCEPT

It can be concluded from previous research that the formation of the Al-Mg intermetallics is the result of thermal input, and the control of processing parameters of any alternative joining technique is directly related to the reduction of heat between the Al and Mg being joined. Therefore, cold spray is well suited for this application due to the low temperature associated with the process. The major technical challenges are to create an exceptional bond with a good

combination of high strength and ductility.

Novel manufacturing methods, such as CS, must be economically feasible, but also should rely on tools, materials, and expertise readily available in the marketplace and be suited not only for a production environment but also for maintenance and overhaul facilities. Finally, the procedure and associated equipment to accomplish the joining of dissimilar materials must be adapted and be robust enough to be utilized in the field by semi-skilled operators and able to be inspected through standard processes and nondestructive techniques, so as not to introduce any undue burden or added expense. In addition to joining dissimilar metals, in the form of conventional sheet, plate, or bar stock, there is a need to build up dissimilar materials in more complex shapes to form tabs, flanges, protrusions, or even near-net parts that are load bearing and can be considered for structural applications. High-pressure CS can achieve these additional criteria because of the low-temperature, solid-state consolidation associated with the process and the superior material properties that are attainable for certain engineering materials.

The methodology of utilizing CS as a practical method to join dissimilar materials, specifically, wrought 6061-T6 Al and 5083 Al alloy to cast ZE41A-T5 Mg, can be explained in some detail. In this study, small rectangular plates measuring 10 x 4.5 x 0.64-cm-thick of cast ZE41A Mg, wrought 6061 Al, and 5083 Al were joined using a combination of cold spray and friction stir welding (FSW) (Fig. 1) to take advantage of the attributes associated with both techniques and mitigate the formation of deleterious intermetallic compounds that adversely affect the mechanical properties of the joint. To join the Mg plate to the Al plate, first a cold spray layer of aluminum (6061 Al for one group of samples and 5056 Al for another set) was deposited onto the edge of the magnesium plate sufficient in thickness to accommodate a friction stir weld — Fig. 1A. The cold spray aluminum layer, referred to as the "transition layer" served to insulate the Mg from the heat generated by the FSW process, thereby mitigating the formation of the Al-Mg intermetallics. Subsequently, FSW was used to join the CS transition layer to the wrought 6061 Al — Fig. 1B. It is important to note that although FSW was chosen, a conventional gas metal arc (GMA) or gas tungsten arc (GTA) process could have also been used. Figure 2 shows a completed joint using the new concept.

A total of six tensile bars were sectioned and subsequently machined from CS 6061 Al deposited to form blocks of material approximately 12 x 12 x 1.3 cm thick. The yield strength (YS) and the ultimate tensile strength (UTS) of the cold spray 6061 Al are

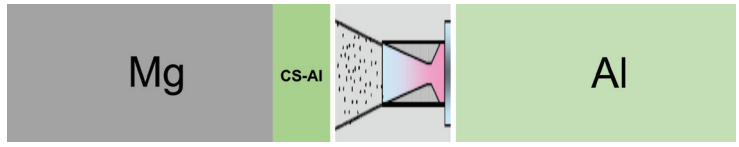


Fig. 1A — Cold spray 6061 Al to the edge of the ZE41A Mg (buttering the edge)

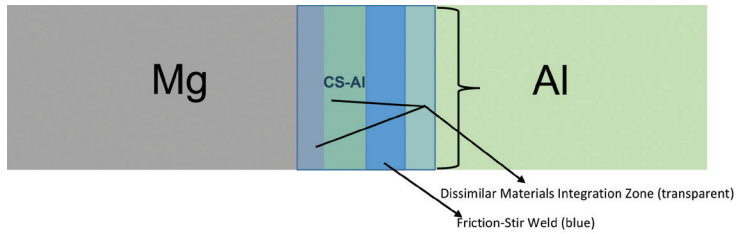


Fig. 1B — Using FSW to join the ZE41A Mg to 6061 Al

listed in Table 1. The tensile test results showed that the CS 6061 Al has a very high strength (324 MPa) in the as-cold-sprayed condition. It is important to note that no postprocessing was performed on the as-cold-sprayed samples. The primary strengthening mechanism was attributed to the strain hardening that occurs during particle impact and consolidation in the solid state. The elongation at failure (%EL) is ~5%, which exceeds that of the ZE41A-T5 Mg, which is about 3.5%, with a corresponding UTS of (205 MPa). Tensile test results for 5056 Al cold spray yielded an ultimate tensile strength of 414 MPa with an elongation of 12%.

The cold spray 5056 Al to 6061 Al/FSW joint had an UTS of 197 MPa but with only a 24% El. The cold spray 5056 Al to 5083 Al/FSW joint had an UTS of 210 MPa (15%) El. The UTS values of both groups of samples are equal to that of the UTS of ZE41A-T5 Mg but the ductility needs to be improved. The outcome of this research showed the samples displayed exceptional strength but low ductility. Tensile testing of the completed welded joint showed high ultimate tensile strength, comparable to that of the weaker material (Mg), but the ductility was quite low < 1% and needs improvement.

NOVEL FEATURES OF THE CONCEPT

The cold spray process offers the ability to join dissimilar metals that does not result in the formation of an intermetallic layer at the dissimilar metal interface because the process is performed well above the melting temperature, and the cold spray feedstock

Table 1 — Tensile Data and Materials Properties of Substrates and Weld Joints

Material	Yield Strength MPa (psi)	Ultimate Tensile Strength MPa (psi)	% Elongation	Modulus GPa (msi)
ZE41A-T5 Mg*	140 (20,300)	205 (29,700)	3.5	45 (6.5)
Wrought 6061Al*	276 (40,000)	310 (45,000)	17	68.9 (10)
Wrought 5083Al*	280 (40,600)	345 (50,000)	7	70.3 (10.2)
Cold Spray 6061Al**	269 (39,000)	324 (47,000)	5	10.1
Cold Spray 5056Al**	379 (55,000)	414 (60,000)	12	9.9
Cold Spray 5056Al to 6061Al/FSW Joint**	194 (28,100)	197 (28,500)	0.24	10.1
Cold Spray 5056Al to 5083Al/FSW Joint**	208 (30,100)	210 (30,500)	0.15	10.3

* MATWEB (*matweb.com*)
** Measured values

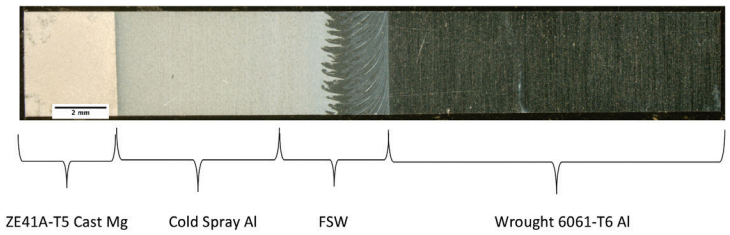


Fig. 2 — Montage of the ZE41A-T5 cast Mg, the cold spray Al transition layer, the friction stir weld, and the 6061-T6 wrought aluminum. The CS transition layer allows the joining of the two dissimilar metals without the formation of deleterious intermetallic compounds or heat-affected zone.

powder is consolidated in the solid state.

The formation of an undesirable heat-affected zone (HAZ) and particle oxidation is avoided using cold spray, as well as deleterious tensile stresses formed during thermal contraction that are associated with most welding techniques.

Cold spray technology is the logical choice for applications where the high temperatures associated with conventional thermal spray technology can result in undesirable metallurgical transformations, including grain growth, as well as oxidation that can have detrimental effects on bond strength and porosity.

Cold spray incorporates very high particle velocities (300–1500 m/s) to achieve consolidation, which results in the formation of beneficial compressive stresses that increase the fatigue resistance of many metals and gas temperatures can be adjusted to avoid undesirable transformations in the feedstock, the resultant deposit, and the substrate, yielding a deposit with low porosity, high bond strength, and high cohesive strength.

SUMMARY

It can be deduced that the results of this work demonstrate a practical method to join dissimilar materials, specifically, wrought 6061-T6 Al alloy to cast ZE41A-T5 Mg, by a combination of the CS and FSW processes. That is not to say that this methodology is ready for immediate widespread transition due to the low ductility of the joint. The strength of the joint certainly satisfies the definition of a weld between dissimilar metals whereas it must have the strength of the weaker of the two metals being joined. The data clearly indicates the ultimate tensile strength of the joint is approximately that of the ZE41A-T5 Mg, which is the weaker of the two metals being joined.

However, it must be understood that years ago, the reported ductility of 6061 aluminum in the as-cold-sprayed condition was also less than 1% until a better fundamental understanding of the feedstock powder, bonding mechanism, and CS process parameters was realized. Recent data showing increases of ductility to 7% El for 6061 and 22.7% for 5056 Al, respectively, was reported at the 2015 and 2016 CSAT Conferences and also at Aeromat 2015 by ARL and UTRC (Ref. 12).

It should be pointed out in conclusion that the aforementioned advancements in CS feedstock powder and processing knowledge in conjunction with improved hardware can only serve to increase the ductility of the joint to at least that of the ZE41A-T5 Mg, which is 3% El min. Keep in mind that the research presented represents the "first horse out of the gate," and additional work is planned. Consideration of improved surface preparation and postprocessing of feedstock powder prior to CS will be pursued. Laser ablation could be used to prepare the surface prior to cold spray within an inert atmosphere in-situ with the CS process. This capability is now an option for the cold spray system, specifically designed and produced by ARL as part of the Defense Manufacturing Science and Technology Program that was unveiled at the Cold Spray Action Team (CSAT) meeting on June 21, 2016, and produced by VRC Metal Systems. A schematic of the new cold spray helium recovery and manufacturing cell is shown in Fig. 3, and the actual system integrated into the MOOG Cold Spray Facility, Webster, Mass., is shown in Fig. 4. It is important to point out that the VRC Gen III

Fig. 4 — Cold spray helium recovery and manufacturing cell designed and demonstrated by ARL under the Defense Manufacturing Science and Technology (DMS&T) Program. More than 100 parts have been developed under the DMS&T.

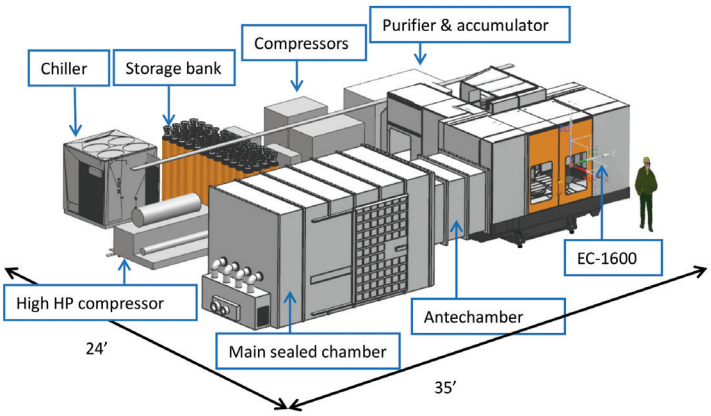


Fig. 3 — Cold spray manufacturing cell equipped with a helium recovery system capable of 95% helium recovery and five-axis machining to 0.0005-in. tolerance.

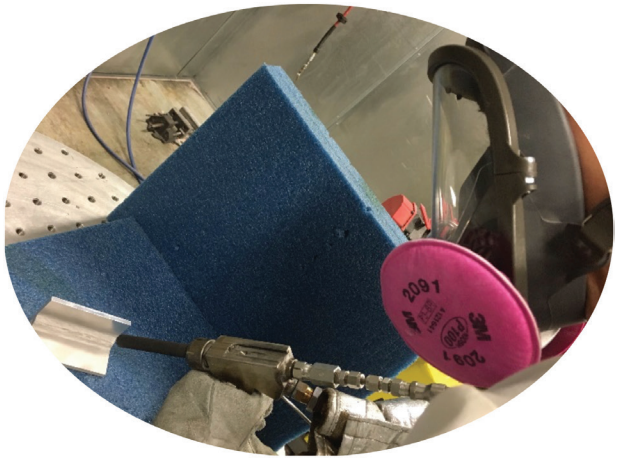


Fig. 5 — VRC Gen III Cold Spray System being used manually to produce a dissimilar metal joint between Al and Mg.

spray gun that is part of this new system can be operated using robotics or manually, as shown in Fig. 5, making it conducive to field repair in remote locations. So, be on the look out for the next set of data that should prove to increase the ductility of the joint, while still maintaining the strength. Then this technique should be ready for implementation.

ACKNOWLEDGMENTS

The Army Research Lab provides innovative science, technology, and analysis to enable a full spectrum of military operations. It serves as the bridge between the scientific and technical communities and the Army, and is the leader in providing innovative solutions for the current and future warfighter. For additional information, please contact Victor K. Champagne, III at the University of Massachusetts, Amherst, MA. Department of Mechanical Engineering, (508)713-1730.

REFERENCES

1. Champagne, V., Leyman, P., and Helfritch, D. 2008. Magnesium repair by cold spray. ARL-TR-4438, (5).
2. Gabriel, B., Champagne, V., Leyman, P., and Helfritch, D. 2013. Cold spray for repair of magnesium components, ARL-TR-6629, (9).
3. Champagne, V. III, et al. 2016. Joining of cast ZE41A-Mg to wrought 6061 Al by the cold spray process and friction stir welding. *Journal of Thermal Spray Technology* 25(1): 143–159.
4. Champagne, V. III. 2016. Joining dissimilar metals. Cold Spray Action Team (CSAT) Conference, June, Worcester Polytechnic Institute. *coldsprayteam.com*.
5. Walsh, M. P. 2000. *Plat. Met. Rev.*, 44: 22–30.
6. Anand, A., Konka, H., and Fritz, P. 2016. Light weight structures — Structural analysis for weight optimization and joining techniques of dissimilar materials. SAE Technical Paper 2016-01-1394, doi:10.4271/2016-01-1394.
7. Cho, K., et al. 2009. Magnesium technology and manufacturing for ultra lightweight armored ground vehicles. ARL-RP-236, (2).
8. Avedesian, M. M., and Baker, H. 1999. *ASM Specialty Handbook, Magnesium and Magnesium Alloys. ASM International*, Materials Park, Ohio.
9. Mordike, B. L., and Ebert, T. 2001. *Mater. Sci. Eng*. A Struct. Mater 302: 37–45.
10. Musfirah A. H, Jaharah, A. G 2012. Magnesium and aluminum alloys in automotive industry. *Journal of Applied Sciences Research* 8(9): 4865–4875, ISSN 1819-544X.
11. Campbell, F. C., editor. 2011. *Joining: Understanding the Basics*. p. 280. ASM International, Materials Park, Ohio.
12. Champagne, V. 2016. Advanced colds spray development for aerospace aluminum alloys. Paper 39751, presented at the AEROMAT 2015 Conference, Long beach, Calif. (5): (*asm.confex.com/asm/aero15/webprogram/Paper39751.html*).

Victor Champagne III (vchampagne@umass.edu) is with the Dept. of Mechanical Engineering, University of Massachusetts; Michael K. West and Todd Curtis are with South Dakota School of Mines; Victor Champagne Jr. (victor.k.champagne.civ@mail.mil) is with Army Research Laboratory; and Baillie McNally is with Worcester Polytechnic Institute.

PROCESS SIMULATION AND MODELING IN HVOF QUALIFICATION AND OPTIMIZATION

BY LIANG ZENG AND BRENTT RAMSEY

Thermal spray coatings are widely applied for better corrosion and wear resistance. High-velocity processes, especially high-velocity oxyfuel (HVOF) spraying, are the preferred methods for producing a coating with low porosity and high adhesion. Most aerospace customers require detailed qualification, ranging from basic microstructure and residual stress, to more complicated damage-tolerant systems, such as fatigue/spalling, wear, or corrosion. Furthermore, HVOF spraying is a complex process that has a large number of variables affecting deposit formation and coating properties. These variables include hardware characteristics, such as nozzle geometry and spraying distance, and process parameters, including fuel, gas flow density, and powder feedstock. In the spray process, the powder particles experience very high speed combined with fast heating up to its melting or semimelting point or even above. This high temperature may cause evaporation of the powder or some of its components, dissolution, and phase transformations.

Due to the complex nature of the HVOF technique, control and optimization of the process to achieve a coating with the desired properties is highly challenging. There are different ways to optimize and analyze the HVOF processes and deposit formation. These include statistical methods such as design of experiments (DOE), numerical modeling and simulation, and finite element methodology (FEM) (Refs. 1, 2). Of all the optimization tools, DOE has been widely used because optimization of coating properties for a given specification needs careful control of the operational spray parameters, and statistical methods can be useful in preparing the experiments and productions. However, DOE alone may not be sufficient. In most cases, the results in DOE, especially the Taguchi approach, are dependent on the design and selection of variables, and the result may be misleading. It is better to combine DOE with other approaches.

Thus, the objective of this study was to find a new way of HVOF process qualification and optimization using process models with a combination of statistics, materials science, and mechanics. This approach can also be used to identify most optimized process-operating parameters or process input variables to meet all customer requirements. In this evaluation, we choose most common aerospace customer qualification requirements, including typical microstructural and mechanical requirements per AMS2448, and additional fatigue requirement. In addition, the process-structure-property relation was also developed by process maps, which were used as a design tool for coating processing.

MICROSTRUCTURE DOE EXPERIMENTAL SETUPS

Equipment Descriptions

The HVOF equipment used was a TAFA JP8000 with a TAFA 1264 powder feeder closed-loop system. The set points were preset based on trials that demonstrated all values within would achieve acceptable coating application. The coating system provided fixtures for mounting the HVOF torch and holding the workpiece, so that torch-to-work distance and transverse rate variations could be minimized. For this process qualification development, a well-defined 1350VF/WC-731 powder per specification AMS 7882 was used.

Microhardness testing was conducted using a Mitutoyo Hm-112 with a 300-g load. All specimens were cold mounted, followed by being fully polished and analyzed using Zeiss Microscopy.

DOE Methodology

As described previously, HVOF is a complicated process containing many process input factors that could impact coating properties. The actual choice of parameters needs some understanding of the process as there are as many as 50 process variables (Ref. 3). To limit the amount of experimental runs, the chosen inputs for experimentation of this DOE were oxygen flow, fuel flow, powder feed rate, stand-off distance, surface speed, and surface preparation roughness (Table 1). Because the relationship between the experimental response and factors is not always linear, the factors at multiple levels have to be used to determine a quadratic or even cubic relationship using response surface.

Table 1 — Setting of Factors and Two Levels for DOE of HVOF Coating

Factors	Low (-1)	High (+1)	Center Point
Oxygen flow, ft^3/h	1800	2000	1900
Fuel flow, gal/h	5.6	6.4	6.0
Powder feed rate, GFM/RPM	64	90	77
Stand-off distance, in.	12	16	14
Surface speed, SF/min	200	300	250
Surface roughness, µin.	79	157	118

Methodology (RSM)

The D-Optimal design is usually constructed and evaluated to calculate the matrix for a given mathematical model, number of experimental runs, etc. (Ref. 3). Statistical analysis software JMP was used for the DOE and analysis. Desirability profiling and optimization within JMP were used to identify the optimal first- and second-order processing map development. In desirability profiling, all responses had a specified desirability function, then the overall desirability was defined as the geometric mean of the desirability for each response.

Based on our extensive scientific literature study and initial experience (Refs. 5, 6), the low, high, and center points for each factor setting were chosen as listed in Table 1. All other process input variables remained constant in all runs. A total of 34 experimental runs were made.

DOE Responses

For DOE responses, it is important to understand the difference between the general output of the process and the characteristics/properties of the final coating deposit. As stated earlier, the final goal of the coating was maximized microstructure and fatigue performance. However, when the coating was initially sprayed, only a set of simple measurements could be used for quality control of the process, as follows:

- Microstructure (primarily measurement of porosity, unmelted particles, and oxides)
- Microhardness
- Almen strip (residual stress)
- Substrate temperature (during coating)

MEC

ISO 9001:2008

"MASS - VIEW" PLASMA SPRAY SYSTEM

MPS-50M / MPS-100M

API Spec Q1 Registered
MECPL REG NO:- Q1-1731

MEMBER OF ASM INTERNATIONAL

CRISIL RATINGS
SE 1B
The High Credit Quality rating assigned to an SME

CE

METALLIZING EQUIPMENT CO. PVT. LTD.

E-101, M.I.A., Phase-II, Basni, Jodhpur-342005 (India)
Ph. : +91 291 2747601 Fax : 2746359
E-Mail : marketing@mecpl.com / sales@mecpl.com / trade@mecpl.com
Web : www.mecpl.com

"Agents exists in all Principle countries"

Table 2 indicates information of test coupons used in the DOE for each run. The coupon size of each type meets the requirement in accordance with AMS 2448. Prior to abrasive blasting, the parts were solvent cleaned by wiping the part with isopropyl alcohol and a lint-free cloth. The parts were then visually inspected to ensure complete removal of all surface contaminants. Abrasive blasting was performed in a manner so as not to remove and/or distort the base material, ensuring there was no abrasive blast pulsation affecting the grit blast process.

Table 2 — Test Coupons Used in DOE for Each Run

Testing	Requirements	Material	Coating Thickness, in.
Bending	N crack	4130 steel	0.001–0.003 in.
Microhardness test	950 min @ HV_{300}	4130 steel	0.009–0.012 in.
Microstructure	Porosity, Oxide <1%	4130 steel	0.009–0.012 in.
Tensile bond strength	10 ksi min.	4130 steel	0.009–0.012 in.
Residual stress	0.003–0.012 in.	Almen N strip	0.0045–0.0053 in.

MICROSTRUCTURE MODEL AND RESULTS

Design of experiments order runs 1 through 34 were tested. Table 3 represents all the results that were analyzed in the DOE study.

Table 3 — Microstructural DOE Results

Runs	Porosity	Oxide	Almen Strip Arc Height	Hardness	Tensile Bond
	(%)	(%)	(um)	HV300	(MPa)
1	0.39	1.32	313	1374	76
2	0.61	0.86	178	1365	82
3	0.71	1.11	130	1338	76
4	1.32	1.60	110	1247	71
5	0.45	0.70	343	1343	73
6	0.34	0.93	257	1314	70
7	0.41	1.30	227	1361	81
8	0.25	0.55	401	1347	81
9	0.18	0.64	371	1427	38
10	0.26	0.57	217	1304	82
11	0.36	0.67	219	1320	82
12	0.26	0.56	270	1318	78
13	0.23	0.73	246	1309	85
14	0.45	1.38	175	1353	81
15	0.41	1.19	217	1319	84
16	0.21	0.73	308	1342	86
17	0.53	0.94	207	1333	80
18	0.52	0.62	223	1342	77
19	0.89	1.25	68	1260	77
20	0.77	1.45	204	1272	82
21	0.52	0.57	172	1291	81
22	0.35	1.23	241	1360	79
23	0.31	0.60	277	1417	69
24	0.37	0.86	235	1402	88
25	0.32	0.64	178	1394	38
26	1.24	1.31	64	1272	77
27	0.89	0.82	130	1288	83
28	0.22	0.66	262	1465	85
29	0.89	0.69	180	1369	83
30	0.65	1.10	266	1388	81
31	0.60	0.56	139	1370	79
32	0.57	0.86	209	1321	77
33	0.25	0.36	347	1458	40
34	0.28	0.54	272	1359	83

All of the 34 DOE orders exhibited no failure in the bend tests. There was no evidence of peeling, cracking, or separation at neither the bent coating surface nor the edges of the alloy strip. It is safe to say that coating adhesion quality is not a concern for each of the 34 DOE orders. In the microstructure, there were multiple orders that showed oxide and/or porosity over 1%. The variations in the porosity and oxides in the microstructure of the HVOF coating was controlled by numerous variables in the parameters. The main controlling factor in the microstructure results was the oxygen/fuel ratio and stand-off distance. This ratio controls the flame temperature, which affects how the powder dissolutes and melts onto the substrate. As expected, lower stand-off distances tended to have lower porosity.

Of the 34 DOE orders, 3 did not meet the required tensile bonding strength of 69 MPa. The other 31 orders only failed due to adhesion failure. To fully understand and analyze the results from this test, it is important to take note of how much coating separation exists after the two test specimens separate. The orders that failed or had a lower tensile bond breaking point were shown to have parameters that led to a higher substrate temperature and high powder feed rate. This was mostly attributed to closer standoff distances and powder grams per minute, as well as the fuel/oxygen ratio.

The minimum Vickers hardness of HV300g-950 was surpassed in each of the 34 DOE orders. The statistical model had 93% R2, indicating it was statistically significant. Factors that produced a hard coating include a closer stand-off distance and higher fuel. Although a harder coating seems optimal for the aerospace field, a softer coating seems logical for the ideal HVOF parameters. Albeit with better corrosion and wear resistance, a harder coating generally tends to be more brittle. Consequently, a more brittle coating has more of a chance to exhibit spallation. The parameters that produced a softer coating were chosen to eliminate the chance of spallation and to increase fatigue life.

Figure 1 shows the developed microstructural model. Based on the model, the first-order process map (representing the relationship between the spray stream measured responses with coating properties such as hardness, microstructural properties, residual stress, etc.) was identified. The overall process map was precisely determined. The process map can be used to establish manufacturing robustness and the process window for a reliable process.

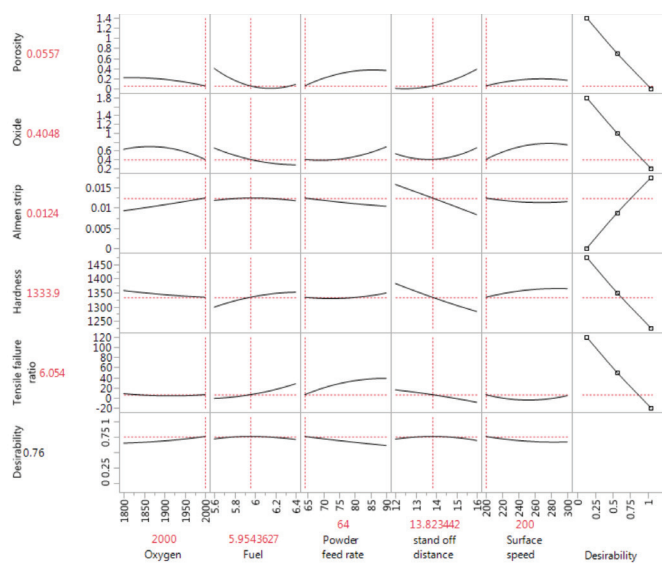


Fig. 1 — Microstructural model.

FATIGUE DOE SETUPS

Fatigue is a very critical property in the aerospace industry because of the repeated cyclic loading for landing gear, actuators, airframe parts, and gas turbine engine components. The purpose of fatigue testing was to evaluate the effect of the coating on the fatigue of the underlying material (Ref. 4). In addition, coatings must maintain their integrity under expected service conditions (i.e., not delaminate during testing at stresses seen in service, although delamination may occur on final failure once specimens break).

It was almost impossible to conduct another 34 runs of fatigue testing. Thus, fatigue testing DOE variable selection was based on microstructural model analysis, plus fundamental understanding of materials science, including fatigue science and the thermal spray process. From the microstructural model, low powder feed rate provided decent bonding strength that was also expected to provide high fatigue/spalling cycles. Thus, the powder feed rate was fixed at 64 g/min. The specimen surface speed was chosen at 200 SF/min due to relatively low sensitivity. Part surface roughness was chosen to be 79 Ra. At both the surface speed of 200 SF/min and roughness of 79 Ra, specimens demonstrated very low porosity and a substrate temperature that was supposed to be good for fatigue, which will be discussed later. Therefore, fatigue testing DOE focused on oxygen, kerosene, and stand-off distance factors (Table 4). The corresponding response was fatigue spalling cycles. Under the ideal situation, the spalling occurred during final fatigue failure. Plus, the spalling location would be exactly the same location as that of the final fatigue failure. In a nonideal case, spalling started prior to fatigue failure or the spalling location was away from the fatigue failure. That situation is generally considered not acceptable.

Table 4 — Fatigue DOE Design Table

Factors	Low (-1)	High (+1)	Center Point
Oxygen flow, ft^3/h	1800	2000	1900
Fuel flow, gal/h	5.6	6.4	6.0
Stand-Off Distance, in.	12	16	14

FATIGUE TEST SPECIMENS AND SETUP

Fatigue testing conditions were based on load-controlled constant amplitude axial fatigue testing in accordance with ASTM E466-96:

- Fatigue testing load: 14.2 lbf
- Specimen gauge diameter (prior to coating): 0.315 in.
- Max fatigue stress: 182 ksi
- Testing frequency: 4 Hz
- Fatigue testing ratio: R = –1
- Fatigue specimen surface finish: As HVOF coated
- Fatigue specimen geometry: Fig. 2
- Specimen material type: 300M with tensile strength 280–300 ksi (1930–2068 MPa)
- During fatigue testing, video cameras were used to precisely record the start of coating spalling. If spalling occurred during final fatigue failure, then the spalling cycles are the fatigue cycle.

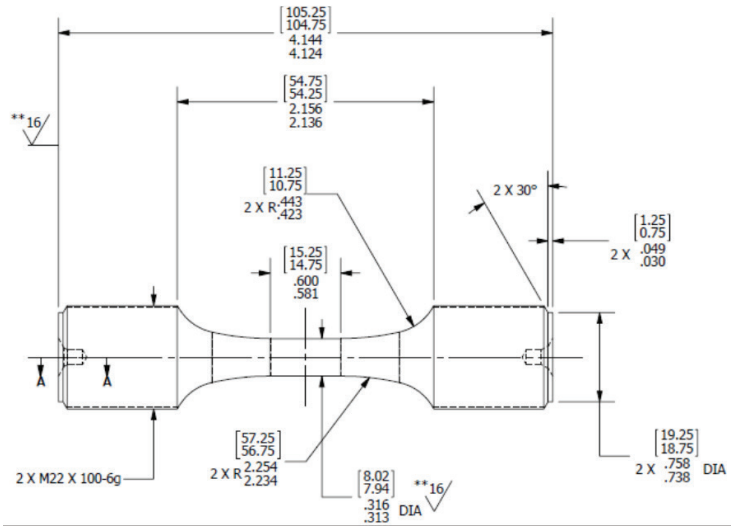


Fig. 2 — Fatigue Testing Specimen Geometry.

All fatigue specimen preparation involved four major steps: rough machining, vacuum heat treatment, finish machining, and shot peening. The heat treat for 300M was in accordance with MTL-1201. All specimens to be tested were prepared in the same fashion to ensure a common starting condition prior to any surface preparation techniques used for the coatings.

FATIGUE MODEL AND RESULTS

Figure 3 shows the fatigue model based on testing results. With R2 of 72% and F ratio of 2.6, this fatigue model is statistically significant. The most significant factors are the oxygen and kerosene contents.

Apparently, for our application, low oxygen and kerosene and high distance was preferred for maximum fatigue/spalling cycles. Table 5 shows one of the best fatigue testing results. For both specimens, all fatigue specimens showed no sign of spalling until final fatigue failure — Fig. 4. After failure, fatigue tested specimens were put back together to measure maximum spalling distance. The measured distance was between 2 and 4 mm.

Table 5 — Fatigue Test Results

Specimen No.	Spalling Cycles	Failure Cycles
NT-1	N/A	10305
NT-2	N/A	11136

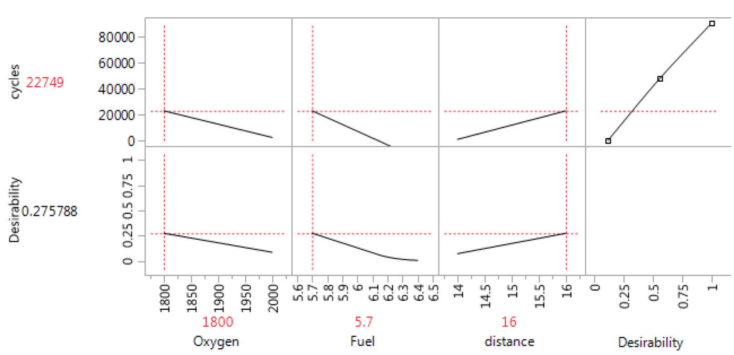


Fig. 3 — Fatigue testing model.

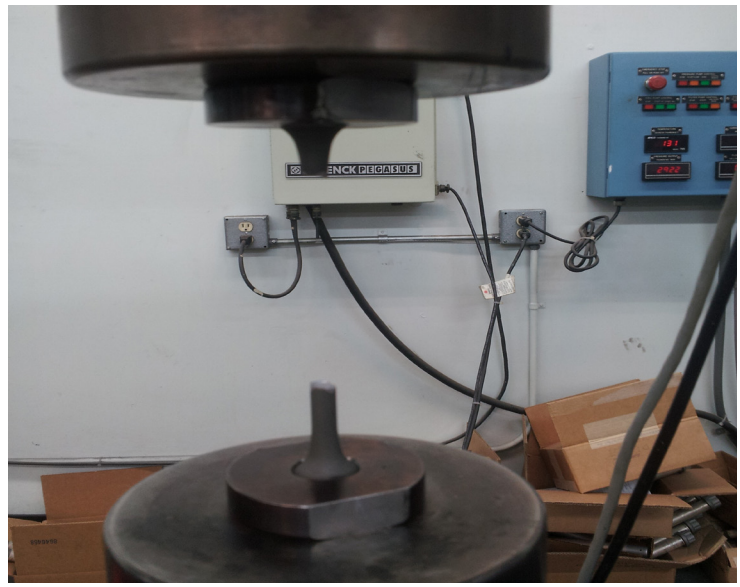


Fig. 4A — Fatigue Testing.

Fig. 4B — Tested Specimens.

COMBINED MODELS

After generating both microstructural and fatigue models, it was time to combine both models to identify appropriate conditions to meet all customer requirements. Interestingly enough, the best conditions to meet each model did not coincide with each other. In other words, the best spray processing conditions to generate lowest porosity did not have the highest fatigue/spalling cycles. Correspondingly, the best spray processing conditions to generate the highest spalling cyles did not have the lowest porosity, either. However, it was not difficult to identify spray processing conditions that could meet both microstructural and fatigue/spalling conditions. Table 6 shows the final fatigue results with decent microstructure as in Fig. 5.

Table 6 — Fatigue Test Results

Specimen No.	Spalling Cycles	Failure Cycles
M6-1	N/A	8967
M6-2	N/A	10736
M6-3	N/A	10712
M6-4	N/A	11324
M6-5	N/A	11356

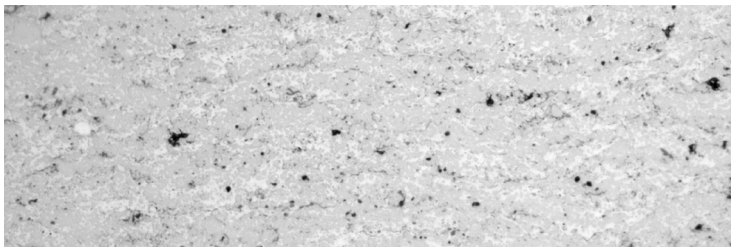


Fig. 5 — Microstructure of the fatigue tested specimen.

DISCUSSION

The current example demonstrated that HVOF process qualification using a combination of statistics, materials science, and mechanics models is a useful and effective approach to successfully meet customer requirements within short time frame. It is interesting to discuss some important aspects of HVOF models as follows.

PRELIMINARY MODEL

One of the most fascinating features of HVOF models are that there is more than one "good" processing condition for the coating process. Due to their complexity, the desired coating properties cannot be achieved by just changing a single variable since there are complicated interactions. There are so many factors in the process that even altering one parameter might have a substantial effect on the coating deposition. That is also the reason statistical analysis could be very helpful. In addition, the variable selection became highly critical to prevent any potential misleading information. This has to come from a fundamental understanding of materials science and the thermal spray process. In the aerospace thermal industry, each piece of equipment is always slightly different. Thus, finding the right niche for an individual piece of equipment is critical. The authors would suggest the conducting of preliminary DOE to identify the most critical variables based on final applications. In this example, the first model, microstructure is the preliminary DOE.

FINAL MODEL

For the second model, the fatigue model is the most important application model. It has to be based on final customer applications. The most critical fatigue model variable selection was determined based off of key trends seen from the preliminary DOE data. For a dynamic environment, such as the aerospace industry, fatigue life and performance should be considered as the most critical factor. So to select the most ideal HVOF spraying condition, fatigue was used as the primary guideline for the model variable selections. Therefore, the primary determinant in the selection is controlling the temperature of the substrate. Thus, these parameters were prioritized for keeping the temperature as low as possible. The combustion gas ratio of oxygen/fuel is another determinant in the selection process. The low points for the oxygen and fuel flow settings kept the porosity and oxides low, while keeping fatigue life high. Therefore, only oxygen, kerosene, and stand-off distance were chosen to be the fatigue model variables.

STATISTICS

Due to the nonlinear relationship, it is highly recommended that response surface methodology or another optimal design be used. There are many commercially available software options.

CONCLUSIONS

This evaluation outlines a new way of high-velocity oxyfuel (HVOF) spraying qualification and optimization using combined statistical, materials science, and mechanics analysis. It proved to be an effective way to be successfully customer qualified within an extremely short time frame.

The approach can also be used to identify and demonstrate the ideal setting of HVOF process operating parameters, with which the deposited coating meets customer requirements, including fatigue. All these models adopted response surface methodology.

This approach includes developing two DOEs. The first processing model, the preliminary DOE, attempted to identify the following goals based on final applications:

1. Equipment niches
2. Processing map: Correlate the processing variables with typical specimens' metallurgical properties, such as tensile strength, oxides and porosity, residual stress, microhardness, etc.

The second model focused on final applications and fatigue properties vs. HVOF processing variables. The variable selections were based on the preliminary model and the fundamentals of materials science. In this example, it would be the substrate temperature.

REFERENCES

1. Mostaghimi, J., Chandra, S., Ghafouri-Azar, R., and Dolatabadi, A. 2003. *Surf. Coat. Technol*. 1: 163,164.
2. Dongmo, E., Wenzelburger, M., and Gadow, M. 2008. *Surf. Coat. Technol*. 202: 4470.
3. Pierlot, C., Pawlowski, L., Bigan, M., and Chagnon, P. 2008. *Surf. Coat. Technol*. 202: 4483.
4. Oksa, M., Turunen, E., Suhonen, T., Varis, T., and Hannula, S. 2011. *Coatings* 1: 17–52.
5. Lima, R. S., Karthikeyan, J., Kay, C.M., Lindemann, J., and Berndt, C.C. 2002. *Thin Solid Films* 416: 129.
6. Fang, W., Cho, T. Y., Yoon, J. H., Song, K. O., Hur, S. K., Youn, S. J., and Chun, H.G. *Journal of Materials*.

LIANG ZENG (lzeng@sargentaerospace.com) and BRENTT RAMSEY are with RBC-Sonic Industries, Torrance, CA

YTTRIA-STABILIZED ZIRCONIA PRODUCES COATINGS WITH LOW THERMAL CONDUCTIVITY

An independent study by the thermal spray team of the National Research Council of Canada (NRC) has observed low thermal conductivity (K) values for coatings manufactured from Innovnano's 7 wt-% yttria-stabilized zirconia (YSZ) powder through air plasma spraying (APS) and suspension plasma spraying (SPS).

The powders were produced using Innovnano's proprietary manufacturing process, emulsion detonation synthesis (EDS). The EDS process transforms precursor chemicals into nanostructured powders through a micro-second exposure to high temperatures and pressures through controlled explosions. Temperatures can exceed 3000 K and pressures are greater than 10 GPa. The process produces nanostructured ceramic powders that can be tailored for unique structures and properties.

Low thermal conductivity thermal barrier coatings (TBCs) are desired as they can increase turbine engine efficiency, reduce emissions, increase durability, and lower costs. A 30% reduction in thermal conductivity translates into an approximately 100°C increase in temperature difference across a 200-micron-thick coating. Alternatively, a 30% reduction in thermal conductivity would require 30% less coating thickness to yield the same surface temperature.

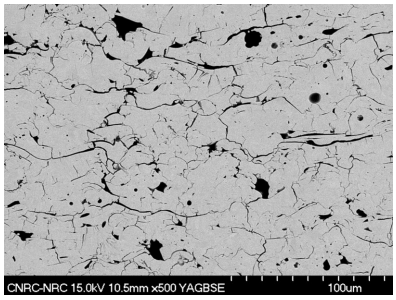


Fig. 1A — APS Benchmark

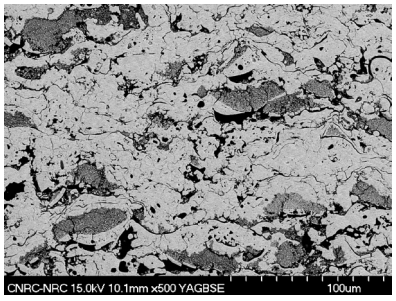


Fig. 1B — Innovnano APS

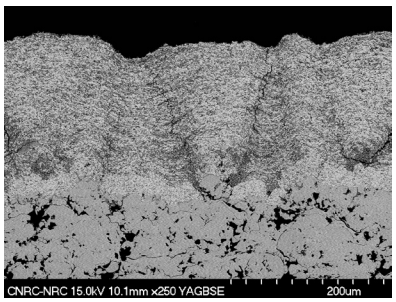


Fig. 1C — Innovnano SPS

The NRC's thermal spray team produced YSZ coatings and thermal conductivity measurements. Figure 1A–C shows the various as-sprayed coatings the team produced.

Figure 1A shows the benchmark APS coating. Figure 1B shows the company's APS coating with regions of partially melted YSZ particles where the nanostructure is retained (dark-grey phase). Figure 1C shows the micro-porosity of the company's SPS coating. These coating features led directly to the lower thermal conductivity values shown in Fig. 2. To provide more representative thermal conductivity values, the as-sprayed YSZ TBCs were also heat-treated for 10 h at 1300°C prior to measuring. At 1300°C, the SPS and APS TBCs showed an approximately 30% and 20% reduction, respectively, in thermal conductivity when compared to the APS benchmark. Low-thermal-conductivity YSZ coatings can be produced though defect-driven, microporous coating structures, without the use of rare earth oxide additions.

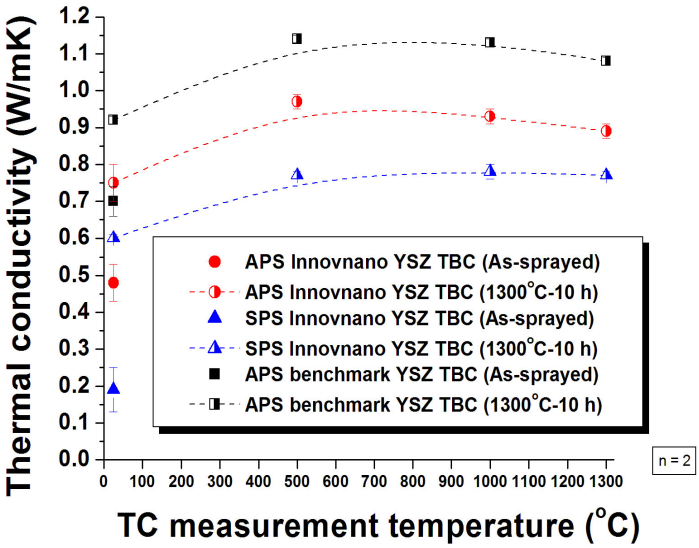


Fig. 2 — Thermal conductivity values of the different yttria-stabilized zirconia thermal barrier coatings.

Further studies will investigate other important properties of YSZ coatings, including erosion resistance, thermal cycle durability, phase stability, and structural stability.

For more information contact *paul.newbatt@innovnano-materials.com*

See pages 10 – 11

METALLISATION EQUIPMENT SUCCESSFULLY USED IN MIDDLE EAST FACILITY

Metallisation equipment is used to protect various structures and substrates from corrosion. One recent project saw the Metallisation Arcbeam spray concentrator successfully used at a Middle Eastern oil refinery.

Anti Corrosion Protective Systems (APS), based in Dubai, offers a range of specialist coating services to the construction, oil, gas, power and utility sectors throughout the Middle East and Asia. The company has been the contractor for many of the region's more notable projects, including the world's tallest building, the Burj Khalifa Tower. In this latest project, APS used the Arcbeam spray concentrator where high velocity arc spray (HVAS) has been previously specified. The Arcbeam produces dense coatings with low levels of porosity, typically lower than 2%.

In this project, the internal shells of two absorber columns, which were 5.2 m in diameter, and two cooling columns, 5.4 m in diameter, were treated on the inner shell as well as at the bubble cap and support ring areas. The surfaces were prepared by grinding to remove sharp edges and smooth out any heavily pitted areas. The coating areas were blasted to SA 3 surface quality grade cleanliness and a minimum of 90 µm profile with garnet. The final surface preparation involved a sweep blast with aluminium oxide.

The internal shells of the absorber and cooling columns were coated with two layers of Hastelloy® 73E at 225–250 µm per coat using the Arcbeam ARC140 system. The surface coating was finished with one coat of Sprayseal F, which was applied by brush until complete joint penetration was achieved. The area coated was approximately 80 m^2 per column.

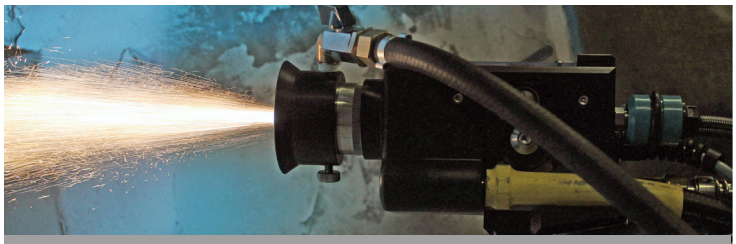


Fig. 1 — The process sends a stream of molten material to form a dense, strongly adherent coating.

In this process, the raw material, in the form of a pair of metallic wires, is melted by an electric arc. This molten material is atomized by a cone of compressed air and propelled towards the workpiece Fig 1. The molten spray solidifies on the component surface to form a dense, strongly adherent coating suitable for corrosion protection or component reclamation. Sprayed coatings may also be used to provide wear resistance, electrical and thermal conductivity, or freestanding shape. The system is flexible with medium throughput for controllability. The pistol delivers a fine coating with a dense structure, ideal for highly corrosive environments. Advantages of the arc spray process are that the coatings are available for almost instant use, with no drying or curing times, and there is no risk of damaging the component.

For more information, visit *www.metallisation.com*.

2016

OCTOBER 2016

- **MS&T16 Conference & Exposition**
  October 23–27 / Salt Lake City, UT
  www.asminternational.org
- **International Sheet Metal Working Technology**
  October 25–29 / Hanover, Germany
  www.euroblech.com

NOVEMBER 2016

- **FABTECH**
  November 16–18 / Las Vegas, NV
  www.fabtechexpo.com
- **PM Management Summit and 72nd Annual MPIF Business Meeting**
  November 19–21 / New York, NY
  www.mpif.org/summit
- **North American Cold Spray Conference**
  November 30–December 1
  Edmonton, Alberta, Canada
  www.asminternational.org

DECEMBER 2016

- **Power-Gen International**
  December 13–15 / Orlando, FL
  www.power-gen.com

2017

FEBRUARY 2017

- **LAM 2017 Laser Additive Manufacturing Workshop**
  February 21–22 / Houston, TX
  www.lia.org

MARCH 2017

- **Coatings & Advanced Innovations for Industrial Gas Turbines Symposium**
  March 7–8 / Greenville, S.C.
  itsa@thermalspray.org
- **Corrosion 2017**
  March 26–30 / New Orleans, LA
  www.nacecorrosion.org

APRIL 2017

- **ICMCTF-17-International Conference on Metallurgical Coatings & Thin Films**
  April 24–28 / San Diego, CA
  www.icmctf.org
- **SVC TechCon 2017 – 60th Annual Technical Conference**
  April 29–May 4 / Providence, RI
  www.svc.org

MAY 2017

- **OTC 2017 - Offshore Technology Conference**
  May 1–4 / Houston, TX
  www.otcnet.org

JUNE 2017

- **ITSC 2017 International Thermal Spray Conference and Exposition**
  June 7–9 / Düsseldorf, Germany
  www.dvs-ev.de/itsc2017/
- **POWDERMET 2017**
  June 13–16 / Las Vegas, NV
  www.mpif.org

SEPTEMBER 2017

- **Eurocorr 2017 and 20th International Corrosion Congress**
  September 3–7 / Czech Republic
  www.eurocorr2017.org

OCTOBER 2017

- **ITSA Annual Meeting and Technical Program**
  Date TBD / Albuquerque, N.M.
  itsa@thermalspray.org

Your **SPRAYTIME** publication is provided to you at no charge by our advertisers. We encourage you to thank these advertisers by visiting, contacting, and referring their products and services at every opportunity.

ADVERTISER INDEX

IS YOUR EVENT LISTED?

Send calendar notice to
spraytime@thermalspray.org

The Simple Choice for a Perfect Surface

The favorite powder feeder for **laser cladding**, **thermal spray** and powder-fed **additive manufacturing** has just gotten better!

With our new **Twin 150** powder feeder you can:

- Easily integrate the Twin 150 into your system
- Access all of its functions from your process controller
- Very accurately and repeatably feed powder for your process
- Tailor your Twin 150 for your needs with our wide assortment of options and accessories

With Oerlikon Metco, your choice is simple!

Visit us at FABTECH 2016 Las Vegas, NV, Booth# C20053
www.oerlikon.com/metco

oerlikon
metco