Crack Prevention in NiCr Alloys Using Laser Powder Bed Additive Manufacturing
Robotic 8-Axes Closed Loop Controlled Multi Process Turnkey Systems

Dual Acoustic Chambers with Centralized Control Chamber

Metallizing Equipment Co. Pvt. Ltd.
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Features
Crack Prevention in NiCr Alloys Using Laser Powder Bed Additive Manufacturing .......................... 16

Departments
Industry News .................................................................................................................. 4
Product Spotlight .......................................................................................................... 8
ITSA Membership ........................................................................................................ 10
ITSA Member News ...................................................................................................... 12
ITSA Welcomes New Members ................................................................................... 14
People in the News ....................................................................................................... 15
Calendar ........................................................................................................................ 22

On the cover: A twin arc spray operation on a roll for the plastic industry. Photo courtesy of Atlas Machine and Supply Inc. (atlasmachine.com).
StandardAero Invests More Than $16 Million to Expand Three Primary U.S. Facilities

StandardAero Component Services, a provider of original equipment manufacturer-aligned repair, overhaul, and new-make capabilities, with thermal spray as one of its major process skills, is investing and expanding three of its U.S. sites this year. The company will increase shop capacity, by a total of 260,000 sq ft collectively, through growing facilities in Cincinnati and Hillsboro, Ohio, and Miami, Fla.

The overall investment to fund the expansions exceeds $16 million in construction and capital equipment. Rick Stine, president of StandardAero Components, Helicopters & Accessories, noted the aim is to grow capacity to meet the demands of users on legacy platforms and next-generation engines.

The Cincinnati expansion will include building an additional 200,000 sq ft of workspace to accommodate component repair growth on new platforms, military and commercial engine component repairs, as well as larger components.

Miami will add 30,000 sq ft of workspace and capital improvements, including the installation of a clean line, an additional vacuum furnace, and waterjet cleaning capabilities, so it will be able to repair large engine cases.

Hillsboro will be completing a 30,000-sq-ft development to support new original equipment manufacturer production, bringing the facility’s total manufacturing footprint to 115,000 sq ft of space.

“These expanded capabilities also include dedicated processes for the repair, overhaul, and manufacturing of various component types to support our customers’ engine needs,” Stine concluded.

Bodycote Joins Forces with Safran; Services to Include Thermal-Spray Coatings

Bodycote, Macclesfield, UK, a provider of heat treatment and specialist thermal processing services, has entered into a long-term agreement with Safran, Paris, France, an international high-technology group and tier-1 supplier of systems and equipment in the aerospace market. Its global network will support the agreement to operate initially from facilities in France and Belgium.

The company will provide manufacturing services, including thermal-spray coatings, electron beam welding, hot isostatic pressing, and heat treatment, to Safran companies and their strategic first-tier suppliers. Its processes and technologies are used to prolong the working life of critical components and provide in-service protection from factors such as abrasion, temperature, and wear.

The agreement ensures manufacturing requirements will be met to support the growth in Safran’s civil aerospace programs.
Apply for an ITSA Scholarship

Applications for the International Thermal Spray Association’s (ITSA) Scholarship Program are being accepted annually, from May 1 through July 16. Up to three one-year scholarships worth $2000 each may be awarded and announced in August.

The form can be downloaded at itsa2. awsmarketing.org/scholarship/. Only those meeting all of the following criteria will be accepted for consideration:

• Student must be actively pursuing a postgraduate degree in thermal spray processes (plasma, flame, arc, HVOF) or materials at an accredited university (U.S. only).
• Student must have at least one more year left in studies (after the current year).
• Student must be recommended by a supervisor of the university the student is attending. Student’s financial need must be verified by a professor.
• Student must be recommended by at least one industrial source.
• Via letter, the student must present his/her interest in pursuing a career in thermal spray (maximum of three typed pages).
• Student must include the completed application form.
• Paperwork must be received May 1 through July 16; if received outside these dates, they will not be considered.

All applications must be sent via regular mail to ITSA, c/o American Welding Society, 8669 NW 36 St., Ste. 130, Miami, FL 33166. Send questions to itsa@thermalspray.org.

MOVING?
Make sure delivery of your SPRAYTIME is not interrupted.
Contact itsa@thermalspray.org with your new address information.
Newly Developed Corrosion Protection Process, Using Thermal Spray, Wins German Innovation of the Year

The offshore wind project Arkona, in the German Baltic Sea, has received the German Renewables Award in Hamburg. Presented by the Clusteragentur Erneuerbare Energien, E.ON and Statoil’s joint project earned the innovation of the year honor for a newly developed process that protects the steel foundations of offshore wind turbines from corrosion.

“The procedure developed by E.ON reduces the environmental impact, and at the same time, lowers the costs for the construction of offshore wind farms,” explained the independent jury from science and industry.

During the 25-year operating life of an offshore wind farm, the metal-dissolving corrosion process is reduced by the new process, and emissions to the sea are reduced by several hundred tons. This is achieved by the thermal-spray aluminum process, where the mono steels, which are up to 81 m long and weigh 1200 tons, are first coated with aluminum and then protected with a synthetic resin layer.

The award was accepted by E.ON Project Director Holger Matthiesen. “We have taken the risk of integrating innovation into our ongoing project process. We are pleased to have successfully implemented this jointly developed innovation in the Arkona offshore wind farm for the first time worldwide. This will further reduce costs for the offshore wind sector and further minimize the environmental impact,” Matthiesen said at the ceremony.

E.ON developed the thermal spray aluminum process with Rambøll, an engineering company. The companies EEW Special Pipe Constructions and Krebs implemented the process industrially at their sites in Rostock, Germany.

The Arkona project will have a capacity of 385 MW, supply up to 400,000 households with renewable energy from 2019 onward and, compared to conventionally generated electricity, save up to 1.2 million tons of CO₂ per year.

Höganäs AB Acquires High-End Tooling Company

Höganäs, Sweden, has acquired Alvier PM-Technology, a developer and producer of high-quality, complex tooling solutions for powder metallurgy. The high-end tooling company was founded 30 years ago in Buchs, Switzerland. Its solutions focus on the entire value chain from engineering and manufacturing to installation and customer service and training.

Höganäs and Alvier have collaborated since 2005 on projects advancing what is possible within powder metallurgy technology. “We see a great potential in Alvier’s offering by fully exploring optimal combinations of powder and tool in the compaction process. Alvier will also be vital to our efforts to apply new digital technology in future process and material solutions,” said Fredrik Emilson, Höganäs CEO.

Valence Wichita Earns Hardness and Conductivity Testing Approvals

Valence Surface Technologies, an independent aerospace and defense product finishing company, has received new Boeing and Bombardier approvals for hardness and conductivity testing at its Wichita, Kans., facility, formerly known as Chrome Plus International. This location, which offers capability for up to 12-ft parts, now holds approvals from Airbus, Cessna, Spirit, Boeing, and Bombardier. An additional site in Grove, Okla., has capability for up to 26-ft parts as well as Lockheed Martin and Northrop Grumman approvals in addition to commercial aerospace approvals. Across these two Midwest locations, Valence offers a range of product finishing services including various spray coatings.

Share your company news, facility improvements, acquisitions, and noteworthy events with us.

Email press releases to spraytime@thermalspray.org.
The SSPC 2018 gathering attracted more than 2460 registered attendees.

The Society for Protective Coatings (SSPC), Pittsburgh, Pa., held its annual meeting and trade show January 15–18 in New Orleans, La. There were more than 2460 registered attendees and 145 exhibiting companies purchasing 283 booth spaces, demonstrating a 12% increase in attendance and a 15% increase in booth sales from 2017.

This year brought new and improved methods for attendees to engage and interact with one another, including a fitness step-up challenge, LEGO building station, and conference app. The mobile app more than tripled mobile engagement from recent years and allowed everyone in attendance access to complete conference information.

The technical proceedings were moved to an online platform as well. Visit spc.org/technical-proceedings.

In addition, SSPC 2018 attendees were treated to a surprise. Kept under wraps for several months during construction, the society’s Mobile Training Unit made its official first appearance. Designed to enable on-site training of abrasive blasting and coatings application, the self-contained unit features the equipment necessary to perform complete training and testing of students. For more information, contact Jennifer Merck at merck@sspc.org.

Supersonic Cold Metal Bonding in 3D Explored

A temperature-based 3D model by Professor Tien-Chien Jen, from the University of Johannesburg, South Africa, unlocks the cold gas dynamic spray (CGDS) film-growing process in the particle deposition zone. The model connects the dots with particle-impact velocity, energy transformation, and temperature rise in the particle-impact zone, in three dimensions.

A de Laval nozzle sprays micron-sized metal particles over a short distance, typically 25 mm, at a metal or polymer surface. The particles impact the surface at speeds from 300 to 800 m/s. As a reference, the speed of sound is 343 m/s. Cold gas dynamic spray has an ideal temperature range and saves energy because no heating is added.

“The new model animates in 3D a single spherical particle ‘falling down’ into the substrate metal. The substrate ‘splashes up,’ and then the particle and substrate bond. The substrate ‘splashing’ looks like milk splashing up when something falls into the cat’s bowl. This is called jetting behavior in industry,” Jen said.

The model uses parameters describing the nature of the particle and surface. Also, it predicts in 3D how the average temperature of the particle impact zone will rise and subside, depending on the size and impact velocity of the particle. The model was published in the Journal of Thermal Spray Technology.

“For this 3D model, we went with the hypothesis that a metal particle has to bond with the substrate at 60% of its melting temperature, to create a strong new surface without damaging the substrate,” Jen said.

The model holds up in experimental results with copper particles sprayed onto an aluminum surface.

“When the impact velocity is within the range predicted by the model for a particle size, sufficient bonding temperature is reached, and a strong CGDS coating is created. As an example, we set up our CGDS equipment in the laboratory for copper particles with an average size of 5 micron, carried by nitrogen, and impact velocity in the range of 700 to 800 meters per second deposited downwards on aluminum. The model predicts that at about 750 meters per second impact velocity, the critical bonding temperature of 650˚C will be attained in the particle impact zone. In line with that prediction, we obtained excellent CGDS bonded coatings,” he added.

The single-particle, single-layer 3D model will be extended into a multiparticle, multilayer model in follow-up projects.
Double-Ply Thermal Spray Masking Tape Increases Efficiency

The DW 498 plasma spray masking tapes are produced from laminates double-ply of silicone rubber, glass cloth, and aluminum foil, as well as coated with a high-temperature silicone adhesive. This pressure-sensitive masking tape is used for plasma flame spraying when a single-ply tape will not provide sufficient protection. The double-ply construction eliminates the need for two-hand lay-up operations, saving labor costs. The high-temperature masking tape is designed to aggressively adhere, ensuring sharp edges, and yet provide a quick, clean removal.

DeWAL
dewal.com / (800) 366-8356

Flame Spray Unit Delivers Wear-Resistant Coatings

The Rokide® flame spray system uses its ceramic oxide rods as the consumable for maximum coating performance. The rods are melted in the patented spray unit, which then projects fully molten particles onto a working substrate at high velocity. The molten ceramic particles cannot leave the spray unit until in a fully molten state. These particles have high kinetic energy and thermal mass, imparting a strong, dense coating. The unit features an easy-to-use lever operation, located on the spray unit main body. An oxygen-acetylene flame melts the rod consumables. The unit accommodates 3/16-in.- (4.75-mm) and ¼-in.- (6.35-mm) diameter rods and can also easily adapt to spray ½-in.- (4.75-mm) flexicords. The handheld system is portable, so coating applications are possible without difficulty in both job shop and field environments.

Saint-Gobain Coating Solutions
coatingsolutions.saint-gobain.com / (800) 243-0028

Report Shows China Thermal Spray Coating Equipment Market and Forecasts until 2021

The China Thermal Spray Coating Equipment Market Research Report Forecast 2017–2021 includes important data on the trends that can help businesses to understand the industry and make plans for the growth and development of their business. Research analysts provide a description of the value chain and its distributor analysis. The study provides an overview of the industry's growth analysis, historical and futuristic cost, revenue, as well as demand and supply data (as applicable). Moreover, it covers the market landscape and its growth prospects over the coming years. A further section of the report gives an interpretation of production, revenue, price and gross margin, company basic information, manufacturing base and competitors of the China market for each region, product types, and applications. The 113-page report provides a pin-point analysis for changing competitive dynamics; a perspective on different factors driving or restraining market growth; and a five-year forecast assessed on the basis of how the market is predicted to grow.

Market Reports World
marketreportsworld.com / (424) 253-0807

Report Studies Top Companies in the Thermal Spray Market, Trends and Growth Factors, and Outlook to 2025

Thermal Spray Coatings Market research report 2018 examines the market dynamics and competitive landscape, as well as discusses major trends. The report offers up-to-date industry data on the actual and potential market situation, segmentation, regional breakdowns, and future outlook. The research also includes historic data from 2013 to 2018 and forecasts up to 2025. The market is examined for price, cost, and gross revenue. These points are analyzed for types, application, companies, and regions. Geographically, this report covers North America, Europe, China, Japan, southeast Asia, and India, with production, consumption, revenue, market share, and growth rates of thermal spray coatings for these regions from 2013 to 2025 (forecast). On the basis of product, this report displays the production, revenue, price, market share, and growth rate of each type, primarily split into ceramic, metals and alloys, and others.

360 Market Updates
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## 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.

## JOB SHOP MEMBER COMPANIES

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SPRAYTIME    |    2018 Second Quarter

thermalspray.org
For the past two years, I have had the privilege to serve as chair to the International Thermal Spray Association (ITSA) and work with a dedicated board and an exceptional team at the American Welding Society (AWS).

As my term as chair comes to an end, I’d like to thank the entire AWS team, including Cassie Burrell, senior executive director, AWS; Alfred Nieves, ITSA program manager; and Cindy Weihl, senior editor, SPRAYTIME; as well as the ITSA board and all of the ITSA members who have always been eager to help grow this association.

I am looking forward to the leadership of David Lee, our incoming chair, and Vice Chair Ana Duminie, starting in May. Both are dedicated to ITSA and have a long history of contributing to this association.

One last thanks to you, the members, for entrusting me to be a part of the leadership team. I have enjoyed serving the members of ITSA, an association I have been very proud to be a part of for the past 22 years. I look forward to continuing to serve as a board member.

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, TechMet Alloys LLC  
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

ITSA MEMBER NEWS

Tradeshow Assessment for ITSA Members Eliminated

ITSA Members were invited to participate in as 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 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 more than 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 aws.org/membership/supportingcompany for a complete listing of additional AWS benefits.

For more information, contact Alfred Nieves at 800.443.9353, ext. 467, or itsa@thermalspray.org. For an ITSA Membership Application, visit the membership section at thermalspray.org.
Stronghold Coating Systems is a veteran-owned consulting company specializing in polymer and thermal spray applications. The company provides custom polymeric products and process development for thermal spray coating applications including cold spray, plasma, and HVOF. It specializes in complex problem solving using a combination of metallic, ceramic, and polymers. Its polymer coatings include Diamant products such as Dichtol, which is a capillary sealer that impregnates micro porosity and hairline cracks on any material without vacuum or pressure processes. This has proved a major sealer for thermal spray and is military approved. Another new product is the MM1018, which is a gap compensation material for steel construction, including bridges, oil rigs, elevated rail, and windmills. The material put between steel to steel or steel to concrete provides 100% load bearing and corrosion resistance.

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Höganäs Adds to Management Team

Kennet Almkvist has assumed the position of senior vice president, commercial at Höganäs AB, Höganäs, Sweden. Mark Braithwaite, formerly CFO, takes on the role as president of Höganäs. Prior, Almkvist held various executive positions in commercial roles at both Bayer and H. C. Starck. Most recently, he was vice president of global sales and marketing for the division surface technology and advanced ceramics powder (STC) at H. C. Stark. “Kennet will be an important contributor to Höganäs, the commercial department, and the management team with his long experience and knowledge in our business and technology,” said Fredrik Emilson, CEO. “He has a great drive, team spirit, and creativeness. He will be integral in forming Höganäs’ new and extended customer offering following the acquisitions of Metasphere Technology and STC.”

Braithwaite has worked at Höganäs since 2003 and has been the company’s chief financial officer since 2014. He now assumes the leadership role for business area automotive APAC.

Franklin Bronze Names Operations Manager

Dave Greene has joined Franklin Bronze Precision Components LLC., Franklin, Pa., as operations manager. His 30 years of experience in manufacturing range from master scheduler, plant manager, manufacturing manager, and site manager. He brings a broad range of valuable skills, experiences, and knowledge that are beneficial to the future growth of the company. As operations manager, Greene will focus on managing scheduling and real-time operations while facilitating the optimization of resources to achieve customer satisfaction and productivity. Additionally, he will leverage and expand upon continuous improvement and lean initiatives. Greene holds an associate’s degree in engineering from Geneva College and a bachelor’s degree in business from Charter Oak State College. Franklin Bronze is a wholly owned subsidiary of Wall Colmanoy.

MOGAS Appoints Vice President

MOGAS industries, Houston, Tex., has appointed Jimmy Walker as vice president of service. In this role, Walker will be responsible for leading the development and implementation of programs and services that ensure the company’s valve repairs and technicians are the best in class. This includes improving valve performance by analyzing underperforming valves and gathering application/unit/process information through site visits. Walker’s affiliation with MOGAS goes back nearly 30 years when he was a coating technician, and eventually general manager for thermal spray specialists F. W. Gartner. In late 2015, he left that company to contract with MOGAS’ international offices as a global business and technology consultant. More recently, Walker joined MOGAS Houston full time as a coatings general manager to develop that business entity.

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Additive manufacturing (AM), including 3D metal printing, is in a period of transition-moving from creating prototypes to production parts for all industries, including medical and aviation. Applications with a low volume of small parts and a high value are good potential targets. Instead of traditional manufacturing, where material is removed in a subtractive process (i.e., machining), additive manufacturing adds material layer by layer, generating less waste and saving resources. Aside from improving time and efficiency, the parts can have an internal complexity that was previously unobtainable by traditional machining methods.

Background

Equipment manufacturers of laser processes offer several metal powders and a parameter set for each alloy. The critical parameters include laser power, layer thickness, and other variables that define the melt pool volume and the scanning strategy. Even though many materials are offered on a commercial basis, there are many more alloys desired by end users to match the properties needed in their historical applications. Several Ni-based alloy powders are produced by vacuum induction melt-inert gas atomization (VIM-IGA, or sometimes shortened to VIGA). Several particle-size distributions are available for many standard thermal spray materials. For example, a coarse plasma cut (45–100 μm) might work well in a directed-energy deposition (DED) laser process, and a high-velocity oxyfuel (HVOF) size (20–45 μm) can be used in a laser powder bed process. But some of these alloys are known to be difficult to weld, and laser parameter and chemical composition strategies are needed to prevent cracking, especially in some high-temperature alloys.

Praxair Surface Technologies (PST) entered the 3D metal printing market partly based on its history in thermal spray coatings, where it has provided commercial aviation coatings for more than 50 years. To improve the consistency of these advanced coatings, the company has manufactured many of the starting powders, including atomized NiCr-alloys, since the 1970s. Later, in the 1990s, PST added laser cladding to its core capabilities. Some alloys that mimic a solid solution can be easier to melt and resolidify without cracking. Other alloys with many phases, and some that solidify at different temperatures, generate stresses from the solidification process that can lead to cracks — Fig. 1.

The American Welding Society, ASTM, and AMS are organizations working to create standards for the laser AM process, powders, and properties of the printed parts. Generally, it is possible to obtain properties within the traditional cast and wrought specifications, especially for nickel alloys like 625 and 718. With a little additional work, many have success with more difficult materials like Alloy X. The authors have presented data at conferences showing Alloy X can be used and reused for many builds without degrading the powder chemistry and particle size distribution. Additionally, tensile specimens were machined from printed bars, and the chemistry and mechanical properties were measured for each of ten builds using the same lot of powder that was sieved each time. Again, no degradation was observed.

Method

A brief description of the laser powder bed method includes using a certified powder with a tight particle size distribution. A powder chamber indexes up one layer and a doctor blade spreads the powder evenly across a build plate. The laser traces and melts a 2D design that has been sliced from a 3D file. Once the 2D layer has been fused, the doctor blade pulls another layer of powder.
across the plate, and the laser melts this layer, while reheating the prior layer, and fuses the two layers together. This creates a series of microwells that form the entire part. A design several inches tall requires a combination of thousands of layers and can take multiple days to complete.

PST sponsored a series of university projects to evaluate Alloy 230, a composition that has caused issues in some AM and welding processes. Part I of the project reviewed the laser parameters and included many design of experiments (DOE). The primary variables that were evaluated controlled the heat input and the melt pool size. The volume can be approximated from traditional energy density equation, but it should be noted that not all of the laser energy is absorbed by the powder bed — Fig. 2. One of the important variables is the layer thickness, and its impact on build and solidification times. Larger melt pools require longer time periods for solidification and allow for potential segregation of phases within the alloy, which could impact part properties and lead to nonideal microstructures.

Initially, layer thickness and power were studied, and then additional variables including speed and scan width were evaluated. Bauer et al. discussed 30-μm parameters using a 200-W laser that minimized cracks (Ref. 1). The reduction in cracks and porosity was enough to eliminate defects after hot isostatic pressing (HIP). Results from the DOE were consistent with this work and showed fewer and finer defects with thinner layers and higher relative energy densities.

Part II of the project focused on composition, with the ultimate goal of eliminating defects, as well as the requirement for HIP (for nonaviation applications). Further, by tightening the chemical composition, it was theorized that thicker and higher productivity parameters could be used successfully.

Like a majority of current materials, Alloy 230 was not designed with additive manufacturing in mind; it is the successor of materials like Hastelloy® X and Haynes® 188. The high heating

### Table 1 — Alloy 230 compositions used in DOEs to reduce and eliminate cracking in the AM process.

<table>
<thead>
<tr>
<th>Element</th>
<th>Original</th>
<th>230W</th>
<th>Trial (e.g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>22.2</td>
<td>21.5</td>
<td>23.0</td>
</tr>
<tr>
<td>W</td>
<td>13.8</td>
<td>14.3</td>
<td>14.4</td>
</tr>
<tr>
<td>Mo</td>
<td>2.1</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Fe</td>
<td>&lt; 2.0</td>
<td>&lt; 2.0</td>
<td>&lt; 2.0</td>
</tr>
<tr>
<td>Co</td>
<td>&lt; 5.0</td>
<td>&lt; 5.0</td>
<td>&lt; 5.0</td>
</tr>
<tr>
<td>Mn</td>
<td>0.62</td>
<td>0.04</td>
<td>0.34</td>
</tr>
<tr>
<td>Si</td>
<td>0.52</td>
<td>0.25</td>
<td>0.26</td>
</tr>
<tr>
<td>Al</td>
<td>0.39</td>
<td>0.38</td>
<td>0.46</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>C</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>O</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

![Energy density equation](image)
and cooling rates characteristic of additive manufacturing introduce challenges unlike many traditional manufacturing processes. Therefore, it is sensible to consider chemistry modifications that address these challenges, while staying within chemistry specification and maintaining the properties that warrant the alloy’s use.

**Results**

Alloy 230 is known for its high-temperature creep resistance, oxidation/corrosion resistance, and high rupture strength while maintaining the mechanical properties expected of the nickel superalloy family. Alloy 230 uses solid-solution strengthening as its primary strengthening mechanism, to which it also owes its high-temperature creep resistance. This solid-solution strengthening is achieved due to the high tungsten content of the alloy. Resistance to surface reactions like oxidation and corrosion is largely due to the chromium content. An additional benefit to using Alloy 230 is the minimal amount of cobalt, which can reduce cost compared to alternatives with similar properties.

In welding, a filler material with a modified composition is used to minimize or eliminate defects when joining sections, especially when thicker welds are needed. Powder was produced with an Alloy 230 filler material (denoted as 230W) composition. Cracking was observed in samples printed with the 230W composition, and a few of the modifications to the chemical ranges fall outside the traditional specification. Even if 230W did not have defects, it is unknown what impact the lower amounts of some elements like C and Si would have on the expected mechanical properties. Therefore, a new powder composition was proposed, atomized, and additively manufactured into samples for evaluation. The composition for each powder can be found in Table 1.

The original Alloy 230 and 230W compositions both resulted in microstructures that included cracking. The microstructure of an AM sample produced from the original powder is shown in Fig. 3A. Both followed the trends noted in the previously mentioned Bauer paper where thinner layers, lower power, and higher energy density resulted in fewer defects. Figure 3B shows benefits from the refinement in the chemical composition when the same laser parameters are utilized.

**Conclusion**

Welding teaches us many terms for the types of cracking seen in difficult-to-weld materials, including solidification, crater, liquation, embrittlement, and hydrogen-induced cracking. The cracking is the result of stresses that form while the melt pool...
solidifies and/or is remelted by adjacent layers. This study has looked at modifications in the laser process to reduce defects like cracking. Additionally, it has looked at modifications in the chemical composition to further reduce cracking and potentially increase productivity of the process. With a few more trials, elemental ranges can be established to tighten the composition within the original specification, while reducing cracks and other defects. The improved composition could enable end users to obtain the properties they require, including oxidation-resistance, corrosion-resistance, and high-temperature strength for additively manufactured parts.

References


William Jarosinski (William_Jarosinski@praxair.com) is associate director, materials, and Jack Lopez is applications development engineer, Praxair Surface Technologies Inc., Indianapolis, Ind.

This article is based on and updated from a presentation made at the International Thermal Spray Association’s Advanced Coatings Symposium, March 2017.
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  worldpm2018.medmeeting.org

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Alloy Coating .................................................................................................................................................................................. 19
DeWal Industries .................................................................................................................................................................................. 5
Fischer Technology ............................................................................................................................................................................. 9
FJ Brodmann ..................................................................................................................................................................................... 19
MEC ............................................................................................................................................................................................... Inside Front Cover
Polymet Corp.................................................................................................................................................................................... 13
Praxair Surface Technologies ............................................................................................................................................................ 9
Thermach Inc .................................................................................................................................................................................... 14
Thermion ......................................................................................................................................................................................... 13
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