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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

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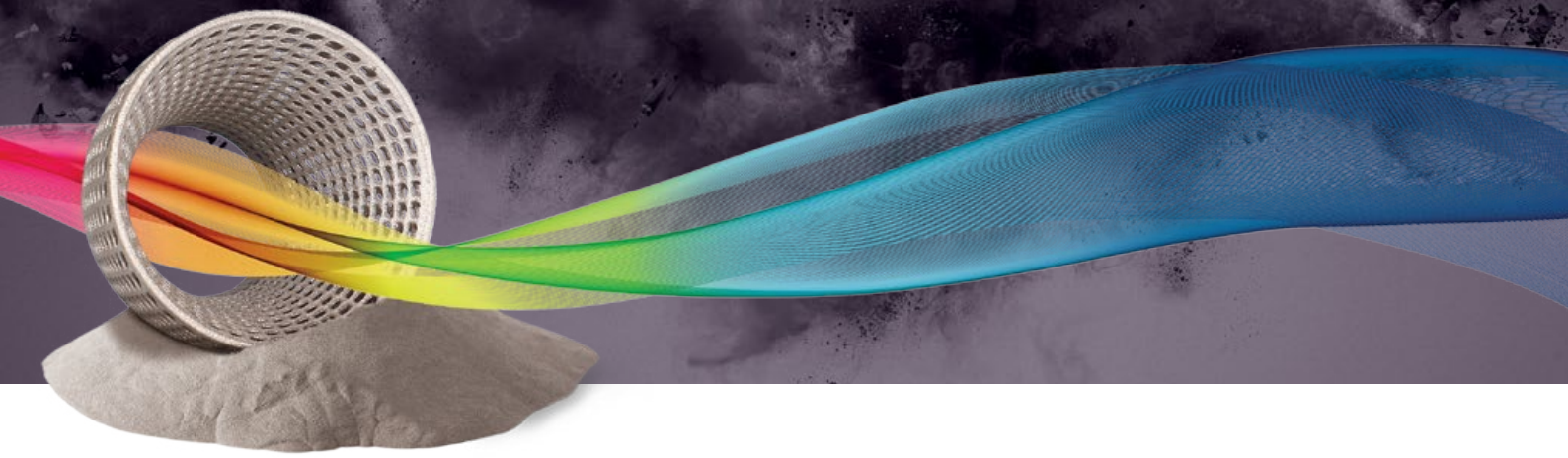

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Publisher & Editorial Offices
Inovar Communications Ltd

11 Park Plaza
Battlefield Enterprise Park
Shrewsbury SY1 3AF
United Kingdom

Tel: +44 (0)1743 469909
www.metal-am.com

Managing Director & Editor
Nick Williams, nick@inovar-communications.com

Group News Editor
Paul Whittaker, paul@inovar-communications.com

Advertising Sales Director
Jon Craxford
Tel: +44 (0)207 1939 749
jon@inovar-communications.com

Assistant News Editor
Charlie Hopson-VandenBos
charlie@inovar-communications.com

Editorial Assistant
Amelia Gregory, amelia@inovar-communications.com

Technical Consultant
Dr Martin McMahon

Senior Digital Marketer
Swetha Akshita, swetha@inovar-communications.com

Digital Marketer
Mulltisa Moung, mulltisa@inovar-communications.com

Production Manager
Hugo Ribeiro, hugo@inovar-communications.com

Operations & Partnerships Manager
Merryl Le Roux, merryl@inovar-communications.com

Office & Accounts Manager
Jo Sheffield, jo@inovar-communications.com

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INOVAR COMMUNICATIONS

METAL ADDITIVE MANUFACTURING

The story of GRCop alloys by those who developed them

It is hard to overestimate the importance of NASA's GRCop family of high thermal conductivity, dispersion strengthened copper alloys. Their successful processing by metal Additive Manufacturing was a significant breakthrough for our industry, driving the development of high-temperature and high-stress rocket engine applications.

In this issue of *Metal AM*, we present the story of these alloys as told by those at NASA who developed them. A journey that started in the era of the Space Shuttle culminated in the development of unique alloys that are ideally suited to AM production, balancing high thermal conductivity with the strength needed to resist thermal stresses during operation.

Whilst GRCop alloys are primarily used in the combustion chambers of rocket engines, their application is anticipated in entirely new propulsion technologies, as well as beyond aerospace in areas such as fusion reactors and thermal management.

As with the continuing rise of the wider AM industry, the story of GRCop is also the story of the collaborative efforts of scientists, engineers, and researchers to overcome challenges and push the boundaries of what's possible at the cutting edge of manufacturing.

From the team at *Metal AM* magazine, we wish our readers every success in the coming year.

Nick Williams
Managing Director

Cover image
PBF-LB GRCop-42 has been flight proven on the Aeon 1 engine by Relativity Space, (Courtesy Relativity Space/photo Michael Baylor)

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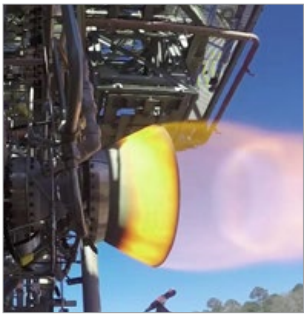

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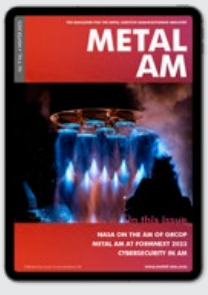

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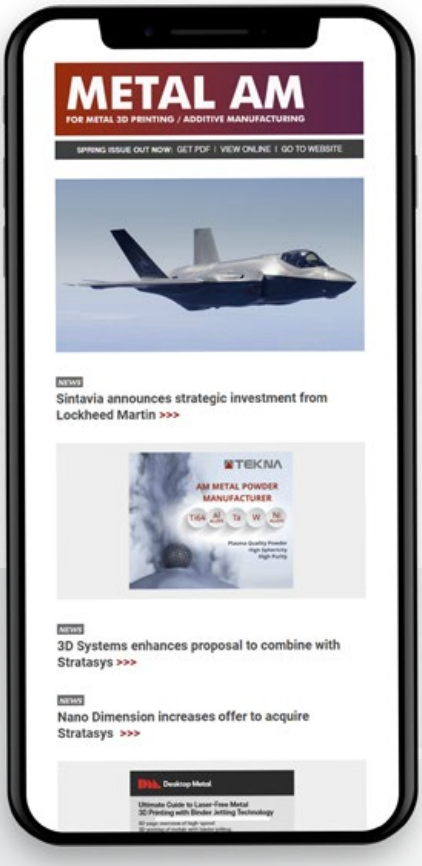

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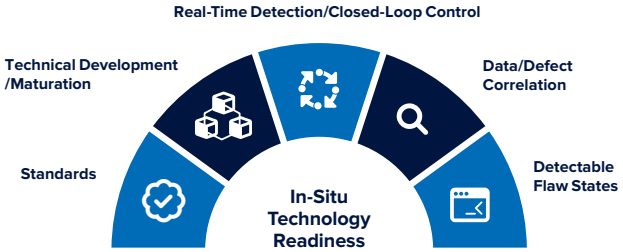

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Industry news

Divergent sees $230 million funding, Czinger 21C named one of *TIME's* Best Inventions of 2023

Divergent Technologies, Inc, located in Torrance, California, USA, has announced the completion of Series D equity financing totalling $230 million. The round was led by a $100 million investment from Sweden's Hexagon AB and included participation from new and existing institutional and family office investors.

Divergent has invented a complete manufacturing method it calls the Divergent Adaptive Production System (DAPS). Operating as a complete software/hardware solution, DAPS is designed to replace traditional vehicle manufacturing. Given a set of digital requirements as input, the machine computationally engineers, additively manufactures and then assembles any complex structure. The system is able to move seamlessly between manufacturing different vehicle models.

Products created using DAPS are said to be superior in performance, lower in cost, rapidly customisable to meet mission and customer-specific requirements, faster to market, and scalable on demand to high-volume production. Divergent uses this system to supply the automotive, aerospace and defence industries with next-generation products as a certified Tier 1 supplier. It has seven blue-chip automotive customers, including Aston Martin and Mercedes-AMG. Within the aerospace and defence industry, the company is actively working with six US government contractors across a diverse range of applications.

"DAPS was created to serve as the foundation for a global system of regional manufacturing facilities that combine and fully exploit supercomputing, AI, robotics and Additive Manufacturing in a novel way," said Kevin Czinger, founder, Lead Inventor and CEO. "We now have entered the '4D Age' of fully digitised design-manufacturing-assembly as a service, dematerialised products using and requiring less material and energy, distributed regional production, and democratised access to the tools, data and production assets necessary for innovation in our human-built world."

***TIME's* Best Inventions of 2023**

Divergent is also the parent company of Czinger Vehicles, maker of the Czinger 21C hypercar featuring over 350 AM components. In *TIME's* Best Inventions of 2023, the 21C is reported to be among 200 of the most significant innovations from the past year, all of which hold the potential to make a profound impact on the future.

The list was assembled by soliciting nominations from *TIME*'s editors and correspondents worldwide. They used an online application process with a strong emphasis on emerging fields like sustainability, green energy, and artificial intelligence. Each potential nominee was then ranked based on factors such as ambition, impact, efficacy, and originality.

"We are proud for the 21C to be included on this prestigious list of inventions that will drive the world forward for years to come," added Czinger. "At Czinger, our devoted team pushes the boundaries of manufacturing."

The innovative hypercar, which boasts over 600 patents, signifies a departure from traditional automotive manufacturing, greatly reducing the car's overall carbon footprint. The car's lightweight body, crafted from carbon fibre, aluminium, and titanium, weighs only 1,250 kg. This allows the vehicle to accelerate from 0-60 mph in just 1.9 seconds, demonstrating the brand's commitment to performance and innovation.

www.czinger.com
www.divergent3d.com

More than 350 additively manufactured components are used in the 21C, helping it to be recognised as one of TIME's Best Inventions of 2023 (Courtesy Czinger Vehicles)

BLT launches 20-laser BLT-S800 and shows parts produced on 26-laser BLT-S1500

Bright Laser Technologies (BLT), located in Xi'an, China, has launched a twenty-laser version of its BLT-S800 metal Additive Manufacturing machine. Featuring a build volume of 800 x 800 x 600 mm, the new AM machine is reported to enable shorter part delivery cycle time, resulting in rapid research and production manufacturing. The Laser Beam Powder Bed Fusion (PBF-LB) AM machine is compatible with titanium, aluminium and high-temperature alloys, as well as stainless, high-strength steel and tool steel. Target industries are said to include aviation, aerospace, engine, medical, automotive, electronics, tooling, and research institutes.

BLT has launched a twenty-laser BLT-S800 AM machine (Courtesy BLT)

"By investing a decade in large format and multi-laser printing, the BLT-S800 has excelled in system stability. Currently, we have deployed dozens of BLT-S800, twenty-laser printers in our customers' factories, and their reliability and usability have been tested in the market," stated Eliza Duan, head of International Business Department, BLT.

The BLT-S800 offers a powder circulation system that is reported to safely transfer, recover, sieve, and recycle metal powders on-site. This system simplifies and secures the movement of large volumes of Additive Manufacturing powders from containers to multiple machines, effectively eliminating the risks of spillage, contamination, explosions, or contact with personnel.

Coupled with BLT-BP software, the BLT-S800 also enables streamlined profiling of large-sized parts. This reduces the time spent on profiling and preparation and reportedly enhances efficiency during the AM process. The software also utilises a dynamic powder laying strategy to adjust the powder fusion speed based on the part contour, allowing for automatic speed adjustments at multiple stages. This approach is said to guarantee both quality and efficiency and, compared to conventional methods, typical parts observe a 30% improvement in single-layer efficiency.

BLT-S1500 with twenty-six-lasers

During this year's Formnext, BLT also showcased parts produced on a 26-laser BLT-S1500 metal AM machine. Although the machine was not on display, it is reported to have a build volume of 1500 x 1500 x 1200 mm and is geared towards the manufacture of singular large and complex parts as well as the rapid mass production of small and medium sized components.

www.xa-blt.com

HP partnership with Indo-MIM looks to advance HP's Metal Jet technology

HP has announced a strategic partnership with Indo-MIM headquartered in Bangalore, India. As part of this collaboration, Indo-MIM will invest in three HP Metal Jet S100 Binder Jetting machines. Two of the three machines will be stationed at Indo-MIM's Bangalore facility. One of them will focus on new material development, while the other will be driving application development and cater to customers in the Middle East, India and the rest of the Asia-Pacific region. The third unit will be based in Texas, USA, reinforcing Indo–MIM's commitment to providing localised support to North American clients and expanding their production capabilities.

"We are proud to partner with Indo-MIM to create new possibilities for their customers leveraging our S100 solution and metals additive manufacturing capabilities. We are thrilled to work with Indo-MIM to drive new metals applications, expand material possibilities and increase precision and productivity," stated Savi Baveja, president of Personalisation & 3D Printing and Chief Incubation Officer, HP Inc. "We share a common purpose to accelerate innovation, grow adoption and scale breakthrough applications."

Krishna Chivukula Jr, CEO at Indo-MIM also added, "Our partnership with HP signifies a milestone in our journey to provide cutting-edge production ready 3D metal binder jet solutions to our customers. The acquisition of HP's Metal Jet S100 printers equips us with the latest technology, enabling us to meet the growing demands of our customers with efficiency and precision, as well as expand the library of materials qualified on the HP printer platform."

The companies are also working to qualify new materials, such as M2 tool steel. Indo-MIM will also leverage HP's process development software.

Mukund Nagaraj, Head of AM, praised the software, stating, "The HP Process Development software is very impressive for managing application development workflows, while the newly-released Digital Sintering software will help Indo-MIM simulate and speed up the process to reach production quality parts in fewer iterations."

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www.indo-mim.com

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ArcelorMittal to produce steel powders for Additive Manufacturing industry

ArcelorMittal SA, one of the world's largest steel companies, has announced it is building an industrial-scale atomiser at its facility in Aviles, Spain, to produce steel powders. It was added that a new company, ArcelorMittal Powders, has been established to commercialise its metal powders, targeting users of multiple Additive Manufacturing technologies.

The inert gas atomiser, which is expected to start production in January 2024, will have a batch-size production capability ranging from 200 kg to 3 tonnes, and an initial annual capacity of 1,000 tonnes. In line with ArcelorMittal's commitment to sustainability and decarbonisation, the atomiser will produce powders from scrap steel, using renewable electricity, atomising with industrial gases produced by renewable energy, and using recycled and recyclable packaging solutions.

The new gas atomiser will provide an initial annual capacity of 1000 tonnes (Courtesy ArcelorMittal)

The steel powders will be offered in size ranges suitable for all existing powder-based metal AM technologies. They can also be used in the latest technological developments such as the brake disc coatings being developed to help automotive OEMs and Tier Ones comply with the EU7 regulation on particle emissions. Here, a layer of powder deposited on the brake disc provides wear and corrosion resistance, significantly reducing the particulate emissions when braking, explains ArcelorMittal.

"Additive Manufacturing is an area we have been investing in and building our capabilities for several years, and we are now ready to scale up our production and offer our customers and partners a reliable and competitive source of high-quality steel powders," stated Colin Hautz, CEO of ArcelorMittal Powders. "From our facility in Spain, we will offer a range of steel powders tailored to our customers' needs. A technology as innovative and disruptive as Additive Manufacturing not only allows us to think about changes in the design and manufacturing process of many parts and components we use today, but also exploit one of the inherently sustainable characteristics of steel – its recyclability."

Marketed under the AdamIQ™ brand name, ArcelorMittal's product portfolio will include stainless steels (316L, 430L, 17-4PH), tool steels (H11, H13, M300) and low-alloy steels (a dual-phase alloy; 4140 equivalent). Drawing on its metallurgical experience, ArcelorMittal's research and development team, dedicated to AM technologies and steel powder production, intends to add further steel powder products for customers to test in 2024.

The company is now looking to scale up its participation in the AM market and intends to scale its steel powders offering in collaboration with customers and industrial partners, through co-design and co-engineering projects.

ArcelorMittal has been producing steel powders in a pilot atomiser at its AM lab in Aviles since 2018. With its dedicated research and development facilities and over fifty full-time researchers, ArcelorMittal reports it has developed a detailed understanding of the interactions between steel alloy design, atomisation parameters, AM process parameters and the final properties of the parts.

powders.arcelormittal.com

Oerlikon announces consolidation and relocation of its Additive Manufacturing business to US

Oerlikon, headquartered in Pfäffikon, Switzerland, has announced that it plans to strategically realign its Additive Manufacturing business and consolidate its AM production in the US. The move, whilst acknowledging the US region as the largest growth market for AM technology, is also said to be in response to the adverse market conditions for AM in Germany that Oerlikon states limits growth opportunities.

Focusing AM production in Huntersville, North Carolina, will bring the business closer to the US growth sectors, such as semiconductor, and also enable the business to benefit from the more conducive US framework conditions and higher market acceptance for disruptive technologies. In the future, European and other international customers are planned to be served from the US.

In close coordination with existing customers, the current production at Barleben and Shanghai are planned to be relocated in 2024. The R&D site in Garching, Germany, will focus on developing new advanced materials, surface coating technologies and digitalisation.

Additive Manufacturing is a business area of Oerlikon's Surface Solutions division. The business was founded as a start-up to develop and produce novel AM applications for sectors such as aerospace and semiconductor, added Oerlikon.

www.oerlikon.com

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additiveindustries.com

Velo3D restructuring expected to lead to profitability in 2024

Velo3D, Campbell, California, USA, has released its financial results for third fiscal quarter ending September 30, 2023. Revenue for the period was $24.1 million, whilst net loss was $17.1 million. The company ended the quarter with a balance sheet showing $72 million in cash and investments. Free cash flow for the quarter was ahead of the company's forecasts and the company expects sequential improvement in cash flow through the first half of 2024.

"Our third quarter results reflect solid execution as we posted year over year revenue growth of 26%, significantly improved our free cash flow on a sequential basis and prudently managed our operational expenses," stated Benny Buller, CEO of Velo3D. "However, while we are proud of our significant success over the last two years resulting from the increasing acceptance of our Sapphire technology, we now believe our industry leading growth has come at the expense of cash flow, profitability and our commitment to the highest level of customer service. As a result, in October 2023, we made the strategic decision to realign our operations to pivot from emphasising top line growth to optimising free cash flow, maximising customer success, reducing expenditures, and improving our operational efficiency. We firmly believe that this strategy will ensure the company will have the liquidity it needs to achieve its profitability goal in 2024," he continued.

"Specifically, we expect this realignment to lower our overall cost structure by approximately 40%, by the first quarter of 2024, including reductions in operating and facilities expenses. Additionally, we have also implemented new go-to-market and service strategies to rebuild our bookings and backlog pipeline which came in below our plan for the third quarter. With the early success of these programmes, we expect to resume bookings growth in the fourth quarter for fiscal year 2024 deliveries. However, given the delays in certain fourth quarter orders, as well as the impact of our realignment, we now see our fiscal year 2023 revenue to be in the range of $91 million to $103 million."

Buller concluded, "With our realignment focused on free cash flow and our expected bookings growth, we believe we are well positioned to execute on a profitable growth strategy in 2024."

www.velo3d.com

Lithoz expands multi-material Additive Manufacturing with investment in Amarea Technology

Lithoz GmbH, based in Vienna, Austria, has announced that it has made a strategic financial investment in Amarea Technology, Dresden, Germany. Amerea Technology is a spin-off of Fraunhofer IKTS, the largest ceramics applied research institute in Europe, and has developed an Additive Manufacturing process that is able to use up to six different materials in a single build.

This Multi Material Jetting (MMJ) process is hoped to unlock new multi-dimensional combinations of various ceramics, metals, polymers and composites in both individual parts and functionally graded components.

Inspired by Low Pressure Injection Moulding, the high-filled thermoplastic base material developed and supplied by Amarea Technology is dispensed drop by drop. Due to the nanolitre volume, the drops solidify in a fraction of a second, considerably speeding up the entire build process. Thanks to the selective droplet-based AM technology, parts are said to achieve a considerably higher level of accuracy, density and surface quality than parts produced with Material Extrusion (MEX) processes, for example. This allows a material change to take place every 200 µm so that highly functionalised components can be additively manufactured.

Beyond that, it is also possible to exactly define requested porosities at any selected position within the component. More than twenty-five different materials have already been introduced to the MMJ production technique, with the portfolio continuously growing, while important parameters such as filling levels, porosity, gradient, layer height and density can be freely and specifically defined.

Dr Johannes Homa, Lithoz CEO, stated, 'With our proud acquisition of a strategic share in Amarea Technology, we can't wait to see how our ultra-precise Lithoz LCM technology and Amarea Technology's MMJ system pointing on maximum material diversity will work hand in hand to unlock previously unachievable potentials. This will create the next generation of multi-material 3D printed applications from the semiconductor to aerospace industry – as first inquiries have already proven."

Steven Weingarten, Amarea Technology CEO, added, "The partnership with Lithoz and their belief in our technology inspire us. Lithoz's global reputation and its successful path to becoming the market leader in ceramic 3D printing are a model for the mission we are now taking in the field of multi-material 3D printing. We would like to express our gratitude to Johannes Homa and Johannes Benedikt for their trust and look forward to the exciting journey together."

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Desktop Metal targets reaching breakeven in 2023, despite revenue fall

Desktop Metal, Inc, based in Burlington, Massachusetts, USA, has reported its financial results for the third quarter ended September 30, 2023. The company announced Q3 2023 revenue of $42.8 million, a decrease from $47.1 million in the third quarter of 2022 attributed to lower product sales and a strategic focus on selling products with higher margins.

"Revenue in the third quarter was disappointing for Desktop Metal and also for the entire Additive Manufacturing industry. However, while we are dissatisfied with our top-line performance, I am incredibly proud of the progress that Team DM has made in executing our $100 million of annualised cost reductions announced in June 2022," stated Ric Fulop, Founder and CEO of Desktop Metal.

"Desktop Metal continues to take aggressive steps to ensure we have sufficient capital to navigate this challenging period. There are several strong, positive currents running through our results today, which adds to our confidence in the future of Desktop Metal as a profitable, high-growth leader in Additive Manufacturing."

Fulop noted that the recurring revenue increased by 34% to $49.2 million in the first three quarters, compared to the same period a year ago. "Despite softer revenue in the third quarter, our recurring revenue streams continue to perform well, contributing to a positive shift in adjusted EBITDA and a path towards reaching breakeven in the fourth quarter of 2023."

The company highlighted its continued execution of cost-reduction plans with year-over-year improvements to non-GAAP gross margins, operating expenses, adjusted EBITDA, and operating cash flow in Q3. As reported in February 2023, these cost reduction plans included a further workforce reduction of approximately 15% during the year.

In Q3, Desktop Metal's GAAP gross margin was 4.5%, and the non-GAAP gross margin was 21.9%, improving by 190 basis points from the third quarter of 2022. The GAAP net loss was $46.4 million, which included $10.4 million for the amortisation of acquired intangibles. The non-GAAP net loss was $24.3 million.

Adjusted EBITDA for Q3 2023 was $(20.5) million, an improvement of $7.7 million from the third quarter of 2022. As of September 30, 2023, cash, cash equivalents, and short-term investments stood at $108.2 million, a decrease of $19.4 million from the end of the second quarter of 2023.

Desktop Metal said it is revising its revenue expectation to between $187 and $207 million and its Adjusted EBITDA expectation to between $(70) and $(50) million for full year 2023, with expectation to achieve adjusted EBITDA breakeven before year end 2023.

www.desktopmetal.com

Renishaw's new Tempus technology reduces build times by up to 50%

Renishaw, headquartered in Wotton-Under-Edge, Gloucestershire, has launched its Tempus™ technology, a new process reported to enable users of its metal Additive Manufacturing machines to achieve significantly higher productivity, with no reported reduction in part quality. Unveiled at Formnext 2023, Tempus incorporates a new scanning algorithm for Renishaw's RenAM 500 series of metal AM machines, which allows the laser to fire while the recoater is moving, saving up to nine seconds per build layer. Over the cycle time of the build, the time saving can cut the build time by up to 50%.

In Tempus technology, the recoater spreads a layer of powder, the lasers then follow the recoater, melting the powder being spread before the recoater completes its stroke. When the recoater goes back to the doser to collect more powder, the lasers pass over the recoater and continue melting the current layer, mitigating wiper time. As the recoater begins spreading the next layer of powder, the lasers finish the previous layer, and simultaneously starts processing the new layer. Tempus technology reduces the dwell time per layer, shortening cycle times.

The process works using advanced scanning algorithms that sequence the layer data in a way that maximises productivity, while maintaining part quality. The optimisation suits some part geometries more than others, adds Renishaw, but all geometries can see some productivity benefits. Those parts with thin, vertical features, for example, are likely to experience higher productivity savings.

"Reducing cost per part is critical to the wider adoption of AM technology," explained Louise Callanan, Director of Additive Manufacturing at Renishaw. "The dominant contributing factor to part cost for most components today is the time spent building the part on the machine itself. Reducing the amount of machine time per part therefore results in more cost-effective production."

"That's why Tempus technology is such a big leap forward," added Callanan. "Usually, the laser would turn off while the recoater is moving. Firing the laser while the recoater is moving minimises the laser off-time per build. The time and cost saving TEMPUS brings will open AM up to mass production applications where the technology would previously have been unviable."

Tempus is standard on the new RenAM 500 Ultra (Courtesy Renishaw)

RenAM 500 Ultra launched

Renishaw also added a new model to its RenAM 500 range of metal AM machines. The RenAM 500 Ultra includes the new Tempus technology as standard, and is available with quad or single laser configuration.

Existing RenAM 500 series customers can also access Tempus as a paid upgrade. Renishaw data shows that retrofitting Tempus technology to an existing system is the equivalent of adding an extra laser, and allows existing customers to make the most of their machine investment.

www.renishaw.com/am

Amaero International ceases Australian operations as it moves focus to flagship US developments

Amaero International Limited, based in McDonald, Tennessee, USA, has announced that its board has decided to cease its operations in Australia. The decision is said to reflect the company's commitment to focusing its executive team's efforts on its core operations in the US, and to responsibly manage operating expenses. As part of ceasing operations in Australia, the company will terminate its leases at its premises in South Australia and Victoria. Any ongoing commercial contracts in Australia will also be ended. Equipment and inventory located in Australia will either be shipped to the Tennessee facility or sold.

The company will continue to assess commercial opportunities in Australia, focusing on adjacent opportunities in mining critical minerals. Additionally, it plans to explore advanced manufacturing opportunities in the aerospace, defence, space, and energy sectors.

Amaero was established with the support of Monash University in 2013 to commercialise opportunities in metal Additive Manufacturing identified by the Monash Centre for Additive Manufacturing.

The company's principal place of business address has now been changed from the Victoria premises to the Tennessee facility in the US.

www.amaero.com.au

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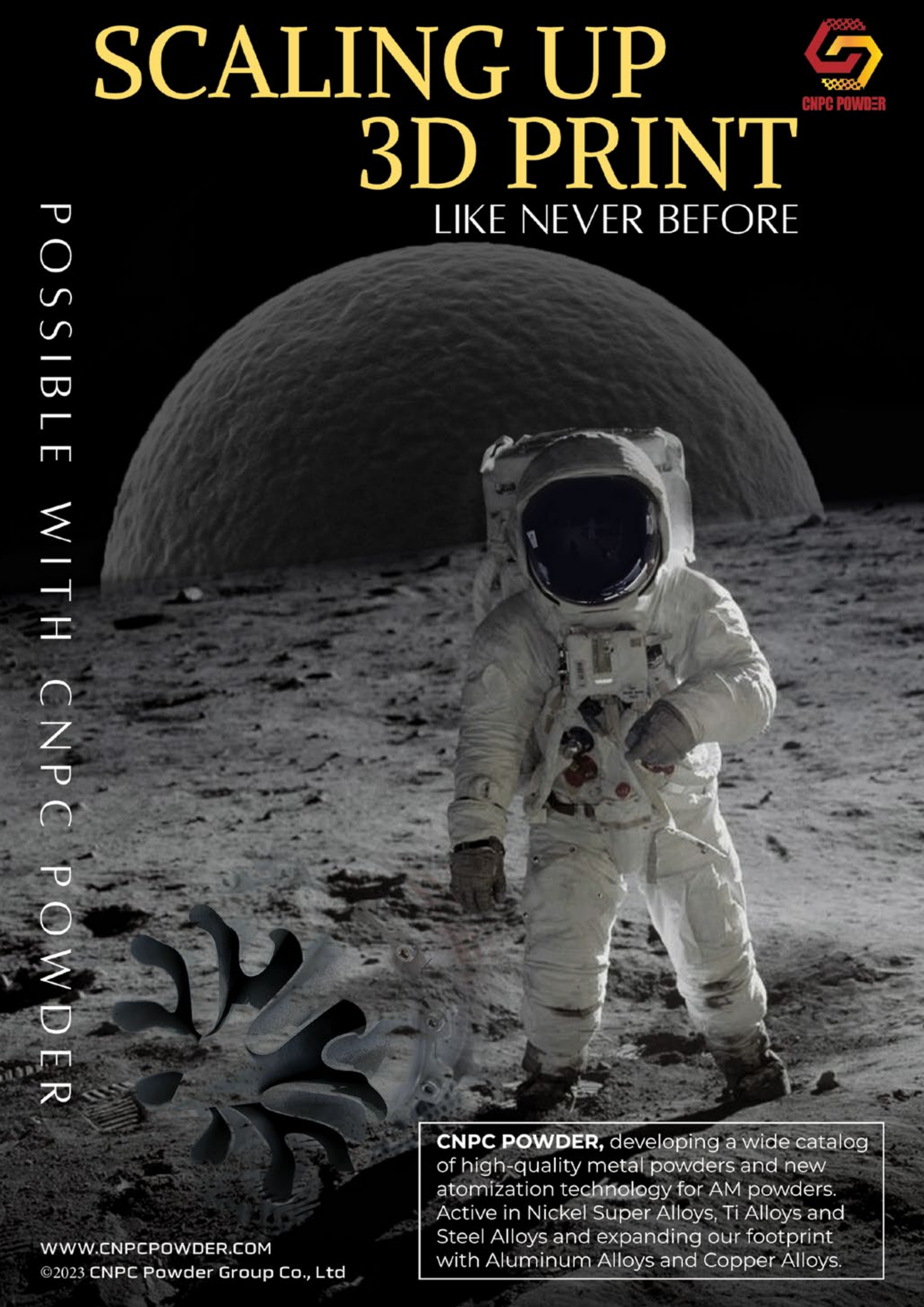

CNPC POWDER, developing a wide catalog of high-quality metal powders and new atomization technology for AM powders. Active in Nickel Super Alloys, Ti Alloys and Steel Alloys and expanding our footprint with Aluminum Alloys and Copper Alloys.

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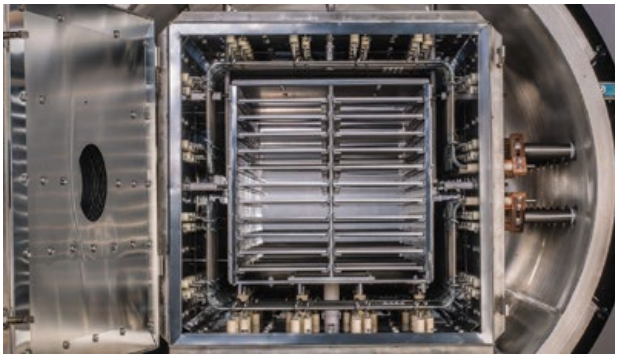
HP and Elnik collaborate to optimise sintering for HP's S100 Metal Jet Additive Manufacturing

HP Inc, based in Palo Alto, California, USA, has announced a strategic collaboration with Elnik Systems, LLC, and its sister company DSH Technologies, headquartered in Cedar Grove, New Jersey, USA, to develop a furnace configuration specifically for processing additively manufactured parts produced on HP's commercial S100 Metal Jet machines.

"This collaboration equips customers using HP's commercial S100 Metal Jet Solution with advanced sintering capabilities, opening up new horizons in 3D printing for industries worldwide," stated Ramon Pastor, Global Head of 3D Metals at HP.

Elnik Systems has modified its standard Metal Injection Moulding furnace to meet the needs of Binder Jetting Additive Manufacturing. The partnership is expected to enhance the capabilities of HP's S100 Metal Jet Binder Jetting machine by leveraging the vast sintering expertise and capabilities offered through Elnik's many years supplying the Metal Injection Moulding (MIM) industry.



HP has partnered with Elnik Systems to develop a furnace configuration for processing metal AM parts (Courtesy Elnik Systems)

As part of the collaborative effort, DSH Technologies is also committed to sharing its technical processing knowledge and expertise. This, it was stated, will help part producers with a go-to-market strategy, based on technical awareness and production scale capabilities.

"Working together with the HP team has been amazing," added Stefan Joens, president of Elnik Systems. "The mutual interest to see the metal 3D printing technology advance through team-effort discussion, innovation, and desire is what will help this manufacturing technology become a fully capable processing method of the future."

www.hp.com | www.elnik.com

Tekna secures $1.5 million order for titanium powder used in medical applications

Tekna Holding ASA, based in Sherbrooke, Quebec, Canada, has announced an order worth CA $1.5 million for titanium alloy powder used exclusively in medical applications. The contract represents a 60% increase in orders from this particular customer, compared to the previous year, and is part of a three-year distribution agreement.

The unnamed customer is reported to be a leading titanium powder distributor in the global medical and dental industry. Delivery is scheduled within the first three quarters of 2024.

"This substantial order is a testament to Tekna's growing influence and reputation in the advanced materials industry, particularly in the medical sector, which has grown to become one of the most advanced and prominent users of additive manufacturing on a global scale. Partnering with a key player in the European market not only strengthens our position but also highlights the trust and reliability associated with our products. We are proud to play a pivotal role in advancing medical technologies through our specialised titanium powders," stated Luc Dionne, CEO of Tekna.

www.tekna.com

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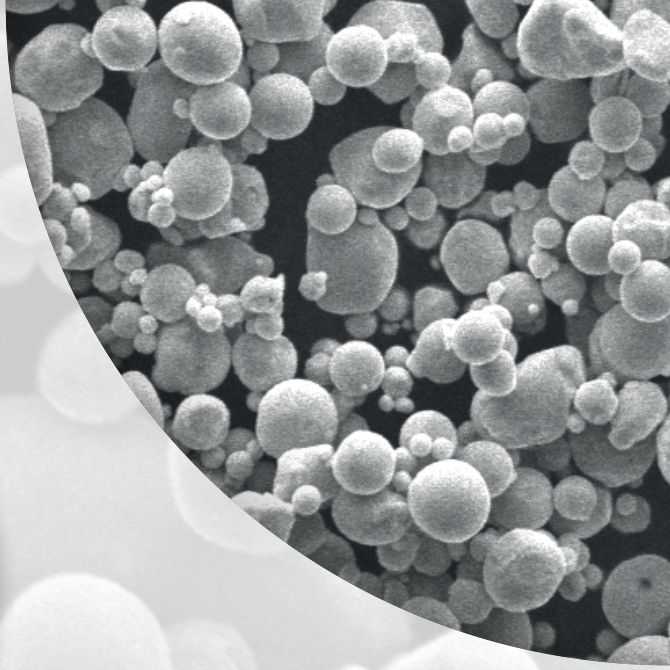

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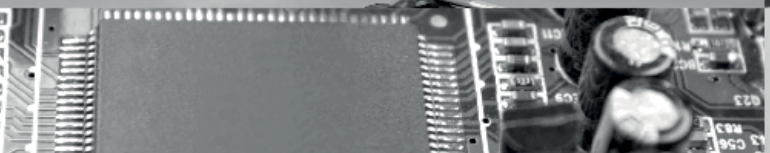

Elmet Technologies acquires HC Starck Solutions Americas

Elmet Technologies, headquartered in Lewiston, Maine, USA, has acquired HC Starck Solutions Americas, a leading manufacturer and supplier of tungsten and molybdenum metals and related alloys. With over 100 years of experience in manufacturing refractory metals, HC Starck Solutions has facilities located in Coldwater, Michigan, and Euclid, Ohio.

Elmet is part of the Anania & Associates Investment Company LLC (AAI) portfolio, and the only fully-integrated, US- owned and -operated tungsten and molybdenum manufacturer. The combined business will offer a broadened portfolio for customers and result in a company with nearly 400 employees across its three facilities.

"Unifying our companies provides customers in defence, aerospace, medical, industrial furnaces, semiconductor, and other industries access to a single supplier with a more comprehensive portfolio of products and capabilities," stated Peter Anania, chairman at AAI and Elmet CEO. "Our organisation now provides a combined 200 years of best practices for increased supply-chain efficiency and resilience as well as improved quality, capability, and innovation. The consolidated portfolio now includes a breadth of capabilities and products from the largest extrusion press for refractory metals to fine wire thinner than a human hair. Combined rolling mill capabilities will increase overall capacity and provide shorter lead times to support the largest and most complex projects."

The merged company will continue to produce and supply all its existing product lines, including foil, sheet, plate, rod, blocks, bars, powder, cubes, and spheres. There are plans to broaden this product range even further, through investment in both the workforce and manufacturing capabilities throughout the company.

"We also anticipate the development of new advanced materials, components, and solutions as a result of our increased capabilities and combined resources and expertise," said Scott Knoll, partner at AAI and Head of M&A and Strategy at Elmet. "To support that innovation, we have immediate plans to invest in expanding our workforce and manufacturing capabilities at all three of our US sites. These future investments will build on the success of recent investments across the group including state-of-the-art tungsten sphere and cube fragmentation production in Lewiston, spray dried and plasma densified Additive Manufacturing powders and 3D processing in Coldwater and new tungsten plate rolling technology in Euclid, Ohio. This combination will help ensure Made-in-the-USA continues in the tungsten and molybdenum sector for the next 100 years and beyond."

www.hcstarcksolutions.com
www.elmettechnologies.com

EOS announces EOS M 300-4 1kW higher-power AM machine

EOS has launched the EOS M 300-4 1kW (Courtesy EOS)

EOS, based in Krailling, Germany, introduced the newest addition to the EOS M 300 family, the EOS M 300-4 1kW, at this year's Formnext. The Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machine features four one-kilowatt lasers and is designed to meet the production requirements of aluminium and copper applications.

"The EOS M 300-4 has already proven to be a highly productive AM machine for our customers, but we need to meet the growing market demand of challenging materials like copper and high productivity processes," shared Sebatian Becker, EOS metal systems lead. "The EOS M 300-4 1kW delivers power and productivity at the highest level of reliability to achieve the lowest cost-per-part in the industry."

"Additive Manufacturing offers transformative potential, especially for products like aluminium cylinder heads that were traditionally made by diecasting," stated Manja Franke, chief strategy officer at AMEXCI, a leading AM company in the Nordics. "The speed and power of new AM platforms, like the EOS M 300-4 1kW, allow us to manufacture complex components, while ensuring enhanced design flexibility, weight reduction and readiness for future emission standards. To rival conventional methods, AM's cost-effectiveness is vital and systems like the EOS M 300-4 1kW offer the possibility to achieve this. Thus, our partnership with EOS aims to maximise productivity and push AM's competitive boundaries."

The EOS M 300-4 1kW can be further optimised using the Volkmann PowTrex EOS Edition powder handling system. This system offers a higher conveying and sieving rate compared to similar material handling systems.

The EOS M 300-4 1kW system will be commercially available in February 2024.

www.eos.info/en

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6K Additive acquires Global Metal Powders to expand sustainable Ti and refractory powder production

6K Additive, a division of 6K Inc based in Andover, Massachusetts, USA, has announced its acquisition of Global Metal Powders (GMP), New Castle, Pennsylvania, USA, for an undisclosed sum. The acquisition will lead to additional proprietary manufacturing and recycling capabilities. These will be used to prepare materials for 6k Additive's UniMelt® spheroidising powder production process.

Leveraging GMP's proprietary technology, 6K Additive will produce custom powders from a variety of revert streams across numerous metal alloys, including titanium (Ti), chromium (Cr), molybdenum (Mo), niobium (Nb), tantalum (Ta), and tungsten (W). GMP's manufacturing plant is located in New Castle, Pennsylvania, USA, where 6K Additive will continue its manufacturing processes. Combined with the recent doubling of manufacturing capacity, this move is said to strengthen 6K Additive's standing as a global leader in sustainable titanium and refractory metal powder production.

"As the market for sustainably produced powder continues to grow, 6K Additive is the only one equipped to meet the manufacturing volumes demanded by customers for sustainably produced powder, specifically titanium and refractory metals," shared Frank Roberts, president of 6K Additive. "Adding the operational horsepower that GMP brings to our organisation allows us to not only keep pace with the high demand we are seeing for our powders but also further close the recycling loop, which leads to a lower overall part cost for our customers. We welcome the team at GMP to our organisation, and we are excited to add their technology and expertise to help advance our leadership position."

Henry Brougham, founder and Principal of GMP, added, "We are excited to be part of the 6K Additive team and look forward to helping expand their market-leading organisation with our proprietary technology. Combining both organisations' years of experience and knowledge, we will propel the company's processing and feedstock preparation to new heights. When you add our expertise in the refractory market, we are confident GMP will enhance 6K Additive's leadership position within this rapidly growing market."

www.6kinc.com
www.gmpowders.com

Markforged reports economic uncertainty leading to restructuring and workforce reduction

Markforged, headquartered in Watertown, Massachusetts, USA, has announced its financial results for the third quarter and nine months ended September 30, 2023. For Q3, the company reported revenue of $20.1 million, down from $25.2 million year on year. In the first nine months of 2023 its revenue was $69.6 million, down from $71.3 million in the first nine months of the previous year.

Markforged stated that a stronger than expected macroeconomic downturn had impacted demand for its Digital Forge and delayed orders toward the end of the quarter, with these challenges continuing into the fourth quarter. The persistent high cost of capital and uncertainty in the macro environment was reported to be restricting capital investment in the short term more than previously anticipated.

In response to these continuing economic headwinds, Markforged announced it has completed a restructuring that, coupled with other cost reduction efforts, is expected to deliver operating costs savings of approximately $9-12 million in 2024. The company added that most of these savings are being driven by a reduction in its workforce of approximately 10%.

"While the medium-to-long-term opportunity for Markforged to help manufacturers reduce costs and strengthen supply chain resiliency remains intact, our third quarter results reflect worsening macroeconomic headwinds in the final weeks of the quarter, which delayed several large deals that we had expected to close," stated Shai Terem, president and CEO of Markforged.

"We remain laser focused on profitability. In light of these headwinds, which have persisted into the fourth quarter, we have implemented cost reduction efforts to align our operating expenses to match anticipated near-term demand. With that, the overwhelming excitement surrounding our new product introductions at Formnext 2023 is a testament to the transformative impact our offerings are set to make in the manufacturing industry. In particular, the customer enthusiasm surrounding the FX10 is reinforcing our confidence that Markforged is well-positioned for strong growth as macroeconomic uncertainty clears," added Terem.

For Q3 2023, gross margin was 45.7% compared to 48.6% in Q3 2022. Operating expenses were $59.6 million, inclusive of a non-cash goodwill impairment charge of $29.5 million as a result of the company's performance during Q3 and decline in forecasted revenue, compared to $35.1 million. Net loss was $51.4 million compared to the $23.0 million in Q3 2022.

www.markforged.com

3D Systems announces restructuring initiative to improve operating efficiencies across the organisation

3D Systems, based in Rock Hill, South Carolina, has released preliminary revenue results for the third quarter of 2023, as well as providing a business update on the next phase of its comprehensive restructuring initiative.

For the third quarter 2023, the company expects revenues between $123.0-124.0 million, reported to be around $9.3-8.3 million lower than its third quarter 2022 results primarily due to continued weak demand for its machines. Although fourth quarter 2023 revenues are expected to improve consecutively, in line with historical seasonal trends, the full-year 2023 revenues will likely be lower than previously anticipated. Given this and the ongoing uncertainty in the macroeconomic and geopolitical landscape, the company has decided to withdraw its full-year 2023 financial guidance.

The company also announced the next phase of its restructuring initiative, aimed at improving operating efficiencies across the organisation and driving long-term value creation. This phase is expected to deliver annual savings of $45-55 million by the end of 2024, with most of the cost reductions occurring by the first quarter of 2024. The initiative mainly focuses on reducing head count and geographic locations across all company functions.

These efforts should streamline the organisation and lower operating costs, while improving customer quality and delivery reliability, states 3D Systems. These cost-saving measures are designed to maintain key investments in new product development. This is expected to result in the launch of several innovative new production AM platforms and advanced engineering materials in 2024. These will meet anticipated customer needs in coming years.

The net effect of these actions is expected to enhance short-term profitability and cash flow, while supporting long-term growth as Additive Manufacturing continues to expand in production environments worldwide.

The company emphasised it has not yet completed its financial and operational closing procedures for the third quarter of 2023. Moreover, the preliminary financial data it provided has not undergone review or other procedures by the company's independent registered public accounting firm. Consequently, the actual results may differ and the final results will not be publicly available until the company releases its third quarter 2023 results.

www.3dsystems.com

Stinako brings Trumpf TruPrint 3000 Additive Manufacturing machine to Slovenia

Stinako, an industrial engineering company based in Maribor, Slovenia, has announced the purchase of a TruPrint 3000 metal Additive Manufacturing machine from Trumpf, Ditzingen, Germany. The new machine is expected for delivery in March 2024.

Stinako, established in 2003, specialises in lifting technology installation, installation of piping systems, power station and boiler maintenance, and component production. The company's production activity is mainly geared towards the manufacture of pressure vessels and complex pipelines made of stainless materials.

Trumpf's medium-format TruPrint 3000 uses Laser Beam Powder Bed Fusion (PBF-LB) technology to produce parts with a diameter of up to 300 mm and a height of up to 400 mm. The machine features two 700 W lasers at a standard diameter of 80 µm, enabling a build speed of 5-120 cm^3/h in layer thicknesses between 20-150 µm.

Stinako's TruPrint 3000 will be used to process stainless steel, tool steel and aluminium alloys, as well as titanium alloys.

www.stinako.si
www.trumpf.com

Stratasys completes sale of Stratasys Direct parts making facility to Cumberland Additive

Stratasys Ltd has announced the completion of the sale of its Stratasys Direct, Inc, facility in Austin, Texas, USA, to Cumberland Additive, Inc, Plugerville, Texas.

Stratasys Direct is the company's on-demand parts service bureau. The sale of the metal AM facility in Austin comes after the August sale of the Stratasys Direct urethane facilities. This decision, coupled with operational transformation efforts initiated in early 2023, aims to improve focus, accountability, internal efficiency, and customer responsiveness, all while enhancing profitability.

"We are focusing Stratasys Direct to maximise synergies with our market-leading Additive Manufacturing business," shared Gurvinder Kahlon, General Manager and VP, Stratasys Direct Manufacturing. "Stratasys Direct has best-in-class technology, deep expertise, and focused management teams that are poised to deliver strong results for our customers and help them achieve their manufacturing needs."

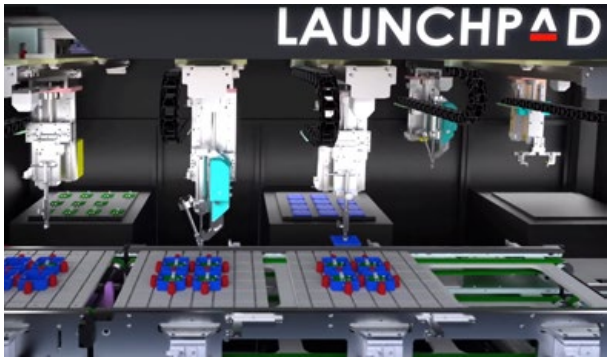
www.stratasys.com

Launchpad.build secures investment from Lockheed Martin Ventures

Launchpad.build, a developer of artificial intelligence-powered assembly planning software and autonomous assembly systems based in Irwindale, California, USA, has closed a strategic funding round with an investment from Lockheed Martin Ventures, the venture arm of Lockheed Martin.

"At Lockheed Martin, we want to stabilise our national security industrial base with an anti-fragility approach," shared Chris Moran, vice president and general manager of Lockheed Martin Ventures. "Launchpad's vision in developing groundbreaking automated, yet highly variable and scalable, solutions aligns with our vision of agile and responsive manufacturing."

Traditional assembly methods often require either labour-intensive processes or costly, inflexible automation infrastructure that needs high-rate, repeatable production for financial justification. In contrast, Launchpad.build proposes a 'one-manufacturing-line-for-all' solution, including affordable, small-batch systems that are assembled on demand.



Launchpad.build, with its 'one-manufacturing-line-for-all' solution, has closed a strategic funding round with an investment from Lockheed Martin Ventures (Courtesy Launchpad.build)

Launchpad.buid is said to offer agile and adaptive manufacturing processes and equipment, enabling design flexibility and economic efficiency which are considered essential for US-based manufacturing to stay competitive in the global market.

Yoav Zingher, Founder and CEO of Launchpad.build, stated, "We are honoured to receive this investment from Lockheed Martin Ventures, and couldn't imagine a better resource to have as we scale."

www.launchpad.build

ERA Industries acquires AM service bureau i3DMFG

ERA Industries Inc, based in Elk Grove Village, Illinois, USA, reports it has acquired Oregon-based i3DMFG. The move brings the Additive Manufacturing service bureau into a portfolio that already includes precision manufacturing specialists Gen-El-Mec (GEM).

Founded in 2013, i3DMFG specialises in metal Laser Beam Powder Bed Fusion (PBF-LB) and operates a fleet of twelve AM machines. The company has gained expertise in various niche applications and materials. In addition to nickel super alloys, i3DMFG also manufactures using GRCop-84 and GRCop-42, which are specifically engineered for space applications. As a result, i3DMFG reports it has attracted customers from new space companies such as Ursa Major.

With a history spanning over forty years, ERA Industries specialises in precision machining and assemblies for key sectors such as aerospace, military, and medical industries. The company is known for its multi-axis capabilities and has been actively involved in aerospace and medical contract manufacturing.

i3DMFG will remain as a separate business unit within ERA, enabling the company to benefit from the financial and operational strengths of ERA and GEM.

www.eraind.com
www.i3dmfg.com

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Sintavia to add large-scale M 8K metal Additive Manufacturing machine from AMCM

Sintavia, LLC, based in Hollywood, Florida, USA, has signed a letter of intent with AMCM GmbH, Starnberg, Germany, to become the North American launch customer of the company's M 8K Additive Manufacturing machine with an extended Z direction. The M 8K is one of the largest Laser Beam Powder Bed Fusion (PBF-LB) AM machines available to-date, with a build volume of 820 x 820 x 1600 mm.

Brian Neff and Martin Bullemer announced the deal at Formnext (Courtesy AMCM)

"Whoever says that there are no economies of scale in AM hasn't been running a large enough printer," stated Brian Neff, Sintavia's founder and CEO. "With over one cubic metre of displacement and eight next generation nLIGHT lasers, Sintavia's new M 8K will not only allow for very large, complex components to be designed and printed, but also dramatically reduce unit pricing on smaller units. In our experience, there is an exponential increase in product design utility when build chamber dimensions increase linearly, and the M 8K has the largest build chamber of all."

Martin Bullemer, Managing Director of AMCM, added, "Over the past six years, it has been a pleasure to work together with Brian and his team as we have collectively pushed the envelope for larger and faster machines across the aerospace & defence industry. It is a natural fit that the first M 8K in North America — and the first one anywhere with an extended Z-axis — would go to Sintavia. We look forward to working with the Sintavia team to see how they apply this game-changing technology."

Sintavia currently operates a fleet of seventeen AMCM and EOS Additive Manufacturing machines, including two M 4K machines it acquired in 2021. The M 8K architecture is based on the M 4K platform, which in turn was based on the architecture of the highly successful EOS M400-4 multi-laser AM machine.

AMCM officially launched the M 8K in September 2023 with ArianeGroup as the European launch customer. ArianeGroup, a joint venture between Airbus and Safran, will use the first M 8K, when it arrives in early 2025, to additively manufacture a large combustion chamber for its Prometheus rocket engine. It is expected that Sintavia's M 8K will run a nickel alloy, with delivery also expected to occur in early 2025.

www.sintavia.com
www.amcm.com

Hittech and 3T Additive Manufacturing create joint venture to target semiconductor market

Hittech Group, based in Den Haag, the Netherlands, and 3T Additive Manufacturing, Newbury, Berkshire, UK, have announced their intention to create a joint venture, either in Germany or the Netherlands, to combine market expertise and manufacturing knowledge. Through the joint venture, the companies will look to expand their existing product portfolio within the semiconductor market and others, creating an eco-system for the industrialisation of final products for customers, from idea generation to the advanced and smart production.

"Already in a very early stage, we indicated that Additive Manufacturing is going to play a crucial role in our industrial landscape," said Marco Verloop, COO from Hittech Group. "We then had a choice to either buy some machines and start learning on our own, or we could partner up with the best companies out there. At Hittech, we choose the latter."

For Hittech Group, the partnership with 3T was a logical step to take. Verloop explained, "Together, we successfully introduced Additive Manufacturing to one of our biggest customers."

Dan Johns, CEO of 3T Additive Manufacturing, added, "For 3T, the partnership makes a lot of sense. In Hittech we recognised the same values, openness and professionalism that 3T stands for, and they have a strong position in the semicon market, it means together we can create a higher value and unique service offering to the customers."

"At the core of our business is a strong vision for setting the sustainable manufacturing standard, and a committed belief that net-zero is achievable if we leverage the entire value chain," he continued. "We can't do this alone, and it's why we want to deepen our partnership with Hittech. Together we can offer a route to component decarbonisation by combining our expertise."

In establishing a joint venture, the companies believe that they will solidify their combined proposition and benefit the companies and their customers, as they will have access to a broader range of expert knowledge whilst working within the company's sustainability targets.

www.hittech.com
www.3t-am.com

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www.pureairemonitoring.com

Holo launches H200 machine for high-volume metal part production

Holo Inc, based in Newark, California, USA, has launched the H200 production metal Additive Manufacturing machine. The H200 uses Holo's PureForm™ AM platform to produce highly-precise metal parts based on a sinter-based Vat Photopolymerisation (VPP) process.

Over the past nine months, Holo reports it has been using the H200 in its Additive Manufacturing services to supply complex metal parts with high resolution and precision. The components demonstrate fine detail up to 50 µm and maintain strict tolerances within +/-25 µm. Unique to PureForm, the final parts match the surface smoothness of commercial MIM parts, exhibiting a roughness of 1-3 µm Ra. This is said to eliminate the need for additional machining or polishing required by other metal AM technologies.

Holo's PureForm commercial offering currently includes stainless steel grades 17-4PH and 316L, along with pure copper. The portfolio is extending to include Inconel and Ti-64 on a pre-commercial basis. All commercial materials from Holo meet the MPIF-35 specifications.

"True to CAD™ from Holo's technology means that our H200 system produces MIM-quality parts without the mould," stated Holo co-founder and Chief Strategy Officer Arian Aghababaie, PhD. "For most applications, our technology does not require parts to go through any post-machining or polishing; it sinters parts to spec for a first-time-right approach suited for demanding, high-volume end-use applications."

Having been developed over multiple generations of machines and with over 10,000 parts shipped to customers so far, Holo believes the H200 has demonstrated its readiness for commercial use.

The Holo H200 has a build volume of 244 x 195 x 200 mm (Courtesy Holo)

"We are thrilled for customers to gain access to the H200," stated Holo CEO Hal Zarem, PhD. "Production volumes of parts in fields like surgical instruments will be within reach, finally fulfilling the promise of Additive Manufacturing as a scalable, production-ready suite."

www.holoam.com

Significant contract increases for NCDMM and America Makes to advance defence manufacturing

The United State's National Center for Defense Manufacturing and Machining (NCDMM) and America Makes have announced that both have received substantial ceiling increases on their major government contracts. It was reported that America Makes, driven by NCDMM, has received a $256 million ceiling increase on its third Cooperative Agreement (CA3) with the Air Force Research Laboratory (AFRL). Initiated in November 2019, the seven-year CA3 government contract's ceiling value is now $483 million.

As it stands, America Makes and its members have already carried out an applied research portfolio exceeding $400 million. These public and private funds are invested in promoting the adoption of Additive Manufacturing to enhance US competitiveness, resilience, and security. With further funding, the Institute plans to continue advancing the technology within the industry, develop the workforce, and expand the AM ecosystem.

"America Makes is thrilled to learn of the increased ceiling limit as this directly impacts the success of our membership, the growth of the industry, and most importantly our warfighter," stated John Wilczynski, Executive Director of America Makes. "The additional funding signifies continued confidence by AFRL in our work and our mission. We are excited by what the future holds for the Institute and our stakeholders."

IDIQ contract funding ceiling at over $246 million

It was also announced that the US Army and the US Army Combat Capabilities Development Command Aviation & Missile Center (DEVCOM AvMC) at Redstone Arsenal, Alabama, USA, had increased NCDMM's Indefinite Delivery/Indefinite Quantity (IDIQ) contract funding ceiling by $176 million to over $246 million. The original five-year contract was awarded at $69 million.

An IDIQ contract allows the Department of Defense and other government organisations to utilise the advanced manufacturing expertise and services of NCDMM and its alliance partner network. It oversees projects nationwide, focusing on manufacturing technology, assessments, process analysis, development and demonstration, and the implementation of manufacturing solutions. This is the fourth such contract awarded to NCDMM since its inception in 2003.

"We are honoured to receive this enhanced award from the United States Army," noted Gary Fleegle, president and CEO of NCDMM. "Our team is dedicated to providing unbiased advanced manufacturing technology to give our warfighters the upper hand."

www.ncdmm.org
www.americamakes.us

KBM's RocketPowder GRCop-42 qualified for Velo3D's Sapphire and now available globally

KBM Advanced Materials, LLC, Fairfield, Ohio, USA, has reported that its RocketPowder GRCop-42 alloy powder has been qualified to run on Velo3D's Sapphire family of metal Additive Manufacturing machines. Furthermore, KBM stated that parts produced using the company's RocketPowder were found to have superior thermal conductivity to those additively manufactured in GRCop-42 powders from alternative sources.

GRCop-42 is a copper, niobium and chromium alloy originally developed and produced by NASA. The material is well suited for space and hypersonic applications due to its high heat transfer and increased strength versus pure copper. Having noticed an uptick in requests for GRCop-42, KBM invested in developing its own exclusive supply chain for this hard-to-source speciality powder.

RocketPowder GRCop-42 reportedly took over nine months to perfect, becoming KBM's first in-house powder offering.

"We formed a unique technical and production partnership to develop this specialty alloy," stated Kevin Kemper, KBM's CEO. "Meeting specifications was a challenge, but we were confident we had a repeatable and reliable process. Having our GRCop-42 added to Velo3D's list of qualified materials ensures all our customers that we are producing the highest quality powder for their production needs."

Velo3D was one of the first Additive Manufacturing companies to work with GRCop-42. The company noticed that this material took more energy to melt, with heat dissipating faster, and therefore undertook efforts to rework process parameters to achieve maximum material properties. As a result of this extensive process, Velo3D has only qualified three companies from which to source this material, with KBM's RocketPowder GRCop-42 reputedly standing out for its thermal conductivity after Hot Isostatic Pressing (HIP).

KBM's RocketPowder GRCop-42 is available for distribution to customers across the world. For US customers, all final processing takes place in-house, ensuring a traceable, domestic, supply chain of GRCop-42.

www.kbmadvanced.com/rocketpowder
www.velo3d.com/material-copper-grcop-42

Impac Additive enhances direct to consumer process with AMFG partnership

AMFG Corp, Austin, Texas, USA, has announced it is partnering with Impac Additive 3D, a Texas-based subsidiary of Impac Systems Engineering, to simplify and streamline the process of ordering parts, projects, and consumer goods through a direct-to-consumer model.

Impac Additive is an engineering services firm producing AM parts for a diverse range of customers. The company is experienced in handling all projects from idea, to design, to simulation, to prototyping, and then to fabrication, assembly, and production.

The direct-to-consumer model has gained significant popularity as companies seek to provide tailored, on-demand manufacturing. The partnership with AMFG will introduce state-of-the-art software solutions designed to improve the entire customer journey, from initial design and ordering to production and delivery.

"Our collaboration with AMFG is an exciting leap forward for Impac Additive," stated Aaron Rawls, Lab Manager of Impac Additive. "By integrating their advanced automation and workflow management software, we are reinforcing our commitment to delivering the best direct-to-consumer experience in Additive Manufacturing."

www.impacadditive3d.com
www.amfg.ai

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Valiant Products adds Velo3D Sapphire XC to expands its aerospace component manufacturing

Velo3D, Inc, based in Campbell, California, USA, announced that Valiant Products, Inc, a contract manufacturer based in Lakeland, Florida, has acquired a fully-integrated Sapphire XC metal Additive Manufacturing machine. The new Sapphire XC is a Laser Beam Powder Bed Fusion (PBF-LB) machine calibrated for Inconel 718, a nickel-based alloy that is extensively used to produce parts for aerospace and industrial applications.

Founded in 1975, Valiant Products has experience in both conventional and Additive Manufacturing technologies. The company reported that it purchased the Sapphire XC after a mutual aerospace customer sought to leverage Velo3D's Additive Manufacturing technology in its supply chain to produce components for its rocket engines.

"Bob English and the entire Valiant team have a long legacy of adopting innovative approaches to solving their customers' challenges. Through the process of installing their Sapphire XC, we've been continually impressed by their attention to detail," said Michelle Sidwell, Velo3D EVP of Global Sales and Business Development. "With their proximity to the Cape Canaveral launch pads, they will be a great resource for aerospace customers looking to produce parts for rocket and air-breathing engines. We welcome them to our contract manufacturer network and look forward to seeing how our joint customers use their services and our fully integrated solution to transform their supply chains."

Valiant Products is an ITAR-registered contract manufacturer. The company works with many innovative companies in the key industries that leverage metal Additive Manufacturing, including space, aviation, energy, and tooling. Other manufacturing services provided by Valiant Products include heat treatment, precision machining, wire EDM, and sheet metal fabrication, which allow the company to manufacture parts and assemblies from start to finish.

"At Valiant Products, we continually evaluate new manufacturing technologies to ensure our customers have access to the best capabilities that can produce the most complex designs and geometries," Bob English, founder and CEO of Valiant Products, Inc, shared. "Solutions like Velo3D's metal 3D printing technology unlock new manufacturing capabilities for us so we can better serve our customers. We are confident that our customers will fully leverage the technology to build lighter weight, more performant parts."

Valiant has stated that it plans to upgrade its new Sapphire XC machine to a Sapphire XC 1MZ, which is capable of producing parts up to 1 m in height.

www.valiantproductsinc.com
www.velo3d.com

Valiant will use the Sapphire XC to produce parts for aerospace applications, including rocket engine components (Courtesy Valiant)

Freemelt and Texas A&M to boost electron beam metal AM in USA

Freemelt AB, based in Mölndal, Sweden, has entered into an agreement with the Texas A&M Engineering Experiment Station (TEES), Bryan, Texas, USA, in an effort to accelerate the industrialisation of electron beam metal Additive Manufacturing in the USA.

TEES began using the Freemelt ONE machine for tungsten and titanium material development in October 2023. Both parties have agreed to enhance their collaboration, with a goal to further the development of high-temperature materials using Electron Beam Powder Bed Fusion (PBF-EB) Additive Manufacturing.

In this collaboration, Freemelt will contribute its expertise and solutions in PBF-EB, along with extensive knowledge in the manufacturing of high-temperature materials, including applications for tungsten and titanium alloys.

Freemelt's CEO Daniel Gidlund commented, "We are extremely proud and excited of this new collaboration with TEES. The US is where the industrialisation of 3D printing technology is developing fast, and strongly supported and funded by government and industry. For example, America Makes is one of the programmes under the industrialisation of 3D printing."

"It is fantastic that Freemelt is a part of this journey, and we are confident that our unique solutions and expertise in E-PBF and high-temperature materials will generate great value," Gidlund continued. "In 2022, Freemelt was very successful in North America and sold six Freemelt ONE machines to new prestige universities and institutes. Thanks to this collaboration, we expect an increased demand for our research machine Freemelt ONE and our industrial machine, eMELT. We are excited and eager to kick off the project as we have high expectations of the outcome."

TEES is a state research agency within the Texas A&M University. It addresses challenges through applied engineering research and development, collaborating with industry, government, and academia.

Dr Mohsen Taheri Andani, an assistant professor in the J Mike Walker '66 Department of Mechanical Engineering at Texas A&M University, will supervise the collaboration on behalf of TEES.

Dr Andani stated, "I look forward to how this collaboration will complement our research in materials characterisation and processing high-temperature metals, including tungsten and titanium alloys."

www.freemelt.com
www.tamu.edu

Wabtec establishes Additive Manufacturing centre for railway part production in the EMEA region

Wabtec Corporation, headquartered in Pennsylvania, USA, has established its first Additive Manufacturing centre in the EMEA region. This centre focuses on the production of additively manufactured parts for the railway industry. Nikon SLM Solutions has been chosen as the supplier of machines and technology solutions, with the inclusion of an SLM®500 Laser Beam Powder Bed Fusion (PBF-LB) machine in the centre.

The Additive Manufacturing centre, located in Tours, France, encompasses the complete AM process chain, from producing high-quality metal parts to quality control and post-processing. Wabtec states that the centre's opening addresses obsolescence issues by enabling high-quality spare parts, produced on Nikon SLM machines, to be shipped within a few weeks after order confirmation, allowing trains to be swiftly returned to service.

Wabtec AM has been using the SLM 280 and SLM 800 machines in its US network. With the addition of the SLM 500, the company will operate nearly the entire product range of Nikon SLM machines.

Henri de Chassey, Head of Additive Manufacturing in Wabtec Transit, shared, "We have selected Nikon SLM Solutions as they were proposing the best technical option on aluminium, but also because some of our previous validated parts have been already produced on their machines. Nikon SLM's technical team additionally has provided us and our applications an amazing support for the implementation of this new project."

With the addition of the SLM 500, Wabtec owns nearly the entire range of Nikon SLM Additive Manufacturing machines (Courtesy Nikon SLM Solutions)

The production encompasses basic spare parts manufactured by Wabtec. These are produced primarily to address supply chain or obsolescence issues. However, new products are also created for a variety of applications such as brake systems, pantographs, HVAC, and doors.

Ralf Frohwerk, Global Head of Business Development at Nikon SLM Solutions, added, "We are excited about our partnership with Wabtec, which has already yielded many production-ready metal parts. The opening of the 3D printing centre is moving the rail industry forward. This example shows the operational feasibility of Nikon SLM technology. Serial parts produced on Nikon SLM machines are made available quickly, meet all safety-critical requirements in the industry, and enable the railway industry for new functional part design revolutions."

The location of Tours is reported to be strategically important for Wabtec. The site comes equipped with post-processing options to finish the parts produced, from machining to painting and surface treatment if necessary. All production lines adhere to the high-quality requirements of railroad standards.

www.nikon-slm-solutions.com
www.wabteccorp.com

Meltio celebrates three-hundred system sales milestone

Meltio, Linares, Spain, has announced that it has sold over three-hundred of its Additive Manufacturing systems. Thus far, its products are being used within industries such as automotive, aerospace, oil & gas, mining, research centres, and universities across sixty countries.

"This milestone of exceeding 300 Meltio systems sold worldwide confirms that the industry is embracing our metal 3D printing solutions for manufacturing and repairing metal parts," stated Ángel Llavero, CEO of Meltio. "It is a recognition of the efforts of the entire Meltio team and a confirmation that we are on the right path of innovation to offer the market new Meltio solutions that respond to their production needs, flexibility and reliability in industrial manufacturing processes."

The wire-based Directed Energy Deposition (DED) metal Additive Manufacturing machines and software solutions offered by Meltio include:

- Meltio M450 metal AM machine
- Meltio Robot Cell
- Engine Robot integration
- CNC Robot integration
- Meltio space slicer software
- Meltio Horizon slicer

A full list of materials compatible with Meltio technology is available on the website.

www.meltio3d.com

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ADDiTEC launches both robotic DED and multi-technology platforms for AM

ADDiTEC, headquartered in Palm City, Florida, USA, has launched AMDroid, a laser-wire-based Directed Energy Deposition (DED) Additive Manufacturing robotic solution, and Hybrid3, a multi-technology manufacturing platform which combines Liquid Metal Jetting (LMJ) and laser-based DED capabilities with CNC machining.

AMDroid

AMDroid is a turnkey deployable machine designed for a wide range of materials, including titanium. The machine is optimised to achieve a high deposition rate and is intended to make forward-deployable, on-demand manufacturing a reality, providing multi-axis and large-scale reactive and non-reactive Additive Manufacturing capability using a robotic architecture within a welded enclosure. AMDroid's architecture enables simple installation and the commencement of manufacturing within a day.

ADDiTEC has collaborated with major industrial robot brands to provide flexibility in robot selection, enabling users to maximise Additive Manufacturing capabilities.

The AMDroid is expected to be available to ship in Q1/2024.

The Hybrid3

The Hybrid3's multi-material capability integrates both LMJ and DED heads, alongside CNC machining, within a single machine. This enables the manufacture of complex components from a variety of materials.

LMJ, with its high-resolution capabilities, allows users to create intricate and finely detailed components. It utilises cost-effective welding wire, with complete material utilisation.

The Hybrid3's multi-material capability integrates both LMJ and DED heads, alongside CNC machining (Courtesy ADDiTEC)

Laser-based DED is able to accelerate manufacturing, making it well-suited to larger components and/or reduced lead times. DED also employs welding wire and complete material utilisation to drive cost efficiency.

The machine's subtractive process, primarily driven by CNC machining, plays a pivotal role in achieving the desired surface finish and tight tolerances for parts manufactured using Additive Manufacturing processes.

www.additec3d.com

RAPID + TCT 2024 Additive Manufacturing expo heads to Los Angeles

SME and Rapid News Publications have announced that next year's RAPID + TCT will take place June 25-27 in Los Angeles, USA. The three-day event, to be held at the Los Angeles Convention Center, will include both a conference and an exhibition.

After nearly a decade, the show is returning to the West Coast, seen as the centre of manufacturing output in the US. This region is home to over 36,000 manufacturing firms that employ nearly 1.4 million people.

A call for speakers has been issued for those wishing to present a paper at the conference. Abstracts that focus on case studies, research findings and technical analyses are being requested. The deadline for submitting an abstract is January 5, 2024.

www.rapid3devent.com

EPMA issues Call for Papers for Euro PM2024 conference

The European Powder Metallurgy Association (EPMA) has announced its call for papers for presentation at Euro PM2024, scheduled to take place September 29 - October 2, 2024, in Malmö, Sweden. As the leading European Powder Metallurgy conference, the three-day event will attract industry leaders, decision-makers, respected academics and PM related companies and personnel from across the world.

Euro PM2024 will feature a technical programme with around 250 oral and poster papers, as well as a 5,000 m^2 exhibition showcasing the latest developments from the global Powder Metallurgy supply chain. There will also be a number of social events, including the welcome reception and gala dinner, which will also provide ideal networking opportunities.

The technical programme, with plenary, keynote, oral and poster presentations, as well as special interest seminars, will focus on all aspects of PM, including:

- Powder production
- Consolidation technologies
- Materials
- Applications
- Tools for improving PM

The Euro PM2024 exhibition, held Monday to Wednesday, will showcase the entire PM supply chain, with international exhibitors ranging from metal powder suppliers, press and furnace makers, to tooling producers and quality testing equipment suppliers.

The abstract submission deadline is January 15, 2024.

www.europm2024.com

Austal orders largest AML3D ARCEMY Additive Manufacturing machine to date

AML3D Limited, based in Edinburgh, Australia, has announced an order for a large-scale, custom-built ARCEMY metal Additive Manufacturing machine from Austal USA Advanced Technologies. The new machine will be installed at Austal's Advanced Technologies facility in Charlottesville, Virginia, USA.

Worth approximately AU $2.2 million, this is the second order received from Phillips Corporation since the start of their reseller agreement in April 2023. Phillips Corporation is sourcing ARCEMY units for the US marine shipbuilding industry, including the US Navy's supply chain and industrial base.

The custom-built ARCEMY unit will be based on the ARCEMY 6700 machine. Once installed, it will be the largest build to date, utilising an 11,000 kg positioner and a linear rail over 4 m, creating a build volume of approximately 35 cubic metres. The unit is expected to be completed and installed by mid-2024.

Austal USA Advanced Technologies leads a team of industry partners and operates the Navy's Additive Manufacturing Center of Excellence in Danville, Virginia. This centre is reported to be the US Navy's flagship for Additive Manufacturing, creating components for the construction of the next generation of ships and boats.

Austal USA is investing in future capabilities to enhance post-delivery support and sustainment services. This investment also supports multiple shipbuilders, maintenance providers, and various naval forces including the US Navy, US Coast Guard, Royal Navy, and Royal Australian Navy. This broad support extends to military ships deployed in the US and its allied fleets.

Austal USA Advanced Technologies has placed an order for a custom-built ARCEMY® machine from AML3D (Courtesy AML3D)

AML3D Managing Director, Sean Ebert, shared, "This second order by Philips over the past few months evidences the success of the reseller agreement with Phillips, which provides us with leverage their long-standing relationships with the US Department of Defense and their suppliers, enabling us to accelerate the development of a US ARCEMY sales pipeline to both navy and its industrial base."

"The sheer size of the custom-built ARCEMY unit demonstrates the breadth of demand and application of our technology, and importantly reaffirms the potential to further expand our footprint within the US Government and defence supply chain," he added.

"As momentum within AML3D's US scale-up strategy continues to grow, we are seeing the commercial benefits. Notably this order, demonstrates strong alignment of our strategy with Austal USA Advanced Technologies efforts to revolutionise the US Navy's supply chain through the implementation of Additive Manufacturing for castings, forgings, and fittings."

"The US is the largest Additive Manufacturing market in the world and AML3D's most important growth market. The company remains confident additional contracts in support of the US defence sector will be executed during the current financial year," concluded Ebert.

www.aml3d.com
www.usa.austal.com

Hexagon brings simulation, QA and digital twin to ColdMetalFusion Alliance

Hexagon AB, based in Stockholm, Sweden, has joined the ColdMetalFusion (CMF) Alliance, bringing its simulation, quality assurance, and digital twin capabilities to the consortium. ColdMetalFusion is an alliance of industry leaders with extensive experience in sintering, Additive Manufacturing and industrial manufacturing. The members work together to offer services, equipment, materials, software, and expertise to CMF customers.

A critical initial contribution to the Alliance will be Hexagon's simulations of the ColdMetalFusion sintering process and materials. With this, manufacturers can now digitally replicate and optimise the sintering process, eliminating the need for widespread trial-and-error. This approach speeds up the development process, reduces expensive errors, and enables efficient production and high-quality standards right from the first build.

"Through our membership in the ColdMetalFusion Alliance, we are taking steps towards realising this vision," stated Dr Tarik El Dsoki, Managing Director Design & Engineering for the DACH region at Hexagon's Manufacturing Intelligence division.

"Our commitment to simulation-driven design, scalability, and sustainability aligns perfectly with the goals of the ColdMetalFusion Alliance, and we are excited about the transformative impact it will have on the industry," El Dsoki added.

www.hexagon.com
www.coldmetalfusion.am

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Sciaky announces small-scale EBAM-53 aimed at laboratory and research applications

Sciaky Inc, Chicago, Illinois, USA, a subsidiary of Phillips Service Industries (PSI) Inc has announced its EBAM-53 metal Additive Manufacturing machine. Aimed at laboratory and research facilities, the new Electron Beam Additive Manufacturing (EBAM) machine is targeted at users who require research on a smaller scale, before a move up to the larger machines in Sciaky's range.

EBAM is a wire-based electron beam Directed Energy Deposition (DED) Additive Manufacturing process. The EBAM-53 features the same equipment for process optimisation and materials development as the larger-scale machines, but requires a smaller floor space and is marketed at a lower cost. The new machine will also use the same electron beam generator, as well as the same sensors, computers, and process control software, making research directly scalable into the larger production-ready EBAM models.

The EBAM-53 fits in a standard shipping container and is targeted at users who require research on a smaller scale, before a move up to the larger machines in Sciaky's range (Courtesy Sciaky)

The EBAM-53 is intended to fit into laboratory and R&D settings with ease and ships in a standard shipping container. It will feature a build envelope of a 635 mm^3 cube, allowing for test coupons, small demonstrators, and geometry trial parts. Like all previously delivered EBAM machines, the new machine will feature the IRISS process control software. Rotary and tilt positioners are also available as options.

"This has been a goal of Sciaky for years. We have been asked numerous times to offer a system appropriate for a research environment," said Scott Phillips, president at Sciaky. "We can now answer this part of the industry's demand. With the EBAM-53, users can conduct meaningful research and development that can easily migrate to larger production-scale systems in the future."

The first EBAM-53 will ship to a customer site before the end of 2023, and will be offered to the wider industry from January 2024.

www.sciaky.com

Equispheres and Aconity3D increase productivity using laser beam shaping and NExP-1 powder

Equispheres, Inc, Ottawa, Ontario, Canada, and Aconity3D, Herzogenrath, Germany, have reported achieving build rates up to nine times greater than is typical for aluminium powder and Laser Beam Powder Bed Fusion (PBF-LB) AM processes. The companies report production speeds in excess of 430 cm^3/hr for a single laser, achieved using Equispheres' NExP-1 AM AlSi10Mg powder, and an AconityMIDI+ AM machine with laser beam shaping.

"There are three pillars supporting this remarkable achievement," stated Evan Butler-Jones, VP – Product & Strategy at Equispheres. "The leading-edge capabilities of Aconity3D's printing technology, the novel application of beam shaping, and the unique powder properties of Equispheres' NExP-1 printing material. This powerful combination allowed us to achieve outstanding results."

Laser beam shaping is used in other industries and has gained attention in Additive Manufacturing due to its potential to improve processing speeds. In PBF-LB, beam shaping modifies how energy is deposited on the powder bed, altering the power density and thermal gradient. To fully explore the potential of beam shaping, the two partners selected NExP-1 AM for its stable melting behaviour as well as a tightly controlled Additive Manufacturing process on an AconityMIDI+ modified with an IPG YLR 3000/1000-AM with beam shaping capabilities enabling 3 kW of maximum power. The shaped beam – rather than a zoomed gaussian beam – reduces overheating and spatter formation in high productivity processing.

"Aconity3D's printing technology and the team's expertise were crucial to this project's success. We're working with extremely high-powered lasers, testing additive manufacturing process parameters far beyond previous capabilities. It was necessary to have the precise control and monitoring capabilities of Aconity3D printers," said Butler-Jones.

"NExP-1 powder is vital to achieve these remarkable speeds," explained Martin Buscher, Aconity3D. "It has exceptional properties that make it ideal for high-speed work. The powder characteristics enable optimal melting behaviour, which is required to achieve consistent printing with high-powered lasers at these extraordinary speeds."

www.equispheres.com

www.aconity3d.com

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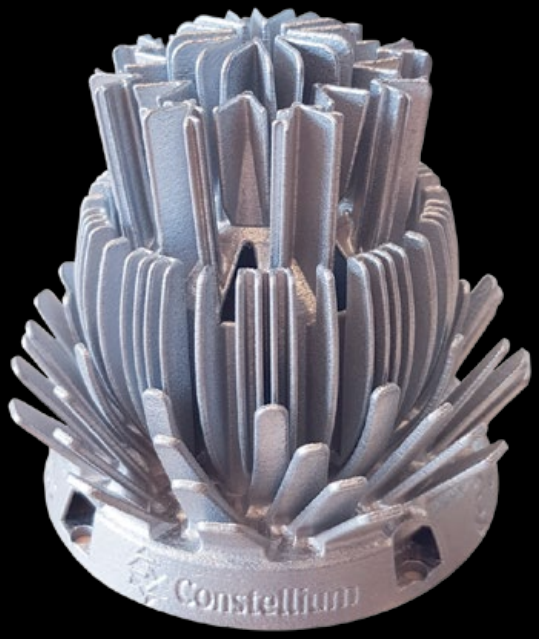

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Dyndrite, Constellium, Elementum 3D & Sandvik establish materials consortium

Dyndrite has announced the formation of an industry-led Materials Consortium for Additive Manufacturing. The consortium aims to make Laser Beam Powder Bed Fusion (PBF-LB) powder parameters and related testing data for common materials freely accessible to end users. The move is intended to promote knowledge sharing, improved outcomes, and faster adoption of materials and techniques.

The rise in the use of AM parts, particularly metal ones, has increased the demand for more choice and flexibility in using various materials for specific applications, explained Dyndrite. As the capabilities of AM machines expand, the industry needs knowledge sharing and standardisation to speed up and broaden market adoption. This is why, in collaboration with leading materials suppliers Constellium, Elementum 3D and Sandvik AB, Dyndrite has formed the materials consortium.

"Materials are a key pillar of Additive Manufacturing," stated Harshil Goel, CEO, Dyndrite. "Unfortunately, maximising the capabilities of a material, especially as it relates to the geometry being printed, is a black art within our industry. If additive is to become a mainstream manufacturing process, users require transparency and standardisation. Public access to a set of trusted, democratised parameters shines a light on the path of adoption."

Andrew Coleman, Head of Additive Manufacturing at Sandvik, added, "Sandvik has manufactured metal powder for about forty-five years and powder for Laser Powder Bed Fusion specifically for more than twenty years, leveraging the widest range of alloy powders on the market. We look forward to working with Dyndrite, Constellium, and Elementum 3D to increase users' access to the knowledge that unlocks the full potential of AM materials."

Ravi Shahani, Chief Engineer, Constellium Additive Manufacturing, added, "I'm excited to participate in the launch of the Dyndrite Materials Consortium. The Materials Consortium will make it easier for our customers to benefit from our high-performance materials designed specifically for laser powder bed fusion, such as our Aheadd® CP1 aluminium-iron-zirconium powders.

"This will help accelerate adoption of aluminium AM across multiple platforms to produce higher performance components at lower qualification cost and lower production cost," Shahani continued. "Customers will quickly achieve predictable, robust properties, precise geometries, better surface quality, simplified post-processing and optimised print cycle times."

The Materials Consortium members will work together to produce, test, and publicly share parameters for their materials.

www.dyndrite.com
www.constellium.com
www.elementum3d.com
www.home.sandvik

ValCUN celebrates first sale of its molten metal Minerva Printer

ValCUN, based in Gent, Belgium, has announced the first sale of its Minerva Printer to Sirris, a Belgian industrial innovation centre.
The sale is seen as a significant milestone for the company and the adoption of its proprietary Molten Metal Deposition (MMD) technology.

"We are thrilled to announce this collaboration with Sirris. Their expertise in technological research and development perfectly complements the groundbreaking capabilities of our Minerva Printer and its MMD technology," stated Jonas Galle, CEO of ValCUN. "Together, we aim to push the boundaries of what's achievable in the world of Advanced Manufacturing. The industrial network of Sirris will be of the first ones in the world to explore and benefit this technology."

The MMD process is a single-step metal deposition method that uses metal wire as feedstock. The aluminium filament is fed into a heating chamber where it is melted. The chamber has a nozzle at the bottom through which liquid metal is extruded, fusing with the previous layer to build up the part.

Molten Metal Deposition technology is said to result in a cost reduction of 75% to 90% compared to other metal AM technologies, as it offers energy efficiency, waste reduction, and the elimination of toxic chemicals or powders. The method also produces parts which don't require debinding, sintering, powder removal or Hot Isostatic Pressing (HIP).

The team at ValCUN will support Sirris in adopting the Minerva Printer, after which,

ValCUN has sold its first MMD printer to Sirris (Courtesy ValCUN)

ValCUN and Sirris will collaborate on research projects to further enhance the technology, with the goal of tackling specific industrial challenges and unlocking additional value for the industry.

www.sirris.be
www.valcun.be

CNPC Powder raises $13.6 million for expansion of metal powder production

CNPC Powder, with its head office in Vancouver, Canada, reports that it has successfully raised nearly $13.6 million in Series A funding. The company plans to expand its atomisation capacity by adding over forty production lines. Its product portfolio includes titanium alloys, aluminium alloys, iron alloys, copper alloys, nickel alloys, and a wide array of high-temperature and custom alloys. Currently, the annual output from its China-based production facility surpasses 3,500 tons.

CNPC Powder's Series A funding round was led by Shunwei Capital and included participation from Dunhong Asset. Jupiter Capital provided long-term exclusive financial advisory and strategic support. As well as expanding production lines, the raised funds will be vital for advancing technical research and development and recruiting top talent, among other key initiatives.

Since the inception of its AM Campus in 2017, CNPC Powder has been committed to the research and production of metal powder materials for advanced manufacturing. Its products, which the company states are supplied to over forty countries, primarily serve the metal Additive Manufacturing industry, but are also used in Powder Metallurgy, Metal Injection Moulding, electronic materials, and various other fields.

The company is certified to ISO9001, ISO41001, ISO45001, ISO13485, and IATF16949 standards, and states that these certifications demonstrate its technological expertise, which is shown through its proprietary process systems, capabilities in alloy research and development, production capacity, and control of powder size and sphericity.

www.cnpcpowder.com

CNPC plans to expand its atomisation capacity by adding over forty production lines (Courtesy CNPC Powder)

Ansys and Materialise partner to overcome workflow challenges in AM

Ansys, based in Canonsburg, Pennsylvania, USA, and Materialise NV, headquartered in Leuven, Belgium, are reported to be working together to deliver integrated digital solutions in an effort to overcome workflow challenges in the AM sector.

The new partnership will integrate Ansys Additive Suite into Materialise's data and build preparation tool Magics. An initial solution, now being previewed at Formnext 2023 and arriving in Q2 2024, aims to provide a best-in-class workflow for managing AM industrial projects across industries, including the medical and aerospace sectors.

In many cases, the AM process requires users to perform build and data preparation tasks on one software platform and run simulations on another. Build defects caught by simulation within Magics will remove the need for data transfer between tools to update build files. This ultimately requires users to master both platforms or transfer information to a completely different user, creating disconnected workflows and eliminating the scrap-saving benefits of simulation.

The Ansys and Materialise partnership intends to alleviate these issues by combining Ansys' simulation software with Magics into one streamlined workflow, resulting in faster time-to-market and efficient distortion compensation. This end-to-end process is also stated to provide fertile ground for advanced AM research and development, enabling engineers and designers to overcome engineering barriers standing in the way of innovation.

"Improving accessibility to simulation is an important step to support our customers in their metal 3D printing," stated Bart Van Der Schueren, Chief Technology Officer, executive vice president at Materialise. "Our goal is to enable a smooth design process by empowering users to seamlessly run valuable and efficient detection and correction simulations in tandem with build and data preparation. This partnership will do so by providing a platform for innovation and a process by which users can 3D print quality products with confidence."

Shane Emswiler, senior vice president of products at Ansys, added, "Simulation changes the way we perceive our interactions with the world. Whether it be understanding the behaviour of new material or revisiting standardised product configurations, the adoption of Ansys technology into the AM workflow signifies the necessity and utility of simulation throughout all levels of the product life cycle."

www.ansys.com
www.materialise.com

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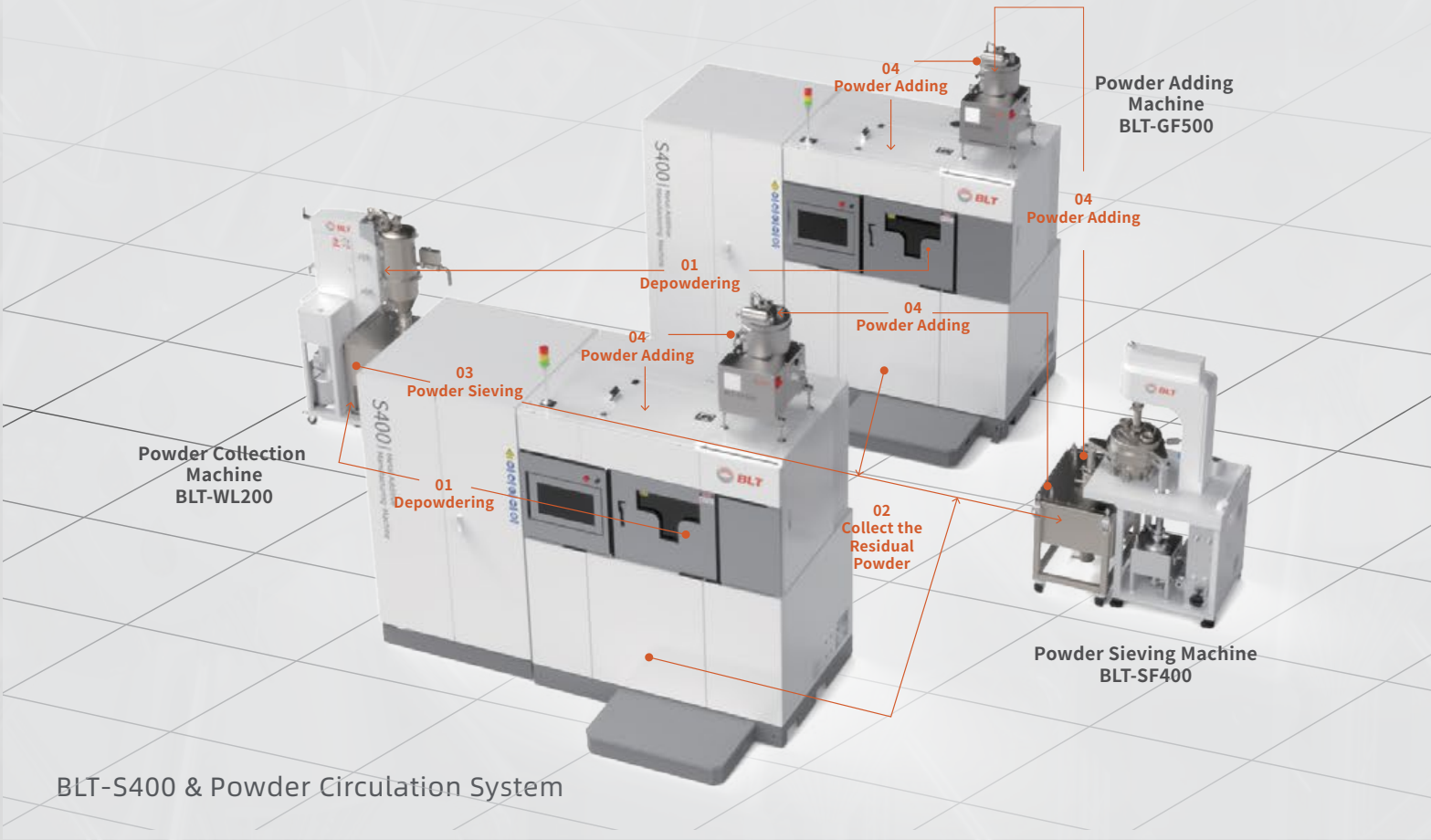

BLT-S400 & Powder Circulation System

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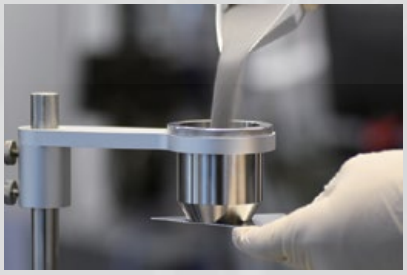

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6K Additive and MPW to develop pure copper and copper alloy powders

6K Additive, a division of 6K Inc., Andover, Massachusetts, USA, and Metal Powder Works (MPW), Clinton, Pennsylvania, USA, have signed a MoU and announced a partnership to produce pure copper and copper alloys, leading to strategically important powders such as copper nickel and bronze alloy powders for Additive Manufacturing.

The high-yield production achievable with both Metal Powder Works' DirectPowder™ Process and 6K Additive's UniMelt® microwave plasma is expected to bring economical advantages, faster time to market, and sustainable production from both feedstock creation and the production of these materials.

From left, Nick Pflugh, John Barnes and Frank Roberts (Courtesy Metal Powder Works)

"The market for copper is eager for a scalable solution that can not only deliver high-quality material, but one that can bring simplicity to the supply chain with a very sustainable process," stated Frank Roberts, president of 6K Additive.

"The synergies between our two organisations ensures customers can source their material sustainably, reliably and with the quality that meets their stringent specifications."

Metal Powder Works CEO and founder John Barnes added, "This partnership is a win for both 6K Additive and Metal Powder Works, but most importantly for our customers who are looking to utilise copper for a variety of applications such as heat sinks, battery components, particularly for the rapidly growing EV market, and critical parts for the marine industry. This alliance with 6K opens up MPW's technology to provide more materials to the AM market."

MPW's DirectPowder patented process can produce powders with a consistent particle size and shape. Its current portfolio includes high-strength aluminium and highly conductive copper powders. New alloys are also in development through the MPW Developer Network.

Barnes told *Metal AM* magazine that the partnership will both support the production of hard-to-atomise materials as well as offer a faster path to increasing the availability in powder. There are more than 2,000 approved AMS specifications for barstock, as opposed to sixteen AMS specifications for powder.

6K Additive produces its AM powder from sustainable sources and offers a full range, including nickel, titanium, copper, stainless steel, aluminium alloys, and refractory metals such as tungsten, niobium, and rhenium. The UniMelt is a microwave production-scale plasma system reported to offer a highly uniform and precise plasma zone, zero contamination and high throughput production capabilities.

www.metalpowderworks.com
www.6kinc.com

Nikon SLM Solutions and Materialise to interlink software with machines

Nikon SLM Solutions, based in Lübeck, Germany, and Materialise NV, headquartered in Leuven, Belgium, have announced a collaborative venture to tailor the next generation of Materialise build processors (BP) for use with Nikon SLM Solutions' Additive Manufacturing machines, integrating them into the Materialise CO-AM platform.

Nikon SLM Solutions' NXG AM machines are designed for high-volume manufacturing. Powered by twelve 1 kW lasers, these machines feature a large build envelope facilitating substantial part sizes and quantities in a single run. However, the expansive build volume necessitates the processing of a substantial data volume, which traditionally elongates calculation times, thus impeding the workflow to initiate build jobs. Bridging the gap between data preparation and actual Additive Manufacturing is vital to harnessing the technology's full productivity.

A BP acts as a conduit, linking AM machines with data preparation software like Materialise Magics. Post-data preparation, an extensive data volume requires processing to furnish the requisite information for the AM machine to fabricate the parts. The forthcoming Materialise BPs expedite this phase, offering AM users the flexibility to customise process parameters to optimise application outcomes.

This milestone was reportedly achieved through the Materialise BP Software Development Kit (SDK), fostering close collaboration during development and allowing machine manufacturers to securely encapsulate their own intellectual property. By fine-tuning build parameters, it is stated that users can attain the sweet spot of cost-efficiency, production speed, and part quality, enabling the manufacture of intricate parts and mass production of identical or personalised products with consistent quality, reduced scrap rates, and abbreviated lead times.

Bart Van der Schueren, CTO of Materialise, added, "Nikon SLM Solutions and Materialise share a vision of open systems that enable AM users to make optimal use of their equipment and connect it to their preferred solutions. We look forward to offering the next generation of BPs to Nikon SLM Solutions users and providing them access to software solutions covering the whole AM workflow."

www.materialise.com
www.nikon-slm-solutions.com

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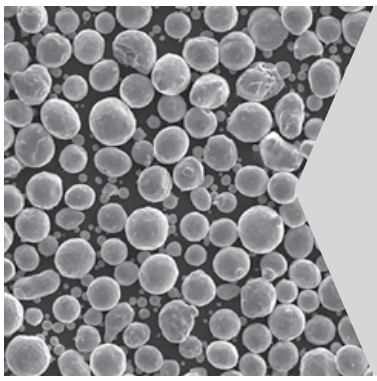

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Ultra Fine Specialty Products announces new line of metal AM powders

Ultra Fine Specialty Products, LLC, an affiliate of Novamet Specialty Products Corporation based in Woonsocket, Rhode Island, USA, has announced a new line of metal powders developed specifically for Additive Manufacturing. With vacuum melt and inert gas atomisation at its purpose-built facility, Ultra Fine has been producing fine, highly spherical metal powders since 1990. These have been widely used by the largest and most successful Metal Injection Moulding (MIM) companies in the world.

"We are excited to announce that we are now introducing a new line of metal powder products based on our research and development of powders specifically for AM," stated Jeffrey Peterson, president and CEO of Ultra Fine and Novamet Specialty Products.

"We have been working with a number of customers for the past few years, optimising a number of powders specifically for improving the quality and speed of printing for our AM customers, particularly in Binder Jet and PBF-LB [Laser Beam Powder Bed Fusion], but also for CSAM [Cold Spray Additive Manufacturing], PBF-EB [Electron Beam Powder Bed Fusion] and DED [Directed Energy Deposition] technologies."

Members of the Ultra Fine team, from left to right: Dr Vlad Duz, Director Technology, Jeffrey Peterson, President/CEO, Dr John Johnson, COO/CTO and Thomas Barth, Sales (Courtesy Ultra Fine Specialty Products)

Dr John Johnson, PhD, COO and CTO of Ultra Fine, added, "These products work because of our unique atomisation process and our ability to put the optimal cuts of powder into a blend for an application."

As well as its atomisation process, Ultra Fine also has the ability to offer smaller (down to 125 kg) or larger (over 1,500 kg) heats to provide small batches for customers testing new materials or for those using high-value, low-volume alloys. These specific powders are said to show increased flowability and density, and have been reported by numerous customers to offer superior additive manufacturability and final product performance.

"We can offer these grades, and even further refine the powder through additional proprietary processes, and still keep the powder at prices far below what others offer for similar or lower performing powders," added Peterson.

www.ultrafinepowder.com

University of Waterloo opens $25M metal Additive Manufacturing facility

The University of Waterloo, based in Ontario, Canada, has opened the country's largest metal Additive Manufacturing facility in Kitchener. This facility, which began as a small room on the University of Waterloo campus, has moved into a 1,400 m^2 space equipped with $25 million worth of equipment. The new facility aims to serve as a hub for future metals research and a central location for advanced Additive Manufacturing machines and characterisation devices.

"The MSAM Lab's expanded facilities will allow for increased R&D capacity, which will enable us to meet growing demands in Additive Manufacturing for advanced scientific discovery, elevated collaboration with industry and a vital training ground for the next generation of engineering innovators," said Dr David Clausi, associate dean for research and external partnerships at the University of Waterloo's Faculty of Engineering.

The MSAM Lab received funding from industry and government partners, including the Federal Economic Development Agency for Southern Ontario (FedDev). In 2021, FedDev provided $8.2 million to establish the Additive Manufacturing Alliance (AMA). Since its inception at the University of Waterloo in 2020, the AMA has supported 119 companies with R&D collaborations, prototyping, testing services, and training. To date, thirty-nine products and services have been commercialised through this initiative.

The founder of the MSAM lab, Dr Ehsan Toyserkani, is a mechanical and mechatronics engineering professor at the University of Waterloo. "With the current geo-political issues and shortage of supply chains, 3D printing technology will be able to help a lot in minimising steps in supply chains. We will be able to rely on local manufacturing rather than other countries to make some components," he stated. "This is the largest academic facility on metal Additive Manufacturing in Canada and one of the top five in the world."

www.uwaterloo.ca

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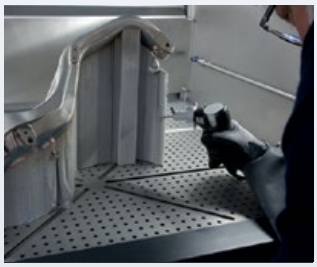

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The full range of AM postprocessing equipment

Seurat raises $99M to deploy new machines and scale AM capacity

Seurat Technologies, Wilmington, Massachusetts, USA, has announced a $99 million Series C round led by NVentures, NVIDIA's venture capital arm, and Capricorn's Technology Impact Fund focused on climate solutions. Seurat's latest funding round includes participation from new investors Honda Motor and Cubit Capital, among others, as well as participation from previous investors True Ventures, SIP Global Partners, Porsche Automobil Holding SE, Denso Global, General Motors Ventures, Maniv Mobility LP, and Xerox Ventures.

According to the United States Environmental Protection Agency (EPA), manufacturing is one of the largest contributors to greenhouse gas emissions, accounting for 31% of the country's emissions. Powered by 100% green energy, Seurat's stated mission is to 'reinvent and reshore manufacturing' with what it calls Area Printing technology, a form of Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing.

Developed at Lawrence Livermore National Laboratory, Seurat believes that its high-precision, high-volume Additive Manufacturing technology has the potential to decarbonise manufacturing and the company anticipates that its technology has the potential to mitigate as much as 100 million tons of CO_2 by 2030.

"Our mission is to create a green manufacturing industry," said James DeMuth, co-founder and CEO of Seurat. "With our Additive Manufacturing technology, our print factories will provide our customers with clean manufacturing that can compete with the volumes, quality, and price points of traditional manufacturing. This new funding will enable Seurat to unlock our next phase of growth, deploy our new machines and scale our factory capacity to meet current demands."

Ion Yadigaroglu, partner at Capricorn, added, "Seurat's potential to disrupt and decarbonise the traditional metal parts manufacturing industry is tremendous. We have been impressed from the early days of the company by James and his team's technical expertise and acumen to build a highly scalable business, with applicability across numerous industries. We are excited to participate in this round of funding, which will enable the company to ramp up production capabilities at greater scale and ultimately grow its client base."

Seurat plans to deploy its AM factories at or near customer sites around the world, enabling parts to be produced in closer proximity to where they are needed whilst reshoring supply chains and reducing emissions from transportation and global logistics.

"Accelerated computing is unlocking new capabilities within the manufacturing industry, while creating a path toward sustainability," said Mohamed 'Sid' Siddeek, corporate vice president and head of NVentures. "Seurat's green approach to manufacturing will help transform industry standards."

Manabu Ozawa, Managing Executive Officer of Honda Motor Co., Ltd., stated, "Seurat has an innovative concept and technologies for metal Additive Manufacturing, and Honda has high expectations for their future potential. The metal Additive Manufacturing technology will enable the enhancement of the value of products through innovative design, and, as Honda strives to create the joy and freedom of mobility, we envision that this technology will be necessary for us. Honda will continue to search for, collaborate with and invest in companies with a promising future through our global open innovation programme Honda Xcelerator Ventures."

Seurat's Boston-area pilot factory will have the capacity to produce more than 25 tons of metal parts annually and is already oversubscribed. Seurat also has commitments to develop 59 tons of additively manufactured metal components for Siemens Energy turbines over a six-year period for parts meeting the material qualification requirements. In all, Seurat has LOIs from six customers totalling 4,000 tons of material and over $750 million in projected revenue over the next few years.

www.seurat.com

The fully swappable build cartridges in Seurat's Alpha system reduce machine downtime to minutes (Courtesy Seurat)

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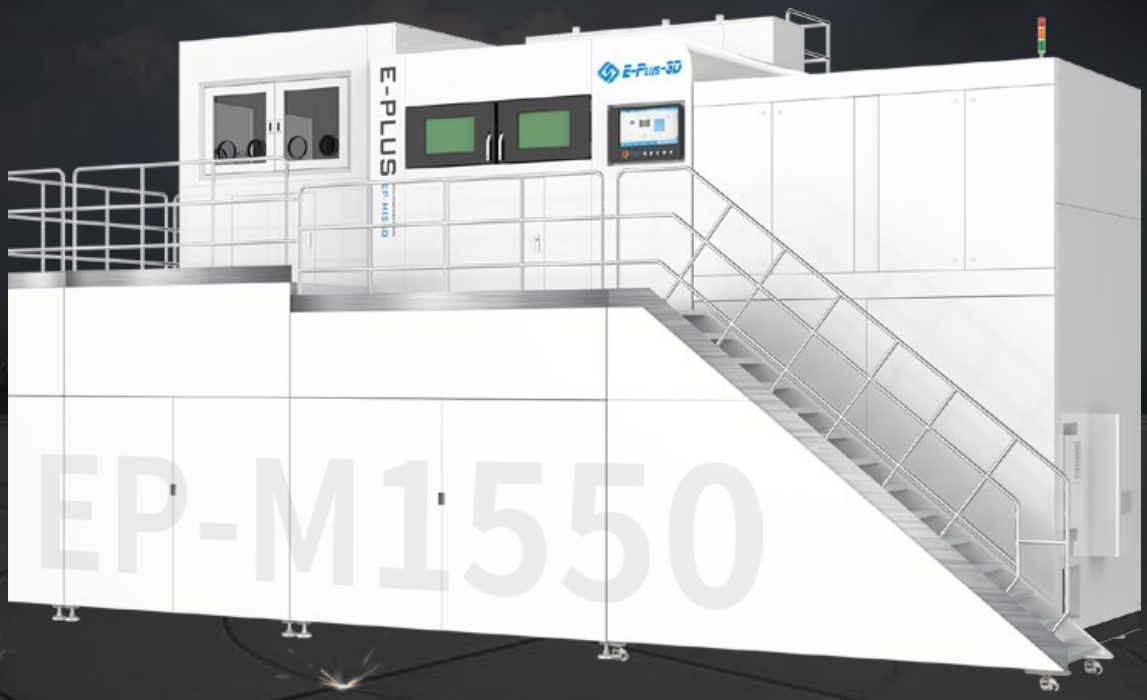

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Granutools introduces GranuPack Permeability Unit to measure powders under different packing conditions

Granutools, based in Awans, Belgium, a developer of advanced instruments to measure powder behaviour, has introduced its GranuPack Permeability Unit, designed for measuring the permeability of powders under different packing conditions. The tool provides detailed insights into how powders behave when subjected to varying levels of consolidation and density.

Granutools has introduced a permeability unit for the measurement of powder behaviour (Courtesy Granutools)

The GranuPack Permeability Unit offers users the ability to measure permeability and density simultaneously, providing a more holistic view of powder behaviour. It is also capable of measuring permeability at low consolidation levels and in static conditions.

It features a permeability measurement cell, with a porous frit at its base, that allows air to pass through the powder sample; this design ensures precise and controlled measurements of permeability. A mass flow controller regulates the flow of air within the cell at controlled air flow rates; this precise control over the air flow enables accurate and repeatable measurements.

The unit employs a distinctive measurement technique whereby alternating the application of taps to the powder with air insufflation through the powder bed, it is possible to measure the powder permeability at various packing fractions; this enables a comprehensive understanding of how powders behave under different conditions

The GranuPack Permeability Unit is retrofit-compatible with the GranuPack Classic and can be included in the All-In Maintenance Plan. This solution allows users to upgrade existing equipment without the need for a complete overhaul.

www.granutools.com

IperionX receives $12.7 million grant and $11.5 million finance offer to grow titanium powder production

IperionX Limited, based in Charlotte, North Carolina, USA, reports it has been awarded a $12.7 million grant from the United States Department of Defense (DoD). The company also announced in a further press release it had received a Letter of Interest (LOI) from the Export-Import Bank of the United States (EXIM) for a provisional finance sum of $11.5 million.

$12.7 million DoD grant

Facilitated through the Defense Production Act Investment (DPAI) Program, the $12.7 million award aims to increase titanium powder production for defence supply chains.

"Robust and resilient defence supply chains are critical to the Warfighting capability of the United States," stated Dr Laura Taylor-Kale, Assistant Secretary of Defense for Industrial Base Policy. "Domestic titanium production is a top priority for the DoD's industrial base programs."

The award will fund the expansion of IperionX's facility in Virginia into a demonstration plant, boosting the company's titanium powder production to 125 metric tons annually. Within five years, IperionX aims to produce 10,000 metric tons of titanium metal powder each year. The company manufactures titanium alloys from either titanium minerals or 100% recycled materials.

As of 2023, the DPAI Program has granted twenty-one awards totalling $674 million. DPAI is overseen by the ASD(IBP)'s Manufacturing Capability Expansion and Investment Program (MCEIP), in the Office of the Deputy Assistant Secretary of Defense for Industrial Base Resilience.

$11.5 million finance offer

IperionX received notification from EXIM that its proposed titanium facility may qualify for equipment finance under two programmes: EXIM's 'China and Transformational Exports Program' and 'Make More in America Initiative'. These programmes allow EXIM to extend its medium and long-term loan and loan guarantee programmes to support projects that aim to reduce Chinese dominance in strategic sectors and promote export-oriented domestic projects.

"Titanium for the US manufacturing sector is currently sourced over long distances from foreign nations," stated Anastasios (Taso) Arima, IperionX CEO. "We are pleased to receive the letter of interest for the provisional sum of $11.5 million in equipment finance from US EXIM that will assist IperionX to re-shore a lower-cost, more sustainable and fully integrated US titanium supply chain that is critical both for the manufacturing of advanced goods as well as for America's national security."

The company is looking to acquire key production assets, such as industrial furnaces and comminution equipment, as it develops its titanium production facility in Halifax County, Virginia. While the LOI is non-binding and conditional, IperionX stated that the potential funding support gives a solid foundation as the company explores various competitive funding options.

www.defense.gov

www.IperionX.com

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Proterial announces launch of Admuster L61P powder for AM

Proterial, Ltd, headquartered in Tokyo, Japan, has introduced its newest Aluminium 6000 (Al6000) series alloy powder. Marketed as Admuster L61P, the powder is aimed at sectors requiring lightweight and high-performance aluminium alloys. The new alloy was developed as part of a collaboration with Singapore Institute of Manufacturing Technology (SIMTech), a research institute of the Agency for Science, Technology and Research (ASTAR). The lab focuses on developing metal Additive Manufacturing powders and related processes for industrial applications.

The powder is based on the Al6061 alloy, a commonly used aluminium material in the aerospace, automotive, and semiconductor industries. This alloy is favoured for aviation interior parts due to its lightweight, good mechanical properties, and easy post-processing. However, its use in Additive Manufacturing has been limited due to the presence of micro-cracks in the material resulting from the manufacturing process.

Proterial and ASTAR's SIMTech addressed this issue by enhancing the composition of the Al6061 alloy. Elemental additives were incorporated and precise guidelines were established for the elements and proportions used in formulating the alloy. This led to the creation of the Al6061-based alloy powder Admuster L61P, which showcases superior strength characteristics compared to the Al6061 alloy material, with its crack issues significantly reduced.

Proterial and ASTAR's SIMTech aim to expedite practical applications through validation testing. They plan to do this by collaborating with industry partners in the aerospace, automotive, and semiconductor manufacturing equipment industries. They will also partner with Additive Manufacturing experts to promote the use of Admuster L61P among end-users.

Dr Sharon Nai, R&D Director, SIMTech, ASTAR, commented, "Developed with the combined expertise of ASTAR's SIMTech in Additive Manufacturing R&D and Proterial in metal powder development, this new aluminium alloy powder will be one of the many solutions from our strong partnership to address metal Additive Manufacturing challenges for impactful industry applications. ASTAR's SIMTech looks forward to further collaboration with Proterial to continue pushing the boundaries in developing new specialty alloys for Additive Manufacturing and meeting industry needs."

www.proterial.com
www.a-star.edu.sg

Indo-MIM adds Incus Hammer Lab35 metal Additive Manufacturing machine as part of strategic partnership

Incus GmbH, based in Vienna, Austria, has announced that Indo-MIM Pvt. Ltd, Bangalore, India, has invested in an Incus Hammer Lab35 metal Additive Manufacturing machine as part of a strategic partnership.

"Our partnership with Incus signifies one more important step in our journey to provide cutting-edge production-ready metal 3D printing technology to our customers," stated Krishna Chivukula Jr, CEO at Indo-MIM. The company explained that Chivukula was of the opinion that Incus technology would greatly boost Indo-MIM's capabilities to support proto-sample development to medical device, fine jewellery and electronic industry and produce complex small components in production volumes offering 360-degree freedom to the design engineers. He further believed that a deeper integration between Additive Manufacturing and powder production processes would add to the speed of technology adaptation in the future.

The Hammer Lab35 uses a lithography-based metal manufacturing (LMM) technology, defined as a Vat Photopolymerisation process (VPP) by ISO/ASTM. The machine is designed for producing complex metal parts with unique features and properties, and is said to be ideal for small series production, prototyping, and seamless integration with LMM.

"We are proud to be supporting Indo-MIM, one of the biggest and highly recognised players in the industry and during their extensive technology analysis having convinced them on our capabilities," stated Dr Gerald Mitteramskogler, CEO of Incus GmbH. "This collaboration would greatly help in promoting the adaptation of our Incus lithography-based 3D printing technology and spur innovation to ultimately benefit the end users."

Indo-MIM has invested in an Incus Hammer Lab35 metal Additive Manufacturing machine as part of a strategic partnership (Courtesy Incus GmbH)

www.indo-mim.com
www.incus3d.com

AML3D to manufacture prototype parts for Royal Australian Navy's Hunter class

AML3D Limited, located in Edinburgh, Australia, has signed a prototype part manufacture and testing contract with BAE Systems Maritime Australia (BAESMA). The prototype part is a test component for use within BAESMA's contract to design and build the Hunter class frigates for the Royal Australian Navy.

The announcement follows feasibility and commercial validation testing programmes that reportedly demonstrated AML3D's Wire Arc Additive Manufacturing (WAAM) as a cost-effective manufacturing solution that meets the standards of the Royal Australian Navy. The contract will be fulfilled at AML3D's manufacturing facilities in Adelaide and is expected to last for eight to ten weeks.

AML3D will produce prototype parts for use in the new Hunter class frigates for the Royal Australian Navy (Courtesy Royal Australian Navy)

In addition to expanding AML3D's relationship with BAESMA, the contract also highlights the potential role of AML3D's Wire Arc Additive Manufacturing technology in bolstering Australia's sovereign manufacturing capability, which could be applicable to other markets.

"We had great confidence that our WAAM technology would satisfy BAESMA's testing and move into component manufacturing," stated Sean Ebert, AML3D's Chief Executive Officer. "AML3D has a focus on the significant demand we are seeing in the US, where we are enjoying a lot of success in winning a steady stream of contracts, but we also have a stated aim to develop our commercial relationships across additional marine and defence sectors. Expanding our relationship with BAESMA in Australia, as part of its work for the Royal Australian Navy, is a great example of delivering on this aspect of our growth plan and diversifying our revenue base."

www.aml3d.com

Fehrmann and Armstrong partner to develop aluminium solutions using AI

Fehrmann Tech Group, based in Hamburg, Germany, and the Armstrong Group, headquartered in Singapore, have signed a Memorandum of Understanding (MOU) which establishes the framework for their joint efforts in developing aluminium-based solutions, as well as those for foam and elastomer. Utilising AI, the partners aim to enhance performance and efficiency in various fields, including automotive and aviation, along with other diverse applications.

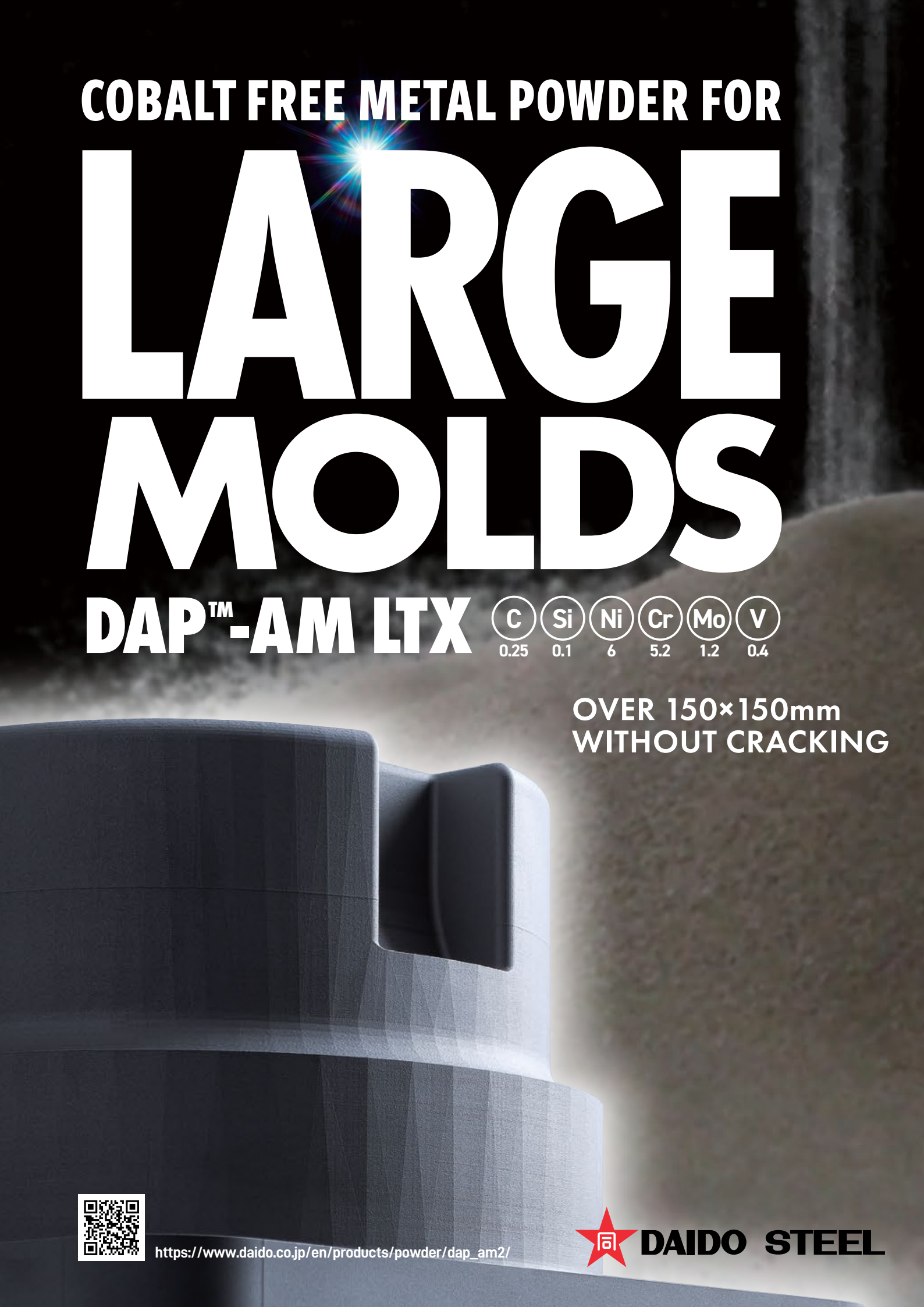
The collaboration is anticipated to produce advanced technologies that leverage Fehrmann's expertise in aluminium alloy development and Armstrong Asia's skills in rubber manufacturing. Potential applications may involve lightweight parts and composite materials that integrate aluminium and rubber.

"As pioneers in aluminium technology, this strategic collaboration allows us to further expand our innovations into new sectors, particularly in the Asia-Pacific market," stated Henning Fehrmann, chairman and CEO of Fehrmann Tech Group.

Armstrong Group added, "Our cross-industry operational expertise across seven countries and sixteen factories will be invaluable in this partnership, as we aim to deliver more innovative and customer-centric solutions in advancing today's noise, vibration, heat and safety management. With fifty of experience, Armstrong Asia serves a broad array of industries including automotive, consumer, office and retail productivity as well as healthcare & medical. Partnering with Fehrmann Tech Group amplifies our commitment to driving innovation and serving our global customer base more effectively."

Fehrmann Materials X, a branch of Fehrmann Tech Group, houses a diverse team of experts with experience in simulation, AI, and data science. They specialise in materials informatics and the rapid digital development of high-performance materials. This team works closely with aluminium and metal foundry specialists at Fehrmann Materials to craft sustainable custom alloys suitable for demanding industrial applications in the automotive, aerospace, energy, and electronics sectors. The expertise of Fehrmann Materials X in digital alloy development and materials informatics is intended to significantly enhance the joint venture, boosting the potential for creating cutting-edge solutions.

www.materialsx.ai
www.armstrongasia.com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Incus launches Hammer Pro40 Additive Manufacturing machine

Incus, GmbH, based in Vienna, Austria, has announced the launch of its new Hammer Pro40 Additive Manufacturing machine. Building upon the principles of the Hammer Lab35 AM machine, the Hammer Pro40 is reported to include an upgraded production capability, while retaining the same level of expertise and familiarity with the technology.

The Hammer Pro40 is designed for the production of large batches of intricate, specialty parts (Courtesy Incus GmbH)

The larger build volume is achieved by using two moving or scrolling projectors instead of one stationary projector, without compromising accuracy. With a platform that is six times larger than the Hammer Lab35 AM, the Hammer Pro40 has a high potential throughput of 700cm^3/hour with a resolution of 40 µm pixel pitch in X/Y. The Hammer Pro40 is designed for the production of large batches of intricate, specialty parts. It can be used in various applications such as dental, medical, automotive, micro robotics, and jewellery manufacturing. Compared to the Hammer Lab35, the Pro40 offers a manufacturing speed that is seven times faster and a cost per cm^3 that is four times lower.

The Pro40 achieves a surface roughness (Ra) of 2 µm after sintering, eliminating the need for additional surface treatments like polishing or sandblasting. Additionally, the high strength of the green parts allows for easy automation in their handling.

The Hammer Pro40 is designed to perform multiple jobs without requiring operator intervention. It is equipped with a feedstock supply that can last for at least 2-3 days. Job preparation, setup, and material changeover are efficiently streamlined, reportedly taking less than five minutes, ensuring a seamless and uninterrupted manufacturing process.

"The Hammer Pro40 was strategically developed to fulfil the growing demand for mass manufacturing with AM while still delivering the unique features of our technology," stated Incus CEO, Dr Gerald Mitteramskogler. "This innovation means a leap forward in terms of speed, precision, and cost-effectiveness, but it also opens up new opportunities to leverage the versatility of our manufacturing solution. Within a single print, you can create intricate medical gripping devices, patient-specific dental brackets, personalised jewellery pieces, prototypes for electronic devices, and customised automotive knobs for luxury interior designs – all in quantities ranging from single prototypes to mass manufacturing."

www.incus3d.com

HP's Metal Jet technology integrates into Materialise's CO-AM platform

Materialise and HP have announced a strategic partnership which will see HP's Metal Jet Binder Jetting (BJT) Additive Manufacturing technology integrated into the Materialise CO-AM software platform. The collaboration is expected to enable manufacturers raise the efficiency and quality of their Additive Manufacturing to match industrial requirements and use it for volume production of end parts.

"To scale Additive Manufacturing, the industry is in need of printers that are designed for high productivity coupled with an integrated end-to-end workflow solution – the partnership between HP and Materialise delivers this solution," stated Arvind Rangarajan, Global Head of Software and Data, HP Personalisation and 3D Printing.

Whilst manufacturers recognise the unique benefits of AM, there can be challenges onboarding the technology: the speed of their selected AM process may not hold up to volume production and they often have difficulties integrating the process with existing manufacturing technologies. In an effort to support these companies, HP offers industrial AM solutions that are said to be manufacturing-ready. In combination with the Materialise CO-AM Software Platform, manufacturers can link HP's Metal Jet and Multi Jet Fusion technology to their existing production systems and optimise the AM workflow.

"Manufacturers are increasingly using 3D printing for end-use parts instead of solely in the prototyping and design phase," added Bart Van der Schueren, CTO of Materialise. "This partnership will help drive this shift by supporting more efficient, repeatable volume production."

The connectivity between HP AM technology and Materialise CO-AM enables users to create workflows that improve traceability, quality control, and machine utilisation. Optimised build job management allows production leads to track planned and actual machine activities and optimise machine time.

To ensure continuous production, real-time machine monitoring provides operators and engineers with critical process data, including build status, material usage, and machine sensor data. This data can then be collected and stored in log files of additively manufactured jobs to enhance traceability and quality control.

www.materialise.com
www.hp.com

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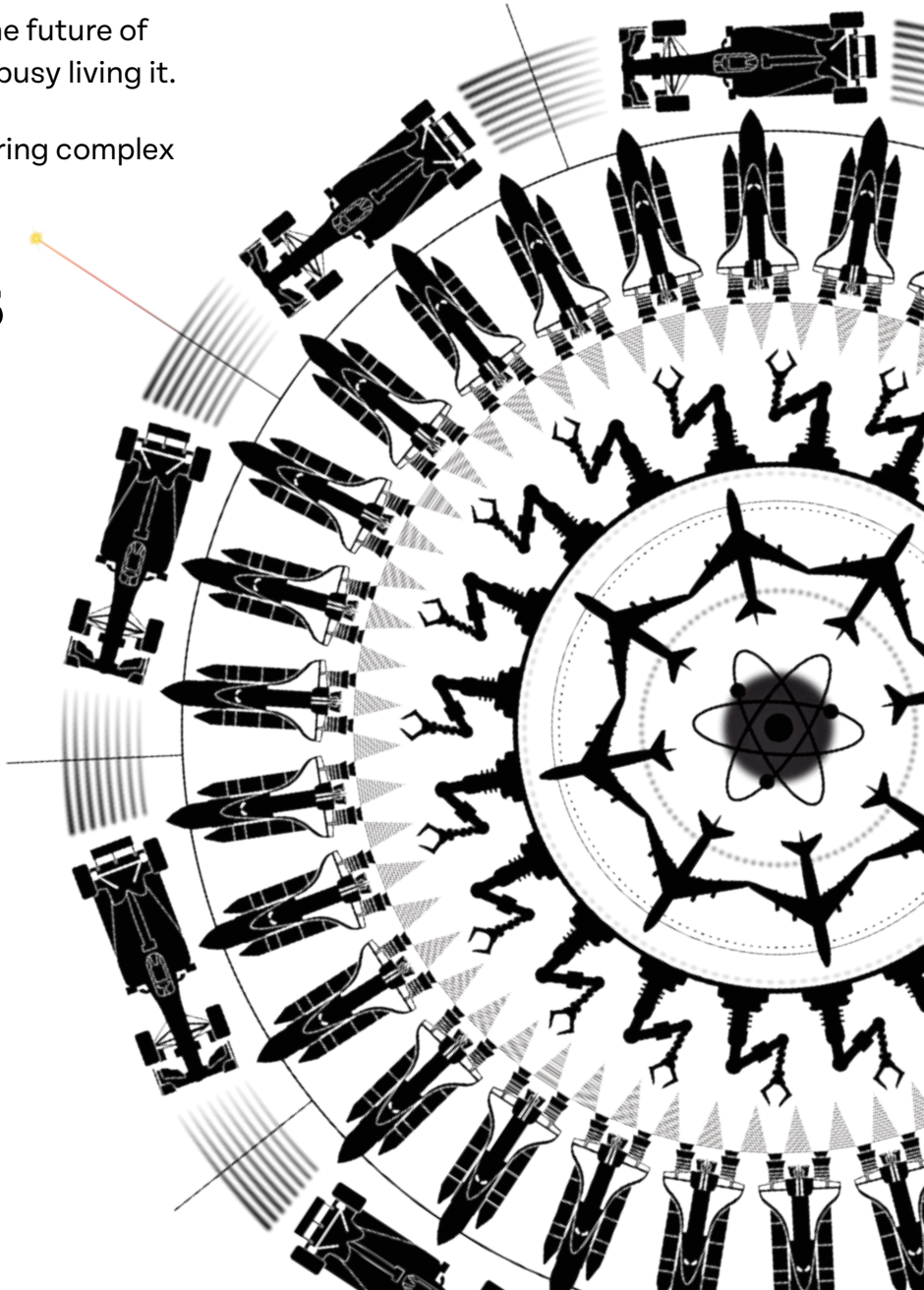


Burloak Technologies

a division of SAMUEL

NASA test fires additively manufactured aluminium rocket engine nozzle

NASA has reported the testing of additively manufactured aluminium rocket engine nozzles. Being lighter than traditional nozzles, the development is anticipated to pave the way for deep space missions capable of carrying larger payloads. Under the agency's Announcement of Collaborative Opportunity, engineers from NASA's Marshall Space Flight Center in Huntsville, Alabama, partnered with Elementum 3D in Erie, Colorado, to develop a weldable type of aluminium that is heat resistant enough for use on rocket engines. Compared to other metals, aluminium has a lower density and allows for the creation of high-strength, lightweight components.

Due to its low tolerance to extreme heat and tendency to crack during welding, aluminium is not commonly used for Additive Manufacturing of rocket engine parts. However, NASA has made a recent development under the Reactive Additive Manufacturing for the Fourth Industrial Revolution (RAMFIRE) project. RAMFIRE, funded by NASA's Space Technology Mission Directorate (STMD), aims to advance lightweight, additively manufactured aluminium rocket nozzles. These nozzles are designed with small internal channels to keep them cool enough to prevent melting.

The RAMFIRE nozzle

With conventional manufacturing methods, a nozzle may require up to a thousand individually joined parts. In contrast, the RAMFIRE nozzle is constructed as a single piece, resulting in fewer bonds and significantly reduced manufacturing time.

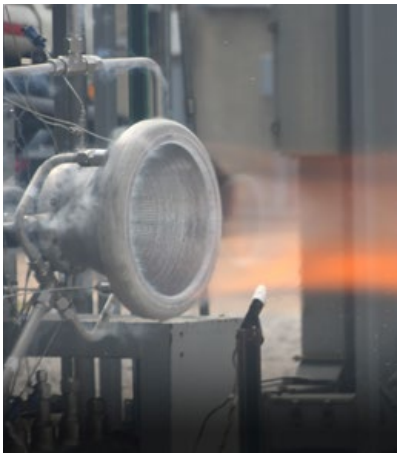
NASA and Elementum 3D collaborated to develop a novel aluminium variant called A6061-RAM2. This variant was used to construct the nozzle and modify the powder used in laser Directed Energy Deposition (DED) Additive Manufacturing technology. RPM Innovations (RPMI), in Rapid City, South Dakota, utilised this newly invented aluminium and specialised powder to additively manufacture the RAMFIRE nozzles.

"Industry partnerships with specialty manufacturing vendors aid in advancing the supply base and help make Additive Manufacturing more accessible for NASA missions and the broader commercial and aerospace industry," Paul Gradl, RAMFIRE principal investigator at NASA Marshall, shared.

"We've reduced the steps involved in the manufacturing process, allowing us to make large-scale engine components as a single build in a matter of days," he continued.

NASA's Moon to Mars objectives necessitate the ability to transport a larger payload to deep space destinations. The alloy could be crucial in achieving this goal by allowing the production of lightweight rocket components that can withstand substantial structural loads.

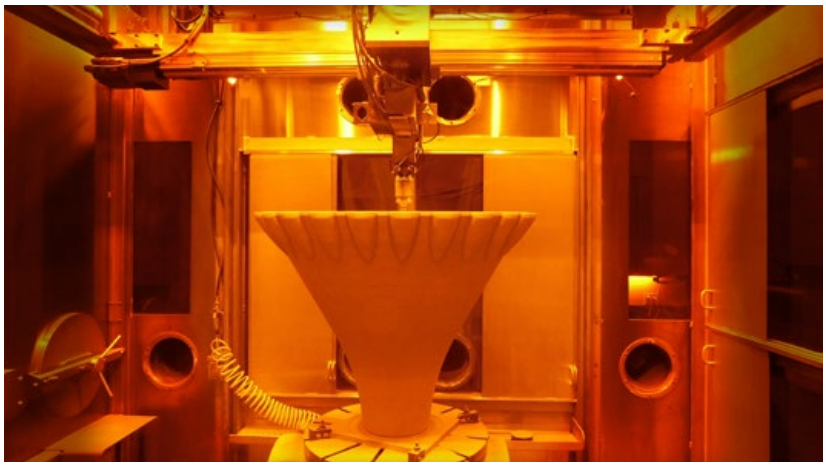
"Mass is critical for NASA's future deep space missions," stated John Vickers, principal technologist for STMD advanced manufacturing. "Projects like this mature Additive Manufacturing along with advanced materials, and will help evolve new propulsion systems, in-space manufacturing, and infrastructure needed for NASA's ambitious missions to the moon, Mars, and beyond."



The RAMFIRE nozzle hot fire test (Courtesy NASA)

Earlier this summer, at Marshall's East Test Area, two RAMFIRE nozzles underwent multiple hot-fire tests using different fuel configurations. These included liquid oxygen and liquid hydrogen, as well as liquid oxygen and liquid methane. Despite operating at pressures exceeding 825 psi, which exceeded the anticipated testing pressures, the nozzles performed successfully, completing twenty-two starts and accumulating a total run time of 579 seconds, or nearly ten minutes. This successful event demonstrates the nozzles' ability to function effectively in the most challenging deep-space environments.

www.nasa.gov
www.elementum3d.com



Additive Manufacturing of a large-scale aerospike demonstration nozzle with integral channels underway at the RPMI facility. NASA engineers will use the nozzle as a proof of concept for future component designs (Courtesy NASA)

MPW and Solvus Global collaborate for Additive Manufacturing material development

Metal Powder Works (MPW), based in Sewickley, Pennsylvania, USA, is partnering with Solvus Global, Leominster, Massachusetts, USA, to develop powders for use in the Additive Manufacturing industry. The partnership involves Solvus Global acquiring a DirectPowder™ machine from MPW, marking the first unit to be placed outside of MPW's Pittsburgh production facility. Under the terms of the agreement, Solvus Global and its business unit Powders on Demand, will be the first to join Metal Powder Works' newly established Developer Network. This collaboration intends to allow startups to combine resources and expedite the production of existing alloys and challenging powders for the Additive Manufacturing sector.

The DirectPowder process converts metal bar stock into powder via a software-driven mechanical process at room temperature. The process is reported to result in powder with a PSD of about 30 µm, and every particle is identical, solving the issues of both consistency and size efficiency.

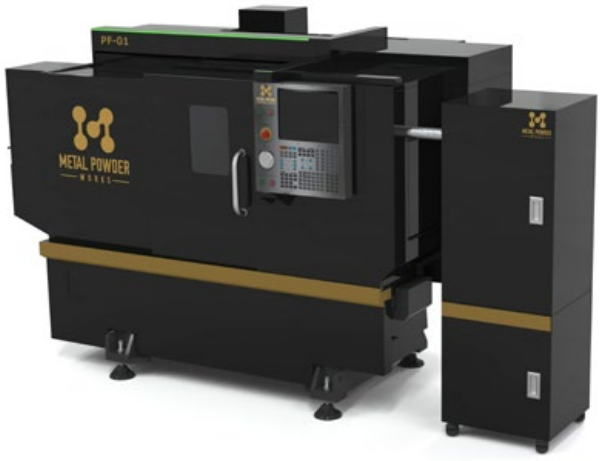
As a key part of Metal Powder Works' Developer Network, Solvus Global will gain access to a broad range of materials not yet available as powder. This is anticipated to significantly decrease the time and cost to access vital resources for innovative projects.

"We're excited to lead the way in economic production of powders starting at R&D all the way through commercial scale to enable our public and private sector customers to push the boundaries of AM and coatings," stated Brad Richards, CEO, Powders on Demand .

Aaron Birt, Solvus Global co-founder & CEO, added, "There are only sixteen approved AMS [Aerospace Material] specifications for powder today while there are more than 2,000 approved AMS specifications for bar stock. AM needs more than sixteen alloys to be successful."

John Barnes Metal Powder Works' CEO and founder commented, "We've known the people at Solvus Global for a very long time, even before MPW existed. It is crucial for us to help the AM community by making more materials available in powder form, so every business case doesn't automatically require a change in material. Solvus Global understands the requirements of the various processes for powder, so this is a natural partnership."

www.metalpowderworks.com
www.powdersondemand.com
www.solvusglobal.com



MPW is partnering with Solvus Global in an effort to develop new materials (Courtesy Metal Powder Works)

AMALLOY-HT high-temperature aluminium powder developed in UAE

The Technology Innovation Institute (TII), a scientific research centre and part of Abu Dhabi Government's Advanced Technology Research Council (ATRC), has announced AMALLOY-HT. This new aluminum alloy powder, developed at TII's Advanced Materials Research Center (AMRC), is reported to be the first metal alloy developed in the Middle East specifically for use in Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machines.

"While there have been several examples of new materials for Additive Manufacturing emerging from laboratories in the US, Europe, and Australia, this is the first time the UAE has joined the elite list of countries with sovereign capabilities in this domain," stated Dr Nesma Aboulkhair, Director of Additive Manufacturing at TII. "We are now cultivating the expertise to produce metal powder and design innovative materials, empowering us to manufacture existing alloys and create new ones for both local and global markets."

TII's research and development efforts have expanded the range of high-strength metals suitable for Additive Manufacturing. AMALLOY-HT is a newly released high-temperature variant of AMALLOY, a low-cost, high-strength aluminium alloy. AMALLOY-HT is reported to have demonstrated impressive thermal stability, particularly in extremely high-temperature environments up to 300°C, the highest operating temperature for aluminium before it begins to degrade.

TII has already filed two patents for AMALLOY and AMALLOY-HT with the US Patent and Trademark Office. Additionally, TII intends to use its framework to develop alloys from other metal families.

"As part of TII's ongoing commitment to innovation, AMALLOY-HT will continue to undergo refinement, fine-tuning, and even more comprehensive testing," added Dr Federico Bosio, Lead Researcher in Additive Manufacturing Materials at TII. "The goal is to commercialise the high-strength aluminium alloy specifically designed for high-temperature applications. While this material creates a plethora of new opportunities and solutions for industries around the world, it will also elevate Abu Dhabi and the UAE's reputation as a hub for cutting-edge research and development."

It was stated that the introduction of AMALLOY and its new high temperature variant are expected to boost international collaboration opportunities for researchers, manufacturers, and industry leaders, and allow them to harness the full potential of these advanced materials.

www.tii.ae | www.atrc.ae

Linde and Ariane Group to optimise copper Additive Manufacturing for future rocket engines

Linde plc, a global industrial gases and engineering company, has announced its collaboration with Ariane Group to focus on research aimed at improving the Additive Manufacturing process for copper alloy parts intended for use in the engine combustion chambers of future heavy-lift rockets.

A computer-generated image of the additively manufactured copper combustion chamber, produced in collaboration with Ariane (Courtesy Linde)

Additive Manufacturing allows for the use of copper in the production of engine components with specialised geometries, such as cooling channels, which are unachievable with traditional manufacturing methods. However, while copper is a superior heat conductor and is vital for the aerospace industry, its refractory nature raises challenges in the Additive Manufacturing process. In Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing, copper reflects the laser and thereby requires a higher laser intensity, which can risk overheating the component and cause oxidation issues.

To overcome these issues, the partners are using Linde's custom gas mixture, ADDvance Laser230, and oxygen control system, ADDvance O2 precision, along with a highly precise Additive Manufacturing process, to deliver consistent, high-quality, copper AM components.

"Linde is very proud to be collaborating with Ariane on this project to improve the Additive Manufacturing process," stated Pierre Forêt, Associate Director, Additive Manufacturing, Linde. "Cooperating with world-leading partners like Ariane is at the core of our innovation culture."

ADDvance Laser230 is specifically designed to optimise manufacturing results in the PBF-LB processes. Its blend of argon and helium reduces fumes and spatter formation, speeds up cycle times, and makes the manufacturing process more reliable, thus reducing the cost per part. It is reported to work with any alloy and is well-suited for the creation of complex or lattice-type structures through Additive Manufacturing.

Incorporating ADDvance O2 precision into the manufacturing process ensures that the build chamber maintains a maximum oxygen level as low as 10 ppm. This significantly low residual oxygen level mitigates overheating and oxidation, leading to more efficient building without the necessity for layers to cool down. Moreover, it enables the reuse of non-oxidised powder, which subsequently reduces material costs.

"To ensure the competitiveness of future launcher engines, improved Additive Manufacturing processes are a key factor, enabling reduced manufacturing costs and improved lead times while maintaining the non-negotiable quality and reliability that has made Ariane an industry leader," Mathias Palm, Process Specialist, Ariane Group, shared. "We are confident that Linde's gas expertise will contribute to optimising the Additive Manufacturing process."

www.linde.com
www.ariane.group

Equispheres materials recognised as enabling technology by US Army

Equispheres, Inc, Ottawa, Ontario, Canada, reports it has been identified by the US Army as a key enabler to fill critical manufacturing and sustainment capabilities for the Department of Defense. Equispheres was announced as one of the five winners in the annual xTechInternational competition seeking advanced manufacturing and materials solutions. This event is intended to recognise innovations with immediate value for American industries.

"We are honoured that DoD has recognised the capabilities of our materials technology for defence applications. Our unique production technology allows us to tailor materials properties to specific end-uses, making metal Additive Manufacturing faster, safer, and more accessible to the defence supply chain," said Kevin Nicholds, CEO of Equispheres. Equispheres was one of a handful of global suppliers chosen from a pool of over 130 candidates as having technology with the potential to significantly impact DoD's near-term and future capabilities.

"US Army collaboration with our international allies and partners is essential to developing state-of-the-art capabilities that benefit the US soldier," added Jessica Stillman, the deputy programme manager for the Army xTech Program. "The latest xTechInternational competition focused on advanced manufacturing and materials and had the largest award amount to-date for this series, leading to record participation."

www.equispheres.com

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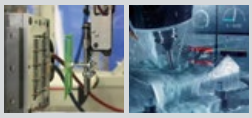

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C01P
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C02P
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C574P*
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W

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H

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H44P (UNS N06044)
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H05P
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H713P (Modified Alloy713C)*
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H929P
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R

R01P
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L

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Proterial, Ltd.

www.proterial.com

EOS and AM Solutions look to automation to optimise process chain

EOS and AM Solutions – 3D post processing technology, part of Rösler Oberflächentechnik, have announced a partnership focusing on the advancement of the Additive Manufacturing process chain through automation.

"In order to truly scale AM production, all steps within the value chain – including post-processing – must work in concert, providing a complete solution for our customers," stated Virginia Palacios, Chief Business Officer Polymer at EOS. "With AM Solutions, we have found a partner with the capabilities to reach the next level in automating the AM process chain. We share the same goal and enrich each other with our different competencies and decades of experience on both sides."

David Soldan, Head of AM Solutions, added, "Our companies are united by the same high quality standards, the pursuit of the best customer solution in each case, and the goal of establishing 3D printing as a whole economically, efficiently, and at the highest level of quality."

The higher the output, the more reliable, faster and more efficient the subsequent steps, such as depowdering, have to be. The key to this lies in automated, economical and highly efficient post-processing. In this way, quantities can be scaled up as required without compromising quality and reproducibility.

"Our technology's ability to provide quality and reliability while performing at peak production levels is why we are the market leader and why we chose AM Solutions as our partner," Palacios adds.

Sustainability and occupational safety are also key considerations.

Marie Langer, CEO of EOS, and Stephan Rösler, president & CEO of Rösler Oberflächentechnik (Courtesy EOS)

The fully automated finishing processes replace manual processing, ensuring greater safety and a much better working environment for employees by significantly reducing the operator's direct contact with the powder.

www.solutions-for-am.com
www.eos.info

Schaeffler acquires Aerosint from Desktop Metal

Schaeffler AG, headquartered in Herzogenaurach, Germany, has acquired Aerosint SA, a developer of powder deposition technology based in Herstal, Belgium, from Desktop Metal. The company will undergo a name change to Schaeffler Aerosint SA and will be incorporated as an additional location for Schaeffler Special Machinery within the Schaeffler Group.

"Schaeffler Aerosint SA offers the first industrial solution for simultaneous, metallic multi-material printing," stated Andreas Schick, Chief Operating Officer at Schaeffler AG. "This expertise, combined with our high level of industrialisation competence and decades of know-how in innovative production technologies, will give us a decisive market advantage. The acquisition is an important milestone in the industrial use of metal-based Additive Manufacturing processes in the area of Industry 4.0."

Aerosint's patented Selective Powder Deposition (SPD) technology is said to enable the creation of homogeneous layers with multiple adjacent material deposits. The deposition is selective, depositing the right amounts of materials at the correct locations. The various material powders are kept separate and deposited by devices known as 'recoaters'. These operate similarly to carriages in standard office printers, 'printing' 3D components at lateral powder pixel resolutions of up to 300 µm. This SPD technology, which is currently on the market, is compatible with Additive Manufacturing processes like Laser Beam Powder Bed Fusion (PBF-LB) and Binder Jetting (BJT), as well as indirect processes. Schaeffler Special Machinery plans to incorporate it into its multi-material Additive Manufacturing system, which is set to be available from 2024.

"By integrating this key future technology, Schaeffler Special Machinery, as a partner for production excellence, will be able to offer its customers a more diversified portfolio of systems, particularly for the manufacturing and medical technology sectors," explained Bernd Wollenick, Senior Vice President Schaeffler Special Machinery.

Aerosint was founded in 2016 and has nineteen employees. It was acquired by Desktop Metal in 2021. Ric Fulop, Desktop Metal's founder and CEO, said Aerosint's technology has a nearer term roadmap with laser systems and Schaeffler can make immediate use of the technology. "With Schaeffler, we have an international partner with a high level of technology expertise and clear roadmap for commercialising the SPD technology with laser-based systems. We will continue to collaborate on the various possibilities for using this technology in Desktop Metal Binder Jetting systems in the future." In addition, Schaeffler and Desktop Metal will continue their collaboration in multi-material solutions, including in the area of toolless manufacturing technologies.

www.schaeffler.com/en
aerosint.com

3D Systems to introduces C-103 alloy and DMP Flex 350 update

3D Systems, Rock Hill, South Carolina, USA, introduced its C-103 niobium alloy and the DMP Flex 350 Triple metal Additive Manufacturing machine at this year's Formnext.

C-103 niobium alloy

Classified as a refractory material, C-103 is resistant to decomposition by heat, pressure, or chemical attack and thus retains its strength and form at high temperatures. The alloy has a high service temperature of between 1,200-1,400°C and is capable of withstanding high stresses at these elevated temperatures. Because of its low ductile-to-brittle transition temperature, C-103 also has excellent resistance to high-frequency vibrations. These properties make C-103 well-suited for rocket, hypersonic, and jet propulsion applications including spacecraft, satellites, and launch vehicles in the space, aerospace, and defence industries.

C-103 niobium alloy is suited to high temperature applications (Courtesy 3D Systems)

3D Systems' DMP vacuum technology is reportedly well-suited to processing C-103. By ensuring a very low-oxygen environment, it helps maintain the material's properties, which are highly sensitive to O_2 exposure. The introduction of C-103 follows the recent successful performance verification of NASA's GRX-810 super alloy, and expands the options for advanced aerospace applications. The company stated that application development services on C-103 and GRX-810 are currently available through the its professional services delivered by the Application Innovation Group (AIG). GRX-810 is currently only available inside the United States.

DMP Flex 350 update

The latest configuration for the DMP Flex 350 Triple metal Additive Manufacturing machine was also introduced at Formnext. This compact, three-laser machine includes the company's vacuum chamber design and extends its novel Removable Print Module (RPM) concept by supporting two distinct RPM modules with different build volumes. This includes a new RPM with a build volume of 350 x 350 x 350 mm and a standard RPM with a build volume of 275 x 275 x 420 mm. This enables cost effective processing of a variety of parts including impellers and cooling plates, for example. The RPMs can also be swapped for increased application flexibility.

The DMP Flex 350 Triple is a three-laser metal AM machine *(Courtesy 3D Systems)*

The DMP Flex 350 Triple also offers multi-laser load balancing and enables seamless surface quality scan strategies. The machine is capable of processing a wide range of aluminium alloys, including traditional cast alloys (i.e., AlSi10Mg, AlSi7Mg0.6), high-strength aluminium alloys (i.e., A6061-RAM2), and high- conductivity aluminium (i.e., CP1), as well as 316L stainless steel. Additionally, nickel-based alloys, such as Ni718, Ni625, and HX, are available for high-temperature corrosion-resistant applications.

www.3dsystems.com

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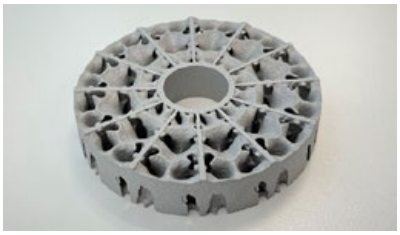
Ricoh and Siemens aim to industrialise aluminium Binder Jetting for mass production

Ricoh Company, Ltd, and Siemens Digital Industries Software are collaborating to advance the use of aluminium Binder Jetting (BJT) for mass production. Under the partnership, Ricoh is leveraging Siemens' Additive Manufacturing Network capabilities to maximise the efficiency of the process and to achieve the scale required to take advantage of BJT in an industrial setting.

Ricoh will also implement Siemens' Additive Manufacturing Network in an effort to optimise the aluminium BJT workflow for production preparation, planning, scheduling, and production management. The company has also implemented Siemens' Brownfield Connectivity (BFC) and has begun collecting and storing information on each process necessary for quality stabilisation and production control.

Ricoh's Binder Jetting process applies the company's inkjet printing technology and expertise to enable the production of complex metal parts that would not be possible with conventional metal processing methods such as machining and casting. Siemens will continue to provide Ricoh with solutions optimised for the aluminium BJT workflow, and both companies aim for early commercialisation of these technologies.

"The production of aluminium parts is a holy grail for the additive industry and we're delighted that Ricoh has chosen Siemens' Additive Manufacturing Network capabilities from the Siemens Xcelerator portfolio of industry software to help them commercialise a much sought-after process," stated Zvi Feuer, Senior Vice President, Digital Manufacturing Software, Siemens Digital Industries Software. "Our collaboration with Ricoh will apply its expertise in Additive Manufacturing with our knowledge and experience in delivering additive-specific operations management technology across a wide spectrum of industries – from order capture, production planning, and manufacturing to part delivery transaction closure. Together, Siemens and Ricoh are working to deliver repeatability and consistency at the scale needed to truly take advantage of using robust and repeatable aluminum additively manufactured parts in the commercial world."



A high-efficiency air-cooling heat-sink created using Ricoh's aluminium Binder Jetting process (Courtesy Ricoh)

Tokutaro Fukushima, General Manager of Additive Manufacturing Business Center, Ricoh Futures Business Unit, Ricoh Company, Ltd., added, "Ricoh will enable our customers to manufacture innovative aluminium components that have never been produced before by any process and will work with them to realise new customer value in the area of electrification of EVs and other forms of mobility. By combining Siemens' powerful solutions and knowledge with Ricoh's aluminium BJT, we will be able to provide our customers with highly-reliable and practical systems for mass production applications. We hope to promote electrification together with our customers and contribute to solving social issues such as realising a zero-carbon society."

additive-manufacturing-network.sws.siemens.com

www.ricoh.com

HP and Sandvik collaborate to bring advanced materials to HP's Metal Jet

HP Inc has announced a strategic collaboration with Sweden's Sandvik AB to bring advanced materials, such as superalloys and 316L stainless steel, to HP's Metal Jet Additive Manufacturing technology. The partnership will build on the existing and successful collaboration to develop 17-4PH stainless steel powder for use in the company's Binder Jetting machines.

Ramon Pastor, Global Head of 3D Metals at HP, stated, "This collaboration is a game-changer. Our collaboration with Sandvik broadens Metal Jet's capabilities, empowering industries to revolutionise manufacturing processes and products."

Sandvik and HP are reported to be working in tandem with Parmatech, an ATW Company, headquartered in Petaluma, California, and Endeavor 3D, Douglasville, Georgia. Alexandre Tartas, Global Head of Go-To-Market, HP Personalisation & 3D Printing, added, "These materials are strategically crafted to empower our valued customers, enabling them to explore groundbreaking applications, especially in the aerospace and industrial sectors."

Andrew Coleman, Head of Additive Manufacturing at Sandvik, commented, "By combining the expertise of our companies, I believe the collaboration will lead to advancements in both materials and manufacturing technology that will ultimately benefit our customers."

www.hp.com

www.home.sandvik

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Deutsche Bahn implements 3D Spark automated solution for Additive Manufacturing costing

German rail network operator Deutsche Bahn has implemented 3D Spark, a software solution that automates the selection, costing, and pricing of Additive Manufacturing technologies based on Deutsche Bahn's manufacturing requirements. 3D Spark utilises artificial intelligence to analyse 3D CAD files, 2D drawings (PDFs), and metadata to generate precise calculations for manufacturability, cost, lead time, and CO_2 emissions.

To respond to incoming Requests for Quotation (RFQ), the Additive Manufacturing team at Deutsche Bahn used to perform several manual tasks, which included performing feasibility checks to ensure that AM is the most appropriate manufacturing approach for a given part or assembly. The system is also used for estimating the cost of AM parts using a variety of simplifications and assumptions regarding material cost, machine time, labour costs and any pre/post processes. It compares different AM technologies to select the most cost-effective and sustainable option.

These tasks are repetitive, time-consuming, and prone to errors. In many cases, spreadsheet calculations, which are susceptible to errors, have been used to perform these tasks.

Implementing 3D Spark aims to significantly reduce the time required for cost calculations, while maintaining an accuracy of ±5%. Specifically, the implementation is expected to reduce cost calculation time by two-thirds, allowing the AM team to allocate more time to addressing customer challenges and generating revenue.

Using the 3D Spark platform, Deutsche Bahn can now track the amount of CO_2 emitted while manufacturing a part. The organisation can also compare this data with other manufacturing technologies to identify the best manufacturing approach.

Deutsche Bahn has been able to make the quotation process more efficient by using 3D Spark's built-in market price insights tool, which allows it to compare its own prices with average market prices.

The use of 3D Spark has reportedly helped Deutsche Bahn improve the accuracy and efficiency of its AM costing processes. This technology provides instant cost estimation, improves workflow efficiency, and reduces the time and resources required for manual tasks. Additionally, Deutsche Bahn can now effectively track the cost of AM parts over time, allowing the organisation to identify cost trends, explore additional opportunities, and optimise their AM processes.

www.3dspark.de

www.indo-mim.com

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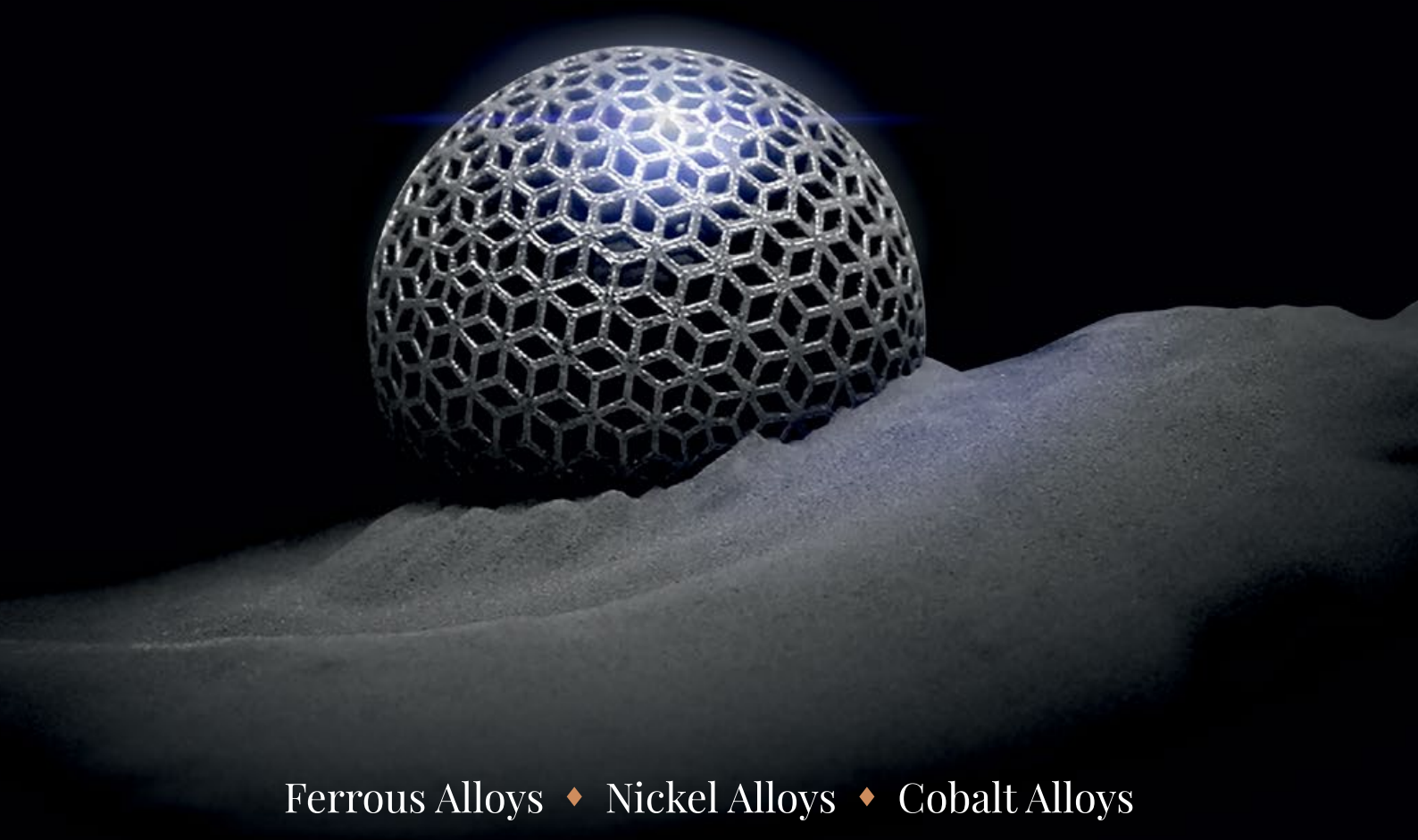

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Trumpf updates TruPrint 2000 metal Additive Manufacturing machine

Trumpf, headquartered in Ditzingen, Germany, reports it has increased the productivity of the TruPrint 2000 metal Additive Manufacturing machine. The updated Laser Beam Powder Bed Fusion (PBF-LB) machine is now equipped with a square build plate instead of a round one, and offers increased laser power options with two 500 watt fibre lasers, as an alternative to the 300 watt laser basic configuration.

"The 3D printer is now also designed for mass production. Users from all industries benefit from the machine's high productivity," stated Mirko De Boni, product manager at TRUMPF responsible for the TruPrint 2000.

The updated TruPrint 2000 has a build volume of 200 x 200 x 200 mm and, with an optimised optical design, both lasers can process the entire build plate simultaneously. This is said to greatly improve productivity and enable dental technology companies, for example, to manufacture up to 36% more removable partial dentures on the square build plate than on a comparable round build plate. The machine's increased surface area and laser power are also an advantage in tool and mould making, adds Trumpf.

"The TruPrint 2000 not only works very productively, but also precisely and with the highest quality," added De Boni. "Safety is the top priority for Trumpf 3D printing, especially for critical areas such as medical technology. With the upgrade of the TruPrint 2000, patients receive high-quality implants with even more long-term stability."

A motorised beam expander allows the TruPrint 2000 to automatically adjust the spot diameter of the laser to either 55 or 80 µm. The 80 µm diameter enables higher productivity, while the 55 µm diameter can be used when special metal powders require a higher energy density.

With this update, the TruPrint 2000 now shares the same process capabilities as other Trumpf AM machines, driven by the 80 µm beam size and the optimised gas-flux. "With this standardisation, users can now easily transfer the parameters for printing their parts from machine to machine, such as from a TruPrint 2000 to a TruPrint 1000 or TruPrint 3000, allowing for more flexible manufacturing," confirmed De Boni.

www.trumpf.com

The square build plate and higher laser power of the updated TruPrint 2000 increases productivity (Courtesy Trumpf)

Velta plans fully-integrated titanium operation and production of medical implants

Velta LLC, located in Dnipro, Ukraine, plans to start commercial production and distribution of finished titanium medical implants by the end of the year. The implants will be additively manufactured using Velta's titanium powder, resulting in a fully-integrated commercial operation encompassing titanium ore mining, powder processing and part manufacturing.

"This enormous milestone is the result of many years of intensive work behind the scenes to scale our powder technology at a pace that the global titanium market demands," Velta CEO Andriy Brodsky stated. "By bringing these titanium medical implants to market, we've proven our concept and are eager to stake out our position as the first and leading integrated titanium operation."

In 2017, Velta launched its R&D centre with the aim of innovating a new method for producing titanium powder as an alternative to titanium sponge. This patented approach to titanium powder is faster and more environmentally responsible. As a result, the company has successfully scaled up semi-industrial production of metallic titanium powder at its R&D Centre in Dnipro.

Velta has also established two new divisions to enhance its vertical integration efforts and strengthen its market position. These divisions are Velta Additive Technology, specialising in finished AM titanium products and Velta Medical, focusing on manufacturing custom Ti medical implants.

As the company continues to expand its commercial and R&D operations in Ukraine, it is currently undergoing a site selection process to establish a state-of-the-art titanium powder production facility in the United States. Last month, Velta announced its partnership with global engineering consultancy Hatch to develop the new facility, which will initially have an annual production capacity of 1,000 tonnes of powder.

velta.us

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BLT premiers industrial-level BLT-S400 metal Additive Manufacturing machine

Bright Laser Technologies (BLT), located in Xi'an, China, premiered its industrial-level BLT-S400 Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machine, its automatic powder circulation system and software solutions at this year's Formnext 2023. The BLT-S400's three-laser configuration makes it suitable for high-volume production of small- and medium-sized industrial parts. Typically, customers with these needs experience high time costs when utilising AM; BLT intends for the BLT-S400 to minimise delivery time and labour costs without sacrificing quality.

The BLT-S400's new Automatic Powder Circulation System enables the safe transfer, recovery, sieving, and reuse of metal powders within an on-site test laboratory. This facilitates the simple and secure transfer of large volumes of Additive Manufacturing powders from containers to multiple machines, eliminating the risk of spillage contamination, explosion, and contact with workers. The Automatic Powder Circulation System is also able to support multiple Additive Manufacturing machines, acting as a potentially cost-effective investment option that can enhance production efficiency.

BLT premiered its industrial-level BLT-S400 metal Additive Manufacturing machine, its automatic powder circulation system and software solutions at Formnext (Courtesy BLT)

Software solutions

Also introduced was BLT-BP, a dedicated slicing software tool for BLT Additive Manufacturing machines. It is reputed to have improved the slicing efficiency for parts that are numerous, large in size, and have complex structures. Even for parts with a 25 G data volume, the required profiling time is 30 minutes. The BLT-BP has a dynamic powder laying strategy that adapts PBF-LB speed to the part contour, enabling multi-stage automatic speed adjustments. This approach enables both quality and efficiency. Typical parts experience a notable 30% improvement in single-layer efficiency compared to the conventional method.

BLT has also integrated its complete series of AM machines with BLT-MES 2.0, a proprietary intelligent production line management system. BLT-MES 2.0 establishes data connectivity between the planning and execution tiers within the Additive Manufacturing landscape. This system offers comprehensive end-to-end digital manufacturing solutions, encompassing product management, project planning, intelligent scheduling, manufacturing execution, data IoT integration, statistical dashboards, online reporting, and more.

www.xa-blt.com

GKN Additive and HP aim to bring together advanced materials and innovative tooling solutions

HP Inc and GKN Additive have announced a collaboration that aims to bring together advanced materials and innovative tooling solutions. Initially, the partnership will focus on qualifying a range of metal powders for users of HP's Metal Jet S100 Additive Manufacturing machines, beginning with ten different steel grades that include M2 tool steel and a dual-phase steel.

A strategic area of focus of the collaboration will be to advance GKN's efforts to combine HP's Metal Jet S100 Binder Jetting technology with unique material offerings, allowing a precision-focused approach tailored to specific customer challenges. This aims to speed up innovations in the tooling industry, resulting in increased productivity and quality, eliminating the need for traditional machining.

The companies stated that examples of such innovations would include the development of near-net shaped tools, significantly reducing material waste and production time.

It was added that together, the partners will continue expanding material availability for the tooling industry, combining GKN's material and production expertise and HP's process knowledge to accelerate qualification work. Customers can purchase powders directly from GKN and access HP's Professional Services to establish a development programme tailored to their specific needs.

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EDMMax 434WW

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Max. workpiece Wt: 600kg . 1320 lbs

EDMMax 818W

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Max. workpiece Wt: 2000kg . 4400 lbs

FC 45HW

400x400x300 mm (x,y,z axis)
Max. workpiece Wt: 100kg . 220 lbs

Horizontal submerged cutting

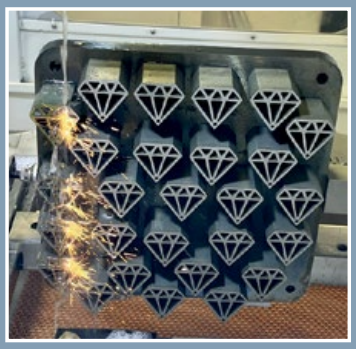
Horizontal submerged cutting

EDMMax 1100HW

1100x1400x1250 mm (x,y,z axis)
Max. workpiece Wt: 3000kg . 6600 lbs

EDMMax 1800W

1000x800x1050 mm (x,y,z axis) - 4 axis
Max. workpiece Wt: 2000kg . 4400 lbs



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AMUG announces keynote speakers for 2024

The Additive Manufacturing Users Group (AMUG) has announced that the keynote speakers for its 2024 AMUG Conference will be Jason Lopes and Olaf Diegel. Lopes, who works in the creative services industry, will focus on 3D scanning, design, and Additive Manufacturing. Diegel will address creativity through tales of Design for Additive Manufacturing (DfAM) as a tool to unleash the transformative power of the technology.

Ed Graham, AMUG's Director of Education and Conference, stated, "Our 2024 keynote speakers embody Additive Manufacturing as an art form for tackling complex challenges and elevating what is possible. I believe that Olaf's and Jason's talks with be complementary, having different perspectives on the creative use of Additive Manufacturing, and they will bring a global view of additive case studies to the stage."

On the AMUG stage, Jason Lopes, a returning favourite, will discuss how Additive Manufacturing and 3D scanning have been advanced by the entertainment and creative services industries through the completion of unique projects that posed remarkable challenges. He assures the audience that they will be astounded by the extensive use of Additive Manufacturing in resolving manufacturing difficulties to transform creative ideas into reality for items ranging from movie props to consumer products to fine art.

Lopes' stories are pulled from the experiences of Gentle Giant Studios, where he now serves as Director – Additive Manufacturing. Here, he has played a pivotal role in shaping Hollywood blockbusters such as Avatar, Terminator Genisys & Salvation, Thor, and the three Iron Man films.

Olaf Diegel's Thursday keynote is titled 'Design for Additive Manufacturing: Understanding Value.'

"I have followed Olaf for many years on social media. I was very pleased and excited when he agreed to travel from New Zealand to Chicago so that he can share his creative, wide-ranging use cases of Additive Manufacturing with our members," added Graham.

In his talk, Diegel will demonstrate how, with good DfAM practices, the technology can be shifted from a slow, expensive approach to one that can transform products into successes that contain value-added features. Diegel will make his points through real-world examples from aerospace, transportation, healthcare, and artistic applications.

For twenty-five years, Diegel has been an enthusiast of Additive Manufacturing and he believes that it has been a boon for innovation. He is both an educator and practitioner in Additive Manufacturing and product development with a strong track record of developing solutions to create innovative products.

AMUG will be held in Chicago, Illinois, USA, from March 10-14, 2024

www.amug.com

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Nidec Machine Tool America adds Lamda500 metal powder DED machine demonstrator

Nidec Machine Tool America, located in Wixom, Michigan, USA, has installed a demonstrator of the company's Lamda500 mid-size metal powder Directed Energy Deposition (DED) Additive Manufacturing machine at its Michigan facility. The Lamda500, with a maximum build size of 500 x 500 x 500 mm and standard five-axis functionality, is currently the mid-size model in the company's AM machine lineup.

"The Lamda500 is immediately available for test printing of customer components, material testing, and multi-material development," stated Dwight Smith, Nidec Machine Tool America's VP.

The Lamda500 is designed for the production of metal components used in various industries such as aerospace, space, automotive products, and construction equipment. It can process titanium, aluminium and copper, and features a local inert gas shield that is said to enable the processing of reactive materials without the need for an inert gas chamber.

The machine includes a two-axis table as standard, allowing for fully five-axis Additive Manufacturing. It also features a fully integrated closed-loop monitoring system that controls laser power to enable consistent build quality and thermal performance, while also providing documentation of the build. The machine uses an AI technology-based function to monitor the build conditions, detecting any abnormalities during the manufacturing process and preventing errors before they occur.

With the inclusion of an optional second metal powder hopper, the Lamda range also has the capability to switch materials during the build process. This allows for the production of functional gradient materials by altering the material blend throughout the build process.

In addition to the Lamda500, Nidec includes the Lamda200 and Lamda2000 in its range of AM machines.

www.nidec-machinetoolamerica.com

Nidec Machine Tool America has installed a demonstrator of the company's Lamda500 metal powder Directed Energy Deposition (DED) Additive Manufacturing machine at its Michigan facility (Courtesy Nidec)

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3D Systems' Chuck Hull receives national honour recognising achievement in AM

US President Joe Biden has awarded the National Medal for Technology and Innovation to Charles 'Chuck' Hull of 3D Systems. The award recognises Hull's work helping to launch the Additive Manufacturing industry through his invention of stereolithography, some forty years ago.

Established in 1980, the National Medal for Technology and Innovation is the United States' highest honour for technological achievement. It is awarded by the President of the United States for exceptional contributions. The medal is given to individuals, teams (up to four individuals), companies, or divisions of companies that have significantly contributed to America's economic, environmental, and social well-being.

US President Joe Biden has awarded the National Medal for Technology and Innovation to Chuck Hull (Courtesy NSTMF)

In a video by The National Science and Technology Medals Foundation, Chuck Hull explained that his invention was borne of a need to prototype more efficiently. When working for a company which used UV light to harden tabletop coatings, prototypes were manufactured using plastic injection moulding, a process Hull found "really tedious." Three years later, Hull had found an answer to this problem with the creation of the polymer stereolithography process. From there, Hull co-founded 3D Systems to market the technology.

Today, 3D Systems is a leading polymer and metal Additive Manufacturing solutions provider, offering hardware, software, materials, and services to its customers in healthcare and industrial markets such as aerospace & defence, automotive, and durable goods.

www.3dsystems.com

Ai Build looks to expand into US following $8.5 million Series A funding round

Ai Build, an Additive Manufacturing software company based in London, UK, has raised $8.5 million in a Series A round led by IQ Capital, with participation from Nikon as a strategic investor, as well as existing investors Superseed, ACT Venture Partners, Atlas Ventures (UK), and Seedcamp. Ai Build, established in 2015, offers manufacturers a cloud-based solution designed to reduce costs, lead times, and material waste in the AM process.

Daghan Cam, Co-founder and CEO at Ai Build, stated, "Despite its clear economic and environmental benefits, manufacturers have difficulty implementing Additive Manufacturing at an industrial scale. This is due to concerns about its reliability and ease of adoption. We believe that automation and smart use of data is the solution to this problem. By partnering with Nikon as a leading technology provider who has a grand vision for the future of manufacturing, and IQ Capital as a deep-tech investor with proven track record of supporting global businesses, we are well positioned to achieve our goal for automating the factories of the future."

Ai Build collaborates with major manufacturing firms, such as Boeing, to expand the use of AM in large-scale industrial applications. These applications encompass specialised tooling and end-use components in the aerospace, automotive, and energy sectors. Early adopters of Ai Build are reported to have witnessed significant enhancements, including a 65% reduction in failed production attempts and a 90% increase in overall build efficiency.

The company's objective is to eliminate all inefficiencies resulting from human error, thereby simplifying the manufacturing process, making it more intelligent, sustainable, and cost-effective.

"Ai Build offers extensive solutions that enable automated workflows, bringing efficiency and sustainability to the field of AM. In tandem with Nikon's capabilities, together we will deliver innovative solutions that revolutionise AM," Yuichi Shibazaki, Corporate Vice President and Officer in charge of Next Generation Project Division at Nikon, contributed.

The company plans to utilise the new funding to expedite its product roadmap, enabling it to onboard a larger customer base with enhanced levels of automation and AI capabilities. The investment will also facilitate the expansion of Ai Build into North America through the establishment of a subsidiary in the US, as well as the continued growth in Europe.

ai-build.com

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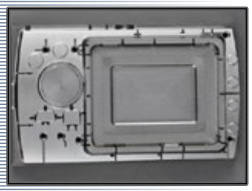

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Epson Atmix begins construction of its new metals recycling facility

Epson Atmix Corporation, a group company of Seiko Epson Corporation, located in Aomori, Japan, has announced it will invest almost $37 million (¥5.5 billion) in a new facility to recycle metal waste in order to produce the raw material for metal powder production.

The company aims to recycle unwanted metals from various sources, including out-of-specification metal powders used in manufacturing processes at Atmix, metal scraps generated within Atmix, and metal end cuts and used moulds discarded by the Epson Group.

Epson Atmix has begun construction of its new recycling facility (Courtesy Epson Atmix)

The planned facility is also seen as a step towards achieving Epson's goal of becoming completely resource-free by 2050, as outlined in its Environmental Vision 2050.

Atmix produces a range of metal powders for a variety of manufacturing processes, including Metal Injection Moulding and Additive Manufacturing. The company also produces magnetic powders for use in power supply circuits, as coils for IT equipment such as smartphones, and for hybrid cars and electric vehicles.

The new factory will be equipped with a high-frequency induction furnace for melting metals, an AOD refining furnace for removing impurities from metals, and a casting machine for forming ingots.

A groundbreaking ceremony for the new facility was held on October 12, 2023, at the Hachinohe Kita Inter Industrial Park, with construction scheduled to start shortly after. The factory is expected to begin operations in June 2025.

www.atmix.co.jp

Dyndrite launches LPBF Pro Software and VIP Onboarding

Dyndrite Corporation, a software developer based in Seattle, USA, has announced the availability of VIP Onboarding for Dyndrite LPBF Pro, a new application for Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing professionals. The software is reported to cater to users who feel restrained using file formats such as STL and legacy applications that primarily rely on manual user interfaces and insider knowledge.

"In AM, software has become the bottleneck limiting industrial users from adopting and maximising the value from AM technologies," explained Harshil Goel, CEO, Dyndrite. "Dyndrite's mission is to break this bottleneck by equipping AM engineers with tools that make them effective at their job. These tools naturally deliver precision, traceability, and repeatability, serving not only those pushing the boundaries but also those seeking an on-ramp as new customers embracing AM as a scalable and reliable manufacturing process."

Dyndrite LPBF Pro provides scalable multi-threaded CPU and GPU-powered performance to solve tough geometry and computing challenges, while streamlining build preparation processes. It enables materials experts to experiment, iterate and innovate, while quality engineers simplify and accelerate their qualification processes. Through the VIP Onboarding programme, customers receive direct hands-on support in applying Dyndrite to their metal Additive Manufacturing.

"For over six years, AMS has worked with aerospace, space and motorsport companies to push the boundaries of what's possible in [PBF-LB]," said Rob Higham, CEO of Additive Manufacturing Services (AMS) Ltd. "Within two days of using Dyndrite we were able to print a thin-walled heat exchanger that, for over eighteen months others attempted and failed to print – such an achievement speaks for itself."

"Renishaw has followed Dyndrite with interest since their launch. Upon receiving Dyndrite LPBF Pro with Quantum integration we immediately wanted to demonstrate how this connection could potentially increase the robustness of the certification of production processes. In particular, we want to show how volumetric segmentation can be used to deliberately induce non-conformance in specific regions of 3D geometry," stated Kevin J Brigden, AMG Applications Engineering Manager, Renishaw, Inc. "This is merely the first step along that journey and in coming work, we will be leveraging machine learning approaches to help customers actually put this information to meaningful use."

Dyndrite LPBF Pro interfaces directly with a wide variety of metal AM machines including: Aconity3D, Renishaw, SLM, and others. Dyndrite is a member of the EOS developer network.

www.dyndrite.com

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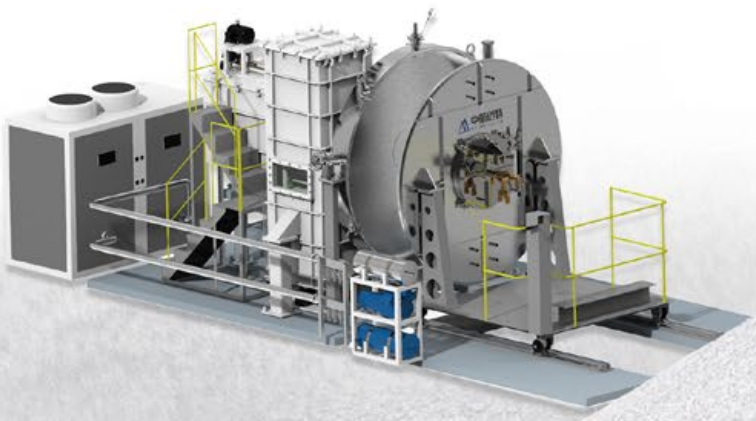

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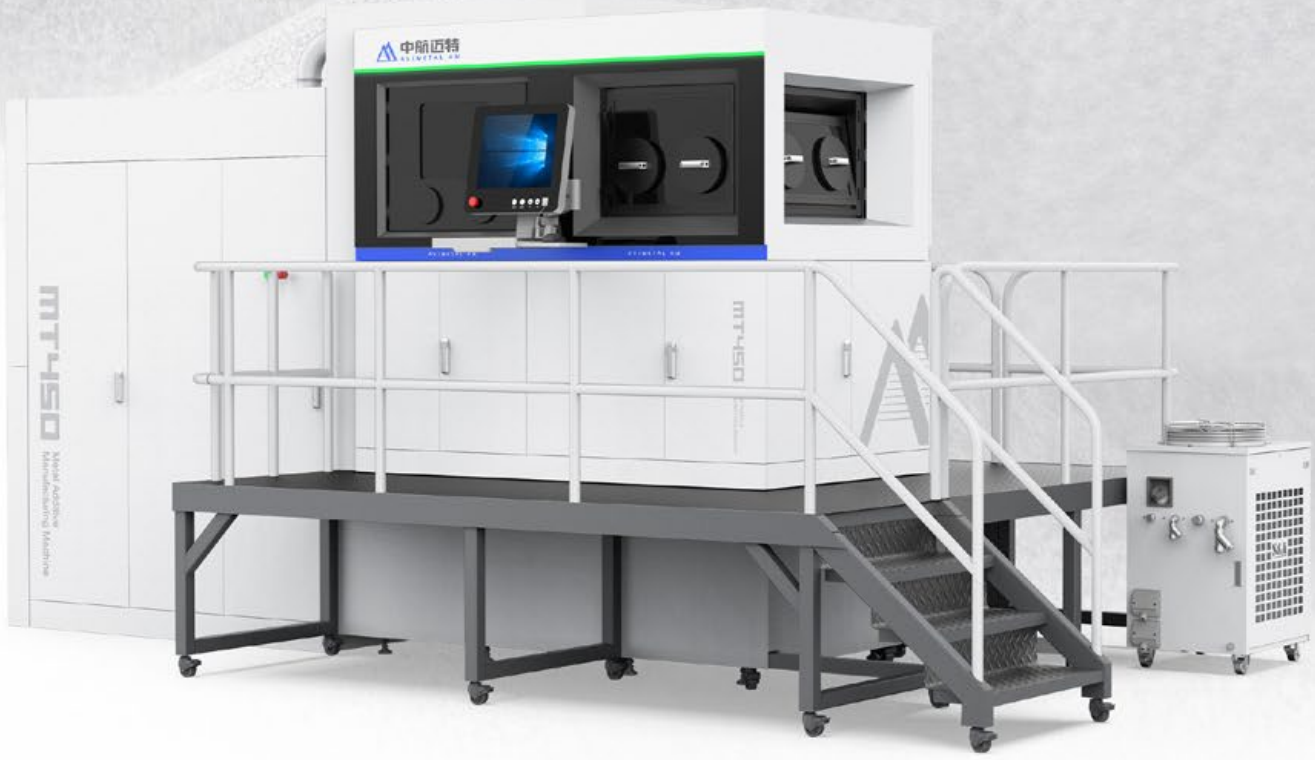

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JEOL's Electron Beam metal AM machine achieves AMS7011 standard

JEOL USA Inc, based in Peabody, Massachusetts, USA, has achieved the AMS7032 operational qualification for its JAM-5200EBM Electron Beam Powder Bed Fusion (PBF-EB) metal Additive Manufacturing machine. The company has also achieved the material requirements for Ti-6Al-4V alloy, as per AMS7011, after Hot Isostatic Pressing.

JEOL has achieved the AMS7032 operational qualification for its JAM-5200EBM AM machine (Courtesy JEOL)

The AMS7032 Operational Qualification Standard evaluates the ability of an AM Powder Bed Fusion machine to consistently meet material specification requirements while maintaining process control and stability over several builds. This includes maintaining process control and stability across multiple builds.

To adhere to the OQ procedures in AMS7032, three identical builds were created, containing a large number of Ti-6Al-4V specimens in all three orientations and encompassing the entire JAM-5200EBM build envelope, using reused powder that conformed to the AMS7015 specification. Afterward, these specimens underwent tensile testing, microstructure evaluation, chemical composition testing, radiography, and other tests to confirm that they met the AMS7011 requirements. An ISO17025-accredited laboratory performed all of the required post-processing and testing of the specimen.

The results of the testing not only demonstrate the machine's stability, but also highlighted a strength of the machine: the JAM-5200EBM produces material with excellent ductility and very low anisotropy. These findings suggest that designers could have substantial freedom in part orientation within the build envelope, thereby enhancing Design for Additive Manufacturing (DfAM) flexibility and unlocking the potential for genuinely optimised designs.

"JEOL has provided metrology, analytical, and electron beam manufacturing instruments for over seventy years and understands that manufacturers must have confidence in their tools," shared Bob Pohorenec, president of JEOL USA. "Meeting the AMS7032 operational qualification standard ensures manufacturers that the JAM-5200EBM is capable of producing aerospace-grade material with stable performance and meets all material specification requirements. This achievement is a testament to our commitment to quality and reliability."

For businesses in the aerospace industry, JEOL's initiative is hoped to provide an alternative for metal Additive Manufacturing of essential parts in the production process. This would give their users access to JEOL's over seventy years of electron beam experience as the companies work to ensuring that parts will meet the compliance standards established to prevent failures.

The results were initially presented at two events in October 2023: the Autumn meeting of the SAE AMS AM Additive Manufacturing Metals committee and the NRC Workshop on Advanced Manufacturing Technologies for Nuclear Applications.

www.jeolusa.com

VBN Components offers high-performance materials development as a service

VBN Components, Uppsala, Sweden, has introduced its High-Performance Materials Development as a Service at this year's Formnext. The new service enables customers to explore the development of traditionally challenging materials such as high-carbon steels, hard metals, or refractories such as Tungsten or Niobium.

"We frequently receive requests from clients for custom materials development," stated Magnus Bergman, CEO of VBN Components. "We believe the time is right to showcase our expertise in this domain to the world and are thrilled to now offer this as a dedicated service. Our participation at Formnext 2023 marks a significant step towards fulfilling the evolving needs of the industry."

Led by material experts, the service will leverage cutting-edge Additive Manufacturing technologies to unravel materials with exceptional wear resistance and unique capabilities.

"Our high-performance materials development service is designed to push the boundaries of what's possible in metal Additive Manufacturing, contributing to enhanced performance and longer lifespan of components," added Ulrik Beste, PhD, CTO and co-founder of VBN Components.

www.vbncomponents.se

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Extreme Manufacturing Engineering adds two BLT AM machines

Bright Laser Technologies (BLT), based in Xi'an, China, has announced that Extreme Manufacturing Engineering (EME), located in Veneto, Italy, has purchased both the BLT-S800 and BLT-S450 Laser Beam Powder Bed Fusion (PBF-LB) AM machines. The BLT-S800 features eight 500 W lasers, allowing for the rapid production of large parts with dimensions measuring up to 800 x 800 x 600 mm. The BLT-S450 is equipped with six lasers and offers a build volume of 450 x 450 x 500 mm, making it suitable for the manufacturing of small and medium-sized parts.

"We have increasing demand for additively manufactured parts in Europe, especially in automotive, consumer electronics, medical devices, and other applications, such as structural parts for amusement rides," explained Eddi Tomat, CEO of EME. "Given their rich history and leadership in Additive Manufacturing, BLT is the ideal partner for us. Additionally, the BLT team has consistently demonstrated professionalism and attentiveness in addressing our needs and inquiries and we anticipate fostering even closer collaboration with BLT."

EME has purchased two BLT machines to expand its Additive Manufacturing solutions (Courtesy BLT)

Dr Xue Lei, CEO of BLT, added, "BLT has taken the lead in introducing the large-format printing system in the industry, with extensive experience in the development of large-sized, multi-laser printing solutions. These two systems have undergone years of market validation. We hope to lower the threshold of adopting this technology and bring metal 3D printing to millions of factories by adhering to the principle of 'make it possible, make it affordable.' We are happy that BLT and EME reached the consensus."

www.xa-blt.com

Globus Metal Powders launched following acquisition of Liberty Powder Metals

Liberty Powder Metals Ltd, has been acquired by a group of private investors and, with immediate effect, will be known as Globus Metal Powders Ltd. The company, based in Middlesbrough, UK, produces a range of metal powders for Additive Manufacturing and Powder Metallurgy technologies.

"Globus Metal Powders and our team of professionals will continue to drive excellence and growth, we are very proud of the successes achieved and are excited about the new opportunities the acquisition will offer in terms of growth, productivity, and profitability," the company stated.

As the company's new website is still in progress, contact Becky.a@globusmetalpowders.com.

Additive Assurance opens Centre of Excellence for metal Additive Manufacturing

Additive Assurance, Melbourne, Australia, has established a Centre of Excellence for metal Additive Manufacturing quality at its Oakleigh facility in Victoria. The company recently installed and commissioned a Trumpf/Sisma Mysint 300 Laser Beam Powder Bed Fusion (PBF-LB) machine to serve as a demonstrator at the facility.

The Centre of Excellence in Oakleigh is said to represent a significant investment for Additive Assurance, and it is expected to be a hub of innovation and collaboration for metal Additive Manufacturing in the region. The facility is equipped to facilitate research, development, and training, contributing to the growth and advancement of the industry.

www.additiveassurance.com

Ermaksan Additive announces Enavision 120 PBF-LB for lab and office use

Ermaksan Additive, located in Nilüfer, Bursa, Turkey, has launched its Enavision 120 metal Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machine. The compact machine features a 300 W laser and a production volume of Ø120 mm x 80 mm within an inert argon/nitrogen atmosphere. The design is specifically tailored to suit laboratories and office environments, making it ideal for universities and research institutes.

Users can adjust machine parameters based on part geometry and specific production requirements. The Enavision 120 functions with Materialise Magics and Modules and Ermaksan's own build processor.

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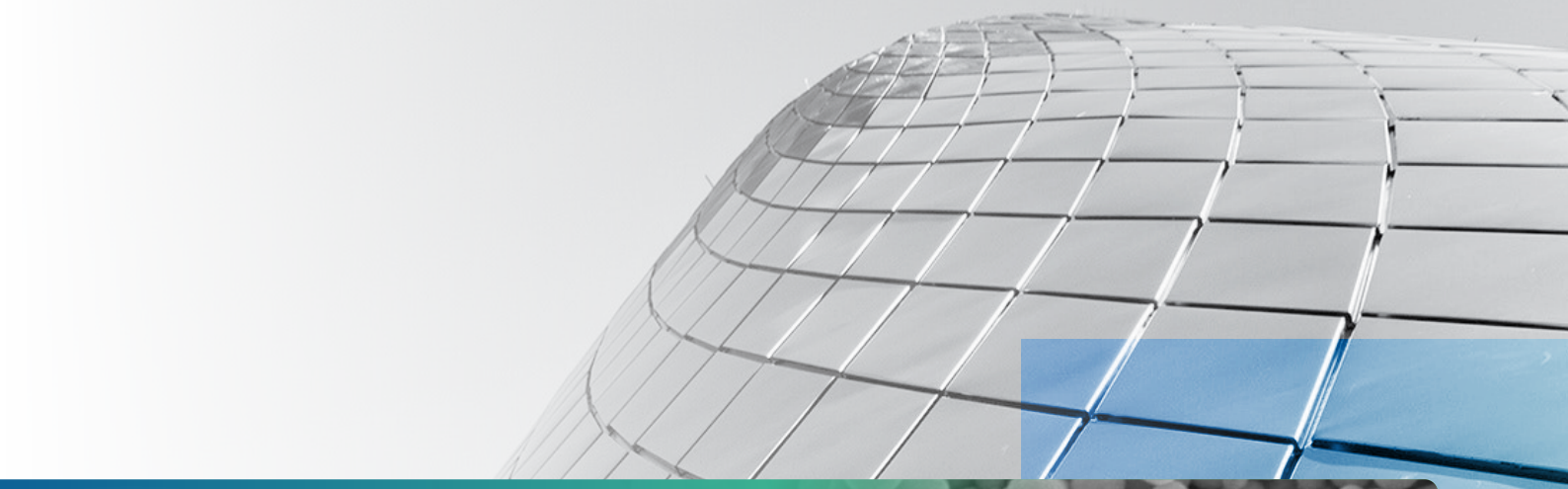

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MAN Truck & Bus adopts Replique's Additive Manufacturing for efficient spare parts production

In partnership with Replique GmbH, based in Mannheim, Germany, transport solutions provider MAN Truck & Bus is now using Additive Manufacturing to manufacture spare parts at point of need. Starting with the production of bronze manifolds, MAN aims to undertake further projects in the future to reduce costs and further optimise service.

In special machine construction, ensuring spare parts supply is often challenging, explains Replique. Small quantities, unpredictable consumption, and sometimes lengthy delivery times typically require stocking critical components to avoid costly equipment or machine downtimes.

As an illustration of these issues, MAN urgently needed to acquire ten out-of-stock bronze manifolds for the cooling water supply of a marine engine. The casting mould for this component was unavailable, however, and conventional procurement methods (involving the creation of models, casting, and mechanical machining) would have been time and cost intensive.

The company's search for an alternative solution led to its collaboration with Replique. Using a 3D model and a manufacturing drawing, all ten m4p™ Brz10 manifolds were able to be reproduced with Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing, undertaken by a local AM service within Replique's partner network. From initial enquiry to delivery was seven weeks.

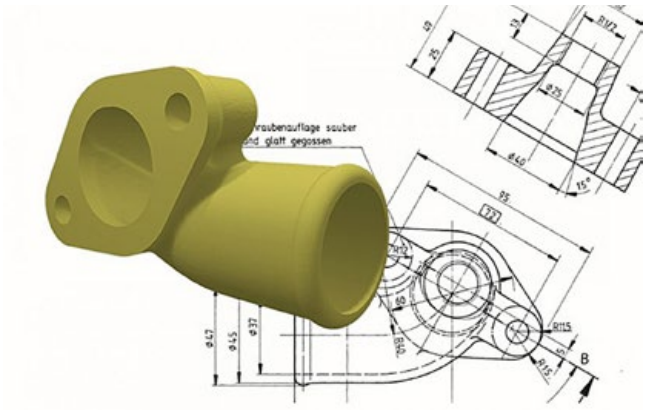
Tensile tests conducted at MAN's Central Material Technology department revealed that the chosen material actually exhibited better technical properties than the original. The AM bronze manifolds were said to surpass the requirements of the original part. Due to the digital availability of production information, they can be reordered at any time with consistent quality. The use in practice of these parts has led MAN to place an additional order for ten units.

As the relevant component has already been qualified for Additive Manufacturing and a corresponding build file is created and digitally available, including information on the used material and technology, the manifolds can be reordered at any time in consistent quality. MAN incurs no fixed costs for moulds and models or storage costs, resulting in attractive overall costs per unit for small quantities.

"The collaboration with Replique was seamless from our initial contact to the moment we received the finished parts. It allowed us to promptly assist our spare parts customers, and we are already in the process of realising another 3D printing project with Replique," said Thomas Hauck, Spare Parts Logistics MAN.

Dr Max Siebert, CEO and co-founder of Replique, added, "The use of Additive Manufacturing enables companies to overcome traditional production challenges. We are happy to work together with MAN to ensure a reliable and efficient supply of spare parts in the transport and marine sectors."

www.replique.io



MAN utilised Additive Manufacturing to urgently procure ten bronze distributors for the cooling water supply of a marine engine, which were no longer in stock (Courtesy Replique)

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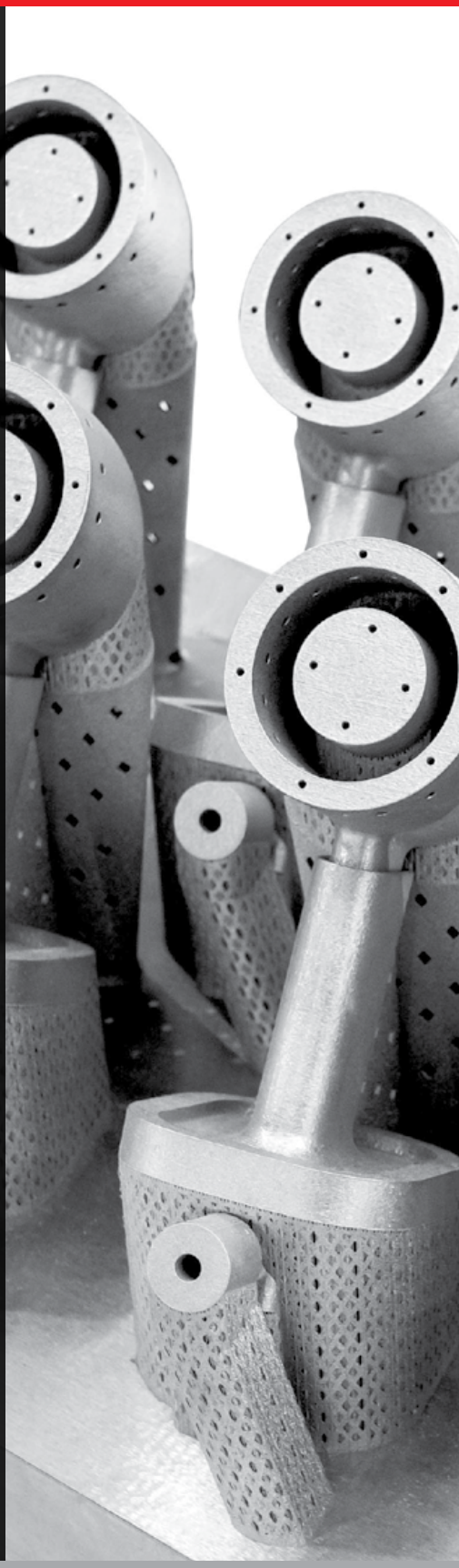

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The GRCop story: The development, production and Additive Manufacturing of NASA's rocket engine alloys

The new space race is powered by metal Additive Manufacturing. In turn, the Additive Manufacturing of rocket engines is powered by advanced alloys. Of these, NASA's GRCop family has found use in numerous critical applications. In this article, Austin Whitt and David Ellis, NASA Glenn Research Center, and Paul Gradl, NASA Marshall Space Flight Center, dig deep into the history, production, processing and maturation of these unique materials. As the authors reveal, there is good reason why Additive Manufacturing of GRCop begins by understanding the process-microstructure-property-performance relationship.

The aerospace industry is truly remarkable and, all too often, we take its astonishing achievements for granted. The seamless connectivity of the internet, GPS, cellular phones, and telecommunications systems are all made possible by the intricate array of satellites launched aboard powerful rockets. In the vast expanse of space, the International Space Station tirelessly orbits 400 kilometres above Earth, pushing the boundaries of scientific discovery. We marvel at high-speed aircraft executing manoeuvres that test the limits of human endurance. We gaze in awe at the captivating images beamed back from rovers exploring Mars and deep-space telescopes venturing into the farthest reaches of distant galaxies. This industry not only enhances our daily lives with materials, electronics, and technological advancements, but also shows us the grandeur of our universe.

What is truly striking is the common thread that runs through all these incredible projects: a vision of the future and an immense team effort, often involving thousands, if not tens of thousands of individuals working together to achieve the extraordinary. In the aerospace world, it's a rarity to single out one person for credit on a project, as the magnitude of these accomplishments necessitates the collective expertise and collaboration of countless dedicated individuals. However, within this collective endeavour, people like Dr David Ellis from NASA Glenn Research Center in Cleveland, Ohio, stand out. Dr Ellis is a materials researcher and an expert on high thermal conductivity materials for rocket engines. Dr Ellis' career work

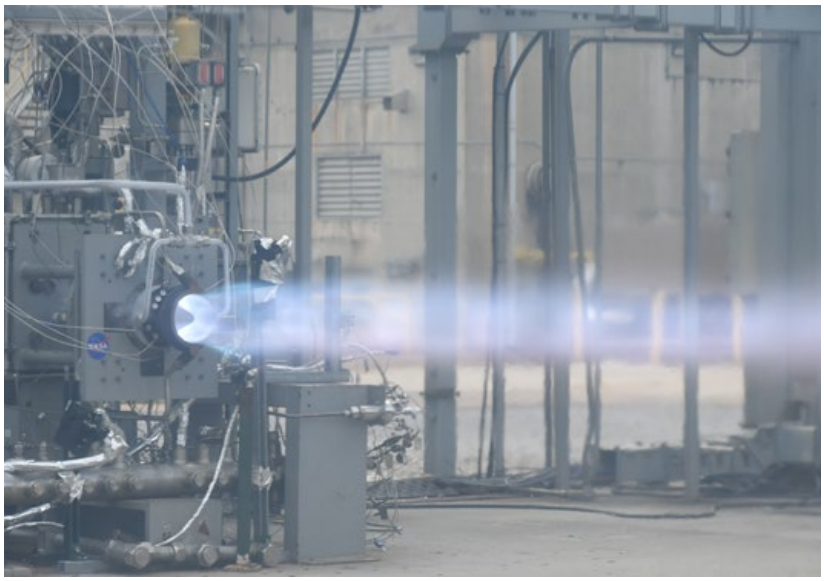


Fig. 1 Hot-fire test of a PBF-LB GRCop-42 plug nozzle and outer body for a Rotating Detonation Rocket Engine (Courtesy NASA)

Fig. 2 PBF-LB GRCop-42 is used for Relativity Space's the Aeon 1 engines (Courtesy Relativity Space/photo John Kraus)

"Pure copper has very high conductivity but lacks the high temperature strength needed to resist thermal stress during operation. Mixing other elements with copper to improve its strength sounds appealing, but even a small addition of other elements can disrupt the atomic structure of copper and drastically reduce conductivity."

on the GRCop alloys serves as a testament to the industry's innovation and ambition.

Rocket engines operate in extreme thermal and structural environments, necessitating the development of innovative materials. The heart of the rocket engine, the combustion chamber, commonly employs intricate internal cooling channels to efficiently dissipate heat from the chamber and transfer it into the liquid fuel. To maximise the amount of heat transferred to the fuel and prevent melting, the chamber liner is constructed using a material with high thermal conductivity. This same concept is used for various heat exchangers with a variety of operating fluids.

Pure copper has very high conductivity but lacks the high temperature strength needed to resist thermal stress during operation. Mixing other elements with copper to improve its strength sounds appealing, but even a small addition of other elements can disrupt the atomic structure of copper and drastically reduce conductivity. This presents an interesting problem for materials scientists, like Dr Ellis, to solve: how can we strike an acceptable balance between strength and conductivity?

History – overnight successes take many years

Development of the GRCop family of Cu-Cr-Nb alloys began in 1987 as part of the Earth-To-Orbit (ETO) programme. NASA needed a replacement for NARloy-Z, a Cu-3 Ag-0.5 Zr alloy used for the Space Shuttle Main Engine (now RS-25) combustion chamber liner. A liner made from NARloy-Z could start to develop cracks in as little as three missions due to fatigue from thermal stress. Since the NARloy-Z liner was one of the longest lead items on the Space Shuttle, frequent replacements were costly. The goal of the ETO programme was to increase both the life and temperature capability of the second-generation SSME engines to decrease operational costs

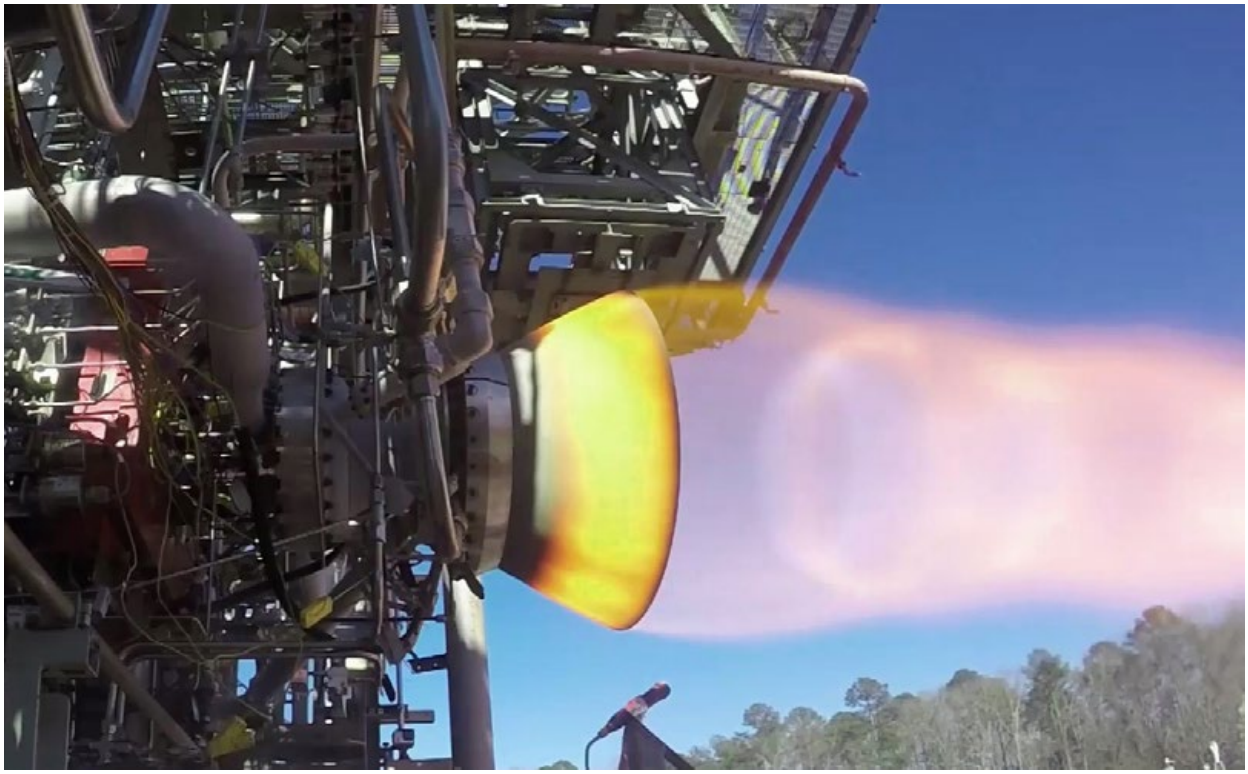


Fig. 3 Liquid oxygen / liquid hydrogen hot-fire testing of PBF-LB GRCop-84 chamber with a bimetallic AM structural jacket and composite nozzle (Courtesy NASA)

and increase performance. Many alloys were examined through this programme, but the Cu-Cr-Nb alloys showed the most potential.

Silver, copper, gold, and aluminium were considered as potential base materials due to their high thermal conductivities. Ultimately, copper emerged as the preferred choice because it boasts the second-highest thermal conductivity behind silver and has a superior melting point. Many copper alloys, such as NARloy-Z, effectively balance the trade-off between strength and conductivity by employing precipitation strengthening. The formation of precipitates results in the extraction of alloying elements from the copper matrix. As the copper matrix is comparatively pure, the material strengthened through precipitation exhibits greater thermal conductivity when compared to a solid solution with an identical overall composition. NASA researcher Thomas Glasgow embarked on a mission to discover more robust and stable precipitates, with the aim of enhancing the reusability and high-temperature performance of copper alloys. It was during this pursuit that Dr Glasgow identified chromium and niobium as a potential winning combination.

"With a hard, stable precipitate and a pure copper matrix, the plan for a new alloy was born. This alloy was later named the Glenn Research Copper alloy, or GRCop."

Chromium and niobium were known to have minimal solid solubility in copper but very high solubility in liquid copper. They form a compound, Cr_2Nb, that could be used for precipitation strengthening. This high melting point compound has a hardness roughly equivalent to alumina and a melting point above 1,700°C. Thermodynamics also shows that a compound has a lower solubility than its constituent elements, so the copper matrix would be nearly pure up to the melting point of copper. With a hard, stable precipitate and a pure copper matrix, the plan for a new alloy was born. This alloy was later named the Glenn Research Copper alloy, or GRCop.

However, in practice, the production of GRCop was a challenge. Over the next thirty-six years, Dr Ellis would tackle the challenges of development, characterisation, standardisation, Additive Manufacturing, and eventually flight of the GRCop alloys GRCop-42 and GRCop-84.

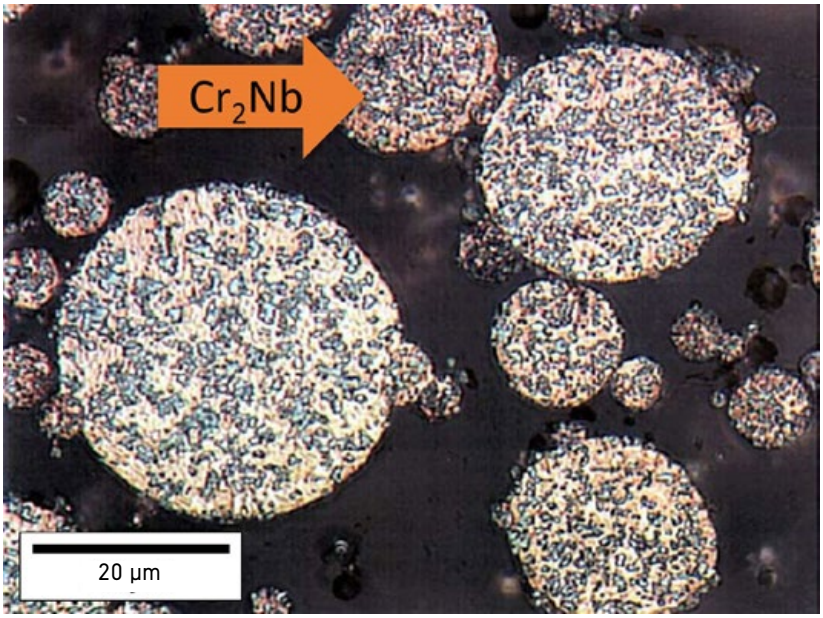


Fig. 4 GRCop powder showing dispersion of Cr_2Nb in the copper matrix (Courtesy NASA)

Mother Nature demonstrated the remarkable stability of Cr_2Nb as, even in rapid solidification, it would precipitate in the liquid copper. Any attempt to cast a large volume of Cu-Cr-Nb would lead to substantial chunks of Cr_2Nb floating on the liquid copper. Achieving the strength benefits sought by NASA required the Cr_2Nb to be in the form of fine particles evenly dispersed throughout the copper matrix. To address this, the molten alloy was heated beyond the melting point of Cr_2Nb then solidified rapidly using chill block melt spinning (CBMS). In CBMS, the molten alloy is deposited onto a heat sink wheel rotating at high speeds. This results in thin ribbons of material that have been solidified and cooled almost instantly. Using this method, Dr Ellis made a range of GRCop alloys by varying Cr from 2-10 at.% and Nb from 1-5 at.% while maintaining a 2:1 ratio of Cr to Nb. These alloys were named according to their Cr and Nb content, with GRCop-XY corresponding to X at.% Cr and Y at.% Nb (i.e., GRCop-42).

Analysis of the ribbon revealed that the Cr_2Nb precipitated out of the molten copper into agglomerations of 10-100 nm particles. Then, the copper matrix solidified around the particles, which prevented further growth. The result was a dispersion strengthened alloy with high conductivity, GRCop [1]. Reusability and life were the main impetus for the ETO programme creating the family of alloys, so a composition with a large amount of Cr_2Nb was further investigated. GRCop-84 (Cu-8 at.% Cr-4 at.% Nb) was chosen as further increasing the amount of Cr and Nb was found to make production less practical.

Compared to low alloy Cu-Cr, Cu-Zr, and Cu-Cr-Zr alloys that are precipitation strengthened, GRCop has a lower thermal conductivity. It also has a lower strength at temperatures below 400°C. However, between 400°C and 800°C, GRCop achieves higher strength than these alloys. Around 500°C, these precipitation-strengthened alloys overage and become very weak. In contrast, GRCop-84 retains a usable strength of >105 MPa up to 700°C. Cr_2Nb dispersoids are even stable enough for GRCop to retain over half its strength after a 100-hour exposure at up to 1,050°C, about 98% of the melting temperature.

From 1997 through 2005, NASA's Reusable Launch Vehicle (RLV) Program looked to GRCop alloys to improve the performance of the engines with targets of reaching 100 missions before depot maintenance and a 1,000-mission life. Based upon data developed under the RLV Second Generation programme, GRCop-84 could have achieved these goals. This was demonstrated by a subscale 22 kN (5,000 lbf) rocket combustion chamber that used the same design as the one used to qualify NARloy-Z. After 250 cycles and two injector failures that sent shards of metal through the chamber, the hot wall (interior) surface of the liner was pristine. The RLV programme also scaled up GRCop production for the 4,448 kN (1 M lbf) engines.

While GRCop-84 was pursued for its high strength, creep resistance, and overall life, GRCop-42 was also produced and characterised for its higher conductivity. GRCop-84 and GRCop-42 have 14 vol.% and 7 vol.% Cr_2Nb, respectively. A reduction in Cr_2Nb results in small performance decreases in mechanical properties but increases the thermal conductivity by 15% for GRCop-42 [2]. As life became less of a concern, this advantage has moved GRCop-42 to the forefront in AM rocket engine parts.

The fine and coarse details of powder production

The production of GRCop powders is by far the most challenging part of GRCop alloys. GRCop powder is produced through gas atomisation. GRCop must be atomised in argon. Atomisation in nitrogen can form nitrides that can initiate fracture in service. The Cr_2Nb has been observed to form within seconds of melting in elemental Cu-Cr-Nb charges. It is necessary to raise the temperature to near or even above the melting point of Cr_2Nb (1,733°C) to achieve a uniform melt. Normally, alumina would be used for the crucible and tundish. At these high temperatures, even a small amount of Nb reacts with alumina and fluxes the crucible, which adds detrimental oxide particles to the powder. These particles can serve as crack initiation sites and reduce the fatigue life of the part.

NASA GRC solved this problem by yttria coating the interior of its crucibles. Other oxides more stable than alumina can also be used as candidate crucible materials. Regardless of the crucible material, there is a need to balance the melt temperature to ensure complete dissolution of Nb while avoiding erosion of the crucible or nozzle used in atomisation. Many powder manufacturers have noted that GRCop-42 is easier to produce than GRCop-84 due to the lower melt temperature. This is another reason for the adoption of GRCop-42 into the supply chain.

Iron and oxygen contamination in the powder is a significant concern. It was observed that an iron (Fe) content of 200-250 ppm is enough to substantially reduce the thermal conductivity of GRCop-84. The Fe originated from contamination in Cr, so the material was modified to utilise a low Fe version of high purity Cr. The detrimental impact of oxygen on the thermal conductivity of copper alloys has long been recognised. Once oxygen content exceeds 1,000 ppm, Cr and Nb oxides are formed, which reduce ductility and other mechanical properties. Since some degree of oxygen pickup is inevitable during AM, the powder specification requires an oxygen content of less than 500 ppm. Given the high surface area of the GRCop powders and presence of relatively reactive Cr and Nb, there is a risk of oxygen uptake even when the powders are stored in sealed containers. Consequently, it became essential to handle the powders in inert environments, such as argon and vacuum conditions. During the handling and manufacturing of GRCop, any changes in colour, such as darkening, should be regarded as indicative of oxygen absorption. If the GRCop powder turns blue or purple, you have an expensive paperweight.

In the production of GRCop alloys, the variability in the amount of Cr_2Nb is manageable, but it is crucial to carefully control the Cr to Nb ratio. The composition of Cr_2Nb can vary depending on temperature and cooling rate. Based upon the Cr-Nb phase diagram, important compositional constraints have been identified. The first constraint is the maximum Nb that can be present in Cr_2Nb. If Cr_2Nb is rich in Nb, the Nb activity is at its peak, and the Cr_2Nb will be susceptible to hydrogen embrittlement, similar to Nb. This is a concern in hydrogen-based application since it can lead to rapid failures.

The other important constraint pertains to the maximum allowable Cr content within Cr_2Nb (Fig. 4). At this specific composition, the Nb activity is minimised. Low Nb activity ensures that GRCop is not vulnerable to hydrogen embrittlement. This specific composition corresponds to a Cr to Nb ratio of 2.05 on an atomic basis. Beyond this ratio, there is a possibility to have an excess of Cr dissolved in the Cu matrix. The consequence of this excess Cr is a reduction in conductivity at room temperature. However, when the temperature is raised above 500°C, the surplus Cr begins to precipitate as elemental Cr. This results in a mild strengthening effect and maximum thermal conductivity. At higher operating temperatures, overaging of the Cr precipitates occurs and their beneficial effects are lost.

The Cr to Nb ratio shown in Table 1 must be met to obtain the benefits of the GRCop alloys. It is permissible to combine powder lots, but it's crucial that each lot adheres to the composition specifications on an individual basis. It is not acceptable to mix a lot with high Cr with

Element	GRCop-42 wt.%	GRCop-84 wt.%
Cr	3.1 - 3.4	6.2 - 6.8
Nb	2.7 - 3	5.4 - 6.0
Fe	Target <10 ppm (50 ppm max.)	
O	Target <250 ppm (500 ppm max.)	
Al	Target <100 ppm (400 ppm max.)	
Si	Target <100 ppm (350 ppm max.)	
Cu	Balance	
Cr/Nb*	2.02 (atomic)	2.12 (atomic)
	1.13 (weight)	1.18 (weight)

Table 1 Specification for GRCop-42 and GRCop-84 powders

"During the handling and manufacturing of GRCop, any changes in colour, such as darkening, should be regarded as indicative of oxygen absorption. If the GRCop powder turns blue or purple, you have an expensive paperweight."

Fig. 5 GRCop-42 chambers being manufactured simultaneously by PBF-LB (Courtesy NASA)

a lot with high Nb, as this can lead to the formation of both niobium hydride and Cr precipitates. Similarly, a lot with elevated oxygen levels will introduce oxide particles into the part regardless of the overall oxygen concentration in the blended feedstock.

Maintaining the 2.05 Cr to Nb ratio is a challenge because the dissolution of Nb into liquid Cu is slower compared to Cr. Additionally, the maximum amount of Nb that can be dissolved at any given temperature is lower than that of Cr, based upon the Cu-Cr and Cu-Nb phase diagrams. This necessitates raising the melt temperature, which adds complexity to both melting and the atomisation process. Additionally, the volatilisation of Cu and Cr also becomes a significant issue. While achieving the desired chemistry is difficult, NASA has collaborated with multiple vendors to successfully atomise GRCop powders [3].

"The NASA Low-Cost Upper Stage Propulsion (LCUSP) project played a pivotal role in advancing the Additive Manufacturing of GRCop-84 and the validation of PBF-LB GRCop-84 liners and jackets through hot-fire testing."

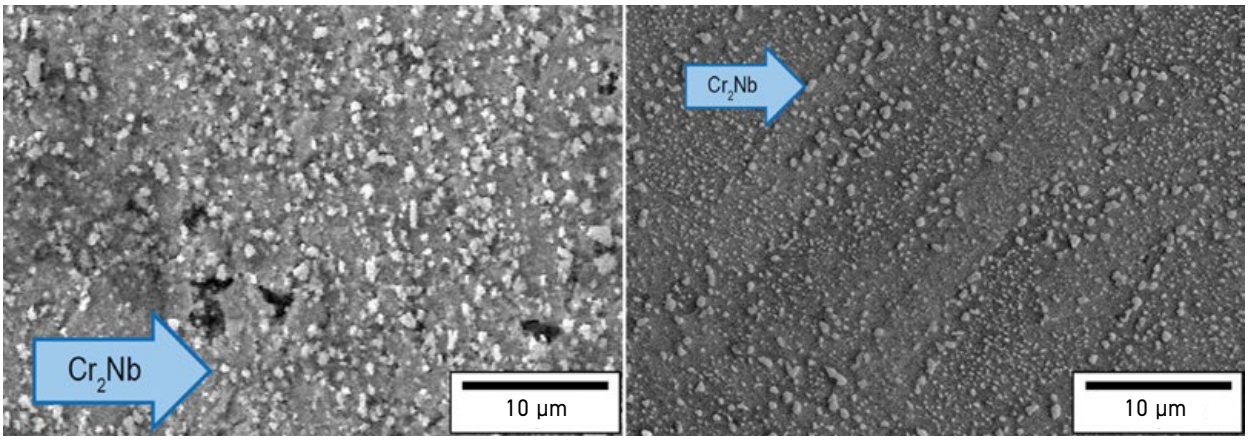
GRCop proves exceptional in AM

GRCop chamber liners were originally produced by Powder Metallurgy techniques such as hot extrusion and Hot Isostatic Pressing (HIP) to create feedstock and near net shapes [4]. Extruded material could be rolled into plate and formed into a liner using forging, friction stir welding, and metal spinning. Machining and closeout of the cooling channels were still necessary to make the liner. Drawing to make tubing for the RL-10 family of engines was also successfully demonstrated. Unfortunately, losses were high, with up to 95% of the starting material being scrapped. No viable recycling method for the scrap was ever developed.

Additive Manufacturing of GRCop allows for the creation of a chamber with integral cooling channels directly into the part, which significantly reduces waste material and process steps compared to traditional combustion chamber manufacturing. This allows for rapid iterations during the development cycle and has made combustion chamber technology more accessible to industry and academia.

The NASA Low-Cost Upper Stage Propulsion (LCUSP) project played a pivotal role in advancing the Additive Manufacturing of GRCop-84 and the validation of PBF-LB GRCop-84 liners and jackets through hot-fire testing. It also showcased the ability to achieve a >60% cost saving and remarkable 3X reduction in lead time versus the same thrust cell made concurrently by conventional subtractive manufacturing.

NASA's current Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) project focused on maturing the GRCop-42 alloy through supply chain improvements, component development with hot fire testing, and publicly-available properties. Collaborative efforts with commercial space partners culminated in a successful flight test that marked a significant milestone in the alloy's application and development.



Extruded GRCop-84 **PBF-LB GRCop-84**

Fig. 6 Micrographs showing more refined Cr_2Nb particles in PBF-LB GRCop-84 (Courtesy NASA)

GRCop was developed ahead of the rise of metal AM but has proven well-suited to PBF-LB and powder/laser Directed Energy Deposition (DED). AM has proven to be advantageous for enhancing the mechanical properties of GRCop alloys. In laser AM processes, the refinement of Cr_2Nb particles occurs and increases strength from Orowan strengthening. The breakup of agglomerated particles or the remelting and precipitation of finer particles, depending on build parameters, contributes to this strengthening phenomenon. The LCUSP project showcased the positive impact of these finer Cr_2Nb particles achieved through the AM process by demonstrating substantial improvements in mechanical properties (Fig. 6) [5].

Unlike the challenges with PBF-LB AM of many copper-based alloys, GRCop exhibits ease of manufacturing. Pure copper has high reflectivity in the near-IR wavelengths commonly used for AM processes. As much as 75% of the laser energy can be reflected. Above room temperature, the reflectivity of copper diminishes rapidly, which enables greater energy absorption. Consequently, melting the powder bed without overheating the melt pool becomes a challenging task. It has been hypothesised that the Cr_2Nb in GRCop absorbs the laser energy more effectively and indirectly heats

"AM has proven to be advantageous for enhancing the mechanical properties of GRCop alloys. In laser AM processes, the refinement of Cr_2Nb particles occurs and increases strength from Orowan strengthening."

Fig. 7 Various GRCop-42 PBF-LB combustion chambers (Courtesy NASA)

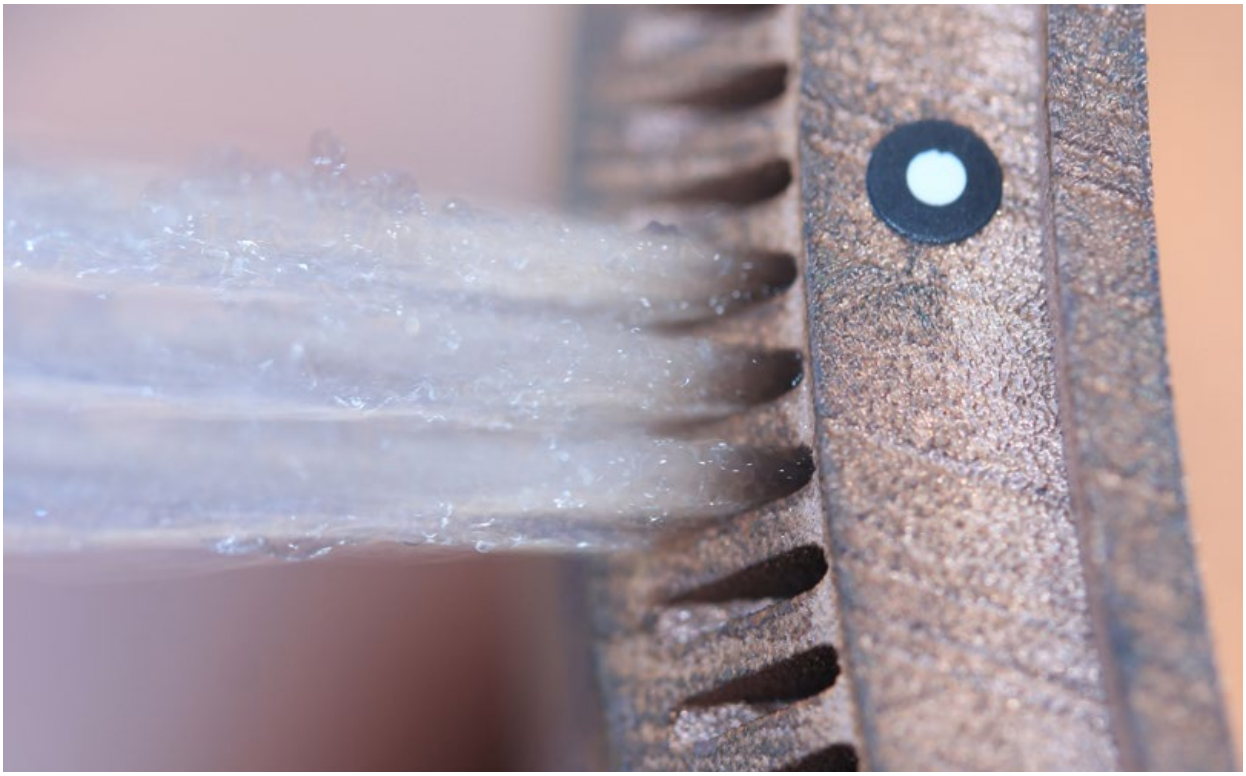


Fig. 8 Water flow test to confirm powder removal from internal cooling channels [5] (Courtesy NASA)

the copper. This phenomenon jump-starts the heating of GRCop powder from room temperature. As a result, lower laser power can be employed, and the risk of keyholing is reduced compared to other copper alloys.

GRCop alloys have been successfully fabricated on a range of machine platforms with diverse layer heights and recoater types. The typical volumetric energy density for GRCop-42 builds falls within the range of 75-95 J/mm^3, though this can vary based on the specific machine configuration. Additionally, various scan strategies have been employed, including continuous, stripes, and checkered patterns. Despite variations in parameters and configurations across different machines and processes, the mechanical and thermophysical properties of GRCop alloys remain consistent with only minor variations measured during extensive testing.

Another advantage of AM GRCop is reduction of waste due to the ability to recycle the powder. Research indicates that GRCop can be recycled at least twelve times without compromising room temperature tensile or low cycle fatigue properties (Fig. 9). While the properties remain robust, there is a reduction in powder flowability as indicated by changes in avalanche energy, avalanche angle, and break energy.

"Research indicates that GRCop can be recycled at least twelve times without compromising room temperature tensile or low cycle fatigue properties. While the properties remain robust, there is a reduction in powder flowability as indicated by changes in avalanche energy, avalanche angle, and break energy."

The proof is in the properties

The primary benefit of GRCop alloys as compared to other copper alloys is increased performance at high temperature. At elevated temperatures, the strengthening mechanisms used in other copper alloys often become ineffective. In contrast, GRCop-42 can maintain its strength for sustained durations at service

temperatures approaching 700°C and limited life applications above 700°C (Fig. 10).

AMZIRC (C15000) is a precipitation-strengthened Cu-0.15 wt.% Zr alloy that is commonly aged and cold worked. Cold worked AMZIRC has substantially higher strength than GRCop alloys at room temperature but loses strength after annealing and overaging. In one study, AMZIRC and GRCop-84 were heat treated at 935°C to simulate a brazing operation. While the GRCop material was hardly affected, the AMZIRC lost up to 90% of its room-temperature yield strength [6].

GRCop-42 achieves a much higher conductivity than GRCop-84 with only a small reduction in strength. Higher conductivity serves to decrease the hot wall temperature and increase the temperature of the liquid fuel, which improves engine performance in expander cycle engines. AMZIRC and Cu-Cr-Zr (C18150) have higher thermal conductivity than GRCop-42 but require solution and aging heat treatments to control precipitate size and distribution. These heat treatments are typically performed near the operating temperature of combustion chambers, so the properties of C-18200 and C-18150 can degrade during thermal exposure. In practice, this limits these alloys to operational temperatures of 250-350°C, with excursions above 500°C causing overaging and annealing if cold worked. These result in reductions in strength and other mechanical properties of 90% or more.

The thermal stability of the GRCop microstructure enables a larger variety of post processing and joining options. Typically, GRCop undergoes HIP treatment after the build. This step serves to stress relieve the parts and close any minor porosity. AM builds of GRCop consistently achieve greater than 99.7% density and, in most cases, exceed 99.9% depending on the specific process parameters. In other copper alloys, a high temperature HIP or stress relief could damage the microstructure. GRCop can withstand these

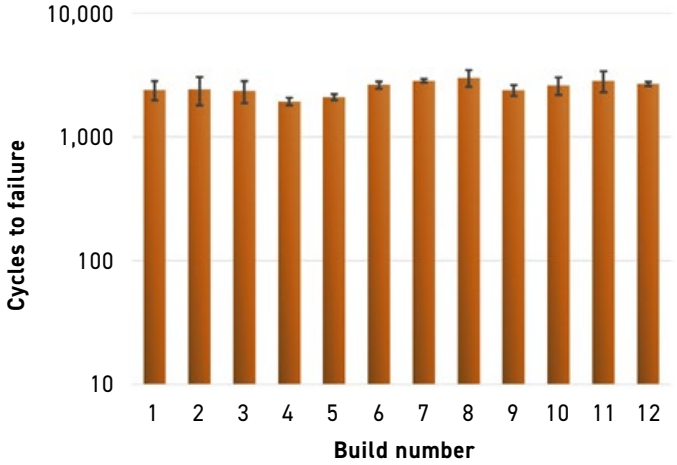


Fig. 9 PBF-LB GRCop-42 powder reuse low cycle fatigue results showing consistent properties across many builds. Error bars represent standard deviation for each of the builds (Courtesy NASA)

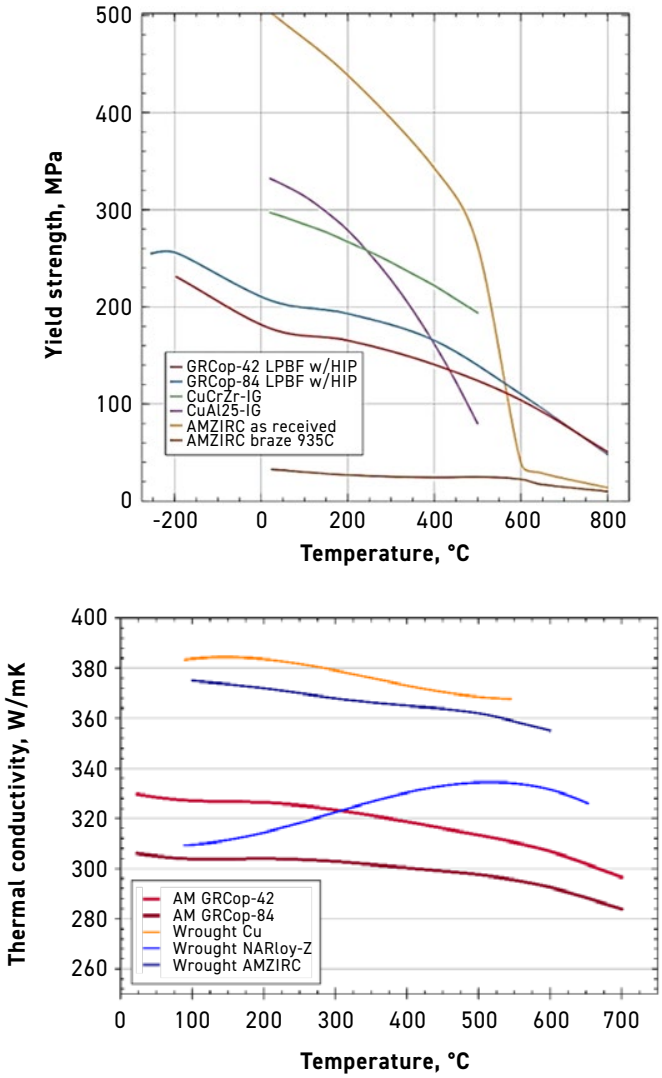


Fig. 10 Yield strength and thermal conductivity as a function of temperature for PBF-LB GRCop compared to several wrought copper alloys (Courtesy NASA)

Fig. 11 Bimetallic thrust chambers using PBF-LB GRCop-42 for high conductivity and other superalloys for higher strength-to-weight ratio (Courtesy NASA)

"NASA has advanced GRCop applications further by demonstrating bimetallic and multi-metallic AM techniques. This allows for deposition of superalloy structural jackets and integral nozzles with continuous cooling passages onto the GRCop liner using DED processes or cold spray."

treatments and other high temperature processes such as brazing and welding.

NASA has advanced GRCop applications further by demonstrating bimetallic and multi-metallic AM techniques [7]. This allows for the deposition of superalloy structural jackets and integral nozzles with continuous cooling passages onto the GRCop liner using DED processes or Cold Spray AM. This approach leverages the properties of different metals to enhance the overall performance and functionality of the components (Fig. 11).

Rocket engine combustion chambers pose a challenging chemical environment for materials. The local conditions within the combustion chamber can swiftly transition from oxidising to reducing and vice versa due to flow instabilities in the fuel and oxidiser. Cyclic oxidation at elevated temperatures can induce blanching and cause erosion, crack formation, and the transformation of the material into a low-conductivity copper sponge. In cyclic oxidation studies at 600°C, NARloy-Z and AMZIRC were both oxidised severely [8]. Under the same conditions, GRCop-84 forms a stable protective oxide layer that prevents further blanching. This allows extended use of GRCop alloys under these harsh conditions.

A critical factor impacting the reusability of combustion chambers and heat exchangers is low cycle fatigue (LCF) of thin-walled cooling channels through which coolant or cryogenic propellant flows. During each firing of the rocket, the channel walls experience thermal expansion and high strains. Due to the liner being constrained, this expansion induces high thermal stresses and plastic deformation. Over repeated cycling, the liner wall could eventually rupture. GRCop alloys exhibit lower coefficient of thermal expansion (CTE) in comparison to other copper alloys. This characteristic

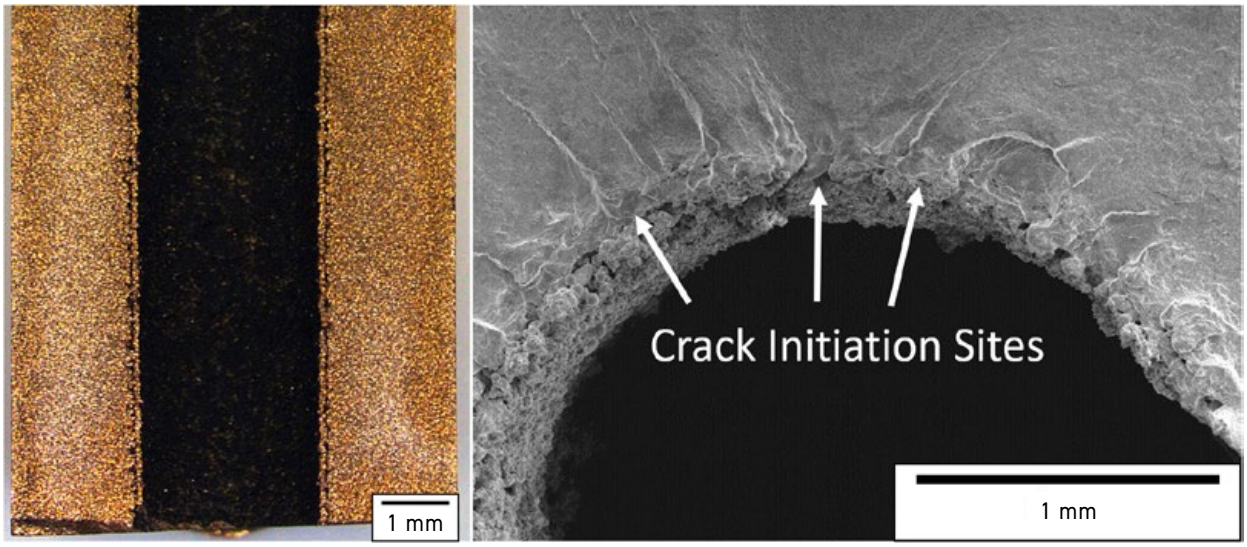


Fig. 12 Low Cycle Fatigue (LCF) fracture surface of a GRCop-84 tube with as-built interior surface (Courtesy NASA)

implies that for a given hot wall temperature, GRCop liners experience lower fatigue strains and thermal stresses.

LCF testing has demonstrated that GRCop samples can endure hundreds of cycles at 2% strain and tens of thousands of cycles at 0.7% strain [9]. NASA conducted investigations into the LCF performance of GRCop-84 tubes to understand the effect of the as-built surface inside of PBF-LB cooling channels. Cracking consistently initiated at flaws in the as-built interior surface and led to reduced fatigue life. Various surface enhancement processes are being developed to improve the interior surface finish of AM GRCop parts.

Both GRCop-84 and GRCop-42 exhibit similar performance in LCF. However, if the same design is applied to chambers made from both materials, the higher thermal conductivity of GRCop-42 would result in lower hot wall temperatures. This improves material performance and transfers more energy to the fuel, which is critical for increasing pressures and performance in expander cycle engines (Fig. 12).

In reusable rocket engines, where high temperatures and extended operating times are prevalent, the creep performance of the material becomes crucial. The liner must resist thermal stress as well as pressure exerted by the propellants inside the cooling passages for prolonged periods. GRCop-84 samples fabricated using PBF-LB were shown to have creep lives one or two orders of magnitude higher than wrought counterparts.

In the Additive Manufacturing of many materials, the processing parameters are tuned to refine the grain structure of the final part. However, in the case of GRCop alloys, the grain structure is primarily controlled by the size and spatial distribution of Cr_2Nb particles. Copper grains grow until they are pinned by Cr_2Nb particles, which leads to a self-controlled grain size of 1-3 µm in GRCop-84 and 2-5 µm in GRCop-42. When Cr_2Nb is well-distributed, the grain size remains within the range of 1-5 µm, irrespective of laser parameters or thermal post processing. This phenomenon explains the consistent properties observed across different AM machines.

An additional potential benefit observed with AM GRCop alloys is related to the solidification process, which results in highly-textured

"...in the case of GRCop alloys, the grain structure is primarily controlled by the size and spatial distribution of Cr_2Nb particles. Copper grains grow until they are pinned by Cr_2Nb particles, which leads to a self-controlled grain size of 1-3 µm in GRCop-84 and 2-5 µm in GRCop-42."

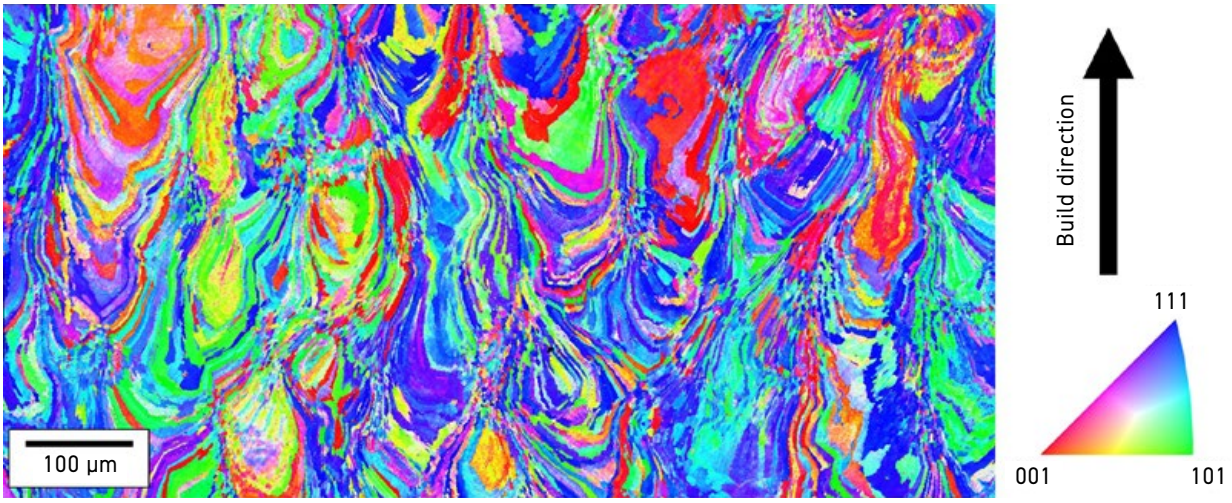


Fig. 13 Electron Backscattered Diffraction (EBSD) map showing crystallographic and microstructural texture of Cu grains (Courtesy NASA)

Powder	Mesh or Micron Size	Notes
GRCop-42 PBF	-140 mesh/+325 mesh 105 (µm)/45 (µm)	1. Particles greater than +140 mesh shall be limited to ≤ 1.0 wt.% per ASTM B214 2. Particles smaller than +325 mesh shall be limited to < 5.0 wt.% per ASTM B214
GRCop-42 DED	-325 mesh/+1250 mesh -45 (µm)/+10 (µm)	1. Particles greater than +325 mesh shall be limited to ≤ 1.0 wt.% per ASTM B214 2. Particles smaller than 10 (µm) shall be limited to ≤ 5.0 cumulative vol.% per ASTM B822

Table 2 GRCop-42 Powder Size Distribution

grains elongated in the build direction. During the solidification process, Cu atoms come together into a cubic lattice structure to form grains. The cube face diagonal aligns with the build direction and creates a crystal texture for the grains. Even after the HIP process, the grains maintain the same crystallographic texture instead of becoming randomly oriented like most recrystallised wrought metals [13]. The solidification process also causes the grains to be elongated along the build direction, creating metallographic texture. Due to anisotropy in the material, a designer may take advantage of a strong crystallographic direction by specifying a build orientation, like a woodworker who carefully orients wood grain. Most AM GRCop samples are tested in the build direction, which is near a weak <101> copper orientation. As a result, the reported values are slightly conservative, and there may be additional benefits in mechanical properties in other orientations.

Processing details that matter

GRCop-42 has been built using a variety of parameter sets, different machine platforms, configurations, and even AM processes. GRCop adheres well to Inconel 625 or Inconel 718 build plates, which are the most compatible, although mild steel has been used. The typical process uses stainless steel build plates with a 1 mm thick alloy 625 or 718 bond layer to promote adherence of the GRCop.

Typical powder distributions are 10-50 µm for PBF-LB and 45-105 µm for DED. Specifics are listed in Table 2. To maintain the quality of GRCop powder, it should be stored under vacuum or in an inert atmosphere to prevent oxidation. After usage, recycled powder should undergo sieving to eliminate agglomerations and spatter particles larger than 45 µm. During powder handling and storage, it is crucial to minimise exposure to oxygen. If a significant buildup of oxygen occurs, cubic niobium oxide particles may form. These particles can act as crack initiation sites and may react with high-pressure hydrogen.

It is speculated that the recycling of GRCop may be practically limited by the coarsening of Cr_2Nb. While Cr_2Nb is stable, repeated high-temperature exposure near the melt pool can eventually lead to coarsening, which may impact the material's performance over successive recycling cycles.

Unlike many copper alloys that use heat treatment to control the size and distribution of precipitates,

Fig. 14 PBF-LB GRCop-42 has been flight proven on the Aeon 1 engine by Relativity Space, showcasing the maturity of the processes Dr Ellis dedicated much of his career to developing (Courtesy Relativity Space/photo Michael Baylor)

the stability of Cr_2Nb means that traditional heat treatment methods cannot be used for refining dispersoids. For AM GRCop-42 parts, HIP is recommended while parts are still on the build plate. The Cr_2Nb increases the required temperature for annealing GRCop-42 compared to wrought rolled or extruded material. A high-temperature HIP process alone is sufficient for annealing GRCop-42. However, annealing at 700-800°C for 30 minutes per 25 mm (1 inch) of part thickness is also effective. Heat treatment should be conducted in a vacuum or a protective atmosphere such as Ar-3% H_2. During HIP, parts are commonly covered in stainless steel or tantalum foil to further limit oxidation.

Despite these precautions, some surface oxide may form. This can be addressed by introducing a small amount of hydrogen to the furnace to create a reducing environment, or using a cleaning solution such as a mixture of ammonium hydroxide and hydrogen peroxide, or a citric or phosphoric acid-based solution.

The culmination of a career: paving the way for future exploration

Dr Ellis' work on GRCop-42 and GRCop-84 began in 1987 and culminated with the launch of the first rocket with GRCop-42 in 2023. Over the course of his career, he witnessed NASA conduct hot-fire testing on numerous GRCop combustion chambers that accumulated well over 60,000 seconds of operation and thousands of starts. Commercial space has embraced the use of GRCop and conducts daily testing of chambers that contributes significantly to the material's maturation. In collaboration with industry partners, Dr Ellis played a pivotal role in transitioning AM GRCop-84 and GRCop-42 from the lab to production at an increasing scale. Notably, PBF-LB GRCop-42 has been flight proven on the Aeon 1 engine by Relativity Space (Figs. 2, 14), which showcases the maturity of the processes he dedicated much of his career to developing.

As the demand for higher-performance engines grows, a material's ability to withstand ever higher hot wall temperatures become crucial. GRCop exhibits excellent high-temperature mechanical properties, high thermal conductivity, high performance in low cycle fatigue, and long creep lives at temperatures exceeding the capabilities of other copper alloys.

NASA's ongoing efforts involve collaborating with industry to advance AM GRCop-42 combustion chambers and feedstock production. Initiatives aim to optimise cost savings through supply chain advancements and increased build rates. Evaluation of green and blue lasers is underway to enhance build rates by improving energy absorption.

While the aerospace industry faces challenges in qualifying complex, AM components, the use of bimetallic AM techniques and advanced alloys like GRCop-42 complicates qualification but offers remarkable cost reduction and performance improvements. AM

GRCop-42 is also enabling advancements in entirely new propulsion technologies, such as the rotating detonation rocket engines (RDRE). Applications beyond the aerospace industry, such as fusion reactors, are being considered. AM GRCop alloys have the potential to be used in any high temperature, high heat flux application.

Dr Ellis' success in developing GRCop alloys highlights the profound impact of fundamental materials science research on the aerospace industry. As he enters retirement, he can witness the layer-by-layer construction of GRCop as a symbol of humans' step-by-step progress in returning to the moon and eventually exploring Mars. His legacy underscores the transformative power of dedicated materials research, aligning with the broader journey of human space exploration.

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Authors

Austin Whitt
Associate Researcher, NASA Glenn Research Center

David Ellis
Materials Research Engineer, NASA Glenn Research Center (Retired)

Paul Gradl
Principal Engineer, NASA Marshall Space Flight Center

www.nasa.gov

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Formnext 2023: Innovations in metal Additive Manufacturing from the industry's leading international exhibition

When it comes to presenting a review of the world's largest international exhibition for AM, one can go about it in two ways: very broad generalisations about the state of the industry or a more focused review of a handful of noteworthy developments. Given the 859 exhibitors at Formnext 2023, spread over some 54,000 m^2, this review by Dr Martin McMahon takes the latter approach, offering broader context where possible. Whilst many more press announcements are covered in the industry news section of this issue, the following report provides an overview of how – and where – AM is evolving and maturing into a credible and dynamic technology.

This year's Formnext was perhaps the most eagerly anticipated since the global pandemic. While 2021 saw a fair number of both exhibitors and visitors, attendance was somewhat subdued in the wake of COVID-19. Then, last year, the buzz was back with noticeably higher visitor numbers; still, I'd made the mistake of only attending for the first three days. So, this year, with all four days a certainty, and on the back of announcements by the organisers that they had booked a record number of exhibitors, levels of anticipation were at a maximum.

Industry appetite for this year's event was fuelled in part by the many press announcements ahead of the event. Whilst some were from the usual suspects, others inspired me to find out more. I'm pleased to report that there were numerous announcements of value at this year's show.

For me, new hardware and the latest technological developments were always going to be key themes to follow, and I targeted these innovations with great interest. On a broader note, what was noticeable this year was the diminishing dominance of Laser Beam Powder Bed Fusion (PBF-LB) as a result of so many more metal AM technologies maturing and becoming commercially viable. Electron Beam Powder Bed Fusion (PBF-EB) machines were certainly a lot more prevalent, and there were far more Directed Energy Deposition (DED) machines, both powder- and wire-based, than ever before.

In this last respect, the show very much revealed that the AM world has gone 'all in' with robotics, and it

Fig. 1 Formnext 2023 attracted some 33,000 visitors, an increase of 11% on the previous year (Courtesy Mesago/Mathias Kutt)

Fig. 2 Top: HP's Savi Baveja (left) and Indo-MIM's Krishna Chivukula Jr (right) announced the partnership at this year's Formnext (Courtesy HP)

occurred to me as I looked for differences between each offering that maybe this could make metal AM feel a lot more familiar to the mainstream traditional manufacturing sector. Why? Simply because multi-axis robot arms have been around for a long time, have been relied upon for some very high precision – or heavy lifting – tasks, and are very much a familiar feature in production welding lines all over the world.

Not to be forgotten were the numerous sinter-based metal AM technologies that take green parts, produced by several types of AM technologies, and then process them via sintering to make parts that are very close to full density. Many in the manufacturing sector have big hopes for sinter-based AM processes, particularly Binder Jetting, to enable them to start high volume manufacturing, and partnerships – such as those between HP and Indo-MIM, the world's largest MIM producer, (Fig. 2), and HP and Elnik Systems, a leading producer of vacuum sintering furnaces for the MIM industry – give a clear indication of where things are going.

Finally, of course, there's no metal AM without metal powders and wire, and there was plenty to discover in the world of AM materials. Notable is the growing recognition that sustainability and reducing harmful emissions in the production, usage, and waste handling of metal powders is a key area of responsibility for our sector. This will be covered in more depth in a separate report.

One observation is that there has also been some change within the AM supply chain. It became clear from this year's Formnext that materials suppliers are still not sure where they are best positioned in the complete value chain. In most other sectors, materials are supplied to manufacturers to produce parts: rolling mills produce sheet metal, that then some other manufacturer takes to turn into car doors, for example. In Additive Manufacturing, however, we have seen nearly all materials producers at one time or another either directly producing the useable parts, or they have, at the very least, given this a lot of consideration. Speaking to some of these companies, it was clear that some may be struggling to turn that into a profitable business.

Advances in laser-based Additive Manufacturing

Formnext presents the opportunity to discover what's new and great in the sector, for suppliers to share their vision, and, perhaps, identify where they should be heading next. I don't think we've arrived at a point in time where a user is able to find their 'dream machine' in the exhibition halls because so much is still evolving in core metal AM technologies. In PBF-LB, there's been a flurry of 'go big' machine stories over the past year or so, but more broadly there hasn't been too much to shine a light on in terms of underlying integrated technology. While this statement is broadly true of this year's show, some interesting developments from nLIGHT and Renishaw, which we will return to, proved that rules always have exceptions.

Others, like One Click Metal, showed off its modular build volumes and new aluminium alloy, whilst Prima Additive bucked the trends by

showing its dual-wavelength PBF-LB machines. It also showed different modes in DED, including a special ability to produce thin wall parts. DED, which has always appeared to be waiting in the wings, seemed to have finally stepped onto the stage this year, and the level of integration with robotics was very impressive.

Laser control at nLIGHT

One interesting development for laser-based AM technology was from nLIGHT Inc, showcasing its beam shaping technology, bringing to the market, for the first time, a 1500 W laser beam shaping solution without any complex lens or focusing arrangement at the 'business end' of the laser optics. The company has made innovative choices in its use of a ring waveguide around the core of the optical fibre and the way in which the light energy is guided by the fibre itself through manipulation of the properties of the waveguide.

This was the first time I'd come across being able to change the radial position of the optical field between two concentric guiding regions in a fibre to control the emerging laser output. nLIGHT neatly demonstrated on its stand how the focused beam can be changed from a small, precise single mode spot to large ring-like patterns up to 3X the diameter, with the extreme benefit of not shifting focus or moving any optics. This allows for 3- to 5-fold increases in build rate with very good control of the melt depth and how the laser power interacts with the powder.

Used in the right way, the company is confident that users are able to produce fully dense (>99.9%) parts with significantly less soot and spatter. Such is the success of this innovation that it lies at the heart of several powder bed machines now on the market and, as displayed at Formnext this year, has been selected to enhance the capabilities of the customised systems offered by AMCM, the sister company of EOS.

However, this wasn't the only technological advancement that caught my eye from nLIGHT: its ultra-compact multi-laser solution, called modulus (Fig. 3), really made me look twice. Walking onto the nLIGHT stand, I think I can be forgiven for thinking that the four and eight laser modules that were on display were only 'mock-ups' of the real thing, such was the compact nature of these units. In fact, the standalone single units were also clearly on display, and yet it has somehow managed to condense down all the necessary controls, cooling, and power requirements to something that is probably only 50% of the equivalent stack of single units.

nLIGHT has also incorporated a clever client-server-based ethernet communications backbone to control

Fig. 3 nLIGHT's modulus m4 outfitted with four 1 kW single mode lasers (Courtesy nLIGHT)

"Such is the success of this innovation that it lies at the heart of several powder bed machines now on the market and, as displayed at Formnext this year, has been selected to enhance the capabilities of the customised systems offered by AMCM..."

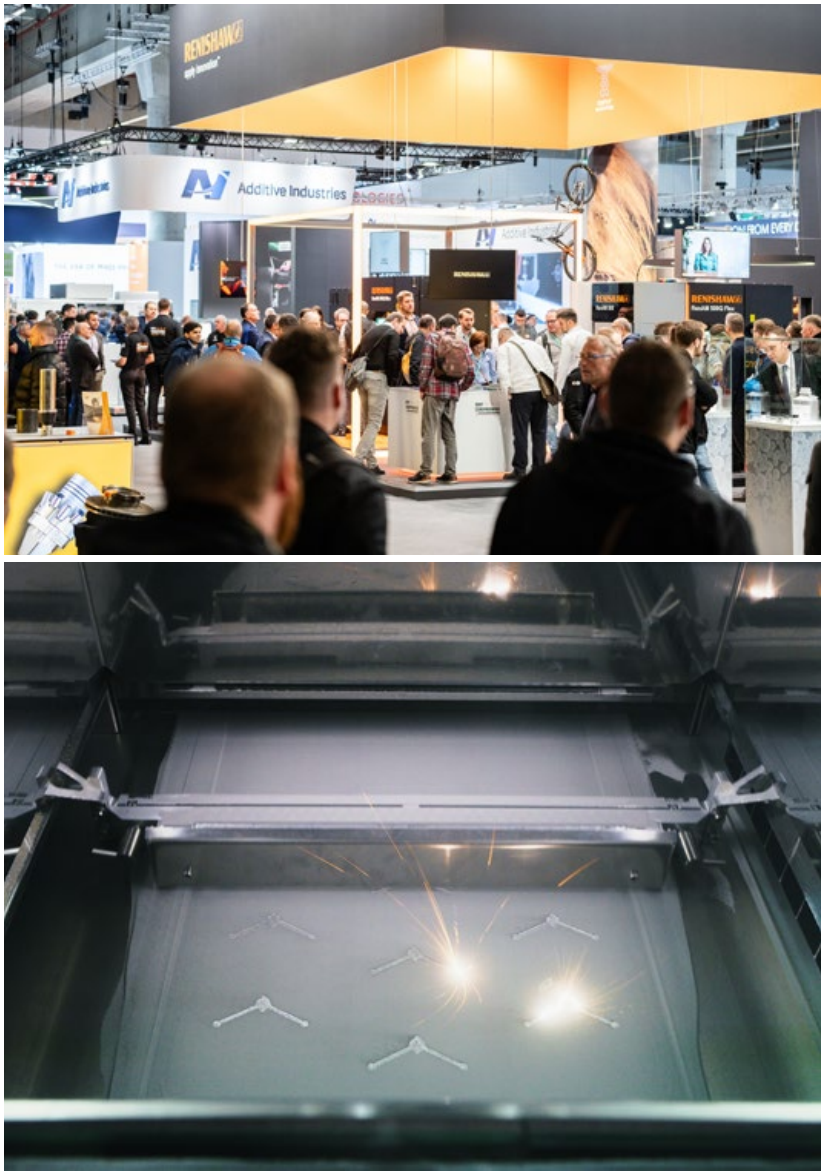

Fig. 5 Renishaw's exhibition stand at this year's Formnext and, below, its new Tempus technology in action (Top image courtesy Mesago/Mathias Kutt, bottom image courtesy Renishaw)

the individual lasers, opening up other possibilities in synchronous scan strategies, process monitoring, self-calibration, and diagnostic reporting.

Renishaw's Tempus

Entering Hall 11 gave me my first surprise, with Renishaw front and centre with its exhibit. Renishaw's staying power in the Additive Manufacturing industry after a turbulent period for the company was reinforced with this year's big reveal: the introduction of its Tempus Technology. Having consolidated its product offering around the RenAM 500 platform, it launched the new Ultra version, incorporating the new 'scan-while-you-wipe' technology. To many this may not seem to be that big a development, but it's taken a long time for machine vendors to come around to realising a working solution.

Renishaw equated this to having a fifth laser in the machine, providing up to 25% more productivity. Watching the scanning starting just moments after recoating began, and without the normal delay of having to wait for a complete layer to be deposited, was certainly something to be seen live at the event.

The message from Renishaw was that it will continue to concentrate on productivity gains in the mid-range machine sector rather than pursuing any developments that require more lasers or bigger chambers.

"Having consolidated its product offering around the RenAM 500 platform, it launched the new Ultra version, incorporating the new 'scan-while-you-wipe' technology. To many this may not seem to be that big a development, but it's taken a long time for machine vendors to come around to realising a working solution."

Additive Industries

Another company that has experienced quite a few changes in recent years is Additive Industries, but once again it made a good impression on the show floor with its impressive display of an Alfa Romeo F1 car. Like most companies that have entered the AM sector, aerospace has been an important market for Additive Industries, and this will continue to be the case – but perhaps this year there was a clear intention to show that it will also be looking to the automotive industry for its next big push.

Fig. 6 While the Additive Industries Metal Fab G2 may have been pushed into second place in terms of attention by the Alfa Romeo F1 car, it did serve to highlight the fact that 250-300 parts per car are produced on the company's PBF-LB machines (Courtesy Additive Industries)

The company's Kartik Rao highlighted partnerships and collaborations with BMW and VW, and how there is a clear intention to use metal AM by these companies for tooling and the production of EV car components, which was very encouraging to hear. The automotive sector has long been a ground where most AM companies have aspired to play, and now it does seem that this is becoming more of a reality. Hence, while the Metal Fab G2 may have been pushed into second place in terms of attention by the F1 car, it did serve to highlight the fact that 250-300 parts per car are produced on the Additive Industries PBF-LB machines.

However, not all parts produced by Sauber Technologies for the Alfa Romeo team are used directly on the car, and pit lane tooling was also on display during the show. One aspect of lightweight structures that really caught my eye was a titanium car jack. It had escaped me previously that each one needs to be customised for each car, and potentially each circuit, and in this case also designed with the pit lane engineers' usage in mind. Being lighter and easier to manoeuvre under the car makes it safer and less stressful for the technicians in the pit lane. Incorporating the now very familiar mesh structures made for a very good-looking part.

"The automotive sector has long been a ground where most Additive Manufacturing companies have aspired to play, and now it does seem that this is becoming more of a reality."

The evolution of Electron Beam Powder Bed Fusion

Despite being in the shadows of Laser Beam Powder Bed Fusion for so many years, from a commercial parts production standpoint Electron Beam Powder Bed Fusion has perhaps been a success for a significantly longer period of time than PBF-LB, particularly when taking into account the production of medical implants. For

Fig. 7 FreeMelt's new eMELT-iD compact development machine (Courtesy FreeMelt)

many years, however, there was only really one player on the block: Arcam, now part of GE Additive. Recently, we have seen a number of new entrants and their collective showing at Formnext made the technology look very impressive.

FreeMelt

FreeMelt is launching its new eMELT-iD compact development machine to bridge the gap between development and full-scale production without changing process parameters. This, it claimed, is because the underlying technology and mode of operation are identical to its larger machine. The company was also very proud about being able to produce crack-free tungsten parts, but it was not alone in this respect; refractory metals were amongst the flavours of the week at Formnext in 2023.

Wayland Additive

UK-based Wayland Additive stated that it is continuing its specific focus on refractory metals, having recently supported customers such as EWI with molybdenum. In addition, the company is now processing Vibenite from VBN Components, thus approaching (almost) impossibly tough tool steels, as well as the previously purely Powder Metallurgy processed stainless steel, CPM420V, to be used in its latest machine shipped to Europe. As the first machine vendor to introduce a targeted charge-neutralising technology into a machine, Wayland has had a very good year since its first machine shipment. Shipping four machines in the past twelve months is impressive, considering Wayland is still a young, modest-sized outfit.

Much of its success in broadening the materials portfolio has been due to the lack of a requirement for a pre-sintering scanning step, which means its development customers have been able to research new applications and parameters in vastly shorter timeframes than previously possible. With Wayland's support, one customer started from a blank page and was able to achieve a sign-off on a new material and application in just five weeks. I don't know many who have achieved that, even with the long-established PBF-LB machines.

ProBeam

Stepping on the ProBeam stand, it was particularly gratifying – albeit somewhat unexpected – to see one of the featured parts from the Autumn 2023 issue of *Metal AM*. A good array of parts from both its PBF-EB and wire DED systems were displayed, the latter being the most impressive with regard to size and diversity. Copper and bi-metallic deposition were featured in the form of what I shall only refer to as a copper-coated 'doughnut'.

JEOL

JEOL had an impressive display of parts and I found it especially pleasing that it had achieved a qualified install to AMS 7032, the recently published SAE standard for machine qualification for fusion-based machines. It is always good to find out that the effort being put into these international standards is starting to have a positive effect.

GE Additive

The incumbent market leader, GE Additive, with its Arcam machines, has not sat idle and came to this event with a few updates of its own. Having decided that small incremental developments are a safer way to stay the course, the company showed me new scanning strategies enabling really – and I mean really – unsupported parts with huge improvements in down-skin roughness. GE Additive has also been concentrating on new materials developments, including the nickel

alloy 247, and, judging from what I saw, it's hard not to agree that it has made some fine progress.

China's rise

The growing presence of Chinese companies in the AM sector has not gone unnoticed over the past few years. Companies such as Farsoon, H3D and EPlus3D all had a significant presence at Formnext this year, and there is a clear intention by these companies to expand their presence in the US and Europe.

This year, however, one company stood slightly above the others, and not only because of the size of its stand. Bright Laser Technology's Sales and Marketing Director for the EMEA region, Slobodan Ilic, made it very clear that the company has had a successful year, both in the domestic and international markets.

Ilic spoke about BLT's intention to present the full extent of the company's vertically integrated complete AM value chain at Formnext, from large-scale metal powder production, with an impressive selection of titanium alloys amongst its offering, to the twenty-six laser machine that boasts a footprint of some 11 x 6 x ~8 m, to one of the world's largest installations of PBF-LB machines inside its own AM contract manufacturing service division.

Casting my mind back to the first time I saw one of BLT's machines and comparing it to what was on display this year, it was clear that the company had matured into a very serious contender in this field. Its staff at the show were quick to point out that the company believes itself to not only offer the world's largest selection of these type of metal AM machines, but now also powder- and wire-based DED machines.

BLT hasn't just been developing these machines on a whim, and announcing a collaboration with automotive giant BMW was clear proof of this, adding to its links with Audi and aerospace sector primes such as Airbus and Safran. Though both the aerospace and medical sectors

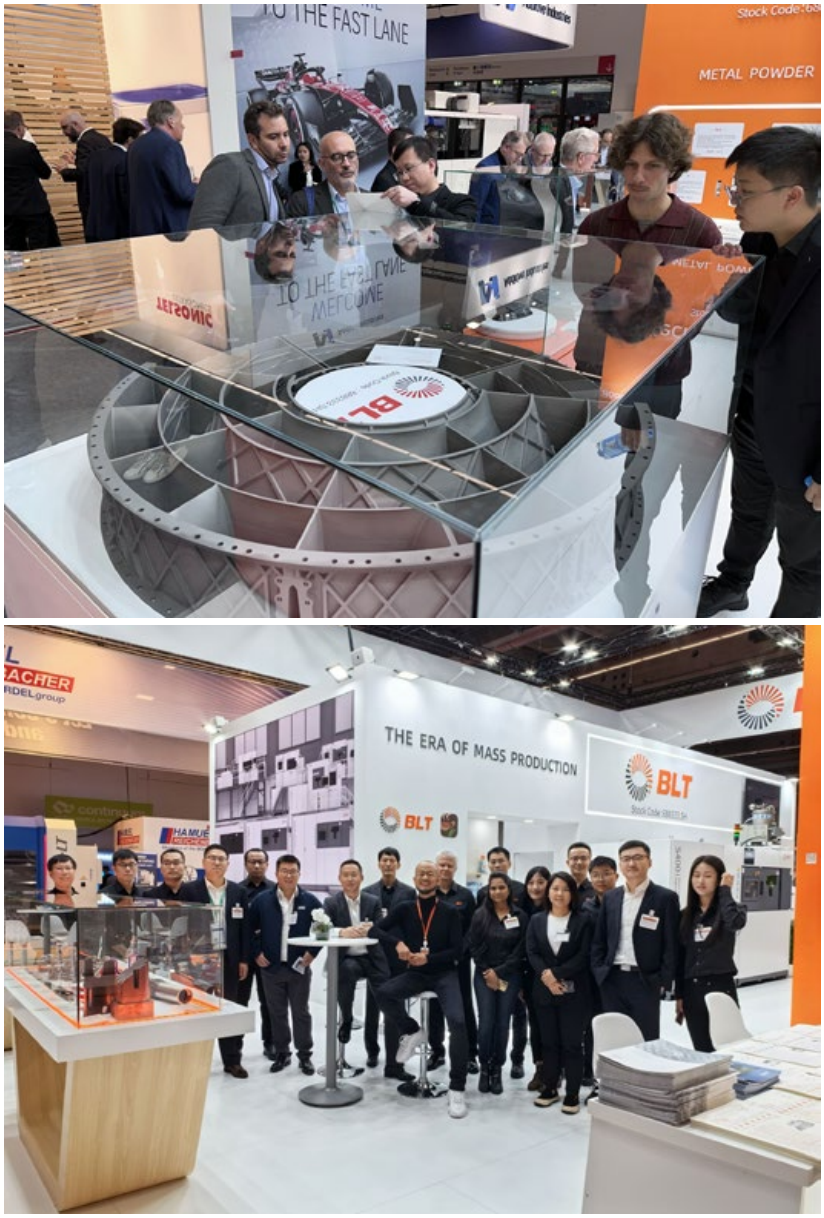

Fig. 8 The BLT stand at Formnext 2023 featured a 1.5 m diameter titanium aero engine intermediate compressor casing (Courtesy BLT)

are very clear target markets for this company, it now has the automotive industry squarely in its sights for future sales in the European arena.

Domestically, it has stated that it continues to work very closely with COMAC in the aerospace sector as well as other primes that have established facilities in the Asia region.

It had a number of very large parts on display, and its 'marquee' part was a large titanium aero engine intermediate compressor casing manufactured as a single piece (Fig. 8). At close to 1.5 m in diameter and built on the new twenty-six laser machine, it was certainly quite an imposing sample part on its stand. However, build times of over one hundred hours do raise many questions and, on closer inspection, it was apparent that it has some work to do on scan strategies and making sure all those lasers are properly aligned.

Despite this, nothing should be taken from the fact that it accomplished such an extraordinary feat, and it wasn't 'just another' display rocket engine. Perhaps, the troubling thought that cranked through my

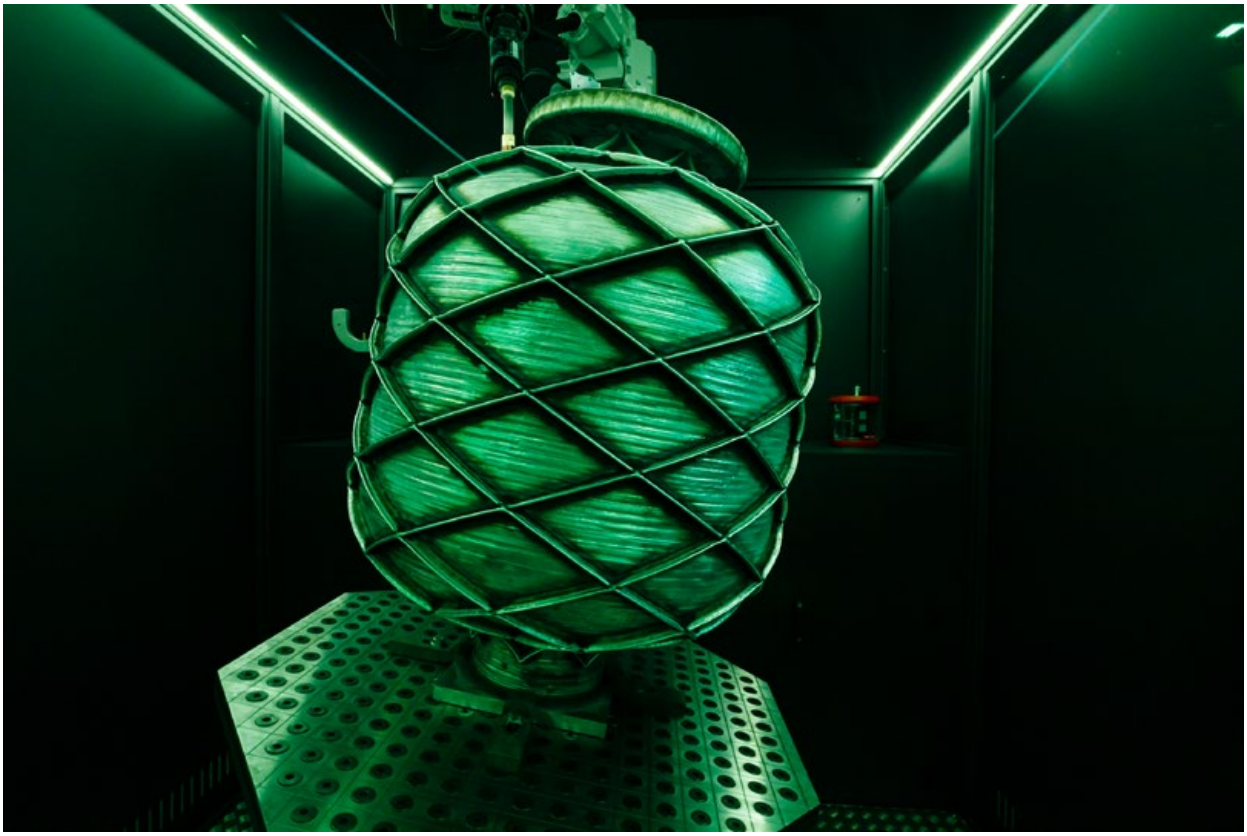

Fig. 9 MX3D's stand featured a 63 kg aluminium pressure vessel built on its M1 machine. The vessel showed just how DED machines can be used not only to build, but also to augment parts (Courtesy Mesago/Marc Jacquemin)

mind as I walked away feeling something bordering on dread, was the requirement of between four and five tonnes of titanium alloy powder to fill the machine and complete such a build.

However, this challenge isn't unique to this large PBF-LB machine alone. I would go as far as to suggest that the jury is still out on predicting the future of all such ultra-large format laser machines. Fortune, as they say, favours the bold!

DED: robots everywhere

Robots and machine integrations were all the rage this year for the DED vendors, and this group of metal AM machines and applications continue to grow at a faster pace than the rest of the sector. I believe this was demonstrated this year more than any other as DED technologies have been easier to integrate into existing machine tool platforms, or enclosures, and the choice of those was already vast.

It struck me that there's little need to convince people of DED technology's robustness or capabilities, and even the most unfamiliar amongst us can look at any one of these machines and instantly equate them to welding, especially the more dominant wire arc DED variant. This did make it a little more difficult to try and establish the major differences between them, and I have to confess given the limited time to look at any of them my first impression was that there was a lot of similarity. By this I certainly don't mean that there wasn't a lot of capability on display – far from it. My impression is that wire arc DED, through its adaptation of existing welding technologies, was shown to be well ahead of PBF processes with respect to in-process monitoring.

Software capabilities for operating the equipment, creating tool paths, and monitoring the build process were all potential key differentiators this year, but there wasn't really the right opportunity to see these in action. All the DED machines at the show fell loosely into one of three categories: either standalone wire arc DED; laser/powder and laser/wire DED; or integrated hybrid machines that offered post- or in-process machining capabilities.

MX3D

From the company that brought us Amsterdam's famous metal additively manufactured bridge, this year MX3D's stand featured a 63 kg aluminium pressure vessel built on its M1 machine (Fig. 9). The vessel showed just how DED machines can be used not only to build, but also to augment parts. The demonstration part was first built as the main vessel, and then subsequently reinforced with the external ribbing structures. Unfortunately, the larger MX machine was only there in concept, but a partially built bronze

propeller left little to the imagination in terms of the overall size capability of the machine that was previously announced at the Formnext Forum in Austin, Texas.

ADDiTEC

While ADDiTEC is no stranger to the DED process, the company managed to breathe life back into the Liquid Metal Printing machine developed by Vader Systems and then sold to Xerox before being killed off last year. ADDiTEC's path has been to integrate it into a Haas machining system along with its own DED technology, then launching the package as the HYBRiD3 (Fig. 10). This unique metal AM capability still only works with low melting point alloys, such as the aluminium alloys on display, but is the only machine to combine two different AM technologies into a hybrid machine tool solution.

The company also happens to have one of the better-named machines on the market with the wire DED AMDROiD. Whilst not quite as mobile as the name might imply (it is designed to be shifted around by a forklift truck), it's still more impressive in that regard than the commonly seen solutions in 6.1 m shipping containers.

MetalWorm

The accolade for perhaps the quirkiest name in the sector has to go to MetalWorm. It was the first time I'd come across this Turkish supplier, and, on the whole, its solution looked like a solid machine. Aside from the impressive choice of integrated arc welding technology, and with any of the usual industrial robot arms, another first for me was the use of vibration in the build platform to try and control microstructure during solidification. This is one area I've pondered many times where DED is concerned, given the very complex nature of welded microstructures. The use of vibrating build platforms certainly has given me food for thought. One other lasting impression was that, by the nature of its software and reporting, it seemed that the company has really understood all that goes into controlling a good weld, and they have carried that into the AM world in a familiar way.

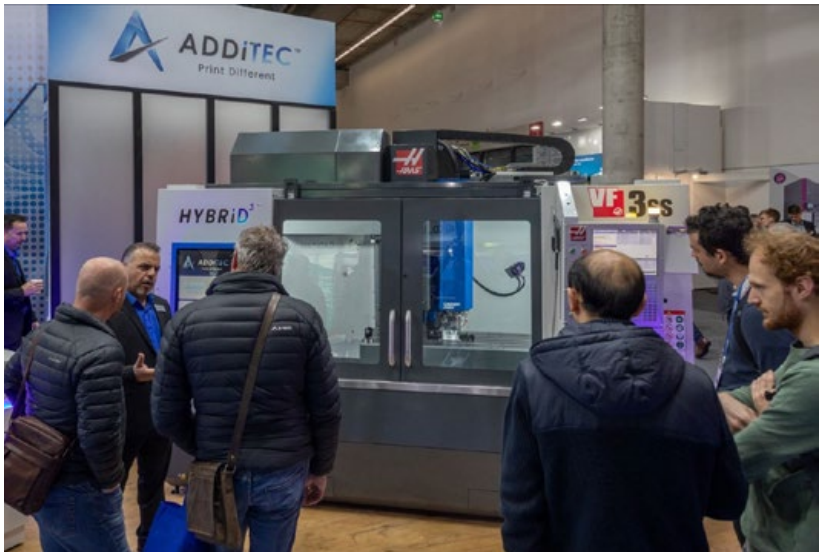

Fig. 10 ADDiTEC's HYBRiD3 machine (Courtesy ADDiTEC)

Fig. 11 A co-deposited bi-metallic valve housing displayed by DMG Mori and manufactured on the company's LASERTEC 65 DED Hybrid machine (Courtesy Martin McMahon)

DMG Mori

While DMG Mori, as expected, arrived with a lot to show in terms of choice of equipment, the thing that struck me most was a co-deposited bi-metallic valve housing. It demonstrated the true advantage of DED over PBF in a very recognisable, neatly machine-finished engineering component (Fig. 11). This type of part is what the world needs to see and understand most about AM: its versatility.

Hwacheon

A newcomer to the event, Hwacheon's laser-DED machine didn't seem to hold any real surprises, but it is

Fig. 12 Large parts produced using HPs metal Binder Jetting technology for engine, construction and agricultural equipment applications (Courtesy Martin McMahon)

always good to see another respected machine tool manufacturer enter the AM sector with a practical system that is free of hype. The DMX 07 being promoted at the show is best described as 'big and boxy,' but there is also something appealing about its simplistic lines. The machine is just one of a range of machines that the company has spent a number of years developing.

Oscar PLT

Lastly, if enthusiasm could be bottled then there'd be a challenge to contain that of the small team from Oscar PLT who are doing clever things with wire DED using multiple lasers from nLIGHT. Whilst an obvious shoe-in for AM, the company chose to highlight its strengths and expertise in repair applications. AM doesn't always have to be about making expensive parts, and Oscar PLT very cleverly explained the value of protecting the investment of existing expensive parts. I saw how the team can work with relatively fine details using thin wires but, at the same time, minimising heat input damage to whatever the workpiece or underlying material. Having up to six lasers positioned around its deposition head, each with beam shaping capabilities, means its PROFOCUS machine is capable of reaching and repairing some very complex geometries.

Overall, I think the tide has changed for DED and there's a level of ease in deploying these solutions compared to PBF machines. DED solutions are intrinsically confined to working with more simple designed parts, and, therefore, I believe that they don't tend to over-stretch the imagination of experienced design and production engineers. They also offer greater freedom of integration and deployability, allowing existing owners of capital equipment an upgrade route rather than all out new capex requirement. This was all well demonstrated this year at Formnext.

Sinter-based AM

Where one would traditionally have expected to see crowds of people at Formnext is the Desktop Metal stand. This year it was somewhat of a surprise to realise that the company was only represented by distributors. Another company with a flag firmly in the ground of the Binder Jetting space is GE Additive. Whilst there were no major customer announcements or product updates from GE Additive, conversations with the Binder Jetting team suggested that good progress is being made with industrial partners. Markforged, who acquired Digital Metal's Binder Jetting technology, also kept things low key. It would be a mistake to take the above as a sign that Binder Jetting has stalled, but the technology saw a distinctly lower profile this year than in previous.

Where others were quiet, HP, whose big metals push last year really did create a lot of buzz around the exhibition, continued to impress with industrial case studies from the likes of VW, Schneider Electric, John Deere, Lumenium (Fig. 12), and Domin. The latter showed that HP has successfully transitioned its technology into a production process for the mass market. The announcements to pursue materials development with Sandvik, supplying systems to yet another MIM producer – Indo-MIM – following its work with early development partners Parmatech and GKN Powder Metallurgy, and its partnership with furnace maker Elnik Systems, underlined its determination to keep expanding on the successes of recent years.

Incus

I was told rather excitedly that I should go and see the parts on display on the Incus stand and I have to say I wasn't disappointed after making my way through the crowds to get there. Already known for the lab-scale machine Hammer Lab35, the big release for the event was the machine aimed at higher-volume production: the Hammer Pro40. Here I saw parts that were so fine and

detailed it was almost impossible to believe that they had been made via AM and not something else like Metal Injection Moulding (Fig, 13).

It was, therefore, of no great surprise that Indo-MIM announced that it will be investing in a Hammer Lab35 system. The machines themselves don't have anything exceptionally new inside them as the underlying technology that has made it possible to achieve this is its Digital Light Processing (DLP) engine, previously developed by Lithoz and coming under the Vat Photopolymerisation (VPP) AM process category. The DLP engine has a pixel resolution of a few tens of microns, and it is this that dictates how small the machines can go when manufacturing parts.

Speaking with the team on the stand, I found out that both machines work with many different metals, all of which are widely available because they rely on commonly sourced MIM-grade powders. This may be a great advantage in the AM sector, since qualification of these alloys has already taken place, and the final sintering step to consolidate the net shape parts has itself already been approved by many industries. Furthermore, it was good to learn that the feedstock materials are all fully reuseable, since all non-polymerised material can simply be recycled. This ability eliminates waste, another aim for the rest of the metal AM sector.

The company had a wide array of very intricate parts on display with as-processed surface finishes not seen elsewhere in this sector, and – other than the obvious debinding and sintering steps – virtually no other post-processing. Parts are all built without any support structures because its process relies on the solid none-polymerised material to support whatever is being made.

Kennametal

Since I love finding cool metal AM parts, there was just one that stole the show for me: the incredibly heavy tungsten carbide drill bit part made with Binder Jetting technology by Kennametal, which developed

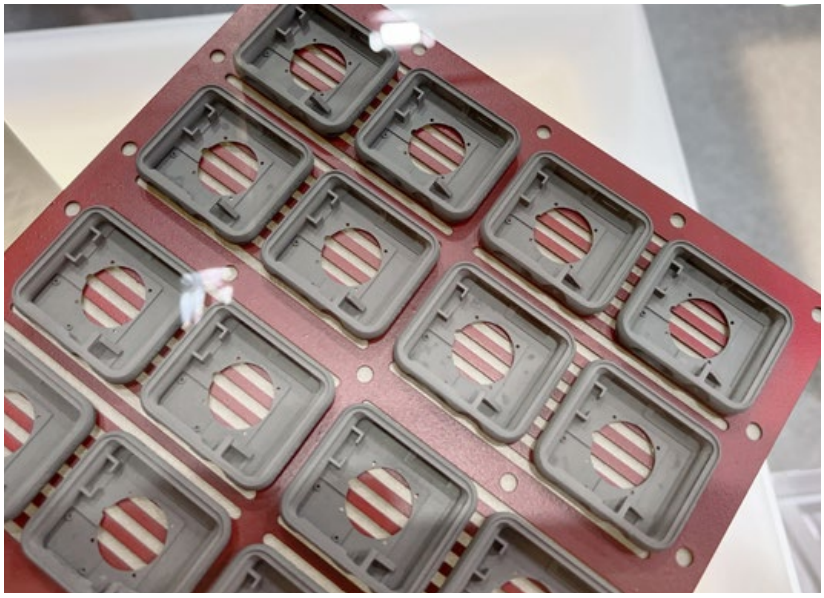

Fig. 13 Demonstration smartwatch cases produced on the Incus Hammer Pro40 machine. These parts are in the 'green', or un-sintered state. The MIM-like surface finish and resolution make this process highly attractive to producers of precision components who wish to minimise post-processing operations

Fig. 14 The Incus Hammer Pro40 machine is aimed at higher-volume production (Courtesy Incus)

Fig. 15 An example of how Elementum 3D uses Dyndrite software to achieve low angle build parameters (Courtesy Martin McMahon)

all of the materials, process and post-processing themselves. Try as I might, I couldn't lift the piece off the bench!

Innovations in AM materials

Setting aside any discoveries on sustainability (particularly in respect of metal powders) to a future article, there were a significant number of newer alloys being marketed this year. The supply chain has taken up the task of delivering a greater selection of useful alloys, and, for the first time, I noticed that steels were being promoted far more this year. There was also a far greater choice for aluminium.

Sandvik, with a new corporate brand, announced two key collaborations – with Dyndrite and HP – and stated that it is also seeking a further expansion of its powder production capabilities in the coming year. Whilst it was impossible to speak with all powder producers, conversations with representatives from the likes of Pometon, Indo-MIM, Atomising Systems Limited, and M4P all indicated a growing realisation that material diversity will be key to the future success of metal AM. Generally speaking, all suppliers include the grades with which we are by now very familiar, and many, including Indo-MIM, have declared new production capacity specifically for the AM sector.

It was M4P, however, who really stood out from the crowd with perhaps the widest selection of commercially available steel grade powders targeted just at AM. As the largest group of engineering materials, I'm convinced that this is a move in the right direction for the industry and no doubt we'll see more suppliers realise this as well. Reassuringly, all of the above companies stated their readiness to experiment and develop different grades of steel when the need arises.

Not wishing to completely ignore sustainability in the materials supply sector, some familiar names were actively promoting this topic. Tekna, for instance, committed part of its exhibition stand to the theme of recycling and sustainability. I also discovered that EOS, though it is not a powder producer itself, will be pursuing changes to its powder specifications in 2024. Starting with the AlSi10Mg alloy powder, it will require its suppliers to reduce their carbon footprint by including at least 30% recycled materials in the feedstock. It claimed at the show that this will result in a 25% reduction in CO_2 emissions.

There are a growing number of smaller companies that have taken advantage of the opportunities presented by sustainability. This year, Amazemet, 6K Inc, and Continuum were all showing the path forward. Continuum spoke about its go-to-market strategy for the Greyhound M2P system and its stated aim to use 100% recycled feedstock materials in powder production.

Whilst on a similar scale to other European companies, Amazemet is coming out of Poland with its interesting ultrasonic rePOWDER atomisation technology, and Continuum has stayed on the path of traditional gas atomisation. If Continuum is a new name to you, it was to me too – however, I learned that it relaunched as a new business just a week or so prior to Formnext. Previously known as Molyworks Materials Corporation, it was perhaps the first company to have emerged solely for the circular economy of metal powder production back in 2015.

Others worth a mention are Elementum 3D, which has joined the Dyndrite parameter consortium, and said it has been able to greatly improve the ability to build with its RAM powders at much lower unsupported build angles, and with thinner wall features (Fig. 15). It used the Dyndrite platform to dramatically reduce the time to develop the parameters for a PBF-LB machines.

Fehrmann Materials took a brave leap on powder pricing, addressing the cost barrier to adopting AM, saying it was about to cut the cost of its high strength aluminium alloy AlMgty.

Finally, I just couldn't leave this part of the review without

mentioning Fehrmann's MatGPT™ materials tool, putting AI to work in helping to resolve problems in the development of new alloys for AM. It was claiming some extraordinary early successes with the software; I can't wait to be able to play with this.

Post-processing continues to grow

When it comes to the post-processing of metal AM parts there is an ever-growing number of market entrants, most of which feature some form of automated depowdering or a transport mechanism for a piece to flow through the end-to-end production process.

There were plenty of suppliers present at this year's event, which made it quite difficult to spot anything more innovative than the rest. That's why I was pleased to stumble across a recent start-up Holdson, from the UK, bringing its patent-pending surface finishing technique to Formnext (Fig. 16). Seeing its process as dynamic electrochemical finishing, with machine learning to enhance the fluid dynamics within the process, it was certainly something I've never come across before, even if others may claim that it is very similar to commonly found electrochemical machining (ECM).

What made this technology stand out more was specifically addressing environmental concerns. Many will know that electrochemical processing often involves acid electrolytes, but that is not the case here, making it a lot less harmful to the environment. Holdson has included recyclable consumables and is claiming reduced energy consumption compared to other systems on the market. Its stated aim was that it wants its entire process to be sustainable, minimising the environmental impact of metal finishing.

Targeting the industrial end of the AM sector, Holdson has already secured good working relationships with the likes of Cummins Turbo Technologies and Wayland Additive and has processed some challenging materials such as tungsten. My walk-away conclusion was that this really might be one of those technologies that opens up several AM applications – particularly where non-line of sight finishing could be advantageous.

Fig. 16 The electroform surface finishing machine from Holdson and some surface finished chess pieces (Courtesy Holdson)

Closing the show

Whilst the organisers were happy to announce a record number of exhibitors, there was a sense that many companies had down-sized their attendance. There were far fewer mega-stands, and, in some cases, participation had diminished to counter-top displays on shared regional exhibition pavilions. There is no doubt that industry consolidation has played a role, yet at the same time a stream of new companies hoping to make their mark helps the industry, and Formnext, to continue to feel like a dynamic place to be.

It was clear that many companies had been thinking long and hard about marketing budgets before they turned up this year. Even those that had substantial stands had reduced numbers of staff manning this year than at previous events. Did this seem to matter? Well, from my impression, not at all. The halls were busy, the talks and presentations were all well-attended, and, knowing how difficult it was to pin people down due to their own busy schedules, it would seem that the majority still had more than enough to occupy themselves throughout the event. To conclude this report - which of course could not possibly cover all innovations at the show, I'll use a phrase that perhaps makes more sense in Additive Manufacturing than any other sector: from here, it's onwards and upwards.

Author

Dr Martin McMahon
Technical Consultant,
Metal AM magazine, and founder of
M A M Solutions.
martin.mcmahon@mamsolutions.uk

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Cybersecurity in Additive Manufacturing: Securing the industry's future

In the digital world of Additive Manufacturing, just how cybersecure are your operations and your customers' critical parts? A survey of AM producers has suggested that the answer is probably not secure enough. In this article, Auburn University's Prof Mark Yampolskiy, and industry analyst Joseph Kowen, present a high-altitude overview of the security threats facing those in the AM community. Cybersecurity, they suggest, should be considered as no less important than metallurgy or 'Design for AM' and, with the development of AM-specific standards and third-party security solutions, it need not be an overwhelming task.

Talk about cybersecurity is everywhere. We worry about cybersecurity in connection to our phones, our home computers and, of course, our work. It's a ubiquitous topic that is frequently referenced and spoken about across many areas of modern life. Similar to Artificial Intelligence – the other information technology topic that seems to occupy an increasingly central place in personal and professional discourse – cybersecurity is a well-discussed issue in broad terms, but its details are less well understood by many, including professionals in the Additive Manufacturing industry. An analysis of the topic should, therefore, be framed by a clear demarcation of what the security risks mean for the real world of AM, and not merely as an esoteric concern or as a best business practice.

The objective of this article is to act as a high-altitude overview of security threats in AM; a detailed discussion of the strategies for how to mitigate and defend against these threats are best left to a separate article.

In the context of Additive Manufacturing, the value of a debate on the issue of security lies in a feet-on-the-ground understanding of what the term means in practice. To start, let's describe a couple of scenarios:

SCENARIO 1

Company A develops an innovative design for a part. It is tested and qualified and is readied for production by AM. Due to a data breach – possibly during the process

Fig. 1 Whilst AM, the digital factory and decentralised, on-demand production, present significant opportunities, what are the security threats and how can we manage the associated risks? (Courtesy Patrick Helmholz/Adobe Stock)

"Cybersecurity experts distinguish between cybersecurity threats and cybersecurity risks, and it is worth pausing briefly on the distinction. A threat is what an adversary could do. A risk is what an adversary would do."

of transmitting a file to an external service provider – the file is stolen and made available on the web. Company B obtains a copy of the file and can produce the exact part in the original quality without having to shoulder the costs of development or qualification.

SCENARIO 2
A digital file belonging to Company C is well protected from leakage into the public domain. However, an adversary might have been able to change parameters in the design, or in the build process, resulting in a part that is different in subtle but substantive ways, creating a potential failure in the part with all the downstream risks that such a failure could entail.

These examples are but two of many possible scenarios. While admittedly selecting examples that lean towards the dramatic, they are illustrative of some of the reasons that make cybersecurity an important topic for additive manufacturers.

Cybersecurity experts distinguish between cybersecurity threats and cybersecurity risks, and it is worth pausing briefly on the distinction. A threat is what an adversary *could* do. A risk is what an adversary *would* do. In the examples above, both scenarios illustrate threats present in AM, but to assess the risk of each of these, additional company and even part-specific factors are taken into account, such as probability of a successful attack and degree of damage it would cause. Risk assessment is commonly used to prioritise allocation of limited resources, deciding which security threats to address and to what degree.

Tackling selected security threats

AM can be a complicated process involving many moving parts, all of which are underpinned by data flows. As Fig. 2 shows, generic data and material flow in an AM environment has many components. What then are the main security issues or defensive objectives relevant to the AM world?

Intellectual property protection
Since Additive Manufacturing, by definition, involves producing products from a digital design, if these digital files are not adequately secured, there's a risk of intellectual property theft. Cybersecurity measures help prevent unauthorised access and protect sensitive design information.

Preventing counterfeiting
Related to intellectual property protection in industries where product authenticity is crucial, such as automotive or aerospace, cybersecurity measures help prevent the unauthorised replication of additively manufactured components. Counterfeit parts, which are often of inferior quality, can compromise safety and performance.

Data integrity
Ensuring the integrity of the digital files used in the Additive Manufacturing process is essential. Any tampering with the digital design files could result in defects in the final product, compromising its quality and functionality.

Production security
Cybersecurity is critical to maintain the integrity of the Additive Manufacturing process itself. Hackers could potentially compromise the Additive Manufacturing process, leading to the production of faulty or substandard products. This is particularly important in industries where safety and reliability are paramount, such as aerospace or medical devices.

Supply chain security
Many industries are increasingly using Additive Manufacturing to create components and parts on demand. Securing the digital supply chain for software and hardware used in AM is crucial to prevent the insertion of malicious code or the manipulation of designs at any stage of the manufacturing process. Protecting the physical supply chain is also critical in an industry dependent upon advanced materials.

Network security
Many AM machines are connected to networks for remote control and in-process monitoring. Ensuring the security of these networks is vital to ensure the quality of parts, prevent unauthorised access, potential sabotage, or the introduction of malware.

Regulatory compliance
In certain industries, such as aerospace and medical, there are strict regulations and standards regarding the security of digital designs and manufacturing processes. Adhering to the AM part-corresponding regulations is not only a legal requirement but also essential for maintaining trust and credibility in the market.

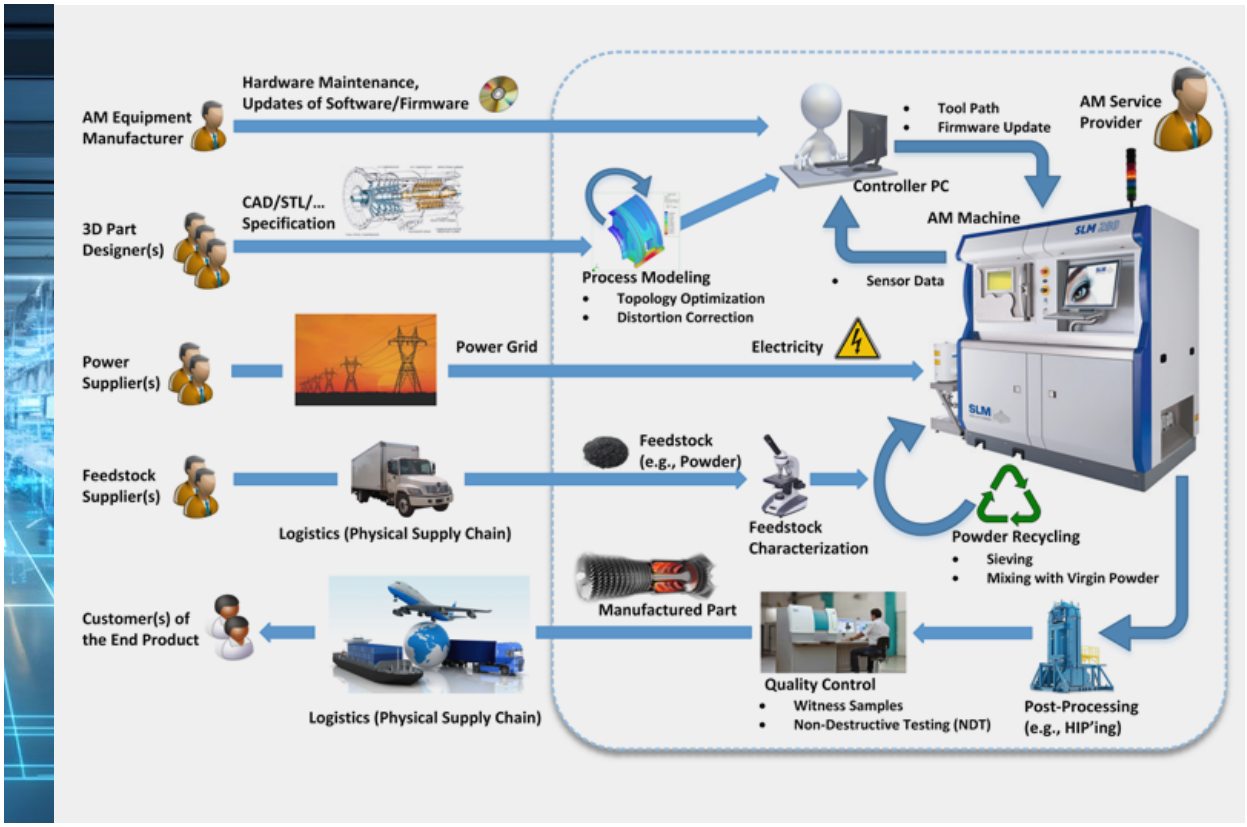


Fig. 2 A generic AM workflow (As published in [2], reproduced with permission)

Data types in AM

As in many areas of our digital world, the volume of digital data surrounding AM has mushroomed. We find data in a wide range of different operations and processes within AM:

Digital design files
The Additive Manufacturing process starts with a digital design file, which determines the geometry for the object to be additively manufactured. Protecting these files is crucial to prevent unauthorised part reproduction or theft of intellectual property.

Build parameters and settings
The parameters and settings used during the Additive Manufacturing process, such as laser power, layer thickness, and material composition, are essential for the quality of the final product. Cybersecurity measures are needed to prevent unauthorised changes to these settings that could lead to defects in the manufactured parts.

Process monitoring data
Many AM machines are equipped with sensors for monitoring the build process in real time. This data is important for quality control and process optimisation. Protecting the veracity and integrity of this data is essential to ensure the reliability and consistency of the manufacturing process. Furthermore, privacy of this data might need to be ensured to protect the 'secret sauce' of manufacturing process parameters.

Digital supply chain
The digital supply chain for AM involves the transfer of digital files and software between various

"The parameters and settings used during the AM process, such as laser power, layer thickness, and material composition, are essential for the quality of the final product. Cybersecurity measures are needed to prevent unauthorised changes to these settings that could lead to defects in the manufactured parts."

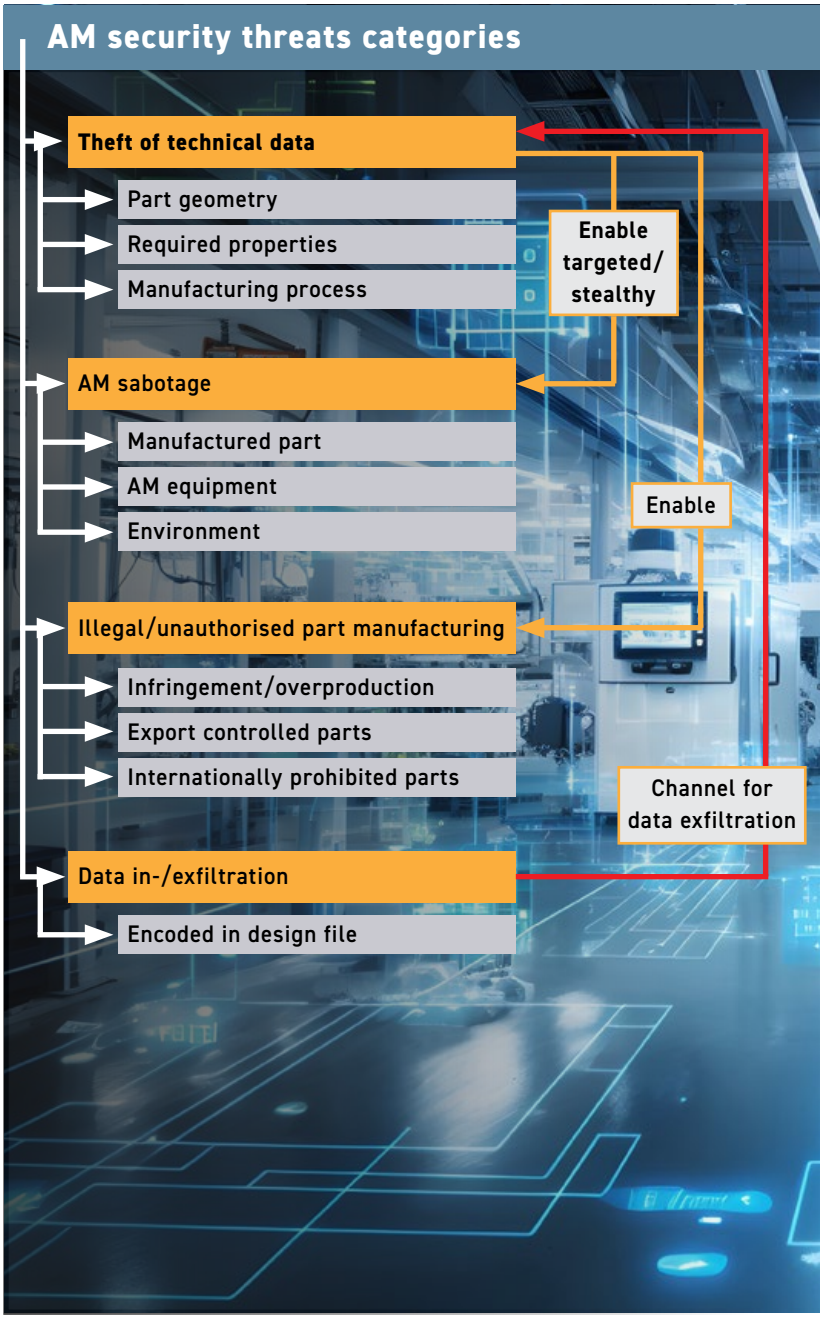


Fig. 3 AM security threat categories and their relationships

> *"...there is a disconnect between an AM community focused on producing physical parts and security professionals – even those active in AM – who are focused on securing this highly digitalised manufacturing technology."*

stakeholders, including designers, manufacturers, and suppliers. Securing this data is essential to prevent the introduction of malicious code into software or the compromise of design files during the exchange. The digital supply chain also involves the data relevant to procuring and storing materials used in the manufacturing process.

Equipment access control data
This involves authentication mechanisms, user permissions, and secure access protocols to prevent unauthorised individuals from manipulating the process. This also includes changing the default name and password set by the equipment manufacturer.

Testing and quality assurance data
Data generated during testing and quality assurance processes, such as material testing results and inspection reports. In many industries these are essential for traceability and thus need to be protected to comply with industry standards.

Network data
As many AM machines are connected to networks for remote monitoring and control, securing network communication is critical. This includes data transmitted between the AM machine and external systems, as well as the security of the network infrastructure itself.

The AM cybersecurity disconnect

With the proliferation and growth of AM technologies, it cannot be said that the community is completely unaware of the issue of cybersecurity. After all, AM is a digital manufacturing technology that is squarely based on information technologies in a wide variety of aspects. However, there is a disconnect between an AM community focused on producing physical parts and security professionals – even those active in AM – who are focused on securing this highly digitalised technology.

A study [1] was conducted in 2021 to measure the depth and breadth of cybersecurity awareness among companies engaging in, or contemplating adoption of, AM. The study was conducted through a collaboration between the Department of Computer Science at the University of Auburn, Alabama, USA, and ASTM International, and published by the latter. Survey respondents were members of America Makes.

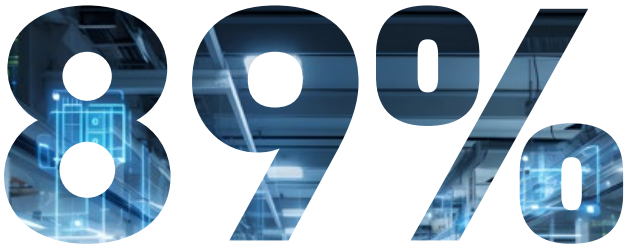
The survey was designed to poll respondents on their attitudes to cybersecurity in AM, and to measure their understanding of the specific risks associated with their AM activities. They were asked how they and their AM service providers were dealing with data security issues. Key questions posed are listed in Table 1.

The findings from the survey make interesting reading. While respondents in general seemed to have knowledge of some key issues in AM security, such as uncontrolled access to intellectual property or data corruption during data transfer from computers to AM machines, the study concluded that most users of AM lack a comprehensive understanding of cybersecurity. In answer to questions on the cybersecurity measures taken by service providers building AM parts, some respondents lacked complete familiarity with cybersecurity terminology and practices. The study concluded that the results indicated confusion regarding the goals that an adversary would hope to derive from an unprotected AM cyber environment.

The study found that 89% of respondents identified theft of technical data as one of their security concerns, and 41% identified the sabotage of parts or equipment as a concern in the manufacturing environment. 84% reported that the objective of the adversarial activity was intelligence gathering, and 41% was for monetary gain. Five respondents – or 9% – (out of fifty-five who answered the question) reported that they had suffered an AM-related cyber incident, though none were willing to share details of the respective incidents. Only 22%

1	What security risks/concerns have you identified related to your manufacturing using AM?
2	What security risks/concerns have you identified related to outsourcing your AM?
3	What security risks/concerns have you identified related to providing your AM manufacturing services?
4	What are your biggest security concerns associated with AM?
5	Who are potential attackers/adversaries you expect would attack AM in your company/agency?
6	What do you assess would be their goals/objectives?
7	If your organisation has conducted an AM risk assessment, which risks, related to AM, have been identified during this assessment?
8	Does your organisation have a security programme in place for AM?

Table 1 Key questions posed in the America Makes cybersecurity survey [1] (partial excerpt of questions posed)



of respondents identified theft of technical data as one of their security concerns

only 22% of respondents indicated that they had hired or partnered with external AM security providers

A majority of the surveyed organisations (62%) indicated a lack of concern about security issues, having not conducted a risk assessment on the topic

of respondents indicated that they had hired or partnered with external AM security providers. A majority of the surveyed organisations (62%) indicated a lack of concern about security issues, having not conducted a risk assessment on the topic. Only 41% of respondents answering the question indicated that they had taken steps to address security threats.

In summary, we can conclude three things. Firstly, there is a general awareness of cybersecurity issues in the AM segment. However, secondly, there is a lack of deeper understanding of the issues and threats involved. And finally, not enough is being done to address the risk.

What's happening with standards for securing AM?

A clear outcome from the findings above is that there needs to be a more organised and standardised approach to issues of cybersecurity in the AM segment. At the very least, players in this space need to have a common language and terminology, and a common understanding of the challenges. As in many other areas of standardisation in AM, no one standard will be able to address every concern for all AM processes or businesses. Some standards are developed by organisations in a particular industry vertical who are deeply familiar with the challenges in that space. For example, shipping and maritime standards are being led by testing, insurance and qualification bodies that are already active in the maritime industry. At the very least, general cybersecurity standards for AM would serve the purpose of creating a common baseline around which future efforts, perhaps driven by industry segments, could rally.

Work is already underway to achieve this. Standards relating to security in AM are under development to improve the industry's posture against threats it is exposed to. Even so, the effort is in its infancy and is a work in process. The Additive Manufacturing Standardisation Collaborative (AMSC), a group sponsored by America Makes and ANSI, published a roadmap in June 2023 to identify gaps in AM standardisation efforts. The relevant parts dealing with data, titled 'New Gap DA20,' found that although numerous groups have standardised IT cybersecurity and privacy guidance, and a growing number of standards address Operational Technology (OT) security, no standardised guidance specifically addresses AM security.

On the question of supply chain security, GAP DA21 found that guidance is needed that addresses cyber and non-cyber threats (i.e. side channel attacks) for securing, ordering, maintenance, repair, and replacement parts. This would ensure that ready-to-build 3D models have not been sabotaged and that IP has not been stolen. Secure storage should ensure that only authorised personnel can access files and print parts, the AMSC committee found.

Regarding technical data and IP protection, GAP DA22 declared, "There is currently no standardised method of labelling, securing and authenticating the intellectual property ownership and related rights to AM designs, files and metadata." This creates a risk for unauthorised use and/or counterfeiting of AM objects. There is no standardised method for authenticating additively manufactured parts against counterfeiting.

There is currently an effort underway to develop guidelines for AM security. It is called: 'WK78322 Standard Guide for Additive Manufacturing - General Principles - Guidelines for AM Security.' This document will establish AM security practices necessary to protect Additive Manufacturing parts' structural integrity, provenance throughout the production chain, and the protection of technical data. The guide will identify and categorise security threats in AM, highlight characteristic aspects of AM security that require special considerations, and describe mitigations in the manufacturing life cycle.

There is considerable work ahead to develop a more comprehensive regulatory framework for data security in AM, but at least the framework is starting to take shape.

Opportunities for solution providers

In many respects, the area of security for AM is still in its infancy, and – separately from standards – opportunities therefore abound for cybersecurity solution providers to enter the market. These providers can propose products or services that shore up areas where manufacturers and most service providers lack expertise, which, until now, have left AM end-users to fend for themselves. As it is, AM technology providers face enough challenges developing their systems and materials, and they should not be expected to devote efforts to deal with very complex cybersecurity issues. This opens the way for third-party cybersecurity solution developers to offer dedicated tools to mitigate security risks in AM.

For example, Assembrix, based in Israel, has developed a 'virtual manufacturing' platform that enables machine operators to control and monitor AM build activity remotely. The cloud-based platform enables a simpler, more efficient, and more secure production process by overseeing the entire AM digital thread, from the initial part model to the verified physical part and beyond. The platform enables multiple in-house users or external clients to monitor, allocate and manage their entire manufacturing space, thereby optimising the utilisation of all Additive Manufacturing resources. The backbone of this solution is a secure data environment. This is made possible through the utilisation of blockchain and encryption technologies.

Assembrix's approach to implementing this secure environment is to partner with AM machine manufacturers by connecting their machines to the Assembrix platform and providing its customers with full management and control over their operation within a secured and networked system. By collaborating with AM machine manufacturers, Assembrix's solution can communicate with these machines at a deep machine level, in a secure way.

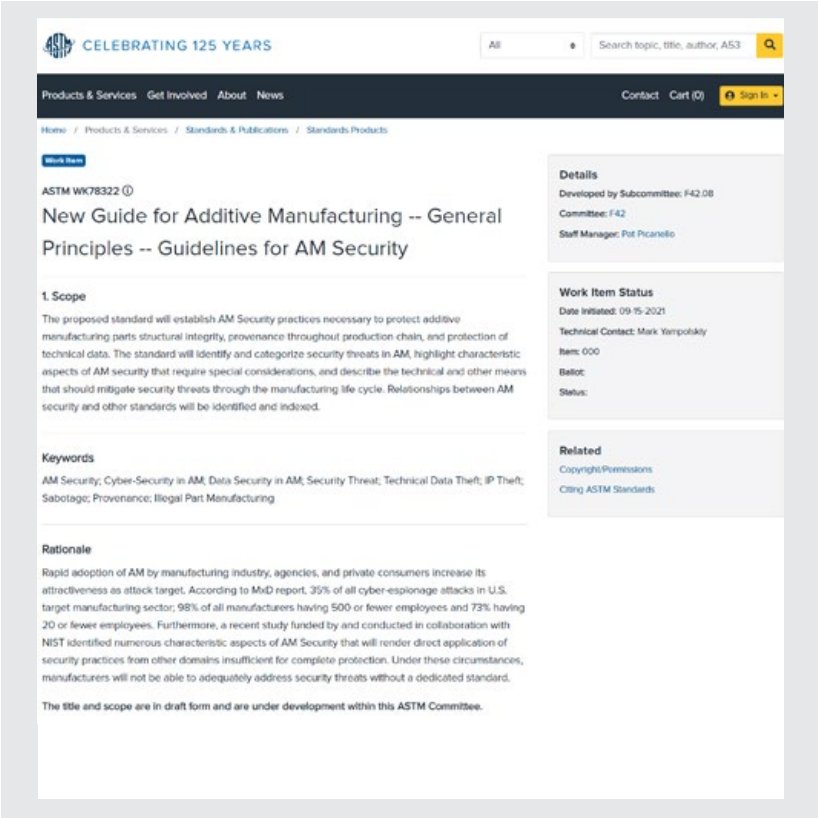


Fig. 4 There is currently an effort underway to develop guidelines for AM security, called: 'WK78322 Standard Guide for Additive Manufacturing - General Principles - Guidelines for AM Security.' The document will establish the AM security practices necessary to protect Additive Manufacturing parts' structural integrity, provenance throughout the production chain, and the protection of technical data (Courtesy ASTM International)

> ***"...AM technology providers face enough challenges developing their systems and materials, and they should not be expected to devote efforts to deal with very complex cybersecurity issues. This opens the way for third party cybersecurity solution developers..."***

In May 2023, Assembrix announced a partnership with Nikon SLM Solutions whereby the Assembrix platform was integrated into Nikon SLM Solutions machines. This integration facilitates built-in remote manufacturing possibilities. For example, an operator at a central location can operate and monitor AM systems located remotely.

Earlier, in 2021, Assembrix partnered with Boeing, EOS, 3T Additive Manufacturing, and BEAMIT, and successfully demonstrated secure cross-continent, distributed Additive Manufacturing. The demonstration showed

how a controlled build job was remotely and directly connected to EOS AM machines.

Another example is Vistory, a French cybersecurity company focusing on AM. It specialises in cybersecurity software development, particularly for supply chain security. Vistory is now leveraging this expertise to provide a mobile platform for the on-demand production of spare parts. Founded in 2015, the company's blockchain-supported operating system ensures the confidentiality and integrity of manufacturing data while providing intellectual property protection and traceability of operations. It enables a manufacturer to control the risks of the digital supply chain for secure decentralised production.

The company's initial focus was offering secure manufacturing for the French armed services. In 2019 the tool was tested and adopted by the French Land Forces. The French army's maintenance division required Vistory to guarantee suppliers' intellectual property while allowing the army to additively manufacture spare parts onsite. More recently, the company, in conjunction with hardware manufacturers, developed a container-based manufacturing cell for deployment in military or war time environments. The company's secure manufacturing operating system forms the basis on which the cell's AM operations are managed. In October 2023, the company participated in a project to provide the Ukrainian armed services with AM capacity for deployment close to front lines. The company addresses the civil sector, enabling manufacturers to offer their customers new solutions for the production and supply of spare parts while retaining control of their intellectual property and manufacturing processes.

Insights

No system is 100% secure, cybersecurity experts are quick to point out. A greater awareness of the risks, however, is the first step in shaping an approach that strives to achieve as close to 100% as is possible in the circumstances. Identification of cyber risks is, therefore, a critical first step in ensuring that AM remains as secure as it can be.

Once risks have been identified, organisations would be wise to understand the economic or strategic meaning of that risk for their business. In this regard, corporate management, risk managers or business owners can best evaluate what the meaning of a data breach is for their businesses. This will differ per industry, by company size, and by risk profile including parts manufactured and what they are used for, among other factors. Most manufacturers know by instinct where the critical path for their business lies. The key is to have as full an understanding as possible of what their exposure to security risks actually is.

"Once risks have been assigned an economic value, companies can begin the task of deciding how to mitigate that risk, understanding the costs of that mitigation, and making an informed decision on what kind of investment makes sense to achieve maximum security within available resources."

Manufacturers, including in AM, naturally have better instincts regarding physical risks. For example, an AM facility using titanium powder has a known risk of explosion if the powder is not correctly managed. Without minimising the seriousness of such real-life risks, a cybersecurity risk is the digital equivalent of a reactive powder explosion and may even have a bigger strategic impact on a business than its physical analogue.

Once risks have been assigned an economic value, companies can begin the task of deciding how to mitigate that risk, understanding the costs of that mitigation, and making an informed decision on what kind of investment makes sense to achieve maximum security within available resources. The approach taken must be calibrated for maximum effect wherever it is needed most, and when the cost-benefit trade off makes sense.

Finally, greater cyber protection will provide manufacturers and their customers with the confidence to adopt new business practices and business models that they cannot currently contemplate. The promise of new opportunities supported by cybersecurity solutions will attract innovative companies with cybersecurity experience to offer solutions to manufacturers using AM. Equipped with a new generation of functional digital security tools, manufacturers will be able to entertain new models of business, such as remote manufacturing, digital inventory of parts, on demand spare parts manufacturing, and other solutions that we may not yet fully envision. Paradoxically, as is sometimes the case in life, a threat becomes a catalyst for change and growth. Instead of cybersecurity risks being a cost or tax on the business, innovative solutions inspired by those risks, properly developed by creative and nimble minds, could turn out to be a differentiating factor for new growth.

An axiom of economics and life is that incentives inspire action. As AM grows, it will become a more valuable industry and, by extension, a bigger target for adversarial interests

wanting to get a piece of others' hard-earned success. But just as cyber threats have not stopped the development of online tools, like banking, accounting, and shopping, to name just a few, so too will AM advance and rebuff the challenges facing it on the cyber front.

The promise of digital manufacturing is simply too attractive a growth opportunity, but growing it safely will be paramount. While there is a relatively anaemic level of awareness on cybersecurity in the industry right now, one could say that the nascent regulatory efforts, as well as innovative efforts to develop new tools, constitute a 'call to action' for the broader AM community. Raising awareness and answering the call will result in better ways to deal with security threats. This will lead to the opening of new doors as well as the application of AM in new ways, adding developments in data processing to the advances we have become accustomed to seeing in machines, processes and materials. Cybersecurity is in its own way not less important to AM than chemistry, metallurgy and DfAM. A secure environment in which AM can operate will provide fertile ground on which the physical act of building parts in new and exciting ways can thrive.

Authors

Mark Yampolskiy
Mark Yampolskiy is an Associate Professor of Computer Science and Software Engineering at Auburn University. He specialises in cybersecurity issues in Additive Manufacturing and helped organise ASTM International's working group on Guidelines for Additive Manufacturing Security.

mzy0033@auburn.edu
www.eng.auburn.edu/directory/mzy0033.html

Joseph Kowen
Joseph Kowen is an industry analyst and consultant who has been involved in Additive Manufacturing since 1999. He is an Associate Consultant at Wohlers Associates, part of ASTM International's AM Center of Excellence.

www.linkedin.com/in/joseph-kowen-a5129b3/

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Additive Manufacturing in the jewellery industry: exploring the potential of platinum and titanium

Metal AM offers the jewellery industry significant creative and commercial opportunities. One such opportunity is the production of platinum and titanium jewellery by Laser Beam Powder Bed Fusion (PBF-LB), a process described as a "match made in heaven" for these metals. This technology offers jewellery designers advantages that include greater creative freedom, the precise control of weight, and a path to scale-up production. Here, Michela Ferraro explores the status of AM for jewellery manufacturers and highlights innovative and critically acclaimed pieces produced by the technology.

Additive Manufacturing has been almost effortlessly integrated into the jewellery industry's manufacturing workflow as a process for making complex forms for casting jewellery using wax or resin. The shift from a handmade process to a digital methodology to create casting forms is, to all intents and purposes, now crucial in order to remain competitive. So, whilst there has been no hesitation about the integration of wax or resin AM as a step in enabling jewellery manufacturers to scale up production, the 'direct' processing of precious metals by Additive Manufacturing has been embraced far more slowly.

My previous article 'Innovation and differentiation: Precious metal Additive Manufacturing in the jewellery sector', published in the Summer 2020 issue of *Metal AM* [1], largely described the evolution of metal AM in the jewellery sector. The article highlighted how the precious metal industry tried to replicate the successful experiences of other industries, such as aerospace and

Fig. 1 'Vertebrae 264' brooch (2020), designed by Stefania Lucchetta. Materials are anodised titanium and steel. Laser Beam Powder Bed Fusion (PBF-LB) was the primary technology used. The piece is hand finished using sand-blasting and polishing (Courtesy Stefania Lucchetta)

Fig. 2 Top right, the original metalPixel, designed and manufactured by Nuovi Gioielli. Other items shown include stainless steel watch straps and textured gold 'fabrics' (Courtesy Nuovi Gioielli S.R.L.)

medical, where metal AM had proved – for the right applications – to bring numerous advantages. Examples might be value gains through a combination of the lightweighting of parts, the creation of parts with improved functionality and greater complexity, the production of parts on-demand, with more efficient material use and, often, in a greener manner. However, when it came to jewellery, the technology in its early form was not providing the same results as conventional processes, often resulting in precious metal AM components that fell below desired standards, or that were simply too expensive to be a viable alternative for well-established jewellery strategies and markets.

One of the biggest attractions of Additive Manufacturing for precious metal jewellery is that it enables manufacturers to better control the weight of products, an undoubtedly cherished ability considering the price per gram of gold and platinum and the relative impact on the retail price. What, however, raised doubts and lead to dampened enthusiasm for the technology was the path of implementation. As mentioned, the early adoption of metal AM by jewellery designers mimicked what had happened in so many other industries: testing metal AM use cases by transposing already successful designs created for manufacture by traditional processes to AM. Inevitably, these results weren't entirely convincing.

Whilst precious metal AM remained well esteemed by engineers, product, and production teams, with a few exceptions it struggled to make headway amongst earlier adopters. This was due in part to the lack of a convincing new design language, new codifications, that could leverage the true creative freedom and commercial potential of the technology. Very few designers could truly harness metal AM's potential and translate it into innovative jewellery concepts that couldn't be manufactured by conventional routes. Often the available manufacturing technologies – the AM machines – were perceived as too technical, resulting in designers failing to take advantage of the new technology enough to result in something unique. Intertwined with this is the fact that customers generally aren't interested in the processes as much as the design, feel, comfort and price of the piece.

Materials: a change of focus brings new opportunities

The focus of metal AM in the jewellery industry has primarily been gold, as it has historically been the main and most widely used metal for jewellery around the world. The reasons for this go beyond the material's intrinsic value and move into less tangible areas of importance, such as tradition and culture. Consequently, designs are mainly created and developed for traditional techniques which still have a stronghold in the industry, given gold's heritage. When it comes to tailored pieces for certain novel purposes, metal Additive Manufacturing can assist, but its use remains the exception rather than the rule for scaling up. The reasons remain the same: in a comparison between historical processes with hand finishing, metal AM rarely delivers a persuasive solution.

Despite this, a number of innovative examples have been created and promoted in international jewellery exhibitions, increasing interest in, and research related to, metal Additive Manufacturing. One early example is Nuovi Gioielli's patented metalPixel,

a precious metal mesh created in 2014 which mimicked fabric. This sort of innovative and unique design showcased what extreme solutions could only be achieved with metal AM. An example of Nuovi Gioielli's AM pieces is shown in Fig. 2.

While those in business development were focusing on gold, unexpected attention was beginning to be paid to platinum, which is said to be a 'match made in heaven' for Additive Manufacturing, in particular the Laser Beam Powder Bed Fusion (PBF-LB) AM process. Platinum has its own niche in the jewellery industry, most notably as the perfect background – given its light grey colour – to enhance the beauty of diamonds.

From the first investigations, in the middle of the 18th century, platinum generated great interest amongst scientists, but it was only towards the end of the 19th century that the first platinum alloy jewellery was made by Cartier [2]. The delicate design, mainly dictated by the specific weight (60% heavier than gold), initiated an exquisite and unique style which would lead to the classic Art Deco style. Its rarity – thirty times rarer than gold – attracted a very niche market, mainly as an exclusive choice for engagement and wedding rings. It continues to do so [3].

To further encourage interest in this precious white metal, one needs only to look at recent reports. The Platinum Guild International's 1st quarter report for 2023 recorded a +20% growth in India in the related retail business. It also noted the return of PlatAfrica – a collaboration PGI India and Anglo-American Platinum. This growing use of platinum appears to be a promising trend that would be well served by PBF-LB Additive Manufacturing.

Metal AM, when applied to platinum, offers not only the opportunity to create pieces with higher standards of precision, excellent finishing and fewer challenges than the standard casting process when creating bespoke rings, but also offers the opportunity to explore truly unique solutions which would be impossible to consider with traditional jewellery techniques.

Fig. 3 A platinum 950‰ ring produced by PBF-LB and designed by Alessandro Paone for Progold's 2023 Design Contest (Courtesy Progold)

Recently, Progold S.p.A., Italy, launched a competition in partnership with the Platinum Guild and exclusive jewellery brands in an effort to bolster the understanding of the possible breadth of AM applications. In 2023, Chaumet selected and awarded the winners; Bulgari will fulfil this role for the coming year's contest. Several international schools of jewellery and design are involved in the competition, allowing students to understand the material, learn about the Design for AM (DfAM) workflow, test their creativity, and design jewellery beyond 'classic' diamond pieces. The results are new, bespoke designs that can only be manufactured with metal AM (Fig. 3).

Fig. 4 'Concretiones 46' necklace (2020), designed by Stefania Lucchetta. The material is anodised titanium. Laser Beam Powder Bed Fusion (PBF-LB) was the primary technology used, and the piece is hand finished using sand-blasting and polishing (Courtesy Stefania Lucchetta)

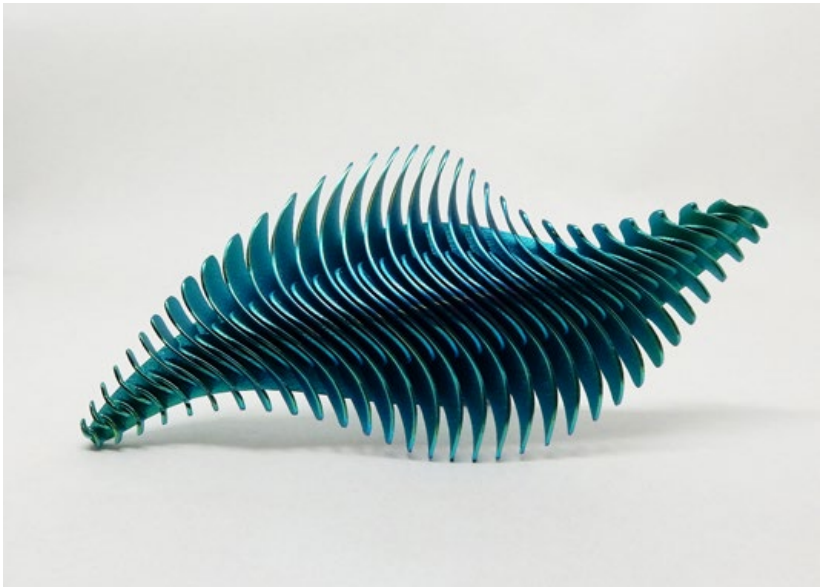

Fig. 5 'Vertebrae 158' brooch (2020), designed by Stefania Lucchetta. Materials are anodised titanium and steel. Laser Beam Powder Bed Fusion (PBF-LB) was the primary technology used, and the piece is hand finished using sand-blasting and polishing (Courtesy Stefania Lucchetta)

Some of the most popular AM products promoted by Progold are hollow rings, that, thanks to the technology, enable rings across different sizes to have the same weight, backing management and marketing strategies. However, this competition encourages students to explore and take risks with their designs, whilst collaborating with technicians to find the perfect solutions.

The increasing interest in Additive Manufacturing's place in the jewellery industry was also highlighted at the recent RAPDASA (Rapid Product Development Association of South Africa) conference held in Pretoria. I was invited to this event to speak about metal AM developments in jewellery, highlighting why titanium and platinum group metals could represent the turning point for this innovative solution.

It is my belief that, thanks to platinum in particular, precious metal AM seems to have finally found its own path in the industry, creating a new and original narrative without compromising on quality and design, and without suffering the comparison with the traditional techniques.

This unexpected twist in the story of precious metal AM suggests that it is very likely that it will gain its own place in the jewellery sector. And, by doing this, it is anticipated that other precious metals may follow in platinum's path, encouraging more exploration in tandem with Additive Manufacturing technology.

Stefania Lucchetta: a new design language tailored around AM

I must confess that my enthusiasm for this technology remains high and I still think that the best is yet to come. My passion for the technology is further enhanced when I look at the work of successful designers using the process. One visionary in the field of AM jewellery in Stefania Lucchetta, whom I can call a friend, as the perfect example of the daring exploration of the aesthetic potential of the process.

Fig. 6 'Digital 13' ring (2010), designed by Stefania Lucchetta. The material is anodised titanium. Laser Beam Powder Bed Fusion (PBF-LB) was the primary technology used, and the piece is hand finished using sandblasting and polishing (Courtesy Stefania Lucchetta)

In a conversation we had not so long ago, Lucchetta shared that her interest in the potential applications for titanium started towards the end of the 1990s when she saw the first titanium casting machines whilst attending international jewellery exhibitions. She comes from a family of jewellers, although the family business was more focused on an Italian-manufactured traditional 18 kt gold collection. It was, however, her curiosity, often the leitmotiv amongst pioneers, that led her to delve further into the potential of this unique metal for jewellery. Its combination of lightness and hardness fascinated her and confirmed for her that she could design with a different mindset from the one used for gold.

It was metal Additive Manufacturing technology's ability to fit a high degree of complexity into a compact form that allowed Lucchetta to evolve her research and designs. The first attempts dated back to 2005, when she could replicate her traditionally cast series 'Crateri' with the Electron Beam Powder Bed Fusion (PBF-EB) AM with good results.

From this first trial, Lucchetta explored further to match her artistic vision with the capabilities of this technology, giving life to unexpected objects that are able to tell a story of fashion's future without foregoing wearability and comfort. These explorations have continued, largely adopting through PBF-LB technology, where unfinished surfaces, or surfaces with clear signs of lasered layers, combine with polished surfaces to become part of the creative language, thus supporting new aesthetic codifications. It is often the case that

"From this first trial, Lucchetta explored further to match her artistic vision with the capabilities of this technology, giving life to unexpected objects that are able to tell a story of fashion's future without foregoing wearability and comfort."

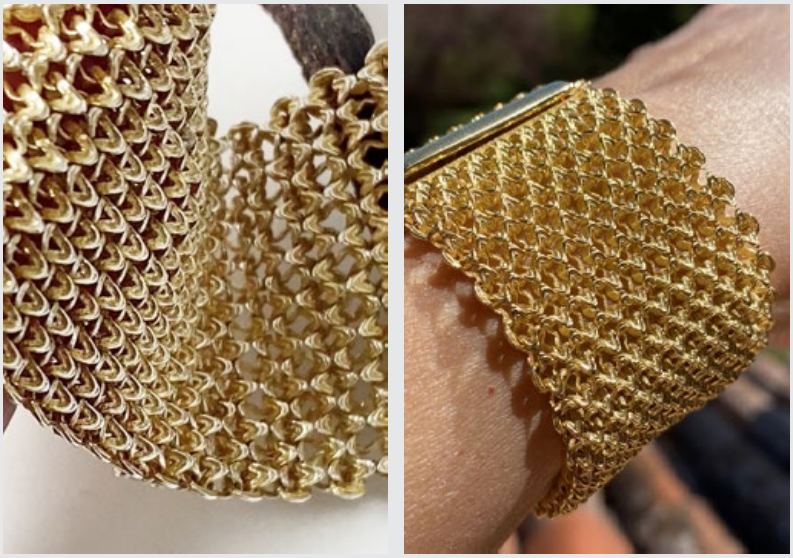

Fig. 7 The 'Arabesque' bracelet, designed by Michela Ferraro. Manufactured by PBF-LB, the bracelet replicates the feel and look of velvet fabric in metal (Courtesy Michela Ferraro)

> *"Like Stefania Lucchetta, I chose to exploit the technology for aesthetic reasoning – the unfinished surface, later redesigned with smaller links, replicating the feeling and look of velvet fabric in metal."*

contemporary jewellery designers anticipate and give an opportunity to solutions that could – much later – become the inspiration for more commercial brands.

Her collection is presented in international art and contemporary galleries, where her jewellery pieces have clearly set a new path, and those that are following her are clearly recognisable. It is often the case that a design pioneer starts a trend or an aesthetic language, and followers confirm that original intuition with their inspired jewellery. It would be a good ethics practice to always cite the inspirations, though sometimes it is hard to admit that initial influence.

Conclusion

Since my last article, I have also continued my explorations on the feasibility and finishing of precious metal AM. My interests remain focused on meshes and the creation of flexible designs, aspects enabled by the adoption of this fascinating technology. I was pleased to have won a silver award from the Goldsmiths' Craft and Design Council in the 2021 for my Arabesque bracelet (Fig. 7). Like Stefania Lucchetta, I chose to exploit the technology for aesthetic reasoning – the unfinished surface, later redesigned with smaller links, replicating the feeling and look of velvet fabric in metal.

So the journey of precious metal AM in the jewellery industry continues, with those already entrenched in the technology aiming to see more designers engage with this innovative technology to produce an exciting future. It's all down to the question of time, and the combination of technology and materials. The place of titanium and platinum in the industry are making it more likely that the time is, if not now, soon.

Author

Michela Ferraro is a jewellery expert with over thirty years of passion and international experience in the industry. She is a multi-award winning jewellery designer for precious metal AM, Senior Lecturer in Luxury Jewellery Management at Birmingham City University, visiting Lecturer in Luxury and Sustainability at Sotheby's Institute of Art, London, and a fervid advocate for ethical and responsible jewellery innovation.

michela.ferraro@me.com

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Mission possible: The five-year plan to gain FAA and EASA acceptance of in-process monitoring

At the European Union Aviation Safety Agency (EASA) and Federal Aviation Administration (FAA) summit in Cologne, Germany, this September, Don Godfrey, Nikon SLM Solutions, and Fernando Lartategui, ITP Aero, co-chaired a Working Group whose mission is of critical importance to the metal Additive Manufacturing industry. What is that mission? To chart a five-year path which ends with in-situ monitoring approved by the FAA/EASA as a method for part acceptance. Here, the chairs present an overview of the current landscape and consider the challenges on the path to this crucial goal.

In response to industry interest and the rapid expansion of Additive Manufacturing (AM) use in the production of aviation parts, the European Aviation Safety Agency (EASA) started offering workshops on the Qualification and Certification (Q&C) of AM in 2015. These workshops had a specific focus on promoting technical dialog and knowledge sharing between key stakeholder groups, including government agencies, industry, public standards organisations and academia.

In the US, the Federal Aviation Administration (FAA) started offering workshops on the Q&C of AM as well in about the same timeframe. The first three FAA workshops were organised in partnership with the United States Air Force (USAF) and the Air Force Research Laboratory (AFRL). As part of this process, and in response to industry requests, the EASA and FAA have been increasingly working together, resulting in collaboration and alternate hosting of an annual joint aviation AM event, with the past events having been hosted by EASA in Cologne in 2019 and virtually in 2021 and by FAA in Wichita, Kansas, in 2018 and virtually in 2020 and 2022. The presentations and outputs from these events are available in the public domain [1,2].

The 2023 event was held in Cologne, from September 19-21, and it continued building on the outcomes of the recent successful workshops, while striving to offer new coverage and technical insights based on the most recent developments in the area

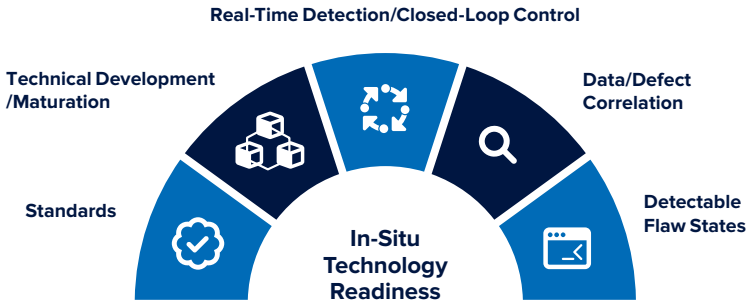

Fig. 1 Key topics for the In-Situ Technology Readiness for Applications in AM Qualification and Certification Workshop (Courtesy ASTM International)

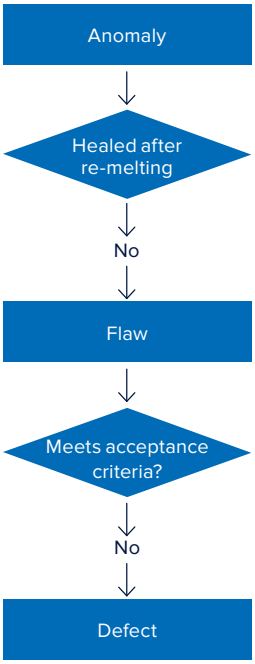

Figure i. Definitions flow chart

Key Definitions

Currently there is no industry consensus on some of these key terms for in-situ monitoring. Some terms used during the workshop and throughout this guide are defined below. These terms synthesize similar concepts from existing standards (primarily NDE-related), with additional context added for application to AM ISM. Often, these terms can be used interchangeably, and nuanced differences primarily matter based on context in which they are used. Users should be aware that the state-of-art in AM ISM applications do not always fit within traditional concepts of non-destructive testing, inspection, or statistical process control, and incur unique physical challenges such as rehealing or remelting of flaws. Definitions may be slightly altered from their original source.

- **Process Signature[2] –** potentially observable physical phenomenon (and not limited to in-situ monitoring or non-destructive testing) that occurs during the AM fabrication process and is potentially correlatable to part quality metrics
- **Indication[3] –** A variation detected with non-destructive examination
- **Anomaly –** Unintended/unintentional variation from the expected result or quality (based on [2])
- **Flaw[4] –** Imperfection or discontinuity that may be detectable by non-destructive testing or in-situ monitoring, but may not necessarily be rejectable
- **Defect[5] –** One or more flaws whose aggregate size, shape, orientation, location, or properties do not meet specified acceptance criteria and are rejectable

[2] As defined in ASTM E3353
[3] Definition based on ASTM E1316
[4]Definition based on ASTM E1316
[5] As defined in ASTM E1316

Fig. 2 An attempt to clarify key terms and their relationships in a concise manner. It should be noted that the previously-addressed complexities within the various applications of in-situ monitoring for AM, and the lack of industry consensus around these terms, render any such diagram to not be comprehensive (Courtesy ASTM International)

of Q&C for AM from an industry-regulator perspective. During the event, breakout sessions were organised for three working groups to cover relevant Q&C topics.

The intent of Working Group 3 (WG-3) was to discuss the most recent relevant development in AM monitoring technologies, and then chart a development plan to mature the technology so that components qualification can be supported via in-situ process monitoring in the coming years.

"Today, when a company uses a new technology or a new material, it must be validated and certified for flight via testing. FAA Code of Federal Regulation Part 25.605 requires that each new aircraft fabrication method must be substantiated by a testing programme, including Additive Manufacturing."

The current status of in-situ process monitoring

Both the FAA and EASA recognise the necessity for safety regulations to be merged to represent a 'single voice' from the global aerospace manufacturing community, and they have been collaborating to achieve this goal for decades. This partnership works to ensure that a global audience travels with the highest level of safety when individuals board commercial airplanes.

Today, when a company uses a new technology or a new material, it must be validated and certified for flight via testing. FAA Code of Federal Regulation Part 25.605 requires that each new aircraft fabrication method must be substantiated by a testing programme, including Additive Manufacturing.

There is a belief held by many that a company can use in-situ

process monitoring technology to qualify a part for commercial aviation; but, today, that belief is not correct. It is the hope of the AM community that sometime in the next few years in-situ process monitoring can be used to accept a component. However, today, the best this technology can do is help give confidence to manufacturers that an AM process is running properly.

What the FAA/EASA community is looking for

There are many aerospace components that are qualified because they are a product of an approved manufacturing process. An example might be a casting with multiple internal chambers that cannot be inspected via CT technology because the part is too large and the energy waves cannot reach the area where the chambers exist. The same is true when using X-ray technology. In such examples, several parts produced in the initial casting process are cut up and inspected. Once dimensional repeatability is proven and structural integrity is validated over several parts, then the tool is viewed not just as a casting tool, but also a tool that can confidently produce a quality part. Thus, the parts coming off the tool are viewed as good because they are a product of the process.

Current Additive Manufacturing components are being qualified as a product of an approved manufacturing process, and this will be the logic used when looking at in-situ process technology. Using multiple sensors that are monitored, an AM machine can be shown to produce a quality component, and those components are viewed as being a product of a quality process. However, this monitoring technique should be validated to demonstrate its repeatability and robustness.

If the sensor outputs of a qualified machine do not vary, one can logically assume that the process does not vary, and thus the component coming off that qualified machine is a quality component. On a larger, global scale, one key issue that must be controlled is that sensors across all machines produce an output that is similar to one another and consistent over time.

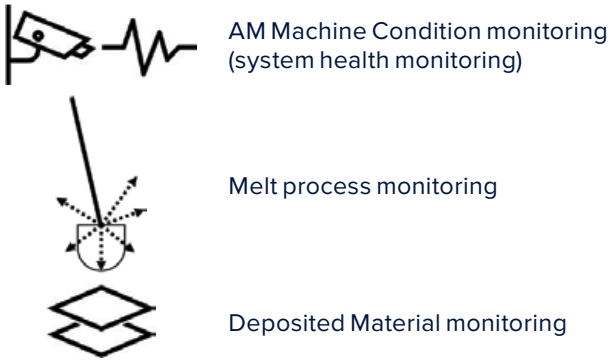

Fig. 3 Three general regimes for in-situ monitoring in AM machines (Courtesy ASTM International)

> *"In-situ process monitoring is contributing to an increasing confidence in the Additive Manufacturing process, but the regulatory community is looking for a proper validation of this technology."*

In short, federal regulation communities are looking for a way to mitigate risks. This means that process repeatability and process predictability over time, and variation in the build process (pre-build/build/post-build), is understood and minimised. In essence, the regulation community is looking for confidence that the build process will produce a component that meets the design intent of the engineering community and is able to be repeated over time. In-situ process monitoring is contributing to an increasing confidence in the Additive Manufacturing process, but the regulatory community is looking for a proper validation of this technology.

Quality

Every aerospace process for commercial aviation applications is fixed, and variation of these fixed processes is prevented without a thorough review and justification for change. However, even with fixed processes, every aviation manufacturing plant in the world still manufactures components that do not meet design intent and are placed in holding areas to be reviewed by Material Review Board (MRB) processes.

1	Basic sensor principles observed and reported	Fundamental Research
2	Sensor concept and/or application formulated	Technological Research
3	Proof-of-concept developed for sensor in laboratory environment	
4	Sensor validated as producing potentially useful signals for part or process health in laboratory environment	
5	Sensor integration on production AM system, but limited or no signal analysis	Product Demonstration
6	Sensor demonstrated with signal analysis in production environment, but not used in part or process certification	
7	Sensor used in production environment to provide general quality metrics on part or system health	
8	Sensor used in production environment to detect defects, in addition to ex situ inspection	
9	Sensor used in production environment to certify parts, as a replacement for ex situ inspection	Production

Fig. 4 Definition of the sensor technology readiness levels for the purposes of the analysis published in 'Strategic Guide: Additive Manufacturing In-Situ Monitoring Technology Readiness: Findings and Path Forward for Applications in Qualification and Certification' (Courtesy ASTM International)

Today, in-situ process monitoring should be used as a monitoring tool to give confidence to the inspectors in the plant that the machine is operating as intended, and, once qualified, will produce a component comparable to components that have been rigorously inspected in previous builds and met design intent.

Every AM process should begin with the creation of a Process Failure Mode Effect Analysis (P-FMEA). This approach to manufacturing is now the foundation for creating a quality manufacturing process with minimal variation.

Working Group 3 (WG-3) debated which processes should be monitored and how that monitoring should occur. Many machines already monitor voltage, oxygen levels and laser dynamics. Some systems monitor moisture content while other machine OEMs do not offer such capabilities. WG-3 will not mandate what sensing technologies will be used, but it can recommend that selected sensors have an assurance of repeatability.

"Many machines already monitor voltage, oxygen levels and laser dynamics. Some systems monitor moisture content while other machine OEMs do not offer such capabilities. WG-3 will not mandate what sensing technologies will be used, but it can recommend that selected sensors have an assurance of repeatability."

Non-Destructive Testing (Inspection): NDT/NDI for metal AM parts

Non-Destructive Testing (NDT) is the process of inspecting, testing, or evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of the part or system.

NDTs would appear to be a solution to inspect components produced by Additive Manufacturing as the part can still be used after

testing; however, the impact of NDT on business cases is substantial. Some WG-3 members shared their experience with current aerospace use cases in which NDTs accounted for more than 50% of their costs. This is the primary reason why the aerospace industry needs to achieve validation of in-situ process monitoring in the coming years.

There are many different types of sensors on an AM machine. One technology that has been on the market for a number of years is the technology that takes a digital photograph of a 'just-built' layer in the build chamber. At the recently held conference in Cologne, Germany, the National Aeronautics Space Administration (NASA) spoke about AMiquam, a company that is using eddy-current technology to monitor on each layer a depth of about 0.5 mm based on electromagnetic signals. This approach allows for inspectors to explore the electromagnetics sensors data to evaluate if the parts are correct, selecting regions of interest and calculating statistics.

Whilst neither NASA nor WG-3 are promoting or endorsing this technology, it serves as an example of how rapidly the field is evolving. The AM world that can be used to give regulators confidence that additively manufactured parts meet design intent.

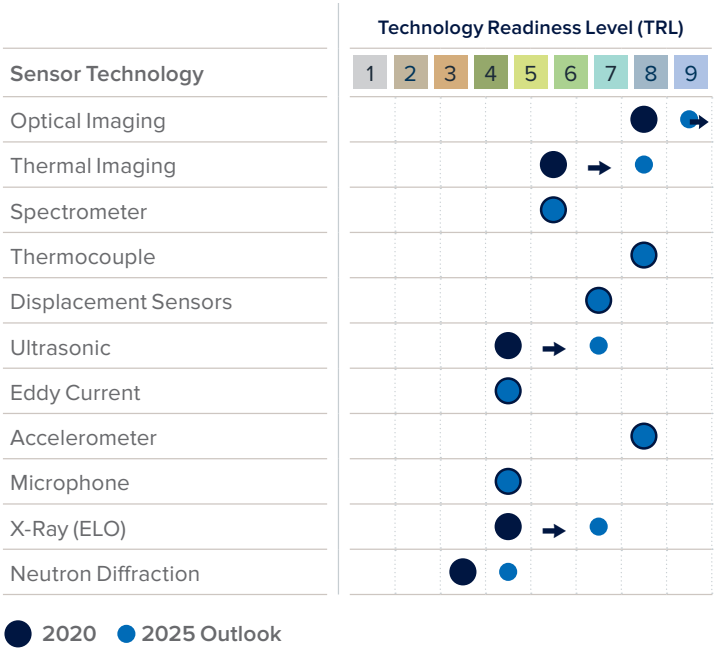

Fig. 5 Technology Readiness Levels of sensor technologies as of 2020 (dark blue) and a 2025 Outlook (light blue), as published in 'Strategic Guide: Additive Manufacturing In-Situ Monitoring Technology Readiness: Findings and Path Forward for Applications in Qualification and Certification' (Courtesy ASTM International)

How this effort will play out

Working Group 3 of the EASA-FAA conference consisted of approximately sixty engineers from aviation companies from all the major continents. After several hours of discussions across three days, the expectation of WG-3 is that in-situ process monitoring technology will be used for process acceptance within five years. The automation of data analysis is a key factor to support the achievement of this milestone. To reach this objective, WG-3 suggested the possibility of conducting a process acceptance demonstration in the near future.

"...the expectation of WG-3 is that in-situ process monitoring technology will be used for process acceptance within five years. The automation of data analysis is a key factor to support the achievement of this milestone."

WG-3 did not, however, expect that in-situ process monitoring technology will be used for full component acceptance within the same time frame, as a known and validated correlation between indications, the physics of the process, and actual defects in the finished part is required. WG-3 only expects partial component acceptance.

In addition, a core group which emerged from WG-3 began drafting guidelines and scope. That core team is global and comprises of experts form Boeing Aerospace, Sandia National Laboratory, NASA Marshall Space Flight Center, Rolls-Royce plc, Materialise, ITP Aero, MTU Aerospace and Nikon SLM Solutions. Once this small team has agreed on the first

ASTM	
ASTM	Strategic Guide: Additive Manufacturing In-Situ Monitoring Technology Readiness
SAE Publications	
AMS7003	Laser Powder Bed Fusion Process
AMS7032	Additive Manufacturing Machine Qualification
ARP7065 (WIP)	Taxonomy and Definitions for Terms Related to In Situ Process Monitoring Modality-Capability Index
AS7766	Terms Used in Aerospace Metals Specifications
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NASA Publications:	
NASA-STD-6033	Additive Manufacturing Requirements for Equipment and Facility Control
NASA-STD-6030	Additive Manufacturing Requirements for Spaceflight Systems

Table 1 Resources that can help a company set up and run a Laser Beam Powder Bed Fusion (PBF-LB) process

position white paper, it will be sent to the entire WG-3 audience, who represent aerospace and technology companies spanning the globe.

Eventually, one goal of this effort will be to author an SAE Aerospace Recommended Practice (ARP) for using in-situ process monitoring for the validation of an AM process and then to lay the foundations for qualifying some elements of an additively manufactured component.

It should be stressed that creating an ARP is not simply writing a white paper. It must get through the fifty to sixty engineers that made up WG-3, and then be submitted to the SAE Committee who will also conduct a similar process. Once that is completed, the effort is hoped to move onto becoming an SAE Standard. This entire process is going to take a while.

Authors

Fernando Lartategui Atela
Associate Technical Fellow in ALM
ITP Aero
www.itpaero.com

Donald Godfrey
Global Director, Business Development for Aviation and Defence
Nikon SLM Solutions
www.nikon-slm-solutions.com

Further resources

Table 1 lists resources that can help a company set-up and run a Laser Beam Powder Bed Fusion (PBF-LB) process. While there is no in-situ process monitoring guide at this time, these documents offer a very good way to set up a process and help gain confidence in the printing process.

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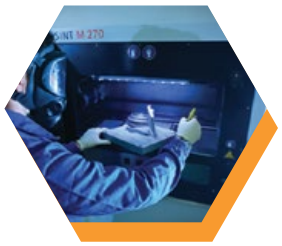

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