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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

PRINTERPREZZ'S ADDITIVE MISSION

LESSONS FROM THE OLYMPIC BIKE CRASH

XEROX'S LIQUID METAL AM

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METAL
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Sure, it's all true. Just with a positive spin

There are few places where social media doesn't reach. On a personal level, it paints a glossy world of perfect people, locations and lifestyles. Real lives, of course, are rarely as joyous as the Facebook and Instagram lives that are presented.

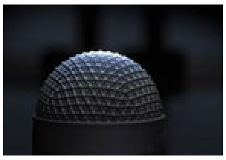
The same is true on a business level: LinkedIn is the place where companies and individuals compete to present their best face, the best of their technology. Whilst many have cautioned for years about the hype around Additive Manufacturing, as a community we often continue to do just that, positively spin everything, from a technology that may not be ready to an event that clearly wasn't buzzing.

Hey, it's just marketing, right? But all too easily we reach a point where we try and censor any negatives. We face the same challenges in *Metal AM* magazine, where at once we see ourselves as a publication with the power to promote AM technology to new and wide audiences, but at the same time strive to present a balanced, more considered view.

So, when exploring the concept for this issue's article on the Tokyo Olympics bike crash in 2021 in which a metal AM part failed so publicly, that social media-heightened self-censorship kicked in. Is highlighting such a story good for the industry? Should we just leave it brushed under the carpet?

In the end, it became clear to us that the story has a lot of valuable lessons that will benefit many existing and potential users of the technology. Thankfully, our decision to publish this article was made easier by the fact that an extensive report on the failed AM part concluded that the part's manufacturer, and the technology itself, were not to blame. But there are, nevertheless, many lessons to be heeded when pushing any manufacturing technology to its limit in an unregulated environment.

Nick Williams
Managing Director



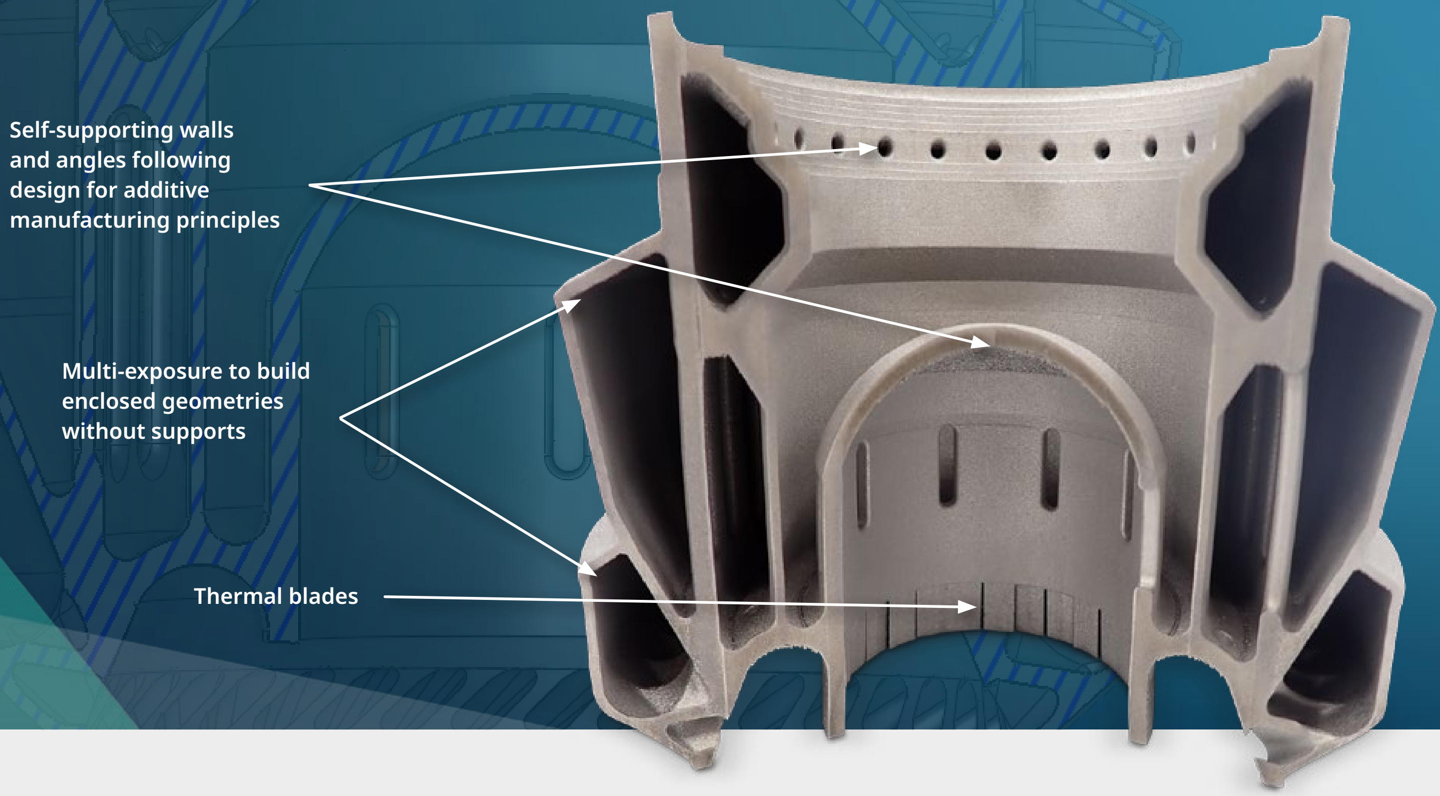
Cover image
Optical Coordinate Measuring Machine analysing the surface topology of an implant (Courtesy PrinterPrezz)


NO CASTING
VIOLATORS SUBJECT TO
OVERSEAS MANUFACTURING
AND ASSOCIATED PROBLEMS.

Contents

NoSupports™ = Less Time & Lower Costs

Metal additive manufacturing makes it possible to produce high performing components that defy conventional manufacturing limitations. Discover how 3D Systems' NoSupports™ metal printing increases productivity, accelerates production time, and makes it possible to successfully print enclosed geometries without support structures.



Get 3D Systems' step-by-step guide to NoSupports metal printing and learn:

- The function of support structures in metal printing
- Advantages and strategies for reducing or eliminating support structures
- How to apply NoSupports strategies to a metal printed part with enclosed features

Discover how you can accelerate your additive manufacturing production with 3D Systems.

Learn more

3D SYSTEMS

127 What Xerox's aluminium liquid metal AM offers for supply chain resiliency

It is too easy to look at metal Additive Manufacturing technologies as neatly fitting into a small number of convenient process categories. The risk, in doing so, is that the best solution could be overlooked. One AM process that does not fit into such neat boxes is Xerox's Liquid Metal Jetting.

Whilst it falls, broadly, under the ISO/ASTM 52900:2015 category of Material Jetting, it is unique among metal AM processes. Here, Bender Kutub considers where it fits into the drive for supply chain resilience, and explores its market potential. >>>

137 Additive Manufacturing for oil, gas and maritime: An evaluation of capabilities and potential

In 2018, a consortium of twenty-three companies, managed by DNV and Berenschot, started a project, ProGRAM JIP, to produce a guideline formulating the necessary requirements to introduce components made by Additive Manufacturing into the oil, gas and maritime industry. This was followed, in May 2020, by ProGRAM JIP Phase II, again managed by DNV and supported by Berenschot. The participants in Phase II spanned the entire value chain, from end-users and OEMs to service providers, material suppliers and testing companies.

Here, DNV's Sastry Yagnanna Kandukuri and Berenschot's Onno Ponfoort present the consortium's preliminary Phase II findings. >>>

145 Multi-material metal parts by Powder Bed Fusion: New application opportunities

As product developers become more and more aware of the possibilities of metal Additive Manufacturing and the design freedom it offers, metal Laser Beam Powder Bed Fusion (PBF-LB/M) has established itself for series applications in numerous industries.

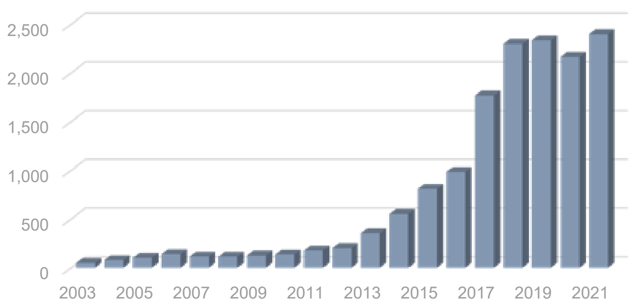
One novel capability of PBF-LB/M which has yet to be fully explored is the production of multi-material metal parts, which would offer huge new potential for designers in many industries.

Prof Dr-Ing Christian Seidel looks at methods and solutions for the AM of parts consisting of two arbitrarily distributed metal alloys and presents use cases with the potential for series production by multi-material PBF-LB/M in the near future. >>>

153 **Findings from *Wohlers Report 2022*: Taking a chance on new technologies and the evolving materials mix**

Getting to grips with what is really happening in our industry can be a tricky business. Thankfully market analysis is available from a number of expert sources, with the longest established being the Wohlers Report.

Here, Noah Mostow, Olaf Diegel, and Terry Wohlers share insight from the recently published 2022 edition, including an overview of machine sales, the acceptance of a new breed of technology suppliers, the growth of service companies, and the evolving metal AM material mix. >>>



159 **The challenge of grain size: X-ray powder diffraction analysis of parts made by metal AM**

X-ray powder diffraction (XRPD) has long been a powerful tool in metallurgy, but its unsuitability for parts with large grain sizes has made its use for the analysis of metal additively manufactured parts a challenge.

In this article, Dr Scott Speakman, Malvern Panalytical, reports on a study in which specimens of soft magnetic Fe-Si steel were made by PBF-LB using a variety of raster and annealing strategies to produce specimens with large grain sizes.

The X-ray diffraction data collected illustrates the tell-tale signs of poor crystallite sampling statistics. Speakman presents some strategies for recovering data fidelity with conventionally available options. >>>

Regular features...

Our advertisers' index serves as a convenient guide to suppliers of AM machines, materials, part manufacturing services, software and associated production equipment.

In the digital edition of *Metal AM* magazine, available at www.metal-am.com, or via the *Metal Additive Manufacturing* app, simply click on a company name to view its advert, or on the weblink to go directly to its website.

Industry news

Divergent Technologies closes funding round with $160 million

Divergent Technologies, Torrance, California, USA, reports that it has completed Series C funding totalling $160 million. The funding will enable the company to industrialise its fully-integrated platform, combining generative design, Additive Manufacturing and automated assembly, expand operations, and meet the growing demand among automotive OEMs for design and production of vehicle structures leveraging Divergent's proprietary digital production technology. Along with the new funding, Divergent states that it is welcoming John L Thornton, former president of Goldman Sachs, executive chairman of Barrick Gold, and board member of Ford Motor Company, to its board of directors.

Divergent Technologies aims to make the vehicle manufacturing process more efficient and less wasteful using Additive Manufacturing. Through the company's Divergent Adaptive Production System (DAPS®), it replaces the conventional structure design and production process, which is reliant on legacy software, vehicle architectures, tooling and related factory assets with a proprietary, patented, end-to-end system for vehicle design and engineering, volume manufacturing and assembly.

The DAPS software-hardware stack was developed in house, with over 500 patent filings across the system. This approach enables both low- and high-volume manufacturing without costly tooling and capital expenses, enabling manufacturers to quickly iterate and invent new product models from anywhere in the world.

Divergent has a team of more than 180 engineers and scientists across four technology divisions: Structures, Software (HPC, GD and AI), Additive Manufacturing (Hardware, Software and Materials) and Automation (Software, Optics and Robotics).

"This funding represents a sterling affirmation of how disruptive we are in the auto manufacturing industry, one that really hasn't experienced such revolution since Henry Ford developed the assembly line more than 100 years ago," stated Kevin Czinger, CEO. "Of great importance, given the global focus on sustainability, DAPS is planet-saving manufacturing in that it radically reduces lifecycle environmental impact by optimising total vehicle 'cradle-to-cradle' efficiency."

Lukas Czinger, senior vice president of Operations, commented, "DAPS creates radically more efficient structures using a fraction of the typical engineering time and transforms automotive companies from CapEx-constrained businesses to flexible, design-driven organisations. It is the first instance of digital industrial manufacturing. The factory infrastructure stays consistent regardless of the design, only the data changes, allowing DAPS to switch between differentiated designs seamlessly with no downtime in-between. DAPS entering serial production this year represents a historic inflection point in automotive manufacturing."

The capabilities delivered by the system are highlighted in the Czinger Vehicles 21C hypercar, the first production car designed and built using Divergent's ground-breaking technology. Divergent plans a scale-up of its advanced manufacturing facilities, with DAPS factories planned for Europe and the USA starting in 2024. The company is currently in development with eight initial OEM brands on vehicle structure programmes with production volumes ranging from hundreds to hundreds of thousands of vehicles across the models' production life, with the first programme entering production this year.

www.divergent3d.com

How the Czinger 21C is redefining next-generation car manufacturing

Read our exclusive article in the Winter 2021 issue of *Metal AM* magazine. Download your free copy at: https://bit.ly/3NXRLBv

The Czinger Vehicles 21C hypercar is the first production car designed and built using Divergent's ground-breaking technology (Courtesy Czinger Vehicles)

Digital Metal launches DMP/PRO series for industrial Binder Jetting

Digital Metal, part of Sweden's Höganäs Group, has launched its DMP/PRO series Binder Jetting (BJT) Additive Manufacturing machine. Developed as a modular component of a complete binder jet solution, the PRO series is designed to offer maximum reliability, accuracy and repeatability in high-volume industrial manufacturing. The DMP/PRO's printhead incorporates 70,400 nozzles, enabling the machine to produce up to 1,000 cm^3 of parts per hour at 1600 dpi. Typical production values, claims Digital Metal, will see customers produce around 500 cm^3 of parts per hour throughout the day. Digital Metal states that this high productivity is matched by a robust platform, custom software and a fast powder change magazine.

"As a team we have previously gone from a single machine to a production machine and now we've launched a true production platform. We're moving away from the rest of the binder jet market towards tighter tolerances, higher volumes and higher precision," stated Digital Metal CEO, Christian Lönne.

"We're heading towards a higher level of maturity. We do not just offer a machine in isolation. We have a true platform optimised to work in concert with debinding, sintering and post processing equipment. This platform is modular, extensible and a stepping stone for Industrialisation," added Lönne.

Built on Siemens MindSphere cloud IoT OS, the software system ensures that future IoT integration and connections will be reliable and secure. The system is said to be intuitive and easy to use, and optimised for production environments. New support structure minimisation increases productivity and reduces part cost. Higher powder utilisation means that 100% of excess powder can now be recycled, states Digital Metal, with this environmental gain also reducing part costs.

Azoth 3D, a precision Additive Manufacturing parts maker based in Ann Arbor, Michigan, was announced as the launch customer for the new DMP/PRO. "Digital Metal's new machine speed, while keeping quality and reliability, is compelling. The PRO Series reduces the capital needed to scale and also reduces part costs through higher machine throughput. We want to run it round the clock, seven days a week, making thousands of parts daily. Azoth 3D wants to be the largest and best independent binder jet manufacturing company and this is the system we need to get us there," stated Azoth's General Manager, Cody Cochran.

www.digitalmetal.tech

The new DMP/PRO is designed to be part of a complete modular Binder Jetting solution, enabling high volume Additive Manufacturing (Courtesy Digital Metal)

Wohlers Report 2022 finds 19.5% AM industry growth

Wohlers Associates, Fort Collins, Colorado, USA, part of ASTM International, has published *Wohlers Report 2022*, marking the twenty-seventh consecutive year of publishing the report on Additive Manufacturing. The 2022 report shows AM industry growth of 19.5% in 2021, up from 7.5% growth in 2020, which was impacted greatly by the COVID-19 pandemic.

The *Wohlers Report 2022* is intended to provide readers with insight, analysis, trends, and forecasts and acts as a tool for decision making and knowledge acceleration. The foundation of the 425-page report is over two decades of data and market intelligence, coupled with a wide network of contacts worldwide. The report includes details on 147 early-stage and corporate investments and seventy-five mergers, acquisitions, and initial public offerings.

"As expected, the industry has returned to a period of advancement and investment," stated Terry Wohlers, head of advisory services and market intelligence at Wohlers Associates. "This expansion cuts across aerospace, healthcare, automotive, consumer products, energy, and other sectors."

Wohlers Report 2022 includes the following new and expanded features:

- Scaling AM into production
- Workforce development and sustainability
- Women in 3D Printing
- Ground-breaking R&D programmes
- Reports from industry experts in thirty-four countries
- The future of AM

Wohlers Report 2022 is available to purchase from Wohlers Associates.

www.wohlersassociates.com

INTRODUCING A NEW ERA OF ADDITIVE MANUFACTURING.

Welcome to the future of additive manufacturing. The Xerox® ElemX™ 3D Printer operates with standard aluminum wire feedstock and replaces the need for hazardous powders in production environments. Depositing molten liquid at 850˚C directly onto a metal build plate enables the ElemX to bypass sintering or shrinkage challenges. With shorter cycle times and more reliable parts, the Xerox ElemX is making on-demand manufacturing a reality for our customers today.

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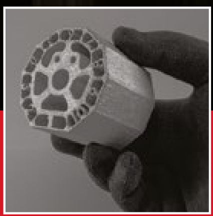
Stronger.



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Additive Solutions

Scan to subscribe to the latest about Xerox ElemX Liquid Metal 3D Printing and learn more at **Xerox.com/3Dprinting**

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BMW reports successful integration of automated AM car parts production line

BMW Group has reported success in its aim to industrialise and digitalise the Additive Manufacturing of components for use in automotive series production. Together with the twelve members of the Industrialisation and Digitalisation of Additive Manufacturing (IDAM) consortium, which was launched in 2019, a digitally connected, fully automated Additive Manufacturing line specifically for series production of automotive components, has been established at the BMW Group Additive Manufacturing Campus in Oberschleissheim, Germany. A further production line has also been established at GKN Powder Metallurgy's facility in Bonn.

BMW states that approximately 50,000 components per year can now be manufactured cost effectively in series part production - as well as more than 10,000 custom or new parts, using its Laser Beam Powder Bed Fusion (PBF-LB) technology. By using this Additive Manufacturing process, the group explains that certain tools are no longer required and new design possibilities can be realised, greatly increasing its manufacturing flexibility.

A fully automated driverless transport system (FTS), which began as a concept outlined in 2019, is used to carry mobile AM build chambers between modules in the IDAM production lines. Further automation sees processed metal powder delivered to workstations for preparation, and post-processing of the additively manufactured components is conducted automatically at specially designed stations.

Quality assurance of the finished parts takes place in-line, during the AM process, using sensors. This includes checking emissions from the molten pool with a CMOS camera and pyrometer. AI algorithms are used to correlate the data collected with actual component quality. The result is that process deviations can be identified during production and component quality evaluated.

The successful implementation of the IDAM project, which was funded by the German Federal Ministry of Education and Research (BMBF) and led by the BMW Group, was said to be due to the combined expertise of all project partners. "From the very first day of the project, you could feel the team spirit among the partners," stated Felix Haeckel, consortium leader and BMW Group project manager.

"Learning from one another, developing innovative solutions together and making the best use of each partner's individual strengths – those were key to successful industrialisation and digitalisation of Additive Manufacturing," concluded Haeckel.

www.photonikforschung.de
www.bmwgroup.com

A fully automated Additive Manufacturing production line has been established for automotive part production at the BMW Group Additive Manufacturing Campus (Courtesy BMW Group)

Triditive and Foxconn partner to develop Binder Jetting machine

Foxconn, the trading name of Hon Hai Technology Group, a leading electronics manufacturing company headquartered in New Taipei City, Taiwan, and Triditive, a producer of automated Additive Manufacturing technology based in Asturias, Spain, have partnered to develop a new Binder Jetting (BJT) AM machine.

Foxconn is one of the largest companies in the technology sector and produces devices for companies such as Apple, Sony and Intel. The company has extensive Metal Injection Moulding (MIM) operations and has been utilising Additive Manufacturing for a number of years.

Both companies are currently developing their first prototype Binder Jetting machine, along with the materials required for subsequent commercialisation.

For the development of the binders, Triditive has collaborated with Tecnalia, the research and technological development centre of the Basque Country (País Vasco), Spain. It has also worked with the Fraunhofer Technology Center High Performance Materials (Fraunhofer THM) for the selection of metal powders.

The key advantages of the innovative technology that Foxconn and Triditive are developing is reported to be the scalability of production and a reduction of costs in the manufacture of complex metal parts for end-use applications.

www.foxconn.com
www.triditive.com

Farsoon expands range of multi-laser metal Additive Manufacturing machines

Farsoon Technologies, headquartered in Changsha, Hunan, China, has announced the launch of three new metal Additive Manufacturing machines. All three machines offer a multi-laser setup, enabling increased production speeds while maintaining part quality, and are suited to a wide range of industrial applications.

FS200M×2

The new FS200M×2 platform is a medium-sized metal Laser Beam Powder Bed Fusion (PBF-LB) AM machine equipped with a versatile build volume of 425 x 230 x 300 mm and dual 500-watt laser configuration. The new machine is said to be ideal for medium to high volume metal series production and prototypes.

As with all Farsoon machines, the FS200M×2 is an open platform system offering a high degree of control and enabling precise tailoring of processing parameters. To improve the productivity further, the FS200M×2 is able to integrate multiple scanning strategies of different layer thickness in a single build, according to an application's needs.

FS422M-4

Also now available is the new Farsoon FS422M-4, a four-laser metal PBF-LB machine with a build area of 420 x 420 x 550 mm. As with the company's FS273M, introduced in 2021 to replace the popular FS271M, the metal powder can be circulated in a closed loop, said to be particularly popular with automotive industry customers.

FS621M-4

Aimed at the aerospace and energy industries where there is a request for significantly larger build envelopes, Farsoon has released the new Farsoon FS621M-4. This four-laser system offers a build area of 620 x 620 x 1100 mm, making this machine one of the largest laser-based AM machines available on the market.

The powder handling for the FS621M-4 also operates in a closed loop, where the powder is fed onto the build area continuously from the top, without interrupting the build job. The powder filter systems are also designed in such a way that the filters can be exchanged (if necessary) without interrupting the build.

en.farsoon.com

The dual-laser FS200Mx2 is said to be ideal for medium to high volume series production and prototypes (Courtesy Farsoon)

Farsoon's new quad-laser FS422M-4 incorporates a closed-loop metal powder system (Courtesy Farsoon)

The new FS621M-4 is one of the largest laser-based AM machines available on the market (Courtesy Farsoon)

Markforged increases revenues in first quarter 2022

Markforged Holding Corporation (NYSE: MKFG), Watertown, Massachusetts, USA, has announced its results for the first quarter ended March 31, 2022, reporting an increase in revenue to $21.9 million, up 8.6% on Q1 2021 figures. Net profit for the quarter was reported to be $4.2 million, compared to a net loss of $10 million in the first quarter of 2021.

Shai Terem, the company's president and CEO, stated, "Markforged is a differentiated player in Additive Manufacturing. We bring a strong balance sheet and a track record of execution to our industry. Our focus on high-value, end-use manufacturing applications, printed at the point of need, solves for today's extreme supply chain challenges, resulting in a growing install base and leading gross margins. We are accelerating organic product innovation as planned and increasing our addressable market. I'm so proud of our team for their execution against our plan."

"We also applaud the Biden administration's Additive Manufacturing Forward initiative, announced earlier this month, which we believe will help accelerate adoption of additive technologies and create more agile and resilient supply chains. Markforged is excited to be part of this important initiative to help strengthen American manufacturing," added Terem.

Subsequent to the quarter-end, Markforged completed its acquisition of cloud-native software provider Teton Simulation Software. Teton's SmartSlice™ technology will be integrated into Markforged's Eiger software as a subscription add-on, enabling customers to optimise and validate advanced composite parts for the most demanding production applications.

Markforged reaffirmed its full-year 2022 guidance. Revenue is expected to be within the range of $114-123 million, and non-GAAP gross margins are expected to be within the range of 55%-57%.

www.markforged.com

Desktop Metal to reduce workforce by 12% as part of strategic initiative

Desktop Metal, Boston, Massachusetts, USA, has announced a strategic integration and cost-optimisation initiative which will include an approximate 12% reduction of its global workforce, consolidation of facilities, and a more focused approach on products with potential for more immediate return on investments. These changes are projected to result in approximately $40 million of annualised run rate non-GAAP cost savings – $20 million of which is to take place in the second half of 2022 – and at least $100 million of aggregate cost savings for the company over the next twenty-four months.

"In 2021, we demonstrated significant growth, expanding our portfolio of products into new markets and innovative materials," stated Ric Fulop, founder and CEO of Desktop Metal. "While the acquisitions we completed in 2021 contributed to this growth and to our total market opportunity as we focused initially on harvesting product and go-to-market synergies, they also increased our cost base and global facilities footprint. Today's announcement of our strategic integration and cost optimisation initiative is the result of a comprehensive portfolio and business operations review conducted across all functions at Desktop Metal."

One element of the initiative is aligning the operational structure of Desktop Metal and its acquired portfolio of brands under the company's corporate umbrella. Key functions such as engineering, manufacturing, marketing, finance, legal, human resources and customer service will now be fully consolidated.

"As outlined on prior financial results calls, we have been focused on identifying opportunities to optimise our expense structure while maintaining our growth opportunities," Fulop added. "We believe this initiative, which builds on steps we began to take in the second half of 2021 to integrate our teams, positions Desktop Metal to meet our near- and long-term financial commitments and supports our path to profitability."

As of March 31, 2022, Desktop Metal had over $317 million in cash, cash equivalents and short-term investments on an as-adjusted basis, after giving effect to the receipt of proceeds from the offering of $115 million aggregate principal amount of convertible notes in May 2022 (less the initial purchasers' discounts, and commissions and estimated offering expenses). The company estimates it will incur one-time termination benefits and associated costs related to the downsizing initiative of approximately $14 million, of which approximately $11 million will be incurred in the second quarter of 2022 and the remaining expected to be incurred by the end of 2023.

Desktop Metal anticipates that the initiative will be substantially complete by the end of 2023.

www.desktopmetal.com

3D New Technologies merger sees Prima Additive spin-off officially established

Prima Industrie S.p.A., Collegno, Italy, reports that it has officially completed the spin-off of its Additive Manufacturing business unit, following its merger with 3D New Technologies Srl, a metal Additive Manufacturing machine developer headquartered in Torino, Italy. In line with the merger, the new company will be known as Prima Additive Srl.

Prima Additive Srl will maintain a close collaborative relationship with Prima Industrie S.p.A., which will be the reference and majority shareholder of the new company with a stake of 50.01%. The company's board of directors is chaired by Gianfranco Carbonato, who is also executive chairman of Prima Industrie S.p.A., while Paolo Calefati has been appointed Chief Executive Officer.

The transaction is also reported to be linked to a larger project that will open in the coming months, when new investors join the company to further accelerate business development plans.

Prima Additive develops, manufactures, sells and distributes industrial metal Additive Manufacturing machines. Its services focus on Laser Beam Powder Fusion (PBF-LB) and Directed Energy Deposition (DED) applications.

"The merger between the spin-off Prima Additive and 3D New Technologies represents growth and an investment in this sector by Prima Industrie, which continues to be our majority shareholder," Calefati stated. "The operation combines the global dimension and the long tradition of innovation in the engineering and production of laser machines of the Prima Industrie Group with the agility and dynamism of the 3D startup New Technologies for Powder Bed Fusion machines in the Additive Manufacturing sector."

Prima Additive's Print 150 family with Powder Bed Fusion technology (Courtesy Prima Additive)

"Furthermore, this operation is a first step in attracting both financial and industrial investors who are already leaders in this market," he continued. "This is an important project to guide and concentrate the skills acquired and the technologies developed in recent years towards significant market and business growth."

www.primaadditive.com

ASTM announces new standard on PBF-LB process for metal parts

ASTM International, Conshohocken, Pennsylvania, USA, has announced a new standard that aims to provide advice for the Additive Manufacturing of metal parts using the Laser Beam Powder Bed Fusion (PBF-LB) process. ASTM's Additive Manufacturing committee (F42) developed the standard, which will be published as F3530.

ASTM International member Farhan Khan explains that the new guide provides an overview of the most commonly used post-processing operations, challenges in carrying out those operations, and best practices on how to address these challenges.

"In spite of the rapidly growing interest from the industry in laser powder-bed fusion for metals, there is a lack of guidance on how and why post-processing is carried out leading to inefficient designs, expensive post-processing, high non-conformity, and scrap rates," states Khan. "This standard provides specific guidance on how to design a component to ensure it can be effectively post-processed for operations such as powder removal, thermal post-processing, build plate removal, support removal, machining, and surface finishing."

Khan adds that the new standard will be most useful to designers and engineers who are considering using PBF-LB. Additionally, managers and decision-makers who are considering the use of PBF-LB in their organisation or supply chain will benefit from the standard.

www.astm.org

PyroGenesis delivers 100 kg plasma atomised titanium powder order to Aubert & Duval

PyroGenesis Canada, Inc., Montreal, Québec, Canada, has announced the completion of a significant commercial order for titanium powder from its partner Aubert & Duval, a subsidiary of the Eramet Group headquartered in Paris, France. The order for 100 kg of titanium powder, produced using the company's NexGen™ plasma atomisation system, is part of an agreement between the companies to supply plasma atomised titanium powder, on a mutually exclusive basis, to the Additive Manufacturing market in Europe.

"We are thrilled to be fulfilling this commercial order, especially given the fact that it came via our partner Aubert & Duval," stated Massimo Dattilo, VP, PyroGenesis Additive. "According to Grand View Research, the global 3D printing market was valued at USD 13.84 billion in 2021 and is expected to grow at a compound annual growth rate of 20.8% from 2022 to 2030. Given the sheer size of this market and our unique manufacturing process, we believe we are well positioned to capture a significant share of the overall titanium powder market."

Dattilo continued, "This order is both an important commercial milestone, as well as further validation of our process and ability to supply some of the highest quality powder produced to the AM industry using our NexGen plasma atomisation process. We are making larger commercial batches now, not just sample batches, and additional batches are underway. For comparison, previous sample batches were a couple of hundred grams, whereas this production batch is 100 kg. It's an exciting time."

Aubert & Duval is a supplier of metal powders for Additive Manufacturing, serving the aerospace, energy, transport, medical, defence, automotive and other large scale, demanding markets.

www.pyrogenesis.com
www.aubertduval.com

Kymera International acquires titanium powder maker AmeriTi Manufacturing

Kymera International, a speciality materials company headquartered in Raleigh, North Carolina, USA, has acquired AmeriTi Manufacturing Company, Detroit, Michigan, USA. AmeriTi is a manufacturer of value-added ferrotitanium, titanium sponge, titanium powders and speciality forms. The terms of the transaction were not disclosed; however, AmeriTi's parts business, known now as TriTech Titanium Parts, was not included in the transaction.

"AmeriTi is a growing company led by a talented, dedicated employee base that culturally aligns with our mission and objectives to be the leading manufacturer of speciality materials that shape the future," stated Barton White, CEO of Kymera. "We believe this is a synergistic acquisition that will give our combined company strong technical and commercial resources to help fuel our growth in the aerospace, medical, defence, and industrial markets."

AmeriTi produces titanium powder using the hydride-dehydride (HDH) process and is able to manufacture both commercially pure and alloyed titanium powder in a wide range of particle sizes. The company is said to have the unique ability to supply enriched alloy powder. This includes enriching powder with alloying elements that are lost during post-processing steps. An example of this is an enriched aluminium version of Ti 6-4 to compensate for aluminium loss during Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing.

Bob Swenson, the owner of AmeriTi for the past twenty-five years, added, "The sale of AmeriTi to Kymera is an exciting next step for the business. Kymera and AmeriTi together will continue to build the product lines and grow into new areas. The combined business will be able to build on its titanium experience and knowledge, and maintain its strong customer focus and service."

Kymera International is owned by the private investment firm Palladium Equity Partners. "We are thrilled to help support the acquisition of AmeriTi, Kymera's fifth to date under Palladium's ownership, and second completed over the last three months," stated Adam Shebitz, a partner at Palladium. "The addition of AmeriTi will help to realise Kymera's five-year business plan to diversify into new, margin accretive, and growing end markets."

www.kymerainternational.com
www.ameriti.com

Kennametal becomes GE Additive Beta Partner to advance tungsten carbide Binder Jetting capabilities

GE Additive has announced that Kennametal Inc., Pittsburgh, Pennsylvania, USA, is the latest member of its Beta Partner Programme. As part of the GE Additive Programme, Kennametal will further advance its Binder Jetting (BJT) production capabilities in tungsten carbide, as it continues to scale its end-to-end metal Additive Manufacturing operations.

Kennametal offers a complete Additive Manufacturing solution, from high-performance metal powders through to the production of additively manufactured components and tooling. Its metal AM parts have already gained wide customer adoption across a variety of industries, such as oil & gas, energy, industrial processing and transportation. The company will work with GE Additive to identify, design and scale specific applications for serial production on GE's Binder Jetting system, leveraging Kennametal's proprietary cemented tungsten carbide materials.

Series 3 of GE Additive's Binder Jet Line Additive Manufacturing machine (Courtesy GE Additive)

"Customers are increasingly seeking our 3D printed tungsten carbide and Stellite [cobalt chrome alloy] solutions to help them maximise their productivity in challenging applications when wear and corrosion resistance are critical," stated Jay Verellen, General Manager, Kennametal Additive Manufacturing. "Our work with GE Additive on binder jet solutions will enable further scaling of our operations to meet strong customer demand — and extend our leadership in proprietary material solutions for additive."

GE Additive is continuing to develop its Binder Jetting solution to make Additive Manufacturing a reality for serial production, targeting millions of parts per year and beyond. Key to that development is ongoing, hands-on input from members of GE Additive's Binder Jet Beta Partner Programme.

"By hands-on, we don't mean tinkering or experimenting. We work closely with our beta customers as they develop their own, real-world business cases, applications and parts. To them, it is important that our solution is not only mature and scalable but is capable, complete and aligns to their product innovation strategies and meets production volume needs," added Brian Birkmeyer, product line leader for Binder Jet at GE Additive.

"We are honoured that Kennametal, an industry leader in 3D printed tungsten carbide, is working closely with us on the development of our binder jet platform. Ensuring we align with Kennametal's production expectations and requirements is a top priority. Their longstanding expertise in materials science mirrors our own, and our team is excited to work together to deliver new and innovative solutions," concluded Birkmeyer.

www.kennametal.com
www.ge.com/additive

Nanoe and Kimya to bring metal and ceramic filaments to North American market

Nanoe, headquartered in Ballainvilliers, France, and Kimya, an Armor Group company based in Nantes, France, have announced a marketing partnership that will bring Nanoe's Zetamix filaments for ceramic and metal Additive Manufacturing to the North American market.

Nanoe specialises in the development and manufacture of innovative ceramic materials for industry. It is a recognised manufacturer of high-performance alumina and zirconia, as well as the world leader in ZTA composite ceramics. Nanoe's Zetamix is a brand of ceramic and metal filaments compatible with Fused Filament Fabrication - a Material Extrusion (MEX) based process.

Operating in the North American market since 2019, Kimya provides support to international industrial operators for their Additive Manufacturing projects requiring the production of finished parts, thanks to the design and production of bespoke AM materials. Through this partnership, the company is expanding its range with the addition of ceramic and metallic filaments.

"We are delighted to be expanding our distribution channels in strategic regions like North America thanks to our partner Kimya, with which we share a vision and the know-how in technical materials for the production of finished parts," stated Guillaume de Calan, co-founder of Nanoe. "We are fully confident in its ability to represent our filament range in this market and to help us extend the use of ceramic and metallic Additive Manufacturing on the international stage."

Pierre-Antoine Pluvinage, Business Development Director at Kimya, commented, "At Kimya, it is our goal to establish a long-term presence in the North American market. Already in 2020, we installed new semi-finished product cutting lines at our Armor USA premises, in order to better serve the specific demands of our American industrial customers. In 2021, North America accounted for 35% of the global 3D printing market, estimated to be worth $17 billion. This is why we are determined to establish even stronger local roots, notably by now extending our range of 3D materials with the Zetamix by Nanoe filaments. These high-tech materials complement our own range, providing solutions for the production of finished parts via Additive Manufacturing."

www.zetamix.com
www.kimya.fr

X-ray and CT systems supplier Yxlon to become Comet Yxlon

Yxlon International, Hamburg, Germany, has announced plans to change its name to Comet Yxlon, effective September 8, 2022. The new brand is said to underscore the company's long-standing affiliation with plasma and X-ray solutions provider Comet, based in Flamatt, Switzerland.

Yxlon develops, manufactures and markets high-end X-ray and CT system solutions for industrial environments, from R&D labs to production environments, with integrated services based on artificial intelligence and data analytics. It has been part of parent company Comet Holding AG, which unites a global group of technology businesses under its umbrella, since 2007.

"The Comet Yxlon brand represents decades of X-ray expertise and a passion for making new things possible – in line with the motto 'Led by experience. Driven by curiosity'," stated Kevin Crofton, CEO of Comet Group and interim president of Yxlon. "The rebranding strengthens our presence and reaffirms our importance within Comet Group."

www.comet-group.com

Conflux Technology and GKN Additive to develop AM heat exchangers

Conflux Technology, Geelong, Australia, and GKN Additive, Bonn, Germany, report that they will collaborate on the development, design and production of additively manufactured heat exchanger solutions in Europe. Additively manufactured heat exchangers can improve the cooling of critical components in the electronics, automotive, aerospace and packaged goods industries by utilising the design freedom that AM enables.

Under the collaboration, Conflux brings expertise in the design and development of advanced thermal management solutions and GKN Additive contributes its experience in high volume production and Additive Manufacturing in the automotive, aerospace and industrial industries.

"We're excited to be able to offer our customers access to GKN Additive's manufacturing services," stated Michael Fuller, CEO, and founder of Conflux Technology. "Its capability to manufacture large volume orders in Europe is a perfect fit for our EU customers looking for serial production near point of use. Being able to provide our technology to their vast array of top tier and technologically advanced customers is already proving fruitful."

John Dulchinos, president of GKN Additive, "We are delighted to be partnering with Conflux Technology. Heat exchangers and thermal management are key areas where 3D printing can deliver high-value solutions. Combining forces with industry application experts such as Conflux enables us to provide best-in-class solutions to our customers."

A meeting between Conflux Technology and GKN Additive took place in Bonn (Courtesy GKN Additive)

www.confluxtechnology.com
www.gknpm.com
www.gknadditive.com

Velo3D announces strong Q1 results as demand increases

Velo3D, Campbell, California, USA, has announced financial results for its first fiscal quarter of 2022, reporting revenue of $12.2 million, an increase of 17% compared to the fourth quarter of 2021 and more than 900% year on year. The improvement in revenue was said to have been driven by an increase in average selling price, as well as higher revenue from support services and recurring payment transactions due to the company's increasing installed base of systems.

"Strong execution enabled us to post our third straight quarter of revenue growth as a public company, add to our backlog and expand our new customer footprint," stated Benny Buller, CEO. "Demand for our industry leading Sapphire systems remains high as our total backlog exiting the quarter increased more than 80% year over year to $55 million and we now have more than 75% of our 2022 revenue either recognised or booked. When combined with our strong first quarter bookings momentum of seven systems, we now have significant visibility and increasing confidence in our ability to achieve our 2022 outlook."

The gross margin for the quarter was 0% and is said to reflect the impact of launch customer pricing for the company's Sapphire XC systems shipped during the quarter (a total of eight). This pricing is expected to impact gross margin through the third quarter of 2022 as the company completes the delivery of its remaining Sapphire XC systems under its launch customer contract. With the completion of its launch customer contract and ongoing material improvements in production efficiencies, Velo3D is said to remain on track to achieve a gross margin of 30% in the fourth quarter of this year.

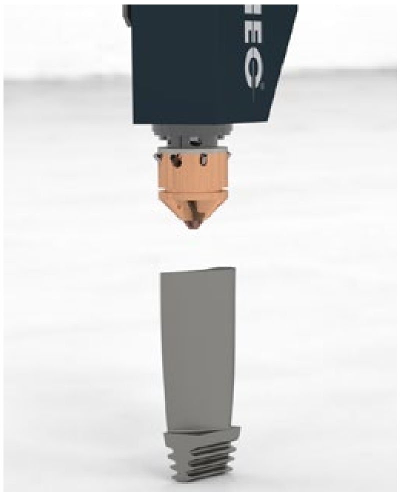
Operating expenses for the quarter rose sequentially to $28.2 million, primarily the result of increased sales and marketing costs to fund the company's global expansion plans as well as higher research and development investment. Non-GAAP operating expenses, which excluded stock-based compensation expense of $5 million, was $23.2 million.

Net loss for the quarter was $65.3 million. Non-GAAP net loss, which excludes loss on fair value of warrants, loss on fair value of contingent earnout liabilities and stock-based compensation, was $23.1 million. Adjusted EBITDA for the quarter, excluding loss on fair value of warrants, loss on fair value of contingent earnout liabilities and stock-based compensation, was a loss of $22 million.

The company ended the quarter with a strong balance sheet with $186 million in cash and investments. As a result, Velo3D believes it has the liquidity for ongoing technology investments as well as providing the resources needed to fund its growth plans.

www.velo3d.com

Optomec celebrates delivery of 600th industrial Additive Manufacturing machine delivery



Optomec's LENS process uses Directed Energy Deposition to produce metal parts (Courtesy Optomec)

Optomec Inc, Albuquerque, New Mexico, USA, has announced the delivery of its 600th industrial Additive Manufacturing machine. The company has now installed more than 250 of its proprietary LENS™ systems for metal AM components, and over 350 of its Aerosol Jet® printed electronics systems.

Optomec reportedly has the largest installed base of Directed Energy Deposition (DED) metal AM machines, marketed under its LENS trademark. These machines are said to be particularly well suited for building large structural parts in titanium, nickel-base superalloys and stainless steel, and for repairing high-value components, where they have been used in production to restore more than ten million aircraft engine parts.

The company also reports the largest installed base of true 3D electronics printers, enabling high volume production applications in advanced 3D semiconductor packaging, consumer electronics, medical device and industrial products. The company's Aerosol Jet printers have the unique ability to additively manufacture circuitry, sensors and antennas onto virtually any surface, with features as small as ten microns. This enables continued miniaturisation of electronic systems, as well as the advance of smart parts that combine structure and functionality.

Optomec's CS 250 AM machine enables high-volume production of reactive metals such as titanium (Courtesy Optomec)

"Our team is delighted, and frankly proud, to reach this latest significant milestone that reinforces our leadership position in the markets we serve," stated Dave Ramahi, Optomec CEO, "As rewarding as the 600 machine figure is, what's most encouraging is that it reflects customers confidence in our solutions' ability to meet their production needs, often having gone through rigorous qualification and regulatory protocols that are a barrier to our competitors. We are working hard to replicate these successes and believe this is just the beginning of more widespread adoption of our solutions across industry."

Optomec's solutions have been adopted across all industrial sectors, including aerospace, energy, electronics, life sciences and defence. These systems enable cost-effective development, production, and even repair of a wide range of end-products, from aircraft engine and industrial tooling, to smartphones and glucose monitors.

Optomec's LENS DED and Aerosol Jet Equipment solutions are enhanced by a suite of high-value digital products, including toolpath, vision, pattern recognition, scanning and process control software, as well as process recipes and AM component libraries (ie, wear coatings, antenna, sensors). Additionally, Optomec offers automation solutions to enable series and batch production.

www.optomec.com

FreeFORM Technologies receives investment from Ryerson

FreeFORM Technologies, St Marys, Pennsylvania, USA, reports that it has received investment from Ryerson Holding Corporation, a distributor of industrial metals headquartered in Chicago, Illinois, USA.

"This investment in FreeFORM marks Ryerson's entry into a partnership with strategically desired exposure to Additive Manufacturing," stated Mike Burbach, Chief Operations Officer. "It is an important step forward allowing us to explore synergies, new opportunities and additional value-added capabilities with our customers as we look towards the emerging present and future of the metals industry."

Chris Aiello, co-founder of FreeFORM Technologies commented, "As we scale our business, it is important for us to align ourselves with people who believe, as we do, that the future of metal manufacturing includes the freedom of design that Additive Manufacturing can offer. Ryerson has a long history in value-added processing and distribution, so our alignment in this aspect of the customer experience is clear."

FreeFORM states that it is continuing to prepare for the future of manufacturing by adding new capabilities and capacity. It has added several key pieces of equipment in 2022 and has plans to add additional machinery to support Additive Manufacturing before the end of the year.

www.freeformtech.com
www.ryerson.com

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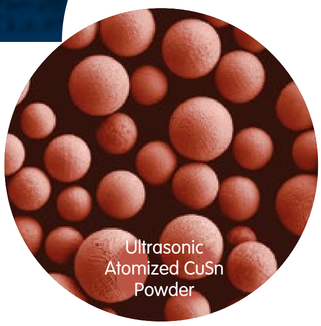

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SSI Sintered Specialties changes name to DSB Technologies

SSI Sintered Specialties, LLC, a manufacturer of sintered metal components headquartered in Janesville, Wisconsin, USA, has changed its name to DSB Technologies. Following an extensive rebrand, the name change is intended to build on the company's recent technology expansion, which has seen investments in Powder Metallurgy, Metal Injection Moulding (MIM) and metal Binder Jetting (BJT) Additive Manufacturing technologies over the last year.

"This organisation has an impressive history and an even brighter future ahead," stated Paul Hauck, COO of DSB Technologies. "From the earliest days, we have operated with a drive for innovation. As our company and customer base continues to evolve, this rebranding embodies our commitment to the growth needed to be a prominent manufacturing partner."

For over forty years, DSB Technologies has collaborated with its customers as a metallurgical solutions partner for high-performance Powder Metallurgy components. Under the name SSI Sintered Specialties, it operated as the sintered components division of a successful precision engineering organisation led by the company's current ownership. In 2019, SSI Sintered Specialties was separated from the organisation and took the opportunity to leverage its existing capabilities and expand the business into new technologies, applications, and markets.

"SSI was historically known as a conventional press and sinter business, but there is so much more at the core of our company," Hauck added. "Our new company name allows us to adopt new technology more freely and bring to light the industry-leading talent and vast expertise we offer to our customers."

With a committed focus on growth, DSB Technologies is reportedly combining its present Powder Metallurgy and manufacturing knowledge with new technology and talent investments to continue designing and engineering complex, functional, PM components. The company houses what is believed to be North America's largest capacity of high temperature sintering furnaces in its 23,226 m^2 facility in Janesville, along with a fleet of over thirty-five presses, a vast range of secondary operations, a hands-free moulding cell and an in-house automation team.

www.dsbtech.com

Sintered metal components maker SSI Sintered Specialties, LLC, has changed its name to DSB Technologies (Courtesy DSB Technologies)

One Click Metal represented in a further seven European countries

Through its partnership with Teximp, One Click Metal's BOLDseries will be available in seven additional European countries (Courtesy One Click Metal)

One Click Metal, Tamm, Germany, has entered into a partnership with Teximp, headquartered in Zürich, Switzerland, that will see One Click Metal represented in a further seven European countries. The new partnership will bring One Click Metal's BOLDseries Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machines into Croatia, Czech Republic, Bulgaria, Slovenia, Slovakia, Bosnia Herzegovina and Serbia, all of which host a Teximp branch.

Teximp, founded in 1982, offers Additive Manufacturing machines and CNC machine tools (vertical/horizontal/5-axis machining centres, CNC lathes/multitasking machines) to its customer base, as well as a range of related services and solutions. The company aims to provide customers with tailored support in a wide range of industries through its network of technology and software.

"With Teximp, we have an established, customer-oriented and very reliable partner who already has experience in 3D printing and is working with us to realise the vision of making metal 3D printing available for everyone," stated Gerrit Brüggemann, CEO of One Click Metal.

Reputedly the largest Haas reseller in Europe, Teximp is strongly established in the industrial sector. Through its partnership with One Click Metal, the company is expanding its metal Additive Manufacturing offering with a system that is applicable to a wide range of industries. In addition to universities and educational institutions, One Click Metal addresses SMEs, which can now be served through Teximp's broad industry network.

www.oneclickmetal.com
www.teximp.com

ASM opens critical metals plant in South Korea

Australian Strategic Materials Ltd has officially opened its first high-purity critical metals plant in Ochang, South Korea. The move is said to consolidate the strong partnership ASM has with Korea, and offers an alternative source of critical metals needed to meet forecast global demand.

The Korean Metals Plant (KMP) will produce critical metals and alloys to customer specifications using ASM's patented metallisation process. The initial focus will be on neodymium iron boron (NdFeB) – a key component in permanent magnets used in electric vehicles and wind turbines – and widely used titanium alloys.

"This plant represents the new direction available for Australia's resource sector and our strategic collaborations worldwide," stated David Woodall, ASM Managing Director. "Australia can harness its world-leading reputation and expertise in the resources sector, moving into the clean energy sector with strategic global partners such as Korea."

"We also know that global demand for the critical metals crucial to industries shaping our planet's future is predicted to outstrip supply. Our Korean Metals Plant represents a new source for these critical metals. Products from the plant will help to de-risk and relieve bottlenecks in the global supply chain."

Woodall added, "The team in Korea, along with our construction partners have done a fantastic job in designing and delivering this facility. This is an outstanding achievement by all, especially given the difficulties we have faced with delays and disruptions due to COVID."

The Korean Metals Plant is Australian Strategic Materials' flagship metals plant and is operated by the company's wholly owned subsidiary Korean Strategic Materials and Metals (KSMM). The plant is an integral part of ASM's vertically integrated mine to metals business model. Future metals plants based on its success are planned in other strategic geographic locations. They will be supported by raw materials mined and processed at ASM's Dubbo Project.

"The Board extends our gratitude to our Korean partners and friends, especially the government of Korea and the Provincial Government of Ochang. All have helped us progress to this important milestone," stated Ian Gandel, chair of ASM. "This is a great moment for our partnership, as we seek to establish a real alternative supply option for the critical metals needed to meet net-zero targets and to leave our world with cleaner energy options for our children and future generations."

www.asm-au.com

Powder improvements increase efficiency for automaker

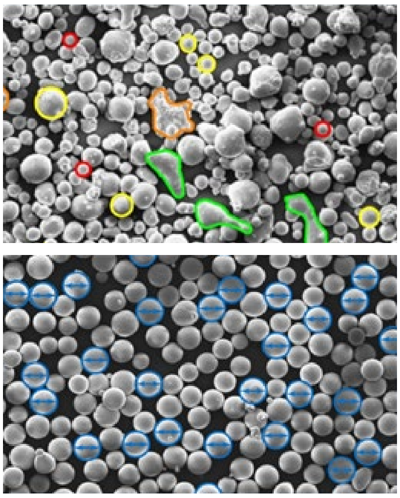
During the recent Additive Manufacturers User Group conference, metal powder producer Equispheres, Inc, Ottawa, Ontario, Canada, and automaker BMW, Munich, Germany, jointly presented a paper that explained how improvements in metal powders, used in Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing, can increase the productivity for automotive parts manufacturing.

Marinus Kolbinger, Specialist AM Pre-Development and Planning, BMW, began with an overview of BMW's AM production network. This, he explained, has progressed from initial polymer-based machines in the 1990s through to laser-based metal AM machines in 2005 and Binder Jetting (BJT) machines in 2018.

Across BMW's AM production network, over 300,000 components are additively manufactured each year. However, Kolbinger added, for an increase in the applications and use of AM in the automotive sector, it is seen as a priority to reduce the overall costs of the AM production process.

Here, Evan Butler-Jones, VP Product and Strategy, Equispheres, explained that cost savings can be made by increasing production speeds – but this needs to be achieved without sacrificing part performance. Key to this is increasing process stability, he stated, because powder variability can result in unwanted process impacts and can lead to inconsistencies.

This is where Equispheres' powder was shown to offer significant advantages. In contrast to legacy powders, Equispheres' uniform, predictable powder used in predictable machines, has shown to increase process stability and produce consistently superior parts, built more quickly.



The difference between legacy powders (top) and Equispheres' powder (Courtesy Equispheres)

BMW turned to Equispheres to see how build time could be improved without sacrificing part performance (Courtesy BMW)

Highly spherical powders of uniform size, and increased flowability of around two and half times that of alternative powders, also improve design capabilities and can result in lighter, stronger, more consistent parts.

Kolbinger confirmed that BMW's calculations show that powder from Equispheres, used with the developed parameter set, can achieve a cost saving of around 12%. "We also saw that the process was significantly more stable," he stated.

www.equispheres.com
www.bmwgroup.com

Rio Tinto produces first North American scandium oxide

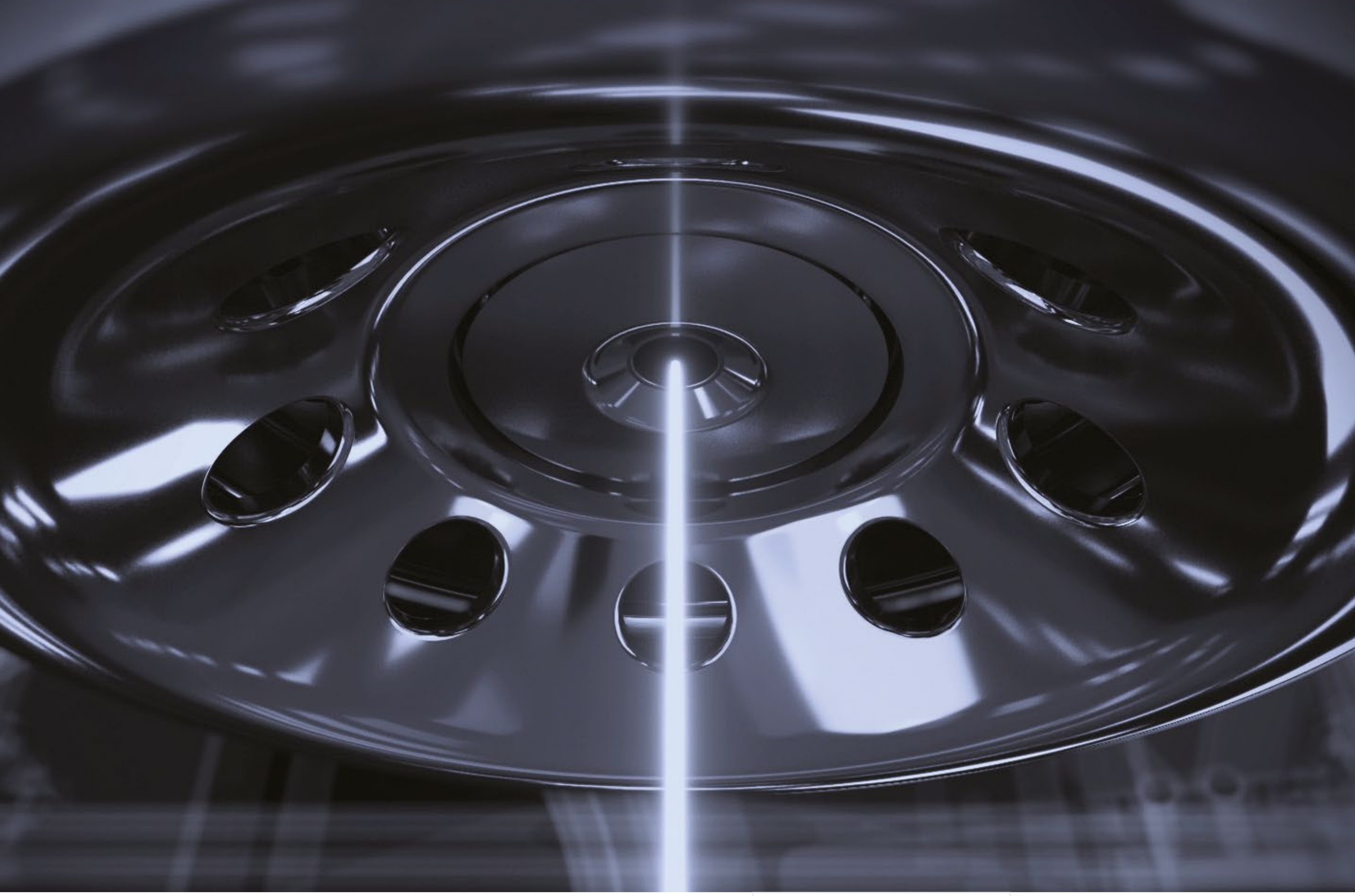
Rio Tinto's Rio Tinto Fer et Titane (RTFT) metallurgical complex in Sorel-Tracy, Québec, Canada, has produced its first batch of high-purity scandium oxide. The company is the first North American producer of this mineral, used to produce aluminium-scandium alloys for the Additive Manufacturing sector, as well as being critical in improving the performance of solid oxide fuel cells.

A process developed by RTFT was used to extract high-purity scandium oxide from the waste streams of titanium dioxide production, without the need for any additional mining.

The RTFT team has completed commissioning activities and is now focusing on production ramp up to bring the plant to three tonnes of scandium oxide per year (approximately 20% of the global market). The company is also considering near-term expansion options to increase production capacity in line with market demand.

"We are very proud of this first production of scandium oxide," stated Stéphane Leblanc, Managing Director, Rio Tinto Iron and Titanium. "This is a key milestone in the development of a secure supply of scandium, demonstrating our ability to de-risk the global supply chain for this critical mineral."

www.riotinto.com



BFW announces large-format laser-based DED machine

Bharat Fritz Werner Ltd (BFW), Bangalore, India, and its subsidiary m2nxt, have announced the development of a new large-format Directed Energy Deposition (DED) Additive Manufacturing machine. The laser-based Photon 4000G, capable of processing both metal and wire feedstock in a controlled atmosphere inert chamber, has a 3 x 3 x 4 m build chamber and is expected to be available from January 2023.

BFW offers a wide range of industrial machines to a global customer base and entered the DED metal AM market in September 2021. Leveraging its sixty years of experience, the company has now developed what it believes will be the world's largest and fastest laser-based DED system available.

With a starting price of €1,990,000, the Photon 4000G incorporates a 36 m^3 hermetically sealed argon chamber and provides a 10.4 m^3 part build envelope. Dual-deposition heads, on a dual ram gantry, enable both powder and wire deposition with a 6 Kw fibre laser.

"I have contract-printed parts priced at more than $250,000, and the BFW Photon 4000G can print similar parts at less than half that cost once amortisation and operational costs are considered," stated Ashok H Varma, EVP & Global Leader, Additive Manufacturing at BFW. "It is also evident that the new wave of metal AM industrial manufacturing will be driven by Laser-DED."

"Most currently installed systems are in laboratories or light industrial applications, many are 'Do It Yourself' systems, many are underpowered, undersized, or overpriced systems, many are idle or under-utilised, with few suppliers and users having the practical experience to optimally utilise this technology and reduce 'time to value'," Varma continued. "We believe we at BFW will be instrumental in closing the gap between supply and demand of large, very large, and huge 3D printed parts using laser-powder and laser-wire metal deposition, for free form fabrication and fine/heavy cladding/repairs."

BFW intends to install Photon 4000G machines in its Dr Abdul Kalam Centre of Excellence in Bangalore for contract manufacturing, as well as marketing the machine globally. The company intends to announce the rollout of several other Photon machine models, including Photon 2500 and Photon 1000 series, with gantry and robot, mobile systems for in-situ repair/manufacturing and hybrid Additive Manufacturing configurations.

www.m2nxt.com
www.bfwindia.com

The Photon 4000G DED AM machine (Courtesy BFW/m2nxt)

AP&C receives ISO 17025 accreditation for laboratory testing

AP&C, a GE Additive company, has received ISO 17025 accreditation for laboratory operations at its plant in Saint-Eustache, Québec, Canada, covering chemical analysis of titanium alloys and particle size distribution testing by sieving and light scattering. This is said to be a milestone for the company, enabling it to meet the requirements of a number of industries, such as medical and aerospace, requiring an ISO 17025 certification for testing. The accreditation is the fourth for the company, which also has ISO 9001, AS9100 and ISO 13485.

AP&C prepared for the ISO 17025 certification for over a year, including performing a gap analysis of its testing management and quality system to identify what needed to be updated. Round robin and statistical analysis of the lab's testing results validated the methods used.

"This accreditation puts an emphasis on the robustness of controls to ensure AP&C's laboratory operates competently and can generate valid results," stated Rachel Riendeau, Quality Leader. "It also promotes impartiality and independence from production, which is crucial to maintain the credibility and integrity of a captive laboratory. To ensure compliance to these additional requirements, procedures and instructions were reviewed or created, risk analyses of laboratory activities were conducted, and all teams involved in the laboratory processes were thoroughly trained."

Following this accreditation, AP&C has expressed its intention to widen its scope from chemical composition and particle size distribution to properties like flow rate, apparent and tap density, and humidity.

www.advancedpowders.com

US President Biden launches initiative to boost Additive Manufacturing

US President Joe Biden has announced a new initiative aimed at improving US domestic supply chain resilience by focusing on Additive Manufacturing. The AM Forward programme aims to encourage large companies to source additively manufactured parts from smaller US-based suppliers. The voluntary compact is open to any OEM provided they are willing to make public commitments to support their suppliers' adoption of additive capabilities. Thus far, GE Aviation, Honeywell, Lockheed Martin, Raytheon and Siemens Energy have joined the initiative.

The initiative will be supported by the non-profit Applied Science & Technology Research Organization (ASTRO). In a White House statement, the Biden Administration highlighted plans to launch federal programmes to help small- and medium-sized manufacturers support the adoption of adequate capacity and increase competitiveness through access to capital, technical assistance, and workforce training.

To fully benefit from the use of AM capabilities, it was stated, SME manufacturers must train their workforce differently to successfully deploy AM technologies, including upskilling workers. For this, America Makes will develop a curriculum for workforce training with AM Forward participants and, along with the US Department of Labor, will assist manufacturers in launching apprenticeship programmes in AM.

"We are honoured to be a part of this new initiative," stated America Makes' Executive Director John Wilczynski. "As America Makes continues to build the foundation for the acceleration of Additive Manufacturing, the AM Forward program represents a proof of concept for the original vision of the institute – to utilise the public-private partnership model in collaboration with private sector innovation to propel advanced manufacturing industries forward."

The need for defining industry standards was also highlighted. It was added that the US Department of Commerce – through the National Institute of Standards and Technology (NIST) – will conduct measurement science research to overcome key barriers to the widespread use of metal AM. It will develop the technical basis for new high-priority standards, and disseminate these results to AM Forward participants through the leadership of standards development within ASTM International, International Organisation for Standardisation (ISO), American Society of Mechanical Engineers (ASME), and other standards bodies.

www.whitehouse.gov

Uniformity Labs releases Ti64 Grade 23 titanium alloy powder

Uniformity Labs, Fremont, California, USA, has released its new titanium alloy Ti6Al4V (Ti64) powder for Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing. Ti64 offers a high strength-to-weight ratio and is biocompatible, making it ideal for medical and high-performance applications, including performance automotive and aerospace components.

Ti64 Grade 23 is an alloy of titanium, aluminium, and vanadium, said to exhibit best-in-class mechanical performance, surface roughness, and uniformity across the build bed, in parallel with greatly improved throughput. Typical builds are reported to deliver an average of 99.96% density in the as-built state and are 1.5X to 2X faster, depending on machine and part geometry, as compared to the same builds performed at the same layer thickness using standard powder and machine parameters.

"The application of Uniformity Ti64 Grade 23 delivers material properties excellence and repeatability for our customers who require parts that perform to the highest standard in extreme conditions," stated Uniformity founder and CEO, Adam Hopkins. "Our powders deliver robust mechanical properties, low surface roughness, and high print yield, in addition to substantially increasing machine throughput."

The availability of this powder follows the recent announcement of a Uniformity collaboration with AddUp, targeted to maximise the productivity of Uniformity's Ti64 Grade 23 ELI alloy using AddUp's FormUp 350 PBF-LB AM machine. This partnership targets regulated healthcare and aerospace production using metal Additive Manufacturing technologies.

www.uniformitylabs.com

Ti64 offers a high strength-to-weight ratio and is ideal for high-performance applications (Courtesy Uniformity Labs)

Freemelt's Pixelmelt enables increased freedom for process optimisation

Freemelt, Mölndal, Sweden, has introduced Pixelmelt, a new software solution designed for faster material development and more productive AM. Available in the third quarter of 2022, Pixelmelt is said to offer the user increased freedom in terms of process optimisation, enabling process parameters to be varied between different components in the same build, and also within each individual component.

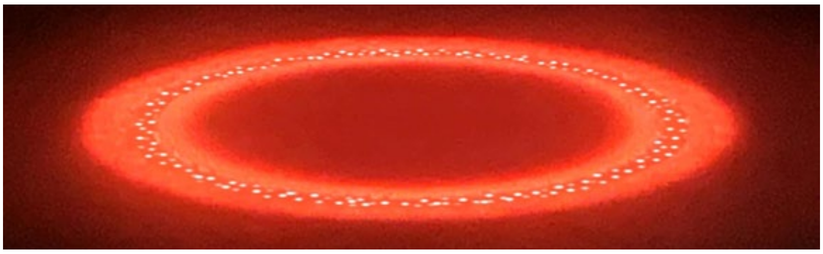
By using an electron beam rather than a laser beam, Freemelt's Electron Beam Powder Bed Fusion (PBF-EB) machines offer several inherent advantages, most notably that materials can be melted at higher power and the beam can move faster. This allows the development of processes that are not possible in laser systems.

"A laser-based 3D printer can scan the beam at around 10 meters per second. Freemelt's proprietary electron beam can move the beam 4,000 meters per second, several hundred times faster than a laser beam. This means that the beam can jump between tens of thousands of melting points every second and distribute the heat in an optimal way," stated Ulric Ljungblad, CEO of Freemelt.

"With Pixelmelt, our customers can now melt powder material in free spot patterns over a surface rather than along parallel lines, increasing their productivity and enabling new material innovations," added Ljungblad.

Philip Nilsson, project manager for Pixelmelt continued, "In a first step, Pixelmelt will be used for the Freemelt ONE research system to make the company's research customers even more innovative and productive. Pixelmelt will initially be a new universal tool in the customer's toolbox to be transferred to future industrial systems."

www.freemelt.com



Freemelt's proprietary electron beam can move the beam 4,000 meters per second, reported to be several hundred times faster than a laser beam (Courtesy Freemelt)

equispheres

WHAT THE FUTURE IS MADE OF

Everybody knows time is money.

Especially on the shop floor. Especially in additive manufacturing.

Aconity3D manufactures printers for metal additive manufacturing. The company was able to reduce the build time for a production component from 52.8 hours to 17.5 hours using Equispheres powder. Let that sink in. The part can be produced three times faster.

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Choosing Equispheres aluminum powder improved print speed and reduced production costs. By a lot.

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Equispheres.com | 1.613.903.5855 | info@equispheres.com

DMG Mori joins the Applied Digital Manufacturing Center

Morf3D, Inc, a Nikon subsidiary based in El Segundo, California, USA, has announced that DMG Mori, headquartered in Nagoya City, Japan, has committed to a technology development partnership in its new Applied Digital Manufacturing Center (ADMC) in Long Beach, California. The ADMC is a partnership of global companies utilising an 8,400 m^2 state-of-the-art facility to industrialise digital manufacturing process across all markets.

DMG Mori will act as a supplier of subtractive, adaptive, automation and hybrid Additive Manufacturing technologies, that will be imperative as the ADMC continues to evolve. The company will also provide post-processing AM solutions and utilise its automation technology to provide complete solutions. Jeff Wallace, General Manager of National Engineering will be the on-site representative and supply technical insight and experience as projects are reviewed and implemented.

"We are privileged to partner with DMG Mori, who will deliver immense innovation and integrated capability," stated Ivan Madera, CEO of Morf3D. "Their incredible contributions – including their best-of-the-best equipment and brightest minds in the industry – will be an excellent addition to the Applied Digital Manufacturing Center and will further evolve our mission to streamline and automate the production process."

Dr Keiichi Ota, president at DMG Mori USA, added, "We are honoured to take part in the Applied Digital Manufacturing Center. Morf3D is making such incredible strides in the Additive Manufacturing industry, and we are excited to work together as partners to keep that momentum going."

DMG Mori has joined the Applied Digital Manufacturing Center as its newest industry partner (Courtesy Morf3D)

The Applied Digital Manufacturing Center is expected to house 150 multi-discipline engineers, research staff, and technical teams. The ADMC will also serve as an industrial base that will improve the quality of Morf3D's products and enhance the company's technical capabilities, as well as enrich its customer applications worldwide.

www.dmgmori.com
www.morf3d.com

Markforged and 3YOURMIND look to scale automation of AM in multi-vendor ecosystems

Markforged, Watertown, Massachusetts, USA, has announced a partnership with 3YOURMIND, Berlin, Germany, to integrate Markforged's Eiger software platform with 3YOURMIND's manufacturing execution software (Agile MES) and other lifecycle management tools via API.

"With Eiger, Markforged is advancing interoperability with cloud and business system tooling to enable deeper penetration of additive into our customers' manufacturing ecosystems with the traceability, reporting and security required in these digital workflows," stated Ted Plummer, Director of Product Management, Software at Markforged. "At a time of global supply chain disruption, making it easier to print, verify and use 3D printed parts in mission critical applications is more important than ever."

Seamless connectivity is the next step toward Industry 4.0 adoption and digital transformation on the factory floor, explains Markforged. A primary barrier to Industry 4.0 is the disjointed nature of tools in the Additive Manufacturing workflow which block adoption of true digital transformation.

3YOURMIND's Agile MES platform for project DIAMOnD by Automation Alley (Courtesy 3YOURMIND)

To address this gap, 3YOURMIND and Eiger now connect to deliver an end-to-end automated solution that is intended to enable users to create, order and schedule prints on Markforged AM machines directly from their product lifecycle management systems. The integration is designed to provide real-time visibility into the state and performance of a multi-vendor fleet of AM machines, allowing a single point of monitoring for a shop's assets from various OEMs. The integration also includes Markforged's proprietary Blacksmith software, which enables in-process part inspection and automatically appends an additively manufactured part's quality assurance report to its digital record.

"3YOURMIND is excited to partner with Markforged to expand API integrations for 3YOURMIND and Markforged users who value secure data handling due to the sensitivity of their data," added Aleksander Cizsek, founder and CEO of 3YOURMIND. "As a result of this partnership, manufacturers will have more intuitive, streamlined access to machine data to further empower their production capabilities and discover new avenues for workflow efficiency."

Eiger is cloud-based and data-driven manufacturing software that enables users to additively manufacture parts on demand, right at the point of need. It is reported to drive the largest connected fleet of AM machines worldwide, providing automated workflows and real-time analytics. The system leverages AI to continuously improve and provide over-the-air software updates to users. Access to Eiger's API is included for all customers of Eiger Fleet.

"Eiger has been instrumental in harnessing the power of our connected fleet of 3D printers during our recent Project DIAMOnD initiative in Michigan," commented Tom Kelly, Executive Director and CEO of Automation Alley. "Over 300 local manufacturers have banded together to create a powerful, distributed network and today they are creating tourniquet parts to assist medical efforts in Ukraine. This use case illustrates the power of true digital transformation in the manufacturing industry, and we're excited to see how 3YOURMIND's integration of Eiger API continues to improve these capabilities."

www.markforged.com
www.3yourmind.com

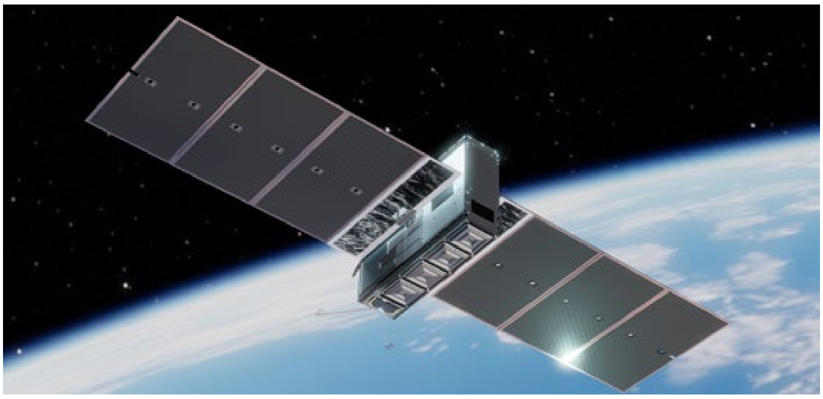
Fleet Space launches Centauri 5 satellite featuring metal AM antennas

Fleet Space Technologies, Beverley, Australia, has successfully launched its Centauri 5 satellite on the Space X Falcon 9 Transporter-5 mission. In what is said to be a world first, the all-metal patch antennas are entirely additively manufactured.

The advances in Additive Manufacturing technology used in the construction of its patch antennas also feed into the development of the forthcoming fully additively manufactured micro Alpha constellation, scheduled for launch in 2023. Together, the two systems are intended to provide continuous coverage, data rates up to 520 kbps and tailored frequency bands servicing current and future generations of IoT devices.

"We've built our business and reputation by consistently delivering on our stated goals, and developing technologies that address real human and commercial needs reliably and cost-effectively," stated Flavia Tata Nardini, CEO and founder, Fleet Space Technologies. "Centauri 5 will bring important new capabilities to our existing constellation. It also supports the development of our forthcoming Alpha constellation, which enables our pioneering ExoSphere mineral exploration tool with transformational benefits for the exploration of critical energy transition materials."

Further upgrades to the Centauri 4 payload include enhancements that mitigate the effects of radiation in low earth orbit (LEO), direct communication links to Fleet's ground station, and an extended S-Band range, allowing uplink at standard ground station frequencies.



Fleet Space has launched its Centauri 5 satellite which features additively manufactured metal patch antennas (Courtesy Fleet Space Technologies)

Digital beamforming provides extra gain, increasing the data rate, and also allows the S-Band frequency channels to be reused on the different beams. This combination increases the satellite's data capacity by 2.6X.

Centauri 5 will be placed in LEO at an expected altitude of approximately 530 km (330 miles). A 6U sized microsat with a total weight of 12 kg, is anticipated to add capacity, reduce latency and provide additional network redundancy in the existing six-strong Centauri constellation, which Fleet operates in collaboration with Tyvak International, Torino, Italy.

The combined constellation is also expected to further enable Fleet Space's ExoSphere system. This uses ambient noise tomography to locate critical resources up to 100X faster with less environmental impact than conventional methods like explosives, vibroseis machines and drilling.

This was the company's third launch with SpaceX, following the successful deployment of Centauri 4 on the Transporter-2 mission in June 2021. The Centauri 5 launch is intended to strengthen Fleet Space's position in the burgeoning Australian space technology industry, which the federal government predicts will be worth $12 billion and create an additional 20,000 jobs by 2030.

www.fleetspace.com

Elmet Technologies expands scope of accredited practices

Elmet Technologies Inc, Lewiston, Maine, USA, reports that it has expanded the scope of its accredited practices at its analytical laboratory, having gained A2LA-accreditation for technical competence in the field of mechanical testing.

In addition to the A2LA-accreditation, this lab is also accredited in accordance with the recognised International Standard ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories. This demonstrates technical competence for a defined scope and the operation of a laboratory quality management system.

The lab's accredited practices have included tensile testing, density testing, hardness testing (Rockwell and Vickers microhardness), as well as microstructure analysis and grain size measurements. Practices now covered by the ISO 17025 scope include chemical composition analyses using optical emission spectroscopy (ICP-OES) and carbon & gas analysis in metals using combustion analysis.

Elmet Technologies is a global leader in high-performance tungsten and molybdenum refractory metal product manufacturing and machining services. Its refractory metals expertise covers a range of pure metals (W and Mo) and alloys (TZM, MoLa, MoTa, WHA, WK, HCT) and serves a number of industries including defence, lighting, electronics, semiconductor, thin-film, automotive, aircraft and medical.

www.elmettechnologies.com

NASA develops durable AM aerospace alloy

NASA reports that it has developed a new metal alloy using an Additive Manufacturing process said to significantly improve the strength and durability of the components and parts used in aviation and space exploration, resulting in improved and longer-lasting performance. NASA Alloy GRX-810, an oxide dispersion strengthened (ODS) alloy, can reportedly endure temperatures over 1093°C, is more malleable, and can survive more than 1,000X longer than existing alloys. These new alloys can be used to build aerospace parts for high temperature applications, like those inside aircraft and rocket engines, because ODS alloys can withstand harsher conditions before reaching their breaking point.

"The nanoscale oxide particles convey the incredible performance benefits of this alloy," stated Dale Hopkins, deputy project manager of NASA's Transformational Tools and Technologies project.

In order to develop NASA Alloy GRX-810, agency researchers used computational models to determine the alloy's composition. The team then leveraged Additive Manufacturing to uniformly disperse nanoscale oxides throughout the alloy, which provides improved high-temperature properties and durable performance. This manufacturing process is said to be more efficient, cost effective, and cleaner than conventional manufacturing methods.

This turbine engine combustor (fuel-air mixer) was additively manufactured from the new GRX-810 alloy (Courtesy NASA)

Hopkins added, "This breakthrough is revolutionary for materials development. New types of stronger and more lightweight materials play a key role as NASA aims to change the future of flight. Previously, an increase in tensile strength usually lowered a material's ability to stretch and bend before breaking, which is why our new alloy is remarkable."

NASA states these alloys have major implications for the future of sustainable flight. For example, when used in a jet engine, the alloy's higher temperature and increased durability capability translate into reduced fuel burn and lower operating and maintenance costs. This alloy also offers engine part designers new flexibilities like lighter materials paired with vast performance improvements.

The team applied thermodynamic modelling and leveraged Additive Manufacturing to develop the new high-temperature alloy. Using thermodynamic modelling, one of many computational tools discussed within the NASA 2040 Vision Study, the team discovered the optimal alloy composition after only thirty simulations.

"Applying these two processes has drastically accelerated the rate of our materials development. We can now produce new materials faster and with better performance than before," added Tim Smith, a material research scientist at NASA's Glenn Research Center in Cleveland, Ohio, USA, and one of the inventors of this new alloy.

This modelling tool produces results in much less time and with lower costs than traditional trial-and-error processes. The tool also avoids dead ends by showing researchers not just what metal types to incorporate but how much of each element to infuse into the composition.

Steve Arnold, materials and structures technical discipline lead at NASA Glenn, concluded, "The performance of this alloy clearly demonstrates the modelling tool's maturity and ability to produce significant results."

www.nasa.gov

Premium Aerotec produces additively manufactured brake components for Airbus A320

Premium Aerotec, headquartered in Augsburg, Germany, has added to the number of Airbus aircraft it now supplies with the production of additively manufactured titanium structural components for the Airbus A320 family. With this, the company is now actively supplying components for three Airbus aircraft programmes, the A320, A400M and A350XWB ranges.

The component, a single aisle brake manifold, is used in the brake system of all A320 family aircraft and, to enable the changeover from conventional production to Additive Manufacturing, was re-designed in the engineering departments of Premium Aerotec and Airbus. The conversion to Additive Manufacturing, with a weight reduction of 56%, leads to a significant cost saving – chiefly due to a significantly lower raw material input. In the future, all A320 family aircraft will be equipped with this additively manufactured component.

Premium Aerotec has delivered additively manufactured titanium brake manifolds for the Airbus A320 family (Courtesy Premium Aerotec)

"With today's delivery, we are once again impressively demonstrating our role as technology leader in Additive Manufacturing in aircraft construction – thanks to a great performance by the entire team and the excellent cooperation with our customer Airbus," stated Dr Thomas Ehm, CEO of Premium Aerotec. "We are thus proving that the future technology of 3D printing is also fully applicable in the field of large-scale production – an important prerequisite for the upcoming ramp-up."

Premium Aerotec has recognised the potential of Additive Manufacturing for a number of years, with initial development measures starting in 2013 and a Laser Beam Powder Bed Fusion (PBF-LB) machine obtained in 2014. In 2016, the first individual part qualifications were achieved for the Airbus A400M, with double-walled titanium tube components used in the fuel system. In 2016, the company also began series production of AM structural components for the Airbus A350XWB long-haul aircraft.

www.premium-aerotec.com
www.airbus.com

Open Additive and Addiguru partner to expand powder bed analytics

Open Additive, LLC, Beavercreek, Ohio, USA, and Addiguru, LLC, Metairie, Louisiana, have announced an agreement to provide Addiguru's Recoater, a Laser Beam Powder Bed Fusion (PBF-LB) analysis software, as a plugin to Open Additive's AMSENSE® multi-sensor data collection and analysis platform.

AMSENSE is a modular hardware/software platform which captures layer-by-layer data of the PBF-LB process in real time during the build. When joined with the Recoater plugin – which utilises computer vision, artificial intelligence, and machine learning to identify critical process errors in real-time – the collected data is processed to provide a layer-by-layer recoat analytical interpretation of the captured data. Together, these two capabilities are hoped to represent the state-of-the-art in real-time Additive Manufacturing machine monitoring and process controls.

Since its introduction in 2018, AMSENSE has sold various configurations for use on its own PANDA™ machines and other industrial PBF-LB Additive Manufacturing machines. Addiguru provides process insights and reduced production costs for Additive Manufacturing service bureaux and other users across several important industrial machines. The software has been commercialised and has multiple installs in the industry.

"I am pleased with the Addiguru collaboration on AMSENSE and look forward to working closely with Addiguru to bring this new analytic to market especially with the actionable information that Addiguru's Recoater Plugin will provide to additive manufacturing systems users and researchers alike," stated Joe Sciabica, Managing Member, Open Additive.

Shuchi 'SK' Khurana, founder, Addiguru, added, "Addiguru recognises the high added costs of part development and production due to lack of useful process insights and controls, and we're excited to work with Open Additive to bring practical and affordable solutions to the metal Additive Manufacturing industry to address this problem."

www.openadditive.com
www.addiguru.com

Multistation signs a robotic integration agreement with Axiome Robotic Solutions

Multistation SAS, Paris, France, reports that it has signed an agreement with Axiome Robotic Solutions, a robotic machines company based in Aizenay, France. The agreement is a robot integrator contract for Meltio's laser metal deposition heads. Multistation is a reseller for Meltio, Linares, Spain, offering the company's range of metal Additive Manufacturing machines.

Axiome is a leading designer and developer of robotic machines. Recognised as an integrator of industrial robots, the company operates in many sectors such as aeronautics, automotive, energy and transport. The company is expected to play a major role in the integration and support of Meltio technology on robots. By bringing its robotic expertise to Multistation's Additive Manufacturing knowledge, the goal is to ensure an excellent user experience explains the company.

Meltio's metal Additive Manufacturing solutions use the company's wire-based Laser Metal Deposition (LMD) technology, a form of Directed Energy Deposition (DED). Multistation states that it develops the French ecosystem around the Meltio technology, establishing partnerships and development opportunities with research centres, universities, robotic integrators, manufacturers or distributors of machine tools, and of course industrial users of this technology.

www.multistation.com
www.meltio3d.com
www.axiome.com

RUAG Space rebrands to Beyond Gravity

As of May 1, 2022, RUAG Space, Zürich, Switzerland, has legally changed its name to Beyond Gravity, the name under which the company has been operating since March 15, 2022.

With around 1,600 employees and sales of 319 million Swiss francs in 2021, Beyond Gravity develops and manufactures products for satellites and launch vehicles and operates in six countries (Switzerland, Sweden, Austria, Germany, Finland and the USA).

RUAG Space is now operating under the new name Beyond Gravity (Courtesy Beyond Gravity)

Beyond Gravity is a supplier of structures for all types of launch vehicles. It is reported that European Ariane and Vega rockets, and many US United Launch Alliance rockets, are equipped with Beyond Gravity payload fairings.

The company uses Additive Manufacturing for the development and production of a number of components and, in 2019, additively manufactured an engine mount for the Beresheet lunar lander designed by SpaceIL. The company is also known for its work in selected satellite products, particularly for satellite constellations in the New Space market.

All existing contracts and offers will remain valid despite the rebrand, as the company ownership (100% Swiss Confederation) has not made any changes

www.beyondgravity.com

Aerojet Rocketdyne secures largest RL10 Engine order from ULA for Amazon's Kuiper satellite broadband system

United Launch Alliance (ULA), Centennial, Colorado, USA, has awarded its largest RL10 engine contract ever to Aerojet Rocketdyne, Los Angeles, California, USA, to deliver 116 RL10C-X engines for its Vulcan Centaur rocket. The new engines will support ULA as it works to fulfil its commitments under a contract from Amazon, as part of the largest commercial launch contract in history to establish Amazon's Kuiper satellite constellation.

Rendering of the new ULA Vulcan Centaur rocket which will incorporate a number of RL10C-X upper stage engines (Courtesy ULA)

Project Kuiper is a low Earth orbit (LEO) satellite system designed to provide fast broadband to unserved and underserved communities around the world. To date, the company has secured up to eighty-three launches from three commercial space companies. These include thirty-eight launches on ULA's Vulcan Centaur rocket, eighteen launches on Arianespace's Ariane 6, and twelve launches on Blue Origin's New Glenn, with options for fifteen additional launches. The agreements provide enough capacity to carry into space the majority of the 3,236 satellites that make up the Kuiper satellite constellation.

"The RL10 engine is the nation's premier upper-stage engine and a true workhorse in the industry," stated Eileen P Drake, CEO and president, Aerojet Rocketdyne. "With the RL10C-X, we've leveraged our industry-leading 3D printing technology to significantly reduce the cost of the engine while at the same time increasing its performance to provide our customer with enhanced mission capability."

The RL10C-X uses an additively manufactured main injector and main combustion chamber, as well as a 239 cm monolithic lightweight composite (carbon-carbon) nozzle. The specific impulse, or Isp, of the RL10C-X is 461 seconds, which puts it near the very top of the RL10 engine family in terms of performance. Specific impulse measures the amount of thrust generated by a rocket engine per unit of propellant consumed per second.

"The RL10 is the highest performance upper-stage rocket engine flying today," said Tory Bruno, ULA president and CEO. "We're proud to be launching the Kuiper constellation with the next generation of this incredibly reliable and high-performance engine."

The RL10C-X engine is designed, fabricated, assembled and tested at Aerojet Rocketdyne's facility located in West Palm Beach, Florida. The RL10 engine line currently powers the upper stages of ULA's Atlas V and Delta IV launch vehicles, and will soon begin supporting NASA's Space Launch System.

www.aerojetrocketdyne.com
www.ulalaunch.com

Ultra Fine Specialty Products adds pilot atomiser for powder development

Ultra Fine Specialty Products, LLC, an affiliate of Novamet Specialty Products Corporation, reports that its manufacturing site in Woonsocket, Rhode Island, USA, has installed capabilities to produce pilot quantities of gas atomised powders. This is expected to enable the development of custom alloys based on iron, cobalt, nickel, and copper for Powder Bed Fusion (PBF) and Binder Jetting (BJT) Additive Manufacturing, as well as Metal Injection Moulding.

Ultra Fine Specialty Products' pilot and production atomisers utilise a unique gas atomisation process to produce high-purity spherical metal powders with tightly sized particle distributions (d90 <30 μm) to meet customers' stringent specifications for MIM and metal Additive Manufacturing, particularly applicable to BJT.

The newly commissioned pilot atomiser enables orders of as little as 50 kg, reducing the amount of material that customers must purchase for development projects. Upon successful evaluation, quantities can be readily scaled to high volumes on existing production equipment. The pilot equipment will enable the development of technology to further optimise particle size distributions, improve sphericity, and reduce satellites to facilitate the growth of these processes.

Ultra Fine Specialty Products was purchased on June 30, 2020, from Carpenter Technology by a group of investors affiliated with Novamet. Novamet Specialty Products Corporation was formed in 1976 to apply technology to the development of nickel-base powders with unique morphologies, shapes, and sizes. The company currently processes and distributes various metal powders and coated products for the MIM, aerospace, automotive, coatings and electronic materials markets.

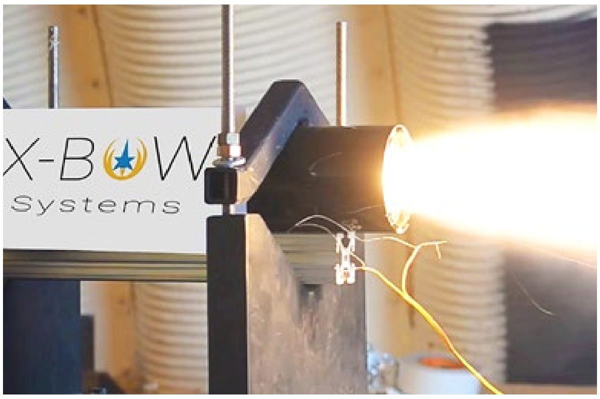
www.ultrafinepowder.com
www.novametcorp.com

X-Bow Launch Systems raises $27 million in series A financing round

X-Bow Launch Systems Inc., Albuquerque, New Mexico, USA, a space technology company applying Additive Manufacturing techniques to the production of solid rocket energetics, has closed a $27 million series A investment round.

This round closes ahead of X-Bow's static fire test of its 81 cm diameter 'Ballesta' solid rocket motor and subsequent launch at White Sands Missile Range, New Mexico. The company states this will be the first large-diameter scale motor designed and tested by a non-legacy systems integrator supplier in over thirty years.

The funding round was co-led by Crosslink Capital and Razor's Edge Ventures, with additional participation from Lockheed Martin Ventures and Broom Ventures. X-Bow's capital raise team was led by its co-founder and CRO Maureen Gannon. The capital raised is said to have come at a time of significant growth for X-Bow as it advances its patent-pending Additive Manufacturing technology for solid rocket energetics and expands its solid rocket motor product portfolio. The new financing is expected to further accelerate customer support, team growth, and investment in the company's next generation of product offerings.



X-Bow Launch Systems has raised $27 million in its series A round of investment (Courtesy X-Bow Launch Systems Inc)

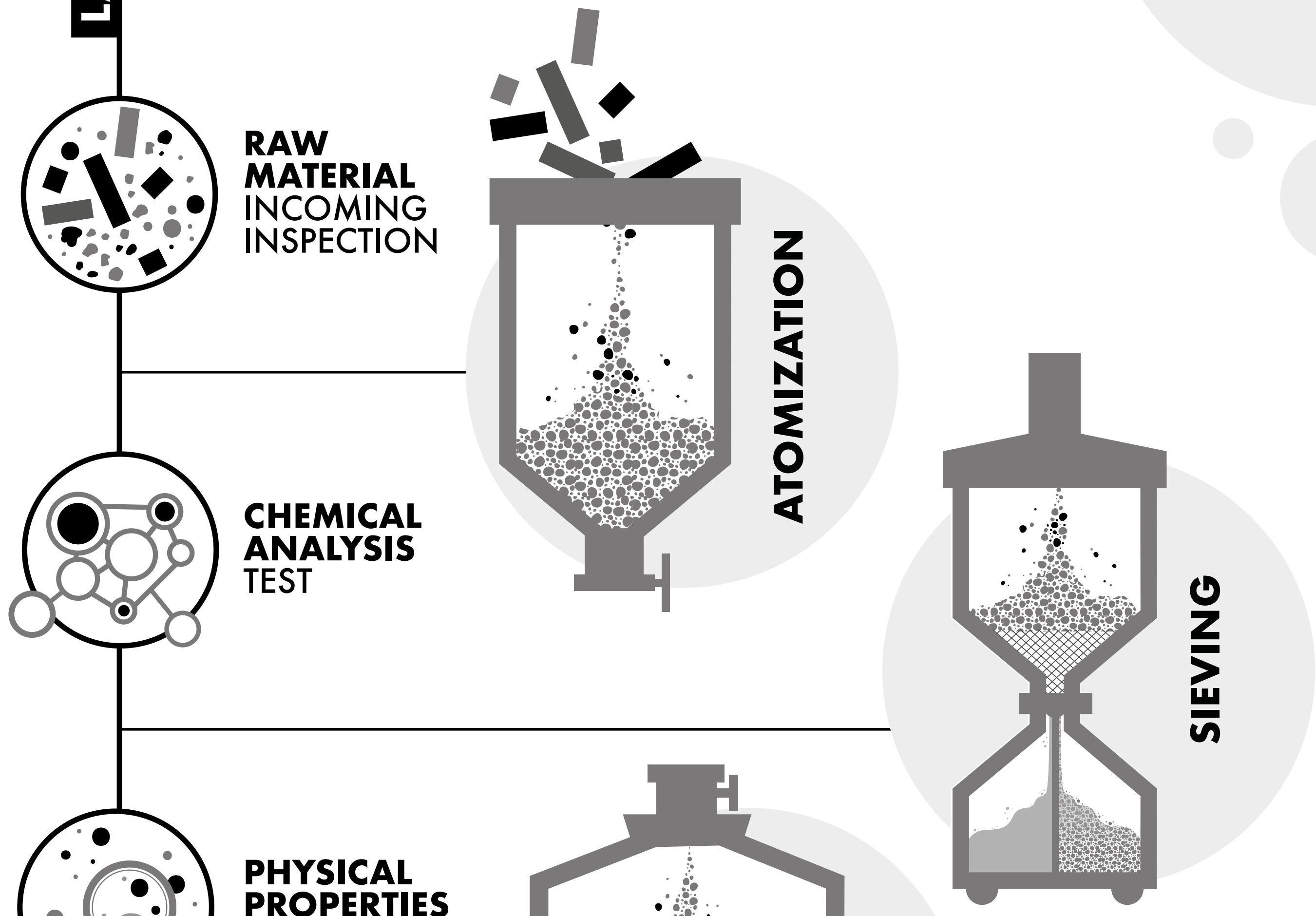
"We are proud of the support we have received from our investors and appreciate the confidence they signal in X-Bow's team, breakthrough technology and innovative approach to solid rocket motor development," stated Jason Hundley, X-Bow CEO and co-founder. "Raising a strong round with these high calibre investors allows us to increase our rapid growth and accelerate our plans to disrupt a critical industry. I am also very fortunate to work with an outstanding team here at X-Bow that is making groundbreaking achievements in the sector."

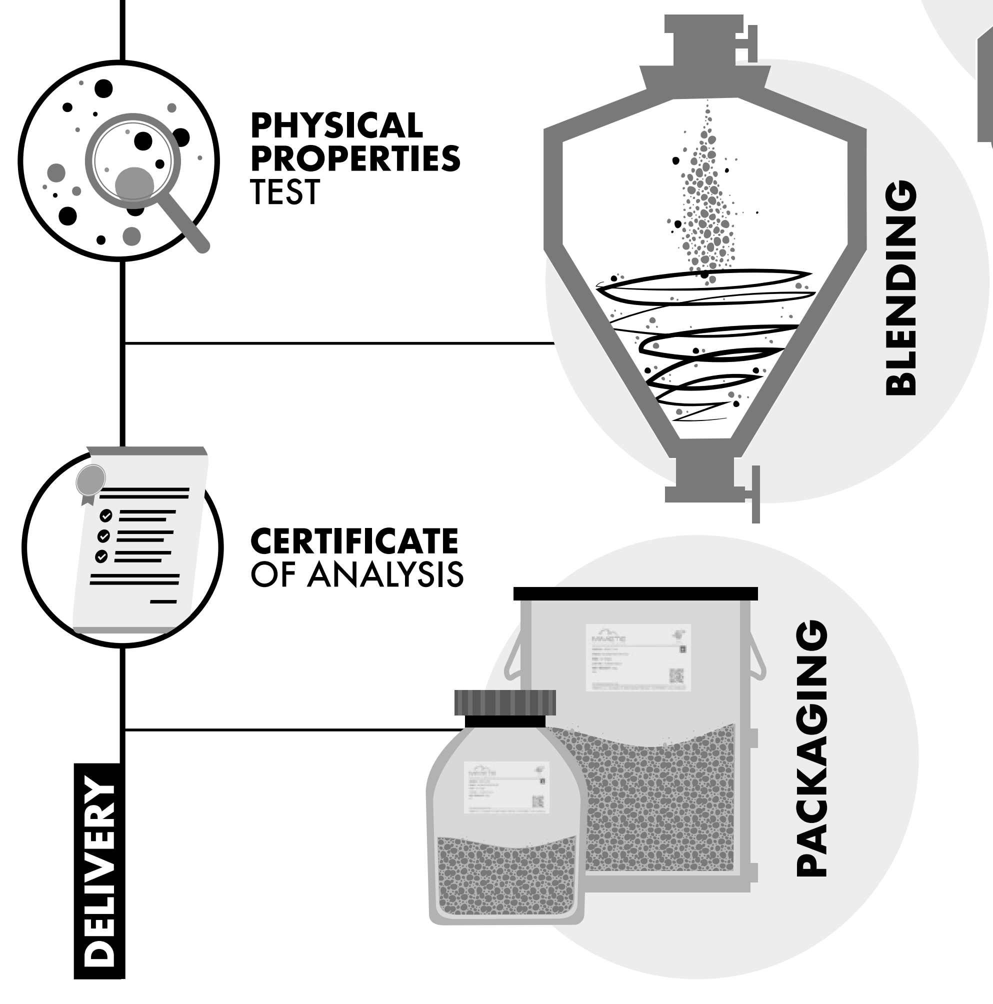
Matt Bigge, Crosslink Capital Partner, commented, "X-Bow has a great combination of experienced leadership and a truly innovative Additive Manufacturing technology for energetics. They are the much-needed changemaker poised to disrupt the energetics market with its disruptive technologies. Crosslink invested in X-Bow because of its ability to catalyse a critical evolution in the national security, defence and commercial space technology markets."

Mark Spoto, co-founder and Managing Partner of Razor's Edge Ventures, added, "The X-Bow team brings a unique perspective and clear vision of the gaps within the traditional ecosystem of solid rocket motor manufacturers. The company's proprietary Additive Manufacturing approach to solid rocket energetics, motors and architectures will, for the first time, enable rapid, agile, cost-effective solutions to be brought to a market that has always thought about product development in terms of years of development time and tens or hundreds of millions of dollars per product. We invest in great management teams with differentiated products that solve large, difficult problems across both national security and the commercial enterprise markets and are extremely excited to partner with X-Bow's team to help accelerate their growth and product expansion."

www.xbowsystems.com

MIMETE METAL POWDERS PROCESS





Gas atomised metal powders in Iron, Nichel and Cobalt base alloys available for additive (PBF, DED, and Binder Jetting) and HIP (Hot Isostatic Pressing) applications.

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www.mimete.com

Exum Instruments oversubscribes $1.8M launch financing round

Exum Instruments plans to launch its Massbox mass spectrometer to customers (Courtesy Exum Instruments)

Scientific instrument and software ecosystem provider Exum Instruments, Denver, Colorado, USA, has announced the oversubscription of its $1.8 million launch round. Incorporated five years ago, Exum launched its Massbox™ mass spectrometer and is now taking commercial orders to deploy the analytical instrument domestically.

"I'm excited to have closed this round of funding and very proud of our team for all their hard work," stated Stephen Strickland, CFO. "We are moving fast and taking the next steps as a company. I'm thrilled by the support of our ambitious, successful investors who see how big this is going to be. I couldn't have asked for a better investment group."

Notable investors highlighted by the company include Cortado Ventures, Alchemy Capital, Amerocap, Oasis Capital and FortySix Venture Capital.

Jeff Williams, CEO/CTO, added, "We have been incredibly overwhelmed with the reception our funding round has received. I believe we have found the right partners to help propel us into a strong position for an A Round later this year."

"The beginning of this year marks the start of establishing a new benchmark for technology and experience in analytical instrumentation. We are delivering the Massbox to the hands of our customers and we couldn't be more excited for them to receive Exum's vision," Williams continued.

Josh Ulla, CDO, added, "The world is realising that tighter chemical constraints are required to develop and maintain the advanced materials of the future. While we have received interest from many different industries, our first focus will be metals testing, specifically in the Additive Manufacturing space. This is an aggressively expanding industry and one that is already evolving and growing at the speed of Exum."

www.exuminstruments.com

New metal powder atomiser in operation following Swerim and Kanthal investment

Swedish heating technology company Kanthal, part of the Sandvik Group, and metals research institute Swerim, based in Luleå, Sweden, report that their ultra-modern atomising equipment designed for the production and development of metal powders is now operational following a previously announced joint investment of €2 million.

With a high degree of flexibility, the new equipment is specially designed for the research and development of both materials and the atomisation process for Additive Manufacturing and Powder Metallurgy applications. It is possible to atomise powder charges of up to 85 kg, suitable for AM, Metal Injection Moulding, surface coating and Hot Isostatic Pressing.

Swerim and Kanthal's investment is said to be a result of the increased demand for research surrounding materials and process development within Additive Manufacturing and Powder Metallurgy sectors. The partnership will see a long-term collaboration, whereby Kanthal will gain access to Swerim's expertise in Powder Metallurgy, Additive Manufacturing of metal products, advanced structural analysis, testing and modelling. Swerim will have the opportunity to build further on knowledge within these areas.

"This investment brings unique opportunities for customised development within Additive Manufacturing and it means that we can bring new materials to the market faster," stated Dilip Chandrasekaren, Head of R&D at Kanthal. "Cooperation with Swerim also gives us the prerequisites for conducting world-class R&D within a strategic area for Kanthal and Sweden."

Annika Strondl, manager of Powder Materials and Additive Manufacturing at Swerim, commented, "It's fantastic that metals research institute Swerim and Kanthal are together investing 20 million kronor in a state-of-the-art atomiser unit. This has enabled a unique platform for R&D activities focussing on alloying and powder development for all of Sweden. The fact that we are investing together with the industry just goes to show that Swerim is an attractive research partner within powder and alloying development."

www.kanthal.com
www.swerim.se

The atomisation unit for the production and development of metal powders (Courtesy Swerim/Kanthal/Anneli Nygårds)

CMG investment to boost its MIM and Additive Manufacturing

CMG Technologies, Woodbridge, Suffolk, UK, has invested more than £250,000 in a new ECM sintering furnace and 3DGence Additive Manufacturing machine. The investment will allow the company to bolster its Metal Injection Moulding services and newer ventures in Additive Manufacturing.

"We're very excited to be able to expand on the technology we already have here at CMG," stated Rachel Garrett, Managing Director of CMG Technologies. "Not only will the furnace be a beneficial addition to our MIM operations but it, along with the printer, will also support our growing 3D printing services."

"This industry and the technologies involved are ever-evolving, so this new machinery will help us stay ahead of the curve and offer more support to our existing and new clients," she continued.

Since late 2021, the company has been offering metal Additive Manufacturing services from initial design to post-processing of the product. The new technology is in addition to the four furnaces and four Additive Manufacturing machines already in use at the company's factory.

Dr Samuel Wilberforce, Head of 3D Printing, added, "Additive Manufacturing is a complementary technology to our extensive MIM services. By using 3D printing, we can create prototypes and moving parts far quicker than traditional methods, while keeping waste to an absolute minimum."

"Thanks to these additional machines, we will be able to offer more services to clients across the world – from design to printing, or just the post-processing of parts to create a dense metal end-product," he concluded.

www.cmgtechnologies.co.uk

CMG has invested in a new ECM sintering furnace (Courtesy CMG Technologies)

CMG Technologies has purchased a 3DGence Additive Manufacturing machine to support its MIM and AM (Courtesy CMG Technologies)

Sigma Labs to operate as Sigma Additive Solutions

Sigma Labs, Inc., headquartered in Santa Fe, New Mexico, USA, has announced that it will begin operating under the name Sigma Additive Solutions. The change is said to reflect the evolution of the company, from its origins as a laboratory engaged in research and development of Additive Manufacturing technology, to a solutions provider focused on enabling its customers use a standard set of patented quality metrics across AM machines from different manufacturers, using different processes.

The company has also changed its corporate web address to www.sigmaadditive.com.

"Our company's decision to operate as Sigma Additive Solutions is an acknowledgement of the progress the Sigma team has made in creating the quality standard in Additive Manufacturing. For some time, we have been working with customers, OEMs and standards organisations to remove the quality barrier through advanced meltpool monitoring and analytics," stated Jacob Brunsberg, president and CEO of Sigma.

"We intend to significantly impact the entire AM quality continuum with scalable solutions that improve machine, process and part quality. We are also pleased that our ticker symbol will be aligned with our brand and our vision," added Brunsberg.

In conjunction with the change, the company's common stock will begin trading on the Nasdaq Capital Market (NASDAQ) under the new ticker symbol SASI, effective at the open of market trading on May 19, 2022. No action is required from Sigma's stockholders and the CUSIP number for the common stock will remain unchanged, the company added.

www.sigmaadditive.com

Gränges launches low CTE aluminium alloy powder for aerospace and automotive applications

Gränges Powder Metallurgy, headquartered in Stockholm, Sweden, has launched its first aluminium alloy for Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing, the S220 AM from its DISPAL® family of high-performance aluminium. The alloy's properties are said to be comparable to steel, but at a third of its weight, making it well suited to industries such as aerospace and automotive.

The S220 AM alloy has a high silicon content, characterised by low density and low coefficient of thermal expansion (CTE). Due to the fine silicon particles being evenly distributed in the matrix structure, the material is said to possess good wear and friction properties.

"I am not aware of any other alloy on the AM market that has such a low CTE," stated Greta D'Angelo, Business Development Manager at Gränges Powder Metallurgy. "In the past, we had many success stories of customers replacing steel and carbon fibre applications with the conventional DISPAL S220. Now, we are excited to offer the same material for Additive Manufacturing, giving our customers the opportunity to take advantage of even more geometrical freedom in the design of their next-generation products."

Gränges Powder Metallurgy has entered into the Additive Manufacturing market with its S220 AM (Courtesy Gränges Powder Metallurgy)

A low CTE is said to be crucial in applications that require extreme precision under high loads and high temperatures, such as linear technology and robotics. It is also a critical attribute in optical applications in the space industry, where a low CTE helps enable high precision communication at large distances.

Gränges Powder Metallurgy has experience in manufacturing aluminium powders that goes back over thirty years. The DISPAL S220 material was invented and commercialised in the 1980s as part of a larger family of alloys, so, while the material itself is not new, its use in Additive Manufacturing marks the company's entrance into the technology.

DISPAL S220 AM powder is currently not commercially available; however Gränges offers an Additive Manufacturing service via a global network of trusted partners. The service is not limited to the manufacturing of the components, but also offers support with part selection, development, engineering and quality assurance.

"We want to support our customers through the whole process, and deliver finished components of high quality, being that prototypes or serial production," D'Angelo continued. "We are aware that onboarding a new material can be a daunting process, especially for a new technology like AM, therefore we take care of that part for our customers so that they don't have to worry about it."

Gränges Powder Metallurgy is working to develop a wide portfolio of both Additive Manufacturing aluminium powders and specialised additively manufactured aluminium alloys. More alloys are already reported to be in the pipeline, and are expected to be released before the end of the year.

www.granges.com/additive

3D Metalforge agreement to supply Woodside Energy range of AM parts and services


3D Metalforge will supply additively manufactured parts to Woodside Energy (Courtesy 3D Metalforge)

3D Metalforge Pte Ltd, headquartered in Singapore, has signed a non-exclusive outline agreement with Woodside Energy Ltd, Perth, Australia, to supply additively manufactured parts, production technologies and digital part library development services.

The agreement, effective from March 2022, is valid for two years with an optional extension. The agreement, to produce metallic additively manufactured components made via Powder Bed Fusion (PBF) and Directed Energy Deposition (DED) Additive Manufacturing technologies to be used in Woodside-operated facilities, will support Woodside's operational supply chains with replacement parts available with shortened lead times compared to traditional sources.

3D Metalforge's agreement, subject to subsequent purchase orders, may include the engineering and design services, printing, post-production processing, testing and delivery of additively manufactured components including but not limited to valves (body, stem, seals), pipe fittings (flanges, elbows, tees), manifolds and pumps (impeller, inducer, body) and other parts as requested by Woodside.

This agreement is expected to allow the rapid production of parts for Woodside, reducing operational risk and local inventory holdings, with a more certain cost horizon and increased sustainability.

Matthew Waterhouse, CEO, 3D Metalforge, commented, "This agreement underlines 3DMF's commitment to expanding within the Australasian market with a major focus upon the oil & gas, mining and defence sectors. 3DMF is currently working with several global companies who face similar challenges to better manage their parts supply chain risks and are addressing that risk by leveraging the benefits of Additive Manufacturing technologies combined with the expertise of 3DMF as an established international provider of AM capabilities."

www.3dmetalforge.com

Epson Atmix to establish recycling facility for metal powder production

Epson Atmix Corporation, Aomori, Japan, an Epson Group company, has announced plans to invest several billion yen to build and equip a new metal recycling facility. The company will process used metals from within Atmix, as well as external sources, to use as raw material for the production of its fine metal powders.

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

The Epson Group has set a goal of becoming non-renewable resource-free by 2050. In addition to this, Atmix believes it necessary to establish a closed-loop metal powder manufacturing ecosystem to address potential issues with the future supply of metals due to resource depletion and rising prices.

Atmix has stated that it plans to invest in an induction furnace for melting metals, refining equipment for removing impurities from metal, and a pig casting machine for forming ingots. The used metal will come from sources such as out-of-spec metal powder products in Atmix's manufacturing process, metal waste from its factory, metal scraps and used moulds and dies discharged by Epson and others.

Operations are scheduled to begin in 2025, and within three years Atmix expects recycled metal materials to meet about 25% of its total raw metal material needs. This new Atmix factory is positioned as the first step toward becoming 'underground resource-free' and is expected to be a crucial part of Atmix's efforts to develop a sustainable metal powders business.

www.atmix.co.jp

The new metal recycling facility will feed Epson Atmix's metal powder production operations, including its water atomisation line at the Kita-Inter Plant (pictured) in Hachinohe, Japan (Courtesy Epson Atmix)

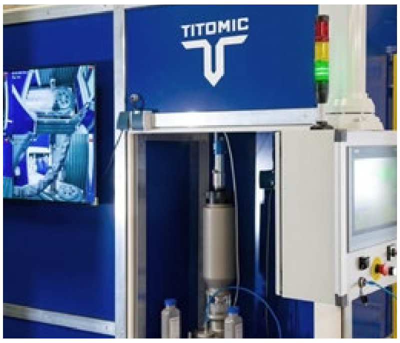
Titomic develops automated cold spray glass mould repair system

Titomic Limited, headquartered in Melbourne, Australia, has developed a system for the coating of glass moulds in collaboration with glass research organisation International Partners in Glass Research (IPGR). The system scans the moulds, and, using AI software, produces a robotic program to automatically coat and repair the mould, which is expected to enhance the performance of moulds for the glass industry. Subsequent generations of this system are planned to introduce automated loading & unloading and polishing of the moulds.

The final step before shipment – Factory Acceptance Testing – has been completed. This testing is said to ensure that the machine is performing as designed and is accepted by the customer for delivery. The system is expected to be received in the coming days by glass manufacturer Vetropack Austria.

This sale represents Titomic's first commercial sale into the IPGR network, which represents numerous partner companies comprising 12% of the glass packaging market. Titomic expects the installation of its cold spray system to provide further opportunity for systems sales within the global IPGR network. Each comparable machine sale is said to have the potential to generate a revenue of AUS $1.7 million over a three-year period.

Herbert Koeck, Managing Director, Titomic, stated, "This entry into the glass packaging and components market represents a new income stream for Titomic. The industry needs this type of mould enhancement to prolong life of production lines and mould machinery. As such, we will be providing machine sales – the first of which we're about to ship to Vetropack – as well as ongoing consumables and servicing enabled by our expanded global footprint. Titomic Europe, together with its collaborators, have made a significant step forward in the development of automated systems, improving conditions for operators as well as adding to the bottom line of our customers."



Titomic has developed a system for the coating and repair of glass moulds (Titomic)

www.titomic.com

6K Additive reports life cycle assessment results for AM powder production process

6K Additive, a division of 6K, headquartered in North Andover, Massachusetts, USA, has reported the results of an independent life cycle assessment (LCA) of its metal powder production process for Additive Manufacturing. The assessment was completed by sustainability and energy firm Foresight Management, Grand Rapids, Michigan, USA, and is said to be the first LCA of a powder for Additive Manufacturing ever completed.

The assessment sought to compare the quantifiable environmental impacts between traditional metal powder production methods and 6K Additive's proprietary UniMelt® process. 6K Additive states that the results show the UniMelt process significantly reduces environmental impact in the key areas of energy usage and global warming, potentially helping 6K Additive customers lower their carbon footprint using metal Additive Manufacturing.

6K Additive produces Additive Manufacturing powder made from sustainable sources and its UniMelt system is said to be the only microwave production-scale plasma with a highly uniform and precise plasma zone offering zero contamination. UniMelt is capable of high throughput production of advanced materials including nickel 718/625, titanium 64 grade 5/23, copper 18450/GRCop, stainless steel 316/17-4, refractories such as tungsten and tantalum.

6K Additive's LCA results show that its UniMelt metal powder production for the Additive Manufacturing process reduced environmental impact (Courtesy 6K Additive)

Frank Roberts, 6K Additive president, stated, "This assessment goes a long way in revealing how the UniMelt process exceeds traditional metal powder processing in environmentally important ways, while also pointing to the inefficiencies of atomisation that currently plague AM material production. Sustainability is at the core of who we are at 6K Additive and providing our customers with quantifiable numbers related to the environment helps them move closer to zero carbon manufacturing with AM."

Foresight Management conducts life cycle assessments on products for companies to help them understand the impact their processes have on a global environmental scale. Its methodology includes primary and secondary data, as well as using professional GaBi software to provide data detailing the environmental impact of sourcing, refining, and processing.

"This is a cradle-to-end user assessment of the UniMelt technology," commented Brad Van Valkenburg, Sustainability Manager at Foresight. "We studied all known industrial processes from raw material acquisition and processing up through manufacturing and customer distribution. This assessment focused on nickel and titanium powders, both of which saw significant advantages when made using UniMelt process. The nickel results showed the UniMelt required 91% less energy and reduced carbon emissions by 92% and the titanium results showed the UniMelt required, at a minimum, 74% less energy and reduced carbon emissions by 78%."

6K Additive explains that organisations are starting to look to their suppliers to offer statistics that help them with their sustainability journey. Many companies are now asking for hard facts to back up sustainability claims and this study provides 6K Additive customers with information that may help them advance their Additive Manufacturing initiatives.

www.6kinc.com/6k-additive

Think3D establishes Sinterize to offer Additive Manufacturing in US

Think3D, one of India's largest rapid prototyping facilities offering Additive Manufacturing, CNC machining and injection moulding, based in Hyderabad, has established Sinterize, a US-based digital manufacturing service provider. For the time being, all orders will be manufactured in India, but Think3D plans to install industrial AM machines in the US to cater to the needs of local customers.

"We are delighted to launch our service in the USA under the Sinterize brand. We got this idea to launch our services in the USA market in late 2019. But with the onslaught of the pandemic, our launch plan took a back seat and we shifted our focus towards manufacturing RT-PCR devices, cartridges and SWABs," stated Raja Sekhar Upputuri, co-founder & CEO of Think3D. "With things getting back to normal now, we felt the time was right to launch the service. Having a one-stop-shop offering 3D Printing, CNC Machining, and Injection Moulding services all under one roof, we are confident of delivering high-quality service to the customers in the USA."

Kishore Karlapudi, co-founder & CEO Sinterize, "I have been observing Think3D over the last seven years and what they have achieved in the digital manufacturing space in India in such a short span is phenomenal. Given the expertise Think3D team gained in this space, we felt it natural to partner with them to launch digital manufacturing services in the USA. We also have plans to roll out an online ordering process and a custom ERP to automate the entire end-to-end workflow. Our goal is to reach $100 million in revenue in the next 3-5 years."

Think3D is headquartered in Hyderabad, India (Courtesy Think3D)

Upputuri concluded, "With a dedicated team of product developers, we helped around 2,000 innovators to date translate their ideas into functional products. In many cases, we are also their manufacturing partner for their batch production and mass production needs. With NPD, 3D Scanning, 3D Designing, 3D Printing, CNC Machining, all under one roof, we could provide seamless experience to product innovators and could reduce their time to market drastically."

www.think3d.in

www.sinterize.com

HP and Legor Group collaborate on jewellery and fashion accessories

HP Inc., Palo Alto, California, USA, and Legor Group SPA, Vicenza, Italy, have announced a strategic collaboration for the development of innovative precious metal materials for HP's Metal Jet system. Legor, a leader in metals science and production of alloys, powders, and plating solutions, is the first to produce speciality precious metal materials for the jewellery and fashion accessories markets designed to work with HP's metal Binder Jetting (BJT) platform.

"Our vision for Additive Manufacturing goes beyond small series and prototyping," stated Massimo Poliero, president & CEO of Legor Group SPA. "We see a future where every modern business will have one or more of HP's state-of-the-art Binder Jetting printers in its facilities, enabled by Legor's technology, design and support to reduce the time to market for both precious and non-precious metal parts. This strategic partnership with HP is the keystone to accelerate this vision and move the industry toward more sustainable manufacturing."

"Our work with Legor aligns perfectly with HP's vision to disrupt manufacturing norms, accelerate digital manufacturing and sustainable impact for customers around the world," added Didier Deltort, president, HP Personalisation & 3D Printing. "The combination of our breakthrough Metal Jet 3D printing platform with Legor's materials expertise and customer-centric approach will disrupt the luxury jewellery and fashion industries. This is an exciting milestone as we prepare to make Metal Jet more broadly available to the market later this year."

Components built with the HP Metal Jet machine (Courtesy HP)

The collaboration will initially focus on enabling the production of functional stainless steel accessories for the jewellery and fashion markets. In parallel, the companies will implement an R&D programme to parameterise and characterise bronze and silver powders and eventually gold powders, the core material in the precious sector.

HP and Legor will work to optimise the printing and sintering parameters for these new materials and the surface finish results. The research will take place in the new Legor 3DMetalHub in Bressanvido, Italy, a centre of excellence focused on accelerating Additive Manufacturing for the luxury industry.

www.legor.com
www.hp.com

Boeing and Millennium Space Systems launch high-throughput small satellite production facility

Boeing has unveiled a new high-throughput small satellite production, integration and test facility designed for efficiency and rapid delivery timelines. Housed in what is reported to be the world's largest satellite factory, Boeing's 92,903 m^2 El Segundo, California, USA, facility, the small satellite production line will be powered by Boeing subsidiary Millennium Space Systems.

"Boeing and Millennium are bringing together Boeing's production expertise, domain knowledge, and manufacturing capacity with Millennium's agility and rapid prototyping," stated Jim Chilton, senior vice president of Boeing Space and Launch. "We're scaling and growing to fulfil our customers' vision for multi-orbit constellations with demand across markets and mission sets."

The companies are applying advanced and Additive Manufacturing techniques, including the Additive Manufacturing of entire space-qualified satellite buses, to offer faster cycle times while improving performance.

"Our customers need satellites on-orbit faster than ever," Chilton remarked. "Much like an airplane or auto production line, we're employing lean production principles and advanced manufacturing techniques to accelerate delivery and pass on cost savings to our customers."

Millennium's team will staff the small satellite factory, bringing the subsidiary's proven processes and infrastructure, in addition to environmental test capabilities tailored to small satellites. Boeing will also provide access to extensive environmental and speciality testing capabilities that have qualified some of the most iconic spacecraft, including the first vehicle to make a fully controlled soft landing on the moon and more than 300 satellites.

Digitally-defined small satellite factory incorporates model-based systems engineering, digital design engineering, and design for manufacturability within a modular footprint equipped to build small satellites for different security levels (Courtesy Boeing)

"Millennium's culture is rooted in creating innovative ways to revolutionise space," commented Jason Kim, Chief Executive Officer, Millennium Space Systems. "We're bringing that culture into our facilities, rapidly building large constellations of high-performance small satellites, taking advantage of a footprint that's larger than two professional hockey rinks."

Designed to build small satellites for different security levels on the same assembly line, the small satellite factory incorporates model-based systems engineering, digital design engineering and design for manufacturability.

"Understanding security protocols and how to build secure systems is critical to national security space, and this is an area where Millennium and Boeing excel," added Kim. "We're excited to leverage this impressive capability to support our customers' critical missions."

Initial operating capability took place in September 2021, and the small sat factory's full operational capability is expected in late 2022.

Millennium Space Systems, a Boeing Company, delivers high-performing prototype and constellation solutions across advanced national security and environmental observation missions. Founded in 2001, the company's small satellite missions support government, civil and commercial space customers' needs across orbits.

www.millennium-space.com
www.boeing.com

XJet announces new CEO and CFO as it focuses on company growth

XJet Ltd, Rehovot, Israel, has announced that Hanan Gothait, founder and CEO of the company, is stepping down from his CEO role and will take up the position of president. Yair Alcobi will take on the role of CEO and is joined in the management team by Orit Tesler Levy who takes the position of CFO.

With its ceramic Additive Manufacturing technology established and its metal AM system now commercially available, XJet anticipates a significant ramp up in business over the next few years. The company explains that with his broad business experience, Alcobi will steer the company through this demanding period with the support of Avi Cohen who joined XJet as executive chairman of the board last year..

Yair Alcobi will take on the role of CEO (Courtesy XJet)

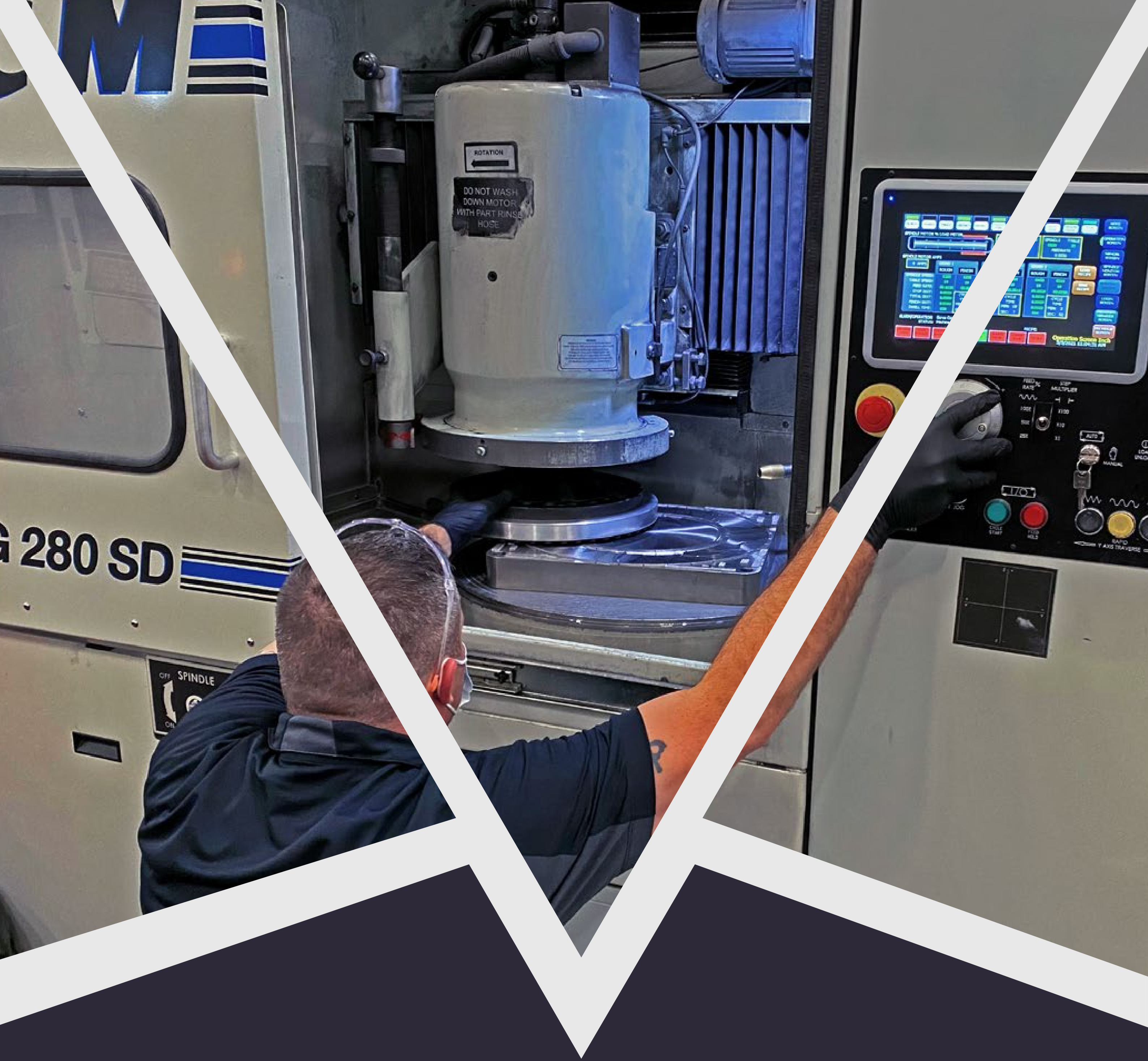
"It has been a comprehensive process to search for a new CEO for XJet," stated Cohen. "We interviewed and considered many candidates before making our decision. Yair's record in scaling businesses is enviable and exactly the right fit for taking XJet to the next level. We have exciting times ahead and I am sure that Yair has what it takes to make XJet successful. I look forward to working closely with Yair."

"I would also like to take this opportunity to thank Hanan for the many years of leadership he's dedicated to XJet, bringing it to this point," Cohen continued. "His vision for the technology has been palpable from day one, building an exceptional team of experts and getting the company to its current position took a great deal of hard work."

Alcobi commented, "As someone who has worked closely with many top-tier, global manufacturers, I fully understand the potential of Additive Manufacturing, and especially in materials like metal and ceramic. XJet technology is remarkable and I'm extremely motivated to expand the business and ensure XJet becomes a clear leader in its market."

Alcobi will also be supported by Tesler Levy, who comes to XJet in the CFO position with experience from Applied Materials in Israel and Silicon Systems Segment in California, USA. Levy also has industry experience following a previous role as VP Finance FP&A Business Partnering at Stratasys.

www.xjet3d.com

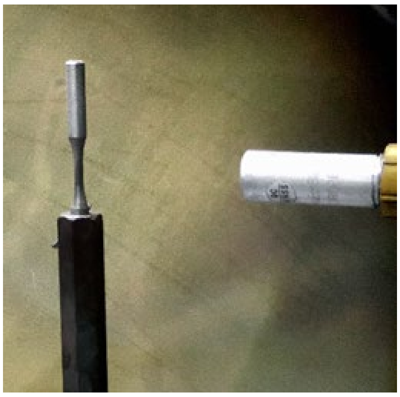

ROTATION
DO NOT WASH DOWN MOTOR WITH PART RINSE HOSE
G 280 SD
SPINDLE

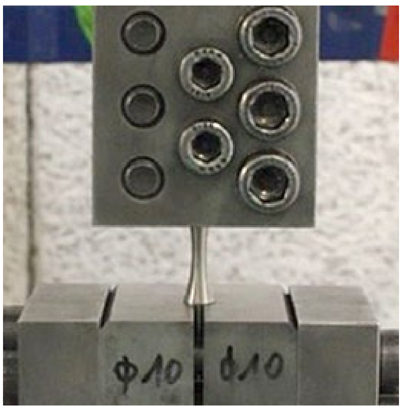
Effects of shot peening on the fatigue strength of AM parts

In a recent study, FerroECOBlast® Europe, based in Dolenjske Toplice, Slovenia, in collaboration with the Jožef Stefan Institute, Ljubljana, Slovenia, and Joanneum Research Centre, Graz, Austria, looked at the effect of shot peening on metal additivley manufactured parts.

Cold micro-forging, better known as shot peening, is a well-known surface treatment process, commonly used on machine parts in demanding industries such as aerospace and automotive, to improve the mechanical properties of machine parts and increases their lifetime.

The question arises as to what extent the porosity and resulting micro-cracks affect the mechanical characteristics of the additively manufactured part and what can be done to improve it. Research is being conducted into various directions: annealing and the consequential change of the metal microstructure, compression/rolling and, probably the most appropriate of all, a modern shot peening process.





Shot peening of the samples (top), was followed by fatigue strength testing (Courtesy FerroECOBlast)

The team chose a common test piece design, often used to perform fatigue strength tests in laboratories, for this project. The test pieces were manufactured using Laser Beam Powder Bed Fusion (PBF-LB) from three frequently used metal alloys:

- Aluminium alloy AlSi10Mg
- Maraging steel MS1 (DIN 1.2709)
- Titanium alloy Ti6Al4V

The test pieces were first cleaned of residual dust and oxides before an annealing or ageing heat treatment process was undertaken. To ensure dimensional accuracy of the test pieces, mechanical post-processing, namely grinding, was required.

The final process before testing was shot peening. Three shot peening methods with different types of shot and different intensities were selected for each tested material: Steel shot ASH110, ceramic shot Z150 and a combination of both ASH110 and Z150 for double peening.

Testing

Tests for fatigue strength were first performed on test pieces that had not been treated with shot peening. The goal was to determine the load required to reach the breaking point of the test piece in 10^5 cycles and at a frequency of approximately 70 Hz. After determining the parameters, the team tested five further reference pieces not treated with shot peening, and five test pieces of each material and each type of shoot peening, resulting in a total of sixty tests.

Results

Shot peening was shown to have a positive effect on the lasting dynamic strength of the tested pieces. A reference piece, not treated with shot peening, reached breaking point in an average of 10^5 cycles, while pieces treated with shot peening survived an average of 5×10^5, and up to 2×10^6 cycles. Tests show that the number of cycles required for failure depended on the shot peening parameters, as well as on the base material of the tested piece. Metallurgical analysis was used to check the effect of shot peening on the base material of the tested samples, the result of which is best reflected in the microhardness. Measurements were performed on the same kind of samples tested for sustained dynamic strength.

The results of the research confirmed a significant positive effect of shot peening on the fatigue strength of parts produced by AM, regardless of the base material. The greatest effect was detected on the titanium alloy Ti6Al4V, where the lifetime was extended up to twenty times. It could have been even higher, but testing was stopped at 2×10^6 cycles. Samples made of MS1 steel showed a lifetime extension of approximately fifteen times, and samples made of AlSi10Mg, where the improvement was up to around 8-10X.

The results show the best outcome is obtained with shot peening using steel shot S110, followed by double peening with steel and ceramic shot S110 + Z150. Results for pieces made of AlSi10Mg presented the largest deviation, followed by the steel samples, while with Ti6Al4V all tested methods of shot peening produced very good results. The effect of shot peening on the microhardness of the material was not shown to be significant. Only a slight increase of microhardness was detected on the surface and up to 200-300 μm in depth. The greatest effect was detected with double peening with S110 + Z150, which displayed an increase of the modulus of elasticity.

It was concluded that shot peening significantly improves the mechanical properties and fatigue strength of products produced with PBF-LB processes, extending part lifetime. This gives manufacturers the opportunity to further optimise part design, reducing weight and enabling faster and more cost-effective production process and significant energy savings during operation.

www.ferroecoblast.com

Ajax supplies Liberty Powder Metals with twenty hoppers

Solids handling solutions provider Ajax Equipment, Bolton, England, UK, has supplied Liberty Powder Metals, part of GFG Alliance's Liberty Steel Group, with fifteen storage hoppers, five blending hoppers and three mass flow screw feeders for metal powder handling.

The geometry of the fifteen stainless steel intermediate bulk containers (IBCs) was designed for efficient discharge and repose fill of powder, while the five larger hopper's steep double cone shape is said to allow the blending of metal powders. The design of both hoppers includes supports enabling handling with a forklift, efficient storage and straight-forward loading onto the screw feeders.

Ajax's cantilevered screws use a variable pitch to help ensure mass flow from the hoppers. The feeders' casing is mounted on ferrules allowing access to the full length of the screw for easy cleaning.

"From the initial phone call and subsequent first meeting, Ajax quickly understood what we wanted to achieve with our powder handling system and provided initial proposals to a fully working powder handling system that we have integrated into our processing equipment," stated Dan Frith, Manufacturing & Engineering Manager, Liberty Powder Metals. "When we had a specification issue on one of our transfer stations, Ajax was quickly able to calculate the new requirement and an alternative gearbox was sourced. Ajax's hoppers and screw feeders perform very well."

Ajax has supplied twenty hoppers and three mass flow screw feeders to Liberty Powder Metals (Courtesy Ajax Equipment)

Eddie McGee, Managing Director, Ajax Equipment, added, "This is one of the largest and most unusual hopper orders Ajax has received. Typically, customers require a substantial hopper that will be static for the length of its service life. These compact, portable hoppers can easily be moved between storage, filling and loading the screw feeders also supplied."

www.libertysteelgroup.com

www.ajax.co.uk

Angst+Pfister releases long-life digital oxygen sensor for AM systems

Angst+Pfister Sensors and Power, Zürich, Switzerland, has developed a new type of oxygen sensor for the metal, ceramic and polymer Additive Manufacturing processes. The new long-life digital oxygen sensors and sensor modules for AM offer ppm signal resolution and no cross influence from most other gases.

A complex combination of long exposure times at low oxygen concentration, together with process generated gases that influence the response of the oxygen sensor, can cause problems, explains Angst+Pfister. While the build chambers are gas tight in order to reduce argon or nitrogen, consumption, this means that certain process-generated gases cannot escape the build chamber. Humidity control – be it for the powder bed itself, powder canisters and/or the chamber walls – is another parameter influencing the performance of certain types of oxygen sensors.

Angst+Pfister Sensors and Power have released a new oxygen sensor for metal, ceramic and polymer Additive Manufacturing (Courtesy Angst+Pfister)

Angst+Pfister's new sensor is a weak acidic electrolyte electrochemical sensor, which enables a long operational lifetime and less cross influence from other gases such as, but not limited to, hydrogen and other reducing gases. Two versions of the sensor are available, one is a 0-25% O_2 type with a signal resolution < +/-30 ppm O_2 and the other sensor is a 0-10,000 ppm O_2 sensor with a signal resolution of +/- 1 ppm O_2. The sensors have a M16 x 1 mm thread for process integration.

The combination of the 0-25% O_2 PO2ES-103PD oxygen sensor and the 0-10,000 ppm O_2 P-41AGWD oxygen sensor makes process and safety control in various Additive Manufacturing processes possible.

The signal output is controlled by specially designed electronics that are protected in an enclosure with EMC and IP65 protection. The output signal from the conditioning electronics is RS485 Modbus (optional 4-20 mA), enabling easy integration into a central PLC unit. The cable length between the electronics and the PLC unit can be chosen arbitrarily long, the cable length between the sensor and the conditioning electronics is 50 cm (maximum 100 cm).

www.angst-pfister.com

MPIF releases 2022 edition of *Standard Test Methods*

The Metal Powder Industries Federation (MPIF) reports that the 2022 Edition of *Standard Test Methods for Metal Powders and Powder Metallurgy Products* is now available to purchase.

This new volume contains forty-eight standards covering terminology and recommended methods of testing for metal powders, Metal Injection Moulding parts, metallic filters, Powder Metallurgy equipment and metal Additive Manufacturing. The most current versions of these standards, which are used in the production of both metal powder and Powder Metallurgy products, are required by Quality Assurance programmes in order to maintain full compliance.

The 2022 edition includes the following three new standards:

- MPIF Standard 73: Preparing and evaluating tension test specimens of materials produced from metal powders by Binder Jetting (BJT), Material Jetting (MJT), Material Extrusion (MEX) or similar metal Additive Manufacturing technologies
- MPIF Standard 74: Preparing and evaluating tension test specimens of materials produced from metal powders by Laser Beam Powder Bed Fusion (PBF-LB) and Electron Beam (PBF-EB), Directed Energy Deposition (DED), and Cold Spray or similar hybrid metal Additive Manufacturing technologies
- MPIF Standard 75: Determination of flow rate of metal powders using the Carney Flowmeter Funnel

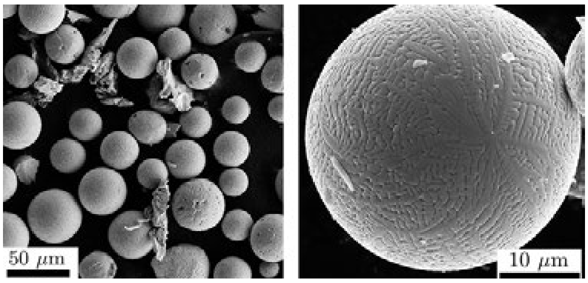
Additionally, an updated version of *A Collection of Powder Characterization Standards for Metal Additive Manufacturing* is now available which contains twelve existing MPIF Standard Test Methods that can be applied for the characterisation of powders used in metal AM processes.

www.mpif.org

Researchers develop abrasion-based process for producing metal powders

A team of researchers at the Indian Institute of Science (IISc), led by Koushik Viswanathan, Assistant Professor at the Department of Mechanical Engineering, have reportedly identified an alternative technique to produce metal powders using an abrasion-based process. Metal powders are predominantly produced using atomisation. However, despite its widespread use, explains the IISc researchers, atomisation returns poor yield, is relatively expensive and limited in the types of materials. The alternative technique developed by the researchers is said to side-step these problems.

In the metal grinding industry, the material removed – known as swarf – is often discarded as a waste product. It is commonly stringy in shape, like metal chips, but can also include perfectly spherical particles. Scientists have long theorised that these particles go through a melting process, which results in the spherical shape. But this raises some interesting questions, such as whether the heat from the grinding causes the melting, or if there is actually any melting at all?



SEM of metal powders produced using the abrasion-based process, showing distribution of powder sizes (left). The typical single powder particle (right) is approximately 30-50 μm in diameter (Courtesy Laboratory for Advanced Manufacturing & Finishing Processes (LAMFiP), IISc)

Viswanathan's team has shown that these powder metal particles do indeed form as a result of melting due to high heat from oxidation, in an exothermic reaction at the surface layer. The team refined this process to produce large quantities of spherical powders, which are further processed to be used as stock material in Additive Manufacturing. The study is said to illustrate that these powder particles perform just as well as commercial gas atomised powders, when used in metal Additive Manufacturing.

Priti Ranjan Panda, a PhD student at IISc's Centre for Product Design and Manufacturing and one of the authors of the study, commented, "We have an alternative, more economical and inherently scalable route for making metal powders, and the quality of the final powders appears to be very competitive when compared with conventional gas atomised powders."

Regarding the applications of their findings, Viswanathan added, "There has been significant recent interest in adopting metal AM because, by nature, it enables significant customisation and allows design freedom. However, the large cost of stock metal powders has been the stumbling block. We hope that our work will open new doors to making cheaper and more accessible metal powders."

Harish Singh Dhami, a PhD student at the Department of Mechanical Engineering and co-author of this study, noted, "Reducing the cost of the AM process (via economical powders) can widen the range of materials in situations such as manufacturing of biomedical implants, which could become cheaper and more accessible."

The researchers reported that making metal powder using abrasion also has potential in other high-performance applications such as in aircraft engines, where a high degree of specification is required.

The full paper, titled 'Production of powders for metal Additive Manufacturing applications using surface grinding,' by Harish Singh Dhami, Priti Ranjan Panda, and Koushik Viswanathan, was published in *Manufacturing Letters*, Volume 32, 2022, ISSN 2213-8463

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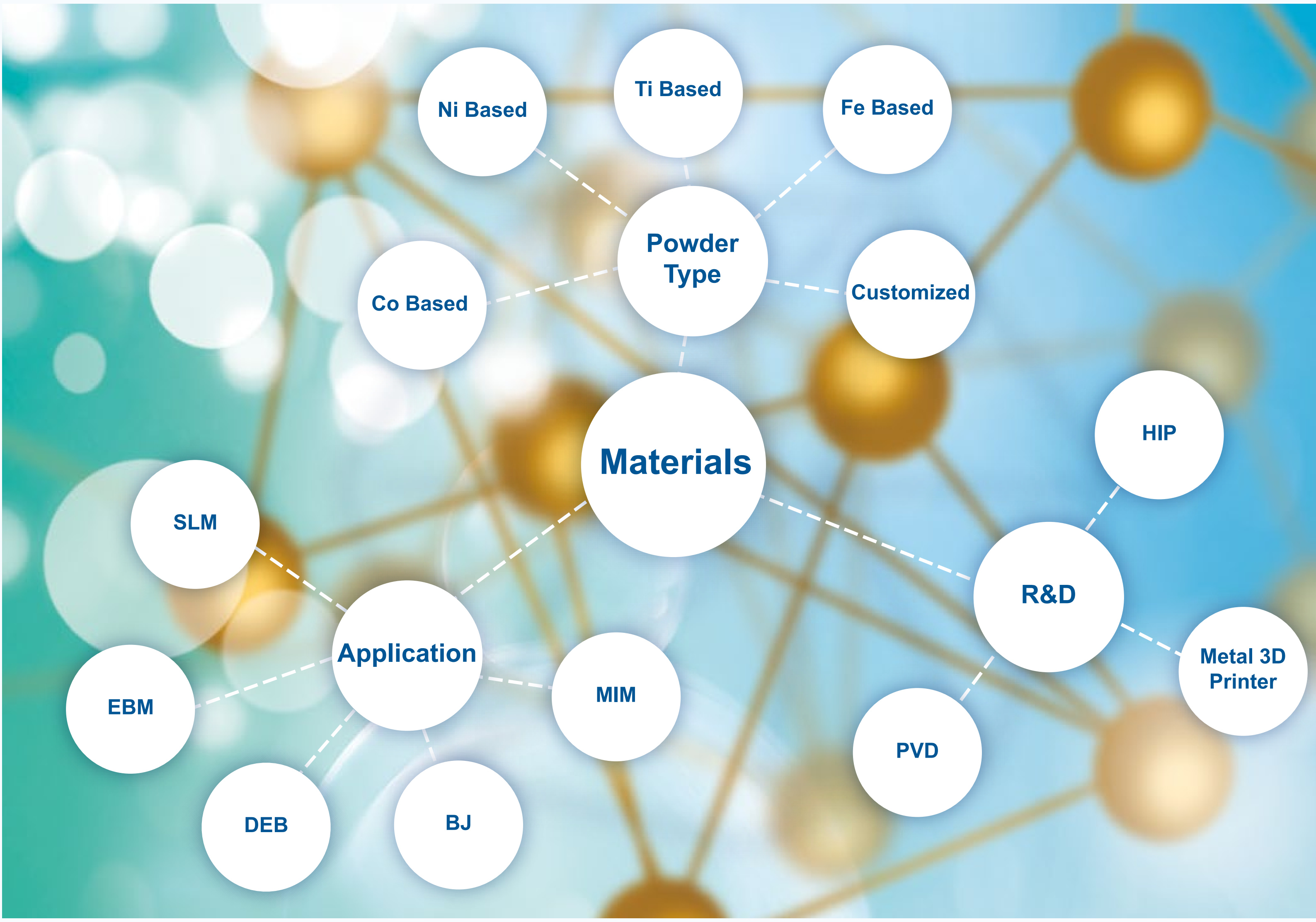

FOR MORE INFORMATION, CONTACT

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Restor3d raises $23 million to expand bespoke additively manufactured musculoskeletal solutions

Restor3d, Durham, North Carolina, USA, has raised $23 million in an effort to expand the delivery of additively manufactured personalised surgical solutions across multiple musculoskeletal specialities, and to develop machine learning software to assist with patient-specific implant design.

Ken Gall PhD, co-founder of Restor3d and a Professor at Duke University, has stated that the company will be deploying the capital on the following:

- New product introductions and enhanced bespoke additively manufactured surgical solutions in upper/lower extremity, spine and trauma
- Ongoing development of machine learning enabled software for surgical planning and implant design
- Fundamental research, preclinical, and clinical studies
- Expansion of the commercial team to support market traction

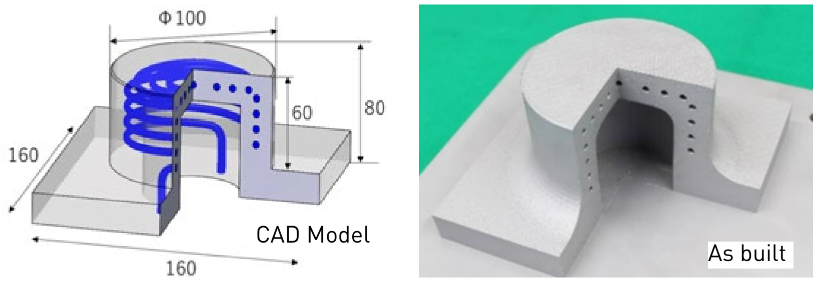
In early 2023, Restor3d intends to move into a new facility in Research Triangle Park that will expand capabilities for patient-specific digital design, in-house manufacturing of implants and instruments, as well as surgeon training and education labs.

Restor3d merged with Kinos Medical in 2021, a move which is said to have helped accelerate the company's expansion into the high-growth extremity arthroplasty markets in the US. Restor3d has multiple FDA product clearances that span lower extremity, upper extremity, spine, and trauma and this new funding combined with the company's additively manufactured implant & disposable instrument model are expected to enable simultaneous expansion across diverse markets.

www.restor3d.com

Restor3d use Additive Manufacturing to produce medical solutions such as the TIDAL subtalar wedge system shown here (Courtesy Restor3d)

Daido Steel introduces hot die steel-based powders for AM



CAD model of an additively manufactured mould using DAPTM-AM HTC40. Built with GE Additive's Concept Laser M2 machine (Courtesy Daido Steel)

Speciality steel manufacturer Daido Steel, Nagayo, Japan, has released hot die steel-based powders for Additive Manufacturing. DAP™-AM HTC™ (Daido Alloy Powder for AM with High Thermal Conductivity) is a cobalt-free powder suitable for Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing, based on H13 steel.

In the fields of aluminium die casting and plastic injection moulding, moulds have been additively manufactured using PBF-LB technology in order to allow more design freedom in cooling channels. Since PBF-LB uses lasers to melt and solidify metal powder in layers, thermal stresses can form in proportion to the size of the moulds.

Die steels like H13, with high hardness, are said to crack relatively easily during the Additive Manufacturing process. Another common option, maraging steel, is less likely to crack during moulding, but the thermal conductivity is lower than H13, meaning cracking may occur in the cooling channels. Another downside of maraging steel is that it contains cobalt, a substance that is regulated in Japan.

Daido Steel created DAP-AM HTC in an effort to mediate these issues. The powders are said to have conductivity 1.5 x greater than that of H13 and two times higher than maraging steel. With these attributes, DAP-AM HTC is said to contribute to shorter cycle times (due to lower mould temperatures) and improved mould lifespan (fewer heat cracks due to lessened thermal stress).

Several die-casting companies in Japan have evaluated moulds made from DAP-AM HTC and are said to have obtained favourable results. Daido Steel expects to continue the development of metal powders suitable for Additive Manufacturing machines and eventually expand the product lineup of the DAP-AM HTC series.

www.daido.co.jp

Sandvik offers additively manufactured cemented carbide components

Sandvik AB, Stockholm, Sweden, has expanded its Additive Manufacturing offering to include the production of additively manufactured cemented carbide parts with superior wear-resistant properties.

Cemented carbides have a unique character as a result of their composite structure – a wear-resistant phase bonded together by a ductile binder metal – and are widely used across multiple industries such as metal cutting, agriculture, food, and oil and gas. Due to their inherent hardness, cemented carbides can be challenging to machine, not least in complex geometries. By leveraging its proprietary process, Sandvik states that it can now offer additively manufactured cemented carbide on a commercial scale with improved design freedom, decreased material waste, and fewer replacements.

In its 'Plan it, Print it, Perfect it' approach to Additive Manufacturing, Sandvik states that the build is just one of the seven steps to master in order to succeed with the industrialisation of Additive Manufacturing – and that obtaining the most optimal material, tailor-made for a customer's AM process and end component, is the first - and perhaps most important - step.

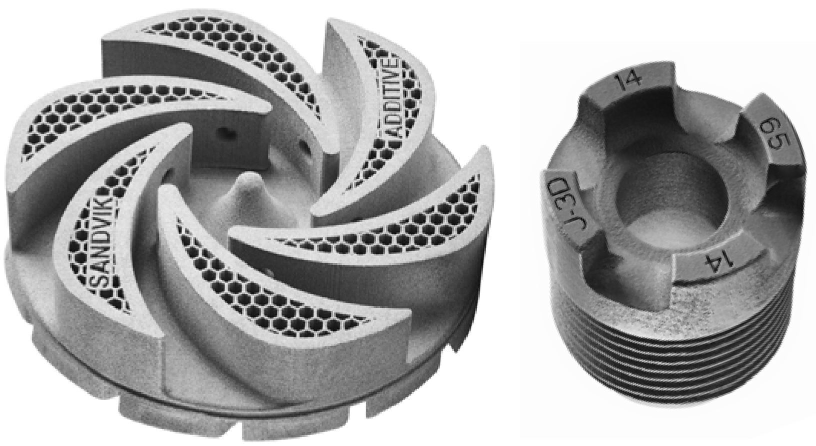
Anders Ohlsson, Lead Product Manager at Sandvik Additive Manufacturing, commented, "The most critical component in our process is working with powders that have the just-right properties. Above all, high density crucially impacts the quality achievable in terms of material properties and geometry. Sandvik has developed both a powder and a process that are unique. My view is that with commercial powders, you can make things that look cool – but don't really work. Our powders are optimised to print components that look great, work well – and are fit for use in actual applications, demanding environments, and serial production. It's also well worth mentioning the ability to 3D print cemented carbide speeds up our time-to-market rather dramatically. Prototyping used to take six to twelve months – and now our lead time to date is a matter of weeks."

"Cemented carbide is one of the very hardest, if not the hardest material available in 3D printed shape as of today," continued Ohlsson. "When implementing Additive Manufacturing into your business, you basically eliminate all previous design restrictions – enabling you to focus on designing components based on operational needs and requirements, without having to adapt to a specific shape or form. One example is this wire drawing nib from a recent R&D project in our workshop. The closed loop spiral coolant channels enable efficient cooling of the nib, while the wire remains dry. This would have been impossible to achieve without Additive Manufacturing."

A key differentiator compared to other hard materials, explains Sandvik, is the fact that these alloys are often brittle to some extent – while cemented carbide, with its matrix structure consisting mainly of cobalt and tungsten carbide, is uniquely tough. Thanks to the extreme durability of the material, the additively manufactured components are well suited for most industries looking to optimise production efficiency – including those operating in challenging environments.

Mikael Schuisky, VP and Head of Business Unit Additive Manufacturing at Sandvik, added, "The main enabler behind us continuously building on our additive offering is the fact that at Sandvik, innovation never stops. Thanks to our long-standing experience in materials technology paired with our expertise along the additive value chain, made even stronger by our partnership with the BEAMIT Group, we can innovate at a speed few others can. This makes us uniquely positioned to drive the shift toward the industrialisation of 3D printing, and prove sustainable manufacturing isn't just possible – it's already happening. 3D printing in cemented carbide is a natural next step for us having perfected these materials for decades, and we are very pleased to offer additively manufactured components that can revolutionise the performance throughout our customers' businesses."

www.additive.sandvik



Additively manufactured cemented carbide components produced at Sandvik (Courtesy Sandvik)

Höganäs adds titanium powders for AM

Sweden's Höganäs AB reports that it has added titanium to its range of Additive Manufacturing powders.

Titanium has the highest strength-to-weight ratio of all known metals, explains Höganäs, which makes it ideal for a variety of applications, from car components to lightweight aerospace parts. It is also highly resistant to corrosion, and has high biocompatibility properties, making it well suited to customised medical implants.

Höganäs' forAM® titanium-based alloys for Additive Manufacturing are designed for optimal performance and material efficiency. The grades available include Ti6Al4V (available in grade 5 and grade 23) and CP-Ti (commercially pure titanium), and are suitable for a range of components covering many industries, and offer good material properties.

www.hoganas.com

Fraunhofer IFAM Dresden names Prof Thomas Weissgärber as its new director

Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), Dresden, Germany, has appointed Prof Dr-Ing Thomas Weissgärber as its new director. Since April 1, Prof Weissgärber also holds the professorship of Powder Metallurgy at the Institute of Materials Science in the Faculty of Mechanical Engineering at Technische Universität Dresden.

Prof Weissgärber has been associated with the Dresden site of Fraunhofer IFAM for many years. During his career as a group and department head, as well as deputy and most recently interim head of the institute, he has conducted research in various areas of Powder Metallurgy. Within his work at the Innovation Center Additive Manufacturing (ICAM), he has established a knowledge base in the field of powder-based AM.

"Fraunhofer IFAM is one of Europe's most important independent research institutes in the fields of adhesive technology, surfaces, shaping and functional materials. Its products and technologies primarily address industries of particular importance for the future viability of the economy, including energy technology, mobility and life sciences," stated Prof Reimund Neugebauer, President of the Fraunhofer-Gesellschaft. "I am extremely pleased that Prof Thomas Weissgärber is now at the helm. He is a long-standing leader who has made a significant contribution to developing Fraunhofer IFAM into one of the leading applied research institutes in the field of powder metallurgical technologies and materials."

www.ifam.fraunhofer.de

Desktop Metal offers sterling silver for jewellery and luxury goods sectors

Desktop Metal, headquartered in Boston, Massachusetts, USA, has qualified 925 sterling silver for use on its Production System, including the P-1 and P-50. The addition of the popular precious metal will enable manufacturers of jewellery and luxury goods to directly additively manufacture high-quality jewellery, watches, and decorative hardware.

The company also announced that it is fast-tracking the development of additional precious metal alloys, including 18K yellow gold, with active research and development also underway on rose gold.

"The qualification of precious metals for direct 3D printing on high-speed Binder Jetting systems is a major milestone for the jewellery and luxury goods industry," stated Ric Fulop, founder and CEO of Desktop Metal. "All the design freedom and customisation of 3D printing can now be delivered directly at high volumes without all of the labour associated with traditional manufacturing processes. What's more, this new direct 3D printing innovation builds on the established legacy of our ETEC brand, which has been a leader in 3D printers for lost-wax casting models for more than a decade — making us the unparalleled leader in comprehensive Additive Manufacturing solutions for the jewellery and luxury goods market."

To advance the technology and materials needed to bring Additive Manufacturing's quality, productivity and economics to the demanding luxury goods and jewellery market, Desktop Metal is partnering with Formula 3D Corporation (for the US market) and Neoshapes (international). Both of these collaborations aim to enable the luxury goods and jewellery markets to adopt metal Binder Jetting processes to produce end-use parts in precious metals, steels and more.

Formula 3D Corporation, Monrovia, California, USA, offers designers and manufacturers a complete end-to-end solution for additively manufacturing precious metals. A video was released with Formula 3D founder Christian Tse showcasing the use of Desktop Metal's P-1 to create jewellery.

"Desktop Metal's Production System adds extraordinary value to our existing jewellery manufacturing processes, increasing efficiency of production, getting new designs to market faster, and offering our customers greater versatility and multiple styling options. We can actually print in precious metals in two hours what we do in two days with casting," added Christian Tse. "In addition, creating jewellery with Binder Jetting is allowing us to consider new options to circumvent some of the supply chain challenges facing the fine jewellery industry. We can bypass shipping delays and mounting costs, as well as avoid duties, by printing the precious silver directly, as opposed to shipping the physical metal."

Neoshapes, based in Geneva, Switzerland, founded by experienced executives in the luxury goods industry, is said to offer a unique end-to-end approach, from the production and supply of powder, to the Additive Manufacturing and post-processing of precious metal components, as well as consultancy services to enable industry players to transition production processes to Binder Jetting technology.

"Binder Jetting opens up new perspectives for the luxury industry, even more now with the qualification of precious metal alloys, giving further leverage to develop and produce creative products from a single file, leaping forward into the digital supply chain," stated Stéphane Vigié, Neoshapes co-founder. "The time to market for new creative products is also reduced considerably, allowing brands to better meet demand while maintaining minimal inventories."

www.desktopmetal.com

Desktop Metal has qualified 925 sterling silver to further its position in the jewellery and luxury goods market (Courtesy Desktop Metal)

AM4EM project researches additively manufactured next-level electrical machines

Additive Manufacturing for Electrical Machines (AM4EM) is an ongoing Belgian research project by VITO, KU Leuven and Ghent University, on the use of Additive Manufacturing to create more energy-efficient electrical motors (stator/rotor cores). The main challenge in creating the perfect motor is combining conductive and insulating materials into complex multi-material geometries. As multi-material Additive Manufacturing is still in its infancy, however, all technologies and designs must be thoroughly evaluated.

VITO is an independent research organisation working in the area of green technology and sustainable development. The organisation has been working with Additive Manufacturing since 2006 with a focus on additively manufacturing viscous powder-loaded paste. This paste-based Additive Manufacturing is one of the technologies used in the AM4EM project.

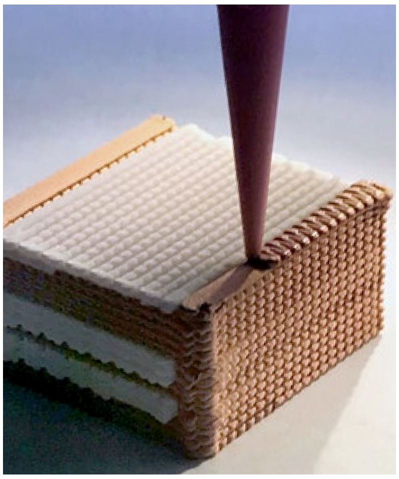
Some important steps forward are said to have been realised. Micro-extrusion Additive Manufacturing of copper paste has led to parts without build defects, a relative density of 95-99% and an electrical conductivity of 90-102% IACS.

Positive results have also been reported with the Additive Manufacturing of Fe-Si steel, needed for the cores of the motors. The next step is to additively manufacture multi-material combinations for the magnetic core stacks, whereby a layer of ceramic insulator alternates with Fe-Si steel layers.

Although the results look satisfying at first sight, there are still challenges related to, for example, uniform shrinkage of the material and warping of the layers.

KU Leuven is known in the Additive Manufacturing industry for having been at the birth of Materialise and Layerwise (now 3D Systems). In this project, the organisation is focusing on Fused Filament Fabrication (FFF) technology for metals and ceramics. More specifically, it is additively manufacturing polymer filaments with a high content of metal or ceramic powder. The polymer in the filament is only needed to make the material additively manufacturable and is removed afterwards. Here, too, the challenge is only partially related to the Additive Manufacturing process itself; debinding and sintering require careful analysis as well to determine the optimal parameters such as temperatures, solvents, extrusion width or speeds, etc.

KU Leuven's efforts, too, are said to have resulted in relative density results above 95% for copper and 97.3% for ceramic, including in combinations of both materials in one build.



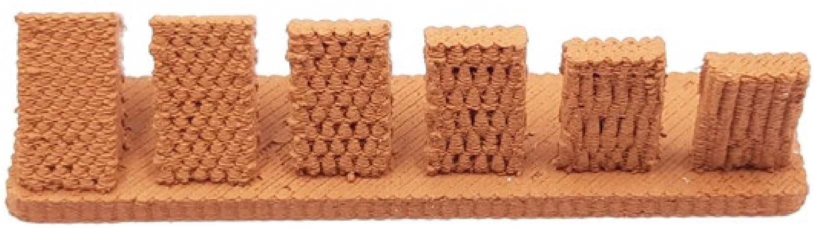
The AM4EM project is researching the use of multi-material Additive Manufacturing to create greener electrical motors (Courtesy VITO)

Ghent University has experience in multi-physics models for electrical machines and was a part of the project to better understand how the design of crucial motor parts impacts how the electrical currents interact with the magnetic field to create torque. As a consequence, the design details strongly determine how efficient your machine will ultimately be.

These combined efforts on different Additive Manufacturing techniques, design and material improvements, are hoped to deliver innovative MM-AM processes applicable to sensors, radars, actuators, electrical machines, etc. Ultimately, AM4EM targets an increase in energy efficiency by 5% point (compared to small induction machines) and an increase in power density by 40%.

www.vito.be
www.kuleuven.be
www.ugent.be

A copper test sample produced at VITO (Courtesy VITO)



Fused Filament Fabrication is one of the Additive Manufacturing technologies used in the AM4EM project (Courtesy KU Leuven)

AddUp joins RISE's Additive Manufacturing Application Center

AddUp, based in Cébazat, France, and the Research Institutes of Sweden (RISE), headquartered in Gothenburg, have signed a partnership that will see AddUp join RISE's new Additive Manufacturing Center which aims to accelerate the use of Additive Manufacturing in Sweden. The new centre will create a platform for industrial partners to collaborate with academia and institutes in order to drive AM adoption. The industrial partners will have access to the latest research carried out by the partners, the ability to test and demonstrate different Additive Manufacturing technologies, as well as access to expertise and competence along the supply chain.

AddUp's Modulo 400 DED machine will be installed at the RISE AM Application Center (Courtesy AddUp)

RISE states that it is important that Sweden continues to invest in AM to strengthen its position in the growing market. As one of the fifteen partners collaborating with the centre, AddUp aims to address various aspects along the value chain, from design and product/material development to manufacturing and post processing including surface and heat treatment and quality control. The company will also work with the partners to develop an alternative, cost-effective production method for the Swedish industry to be implemented and industrialised. It is anticipated that this collaboration will help digitalise manufacturing and optimise the supply chain.

Under the new partnership, the AddUp Modulo 400 Directed Energy Deposition (DED) machine will be installed at the RISE Additive Manufacturing Application Center. This machine is particularly suited to the needs of industrial production and features a build volume of 650 x 400 x 400 mm. It is equipped with two nozzles of different sizes and power: a 24Vx nozzle to produce large parts with speed, and a 10Vx nozzle to produce parts with precision. These nozzles can be changed without interrupting production.

The Modulo 400 is also equipped with an enclosure inerting system which allows it to work with reactive powders. This feature is said to make it one of the few DED machines on the market capable of processing reactive or non-reactive powder. Additionally, process control systems allow for continuous observation of the melt pool and provide early detection of possible drifts during production.

www.ri.se/sv
www.addupsolutions.com

Formnext + PM South China scheduled for September

The second Formnext + PM South China, jointly organised by Guangzhou Guangya Messe Frankfurt Co Ltd and Uniris Exhibition Shanghai Co Ltd, is scheduled to take place from September 14 – 16, 2022, at the Shenzhen World Exhibition and Convention Center. The event will cover advanced technology and equipment categories including materials, Additive Manufacturing, Powder Metallurgy (PM), advanced ceramics, design, software and processing technologies.

In addition to the confirmed exhibitors from the AM and PM sectors, the organisers of Formnext + PM South China will include a 'Start-up Area' at the event. This area is intended to support start-ups who have been in the market for fewer than five years, offering newly established firms the chance to get in touch with the broader community while serving as an effective marketing tool to grow their networks and promote their products and technologies.

A series of concurrent events will be held during the fair, including:

- The 2nd New Energy Vehicle Additive Manufacturing Application Industry Summit
- The 4th South China Injection Moulding and Additive Manufacturing Technology and Application Summit
- The 2nd Discover 3D Printing – ACAM
- The 2nd Shenzhen International Ceramic 3D Printing Application Summit
- The 2nd 3D Printing Application Conference – Powered by UNLANDS
- Advanced Ceramics Summit
- Formnext + PM South China Product Launch Conference

Formnext + PM South China forms part of a series of international events including Asiamold and Formnext. Asiamold will be held from March 1 – 3, 2023. The next edition of Formnext will be held from November 15 –18, 2022, in Frankfurt am Main, Germany.

More information about Formnext + PM South China is available via the event website.

www.formnext-pm.com

Formnext + PM South China will take place at the Shenzhen World Exhibition and Convention Center (Courtesy Messe Frankfurt)

Oqton and Eplus3D enter partnership to streamline dental workflows

Software provider Oqton, San Francisco, California, USA, and Eplus3D, Hangzhou, China, have entered into a strategic partnership in an effort to enable dental laboratories to increase productivity and traceability by making Oqton's AI-powered Manufacturing OS platform available to users of Eplus3D's metal Additive Manufacturing machines.

"We're excited to officially recognise Eplus3D as a trusted partner amongst a host of forward-thinking industry leaders," stated Kris Wouters, General Manager – Healthcare, Oqton. "We are impressed with their commercial success based on the metal 3D printing technology they've developed, and its ability to help dental labs produce patient-specific devices such as crowns, bridges, and RPD frames. As we move forward, we will continue to deepen our technical collaboration, further helping customers achieve desired results with improved productivity while maintaining regulatory compliance."

Oqton's AI-powered Manufacturing OS platform will enable users of Eplus3D's metal AM machines to increase productivity (Courtesy Oqton)

Mary Li, Head of the Overseas Division, Eplus3D, added, "Our collaboration with Oqton first began in 2018, as we set out to fully integrate their innovative Manufacturing OS into our Eplus3D printers. Since that time, we've become increasingly acquainted with their expertise and technology, and are impressed by the easy-to-use, smart algorithms they've created. We're looking forward to our continued collaboration to simplify production workflows for our customers – helping them unlock the full potential of AM to accelerate industrialisation."

Additive Manufacturing solutions provider MT 3D, Kuurne, Belgium, has been using Oqton's software with its Additive Manufacturing machines from Eplus3D and reported positive results, noting an improved workflow and nearly automated data preparation of dental parts.

www.oqton.com
www.eplus3d.com

World PM2022 Congress & Exhibition to showcase the global Powder Metallurgy industry

The technical programme for the World PM2022 Congress & Exhibition, organised and sponsored by the European Powder Metallurgy Association (EPMA), has been published and is now available to view online. Taking place in Lyon, France, October 9–13, 2022, the international event will feature a comprehensive programme of oral and poster presentations, as well as an exhibition showcasing the latest developments from the global Powder Metallurgy supply chain.

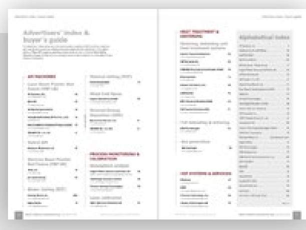
Held in Europe once every six years, the World Congress is an essential destination for the international PM community to gather and discover the latest technology innovations, as well as meet suppliers, producers and end-users.

The all-topic technical programme includes sessions covering Press & Sinter Powder Metallurgy, Metal Injection Moulding, Hot Isostatic Pressing (HIP) and metal Additive Manufacturing. It also focuses on powder production technologies, materials, post processing and end-use applications.

A number of awards will also be presented during the event, including the Powder Metallurgy Component Awards and Distinguished Service Awards, along with technical paper awards.

Early registration discount is available until September 8.

www.worldpm2022.com

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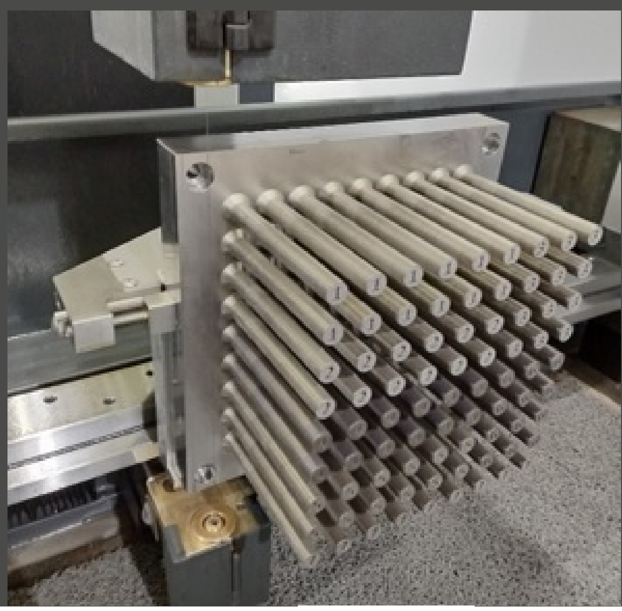

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Information@edmperformance.com

See the video on youtube

WWW.EDMPERFORMANCE.COM

Launcher awarded $1.7M by U.S. Space Force to develop additively manufactured rocket engine

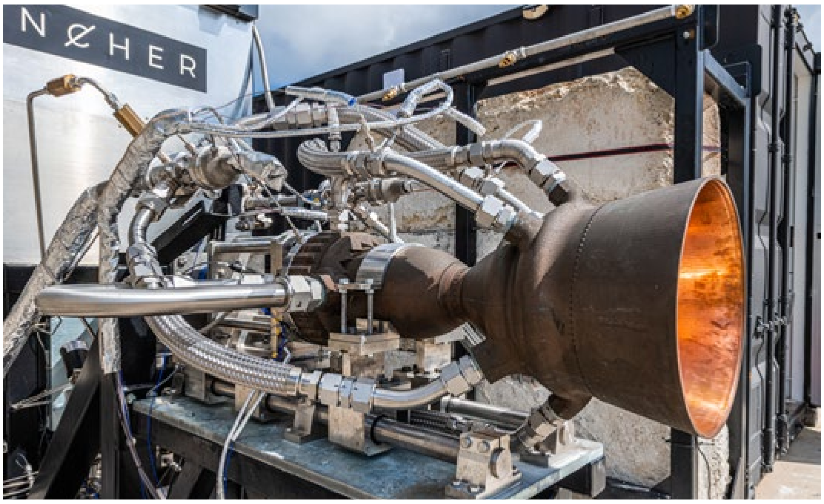
Launcher, headquartered in Hawthorne, California, USA, reports that it has been awarded $1.7 million by the U.S. Space Force to further develop the company's additively manufactured E-2 liquid rocket engine, which was successfully tested at the NASA Stennis Space Center earlier this year.

The E-2 is a closed-cycle, additively manufactured, high-performance liquid rocket engine in development for the Launcher Light launch vehicle which has an inaugural launch scheduled for 2024. A single E-2 engine is said to be able to boost Launcher Light to low Earth orbit with 150 kg of payload.

E-2's chamber is liquid oxygen cooled and additively manufactured in copper alloy in one piece. It uses standard industrial copper chromium zirconium alloy (CuCrZr), reducing costs and supply chain constraints compared to aerospace-grade copper alloy optimised for rocket engines. The U.S. Space Force's support to advance E-2 development is expected to help meet the goals of the Department of Defense (DoD) by maximising performance and payload capacity for small launch vehicles, accelerating vehicle production, and removing both geographic and supply chain constraints for volume production.

The US Space Force stated in the US Space Force Memorandum, June 2021, "Launcher's high performance engine design materially increases a rocket's payload capacity by consuming less propellant while generating the same thrust. As a result, Launcher's E-2 liquid rocket engine also has the potential to significantly reduce the price to deliver small satellites to orbit on dedicated small launch vehicles, which is a key capability and priority for the Space Force."

www.launcherspace.com



Launcher will develop its E-2 liquid rocket engine with the $1.7M award from the U.S. Space Force (Courtesy Launcher/John Kraus Photography)

Spare Parts 3D partners with Ocyan to accelerate Additive Manufacturing in oil and gas sector

Spare Parts 3D (SP3D), headquartered in Paris, France, has partnered with Brazil's Ocyan to further advance the use of Additive Manufacturing in the oil and gas sector. Using Spare Parts 3D's DigiPART end-to-end software solution, Ocyan has introduced Additive Manufacturing to its spare parts supply chain.

Ocyan provides solutions for the offshore upstream oil & gas industry and, despite being new to AM, the company wanted to look at a significant number of parts to evaluate their potential for AM production. In eleven weeks, DigiPART enabled the project team to analyse 17,000 spare parts from Ocyan's inventory (with no 3D files). Depending on which supply chain issue the team looked at (lead time reduction, minimum order quantity optimisation, simple cost reduction, etc.), the number of viable AM parts totalled up to 11% of the total parts analysed.

Despite there being no 3D files on hand, Spare Parts 3D's software, DigiPART, and its machine learning-based algorithms, allowed the team to process the available ERP/PLM data. Starting with DigiPART's semantic recognition algorithms, the team managed to structure the inventory into part categories (valve, gaskets, filters, seal ring) and match equipment (eg drilling), as well as the working environment (eg underwater), to establish the functional specification blueprint of each part. With those prerequisites, DigiPART then ran its 'AM transfer' algorithm which yielded a set of AM technical solutions for each part.

DigiPART's machine learning-based algorithms are reported to be 'trained' on over 250,000 parts, clustered into 2,000 part categories. This is said to have made it very efficient to precisely identify and select the most suitable Additive Manufacturing solutions for the applications at Ocyan.

www.ocyan-sa.com
www.spare-parts-3d.com

Shell moves towards digital inventory with additively manufactured impellers

Global energy and petrochemical company Shell has announced the recent deployment of additively manufactured critical spare parts for a pump at the Shell Energy and Chemicals Park Rotterdam, the Netherlands. Working in collaboration with energy technology company Baker Hughes, the goal was to illustrate that additively manufactured impellers can safely and reliably meet the needs of critical pumps, removing the need to store these as costly spare parts. Additive Manufacturing has been used at Shell over the last decade, but the criteria and testing to ensure the technical integrity of additively manufactured parts remains demanding. In 2019, Shell began to work with global suppliers to increase the portfolio of additively manufactured spare parts that can be supplied to the company. These cooperative relationships enable Shell to work together with suppliers to define the digital documentation of parts and agree on what information is necessary to buy spare parts on demand rather than keeping parts in storage.

The company has worked with Baker Hughes to additively manufacture impellers for a medium-critical seven-stage centrifugal pump. The project showed that Additive Manufacturing can achieve the quality required for Shell's operations and give confidence to the assets team that they don't need to hold these items in stock, thereby saving a hundred thousand dollars for each stocked pump in operation. This is expected to open the door to significant, scalable savings for the company.

A key objective of this collaboration with Baker Hughes was to design a repeatable qualification process for vendors of additively manufactured parts, noted as a crucial step to scale up the use of Additive Manufacturing in the energy sector. Shell qualified Baker Hughes facilities in Talamona, Italy, to supply its assets with additively manufactured spare parts. The two companies are working together to further create a digital portfolio of impellers that can be additively manufactured for Shell.

"This is an exciting development," stated Leo van Driel, Senior Rotating Equipment Engineer, Shell Energy and Chemicals Park Rotterdam. "Shell and Baker Hughes' 3D printing experts developed extensive research and quality verification steps. This helped convince us that Additive Manufacturing is a safe and reliable manufacturing technique for pump impellers. I feel that this may well be a game changer in spare parts management."

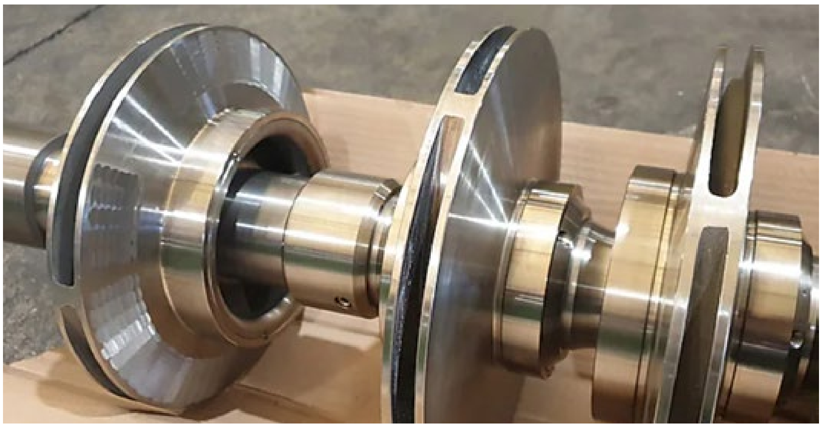
The centrifugal pump was successfully started up with the additively manufactured components in May 2022. The pump has been subjected to intensive pre-installations testing to be accepted for operation and time will tell if, as the company anticipates, the new components will perform on par – if not better – than traditional impellers.

"Our journey with Additive Manufacturing started more than ten years ago in our laboratories, and today we use the technology in our manufacturing sites," stated Enrico Mangialardo, General Manager, Baker Hughes Pump Division. "In collaboration with Shell, we are adopting innovative Additive Manufacturing solutions to reduce lead time and decrease physical inventories, while minimising the carbon footprint of operations. We believe it can significantly improve the way the supply chains work, including that of centrifugal pumps."

Both teams stated they have learned a lot from mapping out the qualification requirements for the spare parts and in understanding the differences between companies in how they order parts and manage their supply chains. Embracing Additive Manufacturing will not only require technical expertise and building trust in the technology, but means companies must re-think internal processes and define new commercial models. The project is said to have proved that these are necessary steps to embrace a digital inventory strategy and ensure robust, secure and compliant exchanges of data for both parties.

www.shell.com
www.bakerhughes.com

A centrifugal pump unit at Baker Hughes Bari service facility in Italy before shipping to the Netherlands (Courtesy Baker Hughes/Shell)



A centrifugal pump rotor with AM impellers at Baker Hughes Bari service facility in Italy (Courtesy Baker Hughes/Shell)

Transforming access to medical implants: How PrinterPrezz and Additive Manufacturing will improve global healthcare

Some companies have bolder missions than others. Whilst Elon Musk leverages metal Additive Manufacturing to transform space exploration, the founders of PrinterPrezz, Alan and Alexis Dang, Kishore Karkera and Shri Shetty, are aiming to do something equally bold with the same technology: bring safe, affordable, right-fit medical implants to the 97% of the world that can't currently access them. Todd Grimm interviewed Alan Dang and Shri Shetty to discover more.

Casual awareness of PrinterPrezz, which was incorporated in 2018, would lead you to believe that it is just a medical device company that leverages Additive Manufacturing. However, it is much more: it is a unique company on a mission. For one, its Vertex Manufacturing division is AS9100D certified for aerospace and ITAR registered (a regulatory regime to restrict and control the export of defence and military related technologies), supporting the United States' aviation and aerospace industry with advanced manufacturing, executing many projects in secrecy. More publicly, one of PrinterPrezz's primary missions is to change the medical device market as a disruptor, innovator, and market creator.

The company's stated focus is the production of medical devices and supporting instruments in high volumes with lower costs, all while accelerating the design-to-release timeline. As Shri Shetty, CEO, explains, "We deliver equitable access to life-changing medical devices." To achieve these lofty goals, the company uses technology, such as metal Additive Manufacturing, process and procedural refinements, and extensive, multi-disciplinary experience. "The value is not only in that we can take devices to market faster. The value is also that we can reduce costs exponentially by using advanced technologies that overlay on our digital backbone."

Shetty also stated, "The reason we founded this company is that there are a lot of benefits in patient outcomes that have grown from technologies such as Additive Manufacturing and those for semiconductor production." However, control over medical devices is held by a small number of companies that provide the benefits to a small part of the global population. The vision of the four founders is to change that and disrupt the medical device market.

Fig. 1 FDA cleared GAIA lumbar cages manufactured by PrinterPrezz (Courtesy PrinterPrezz)

Fig. 2 Alan Dang, a practicing spine surgeon and one of the co-founders of PrinterPrezz (Courtesy PrinterPrezz)

Fig. 3 Alexis Dang, a practicing orthopaedic sports surgeon and co-founder of PrinterPrezz (Courtesy PrinterPrezz)

Combining experience from many industries

PrinterPrezz's advantages begin with its multi-disciplinary team which brings medical and manufacturing expertise to the business's operating principles. Initially, this came from the four co-founders, but with strategic additions, the breadth and depth of the company's knowledge have grown.

The founders include brothers Dr Alan Dang and Dr Alexis Dang, who share the title of Chief Medical Officer; Kishore Karkera, Chief Operations Officer; and Shri Shetty. Their varied backgrounds formed the baseline of the company's visions, plans and actions.

Alan and Alexis are board-certified, licensed surgeons with academic practices based out of the University of California, San Francisco, and San Francisco Veterans Administration Hospital. Alan is a spine surgeon, and Alexis is an orthopaedic sports surgeon. "We have the mindset of giving patients the best and most cost-effective care," stated Alan.

As practising surgeons, the Dang brothers have a real-world understanding of the problems that exist in the medical industry and the needs of clinicians, hospitals and patients.

In 2012, Alan and Alexis bought a MakerBot Replicator 2X. At the time, this polymer AM machine was considered experimental, and no one knew how to make it work. Unaware that it was not expected to make parts, good ones or bad, Alan and Alexis got the machine to work through diligence and determination. "We completely rebuilt the nozzles and figured stuff out on our own. That adventure gives us bragging rights," said Alan. That first desktop Additive Manufacturing experience started these doctors on the path to co-founding PrinterPrezz.

Karkera brings digital experience, having worked for Apple for eleven years. During that time, he spearheaded the production support group in iTunes operations, building its processes from the ground up. He also headed operations groups within Apple Maps and the App Store. He blends technical, operational, and leadership skills.

Shetty is from the semiconductor industry, where he worked for twenty years with companies like Applied Materials and Ultratech. Having run semiconductor and Additive Manufacturing facilities, he has the eye and experience for process innovations that drive efficiency, increase manufacturing yields, and lower costs.

"By combining [these varied experiences], we can take life-changing medical devices to market and reduce cost exponentially, which opens large markets, both in the US and internationally," explained Shetty. PrinterPrezz used that wealth of experience and know-how to create an end-to-end platform that spans product design to distribution.

As the team has grown — it is now at seventy employees — the depth and breadth of its experience has expanded. For example, nearly

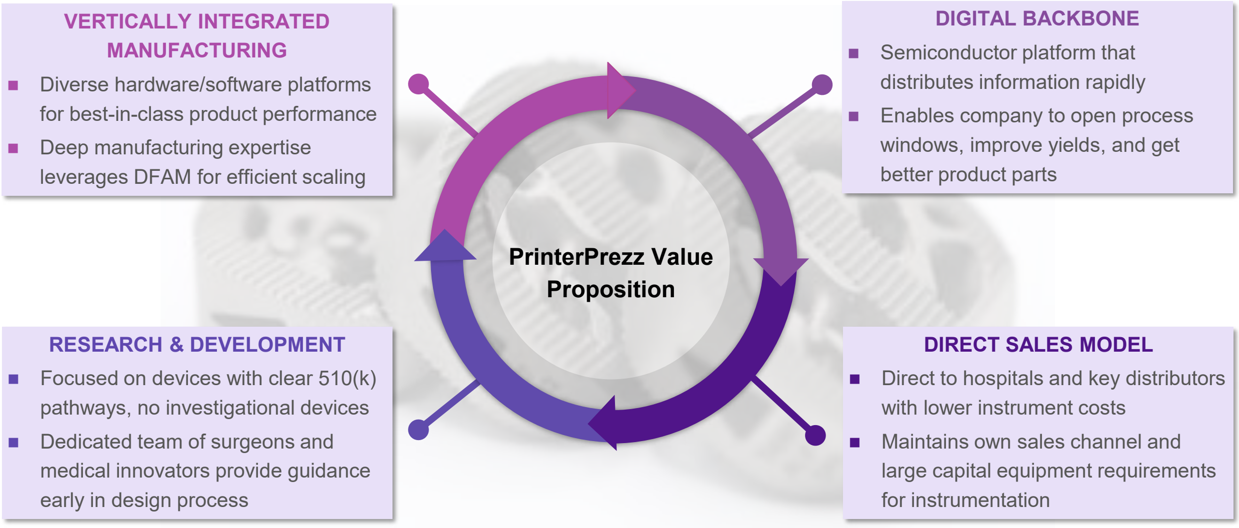


Fig. 4 An overview of PrinterPrezz's proprietary low-cost, vertically integrated business model that leverages industry-proven designs optimised for Additive Manufacturing (Courtesy PrinterPrezz)

a quarter of PrinterPezz's team are medical doctors, seasoned medical device industry professionals, or graduates of translational medicine or biodesign programmes. Originally focused on in-house Additive Manufacturing, nanotechnology and integrated medical regulatory processes, the acquisition of Vertex Manufacturing has brought broader conventional manufacturing capability to its resource pool.

"We have twenty veterans of the medical device industry," stated Shetty. "We have doctors that have given up their practices to join PrinterPrezz. We also have people with twenty-five-year careers at companies like Apple and in the semiconductor industry. We round that experience out with team members that have thirty years of experience in CNC machining and Additive Manufacturing."

In the Additive Manufacturing world, the company's acquisition of Vertex Manufacturing was big news because it included the addition of Greg Morris, an industry veteran and early metal Additive Manufacturing pioneer, to the team. Morris, who was an early advisor to the company, now serves as PrinterPrezz's Chief Technical Officer.

"...the company's acquisition of Vertex Manufacturing was big news because it included the addition of Greg Morris, an industry veteran and early metal AM pioneer, to the team. Morris, who was an early advisor to the company, now serves as PrinterPrezz's Chief Technical Officer."

Vertically integrated operations

Another vital aspect of PrinterPrezz is its vertical integration, which covers design through distribution (Fig. 4). Typically, medical device manufacturers will turn to their external supply chains for many of the eighteen significant steps in creating, making and delivering implants and instrumentation. More than half of the global market for orthopaedic manufacturing is with contract manufacturers. According to Shetty, nine to twelve suppliers can be in a traditional supply chain, making the process, workflow and information flow challenging. "It's extremely complex. Each supplier controls its data. It becomes a very complicated supply chain from start to finish," he said.

As an example, Alan explained, "There are companies that help you prototype, but the problem is that they don't understand the complete end-to-end process, including FDA reviews." He also cited design decisions that don't consider all aspects of the manufacturing process. In terms of elevated implant costs, Shetty noted that each supplier needs to have a reasonable gross margin with the piecemeal approach. When stacked across twelve suppliers, the

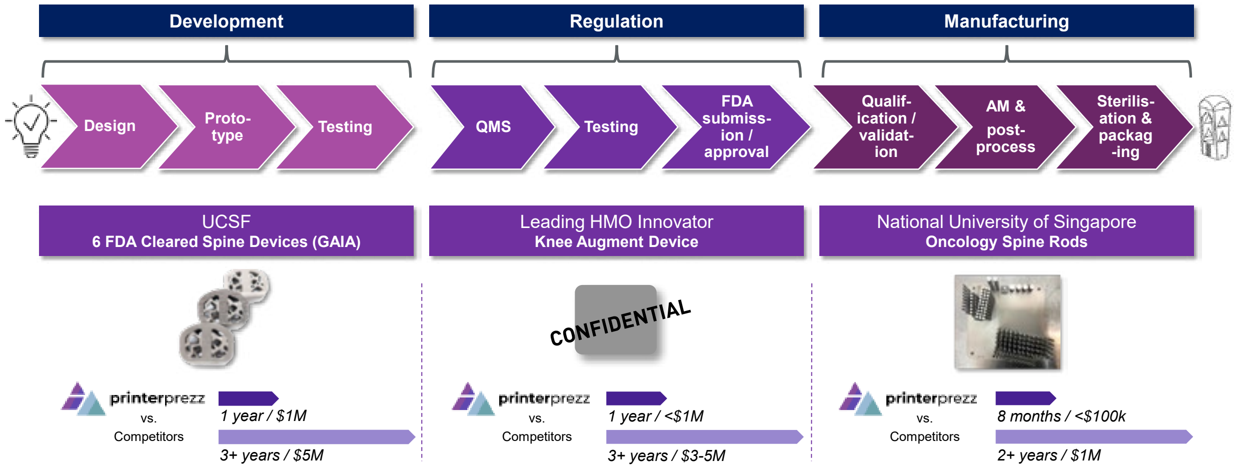


Fig. 5 Product innovation at PrinterPrezz: the entire medical device innovation pipeline is done on the company's digital backbone (Courtesy PrinterPrezz)

> *"We've taken six spinal devices through the FDA in less than a year for less than one million dollars, which historically would have cost tens of millions of dollars and taken three-to-five years."*

result is very high medical device costs that are passed on to hospitals and patients.

Within PrinterPrezz, parts and data flow seamlessly, and all decisions are made with an eye to the impact on downstream processes. Shetty added, "Everything from design through ready-for-sterilisation is done in-house." The outcome of this vertical integration is measurable in terms of both cost and time, he explained: "We've taken six spinal devices through the FDA in less than a year for less than one million dollars, which historically would have cost tens of millions of dollars and taken three-to-five years" (Fig. 5).

Today, the PrinterPrezz process chain resides within four US facilities and one international facility. Innovative ideas are advanced at the company's Fremont, California, headquarters (or its new Singapore location), ported to its New Jersey regulatory operations and passed to the Ohio manufacturing facility. A Massachusetts advanced development site focuses on enhancing additively manufactured devices with next-generation nanotechnology surface modulation. A digital backbone connects all of these facilities and their operations.

As Shetty explained, "Our value is not only that we can make things faster. The added value is that we can reduce costs exponentially using advanced technologies that overlay on our digital backbone. We have built a semiconductor-like and Apple-like backbone that lets us get yields in the high 90s [as a percentage]. In the traditional manufacturing process, the yields are in the 60s." Combined with vertical integration, the digital backbone facilitates sound decisions across the entire process chain. Shetty added, "If a company is only worried about a single step in the process, it is not going to achieve high yields." Considering that all of its medical devices are produced with Additive Manufacturing, yields above 90% are even more impressive. The digital backbone will also facilitate future expansions by PrinterPrezz, both within the United States and internationally.

Clinical innovation

According to Alan, "The innovation piece is an essential part of the company." He cites actions like leveraging technology used to make better computer chips and better software that Shetty and Karkera brought into the company. Yet, as he quickly pointed out, "The innovation on the clinical side is very important. If you look at our implants, they're designed to be transparent to the patients and the surgeons so that they are not required to relearn an entirely new technique." So, PrinterPrezz's innovations align with making implants better, solving problems and addressing underserved markets.

As with other aspects of the business, the company looks outward for innovative ideas through partnerships and collaborations from within healthcare networks. For example, PrinterPrezz has an IP agreement with the Regents of the University of California, which is the governing board, allowing the company to bring new ideas from other clinicians to market. Alan stated, "These ideas are normally too early for big companies to develop or too complex for someone to do it in their garage or research lab. They just don't happen." PrinterPrezz, on the other hand, has unique expertise supported by a business model that facilitates bringing these innovations to market collaboratively with the university.

"It is about laying the groundwork rules for IP so that innovative surgeons and clinicians don't have to worry about all the aspects that go into bringing a new medical device to market and universities retain their fair share of the IP," he said. Considering the substantial barriers to entry, the solutions to problems experienced in the operating room or clinic would stall at the idea stage if a company like PrinterPrezz lacked the capabilities, talents and appetite for bringing new, innovative products to market while working within the university technology transfer system.

Shetty added, "The main motivation is the fact that the value of the technology isn't in the yield or capabilities. The value of the technology is the products that are created." Alan agreed, "We don't want just to make things cheaper – we want to make better things even cheaper." For an example, he cited the innovative work of the Massachusetts nanotechnology lab to address issues around healing and surgical site infections, problems that affect all surgeons and all patients.

The nanotechnology, which will be applied to additively manufactured devices, alters surface energy, which affects the way the implant behaves biologically. Having filed patents and performed inde-

Locations and areas of expertise

PrinterPrezz headquarters
Fremont, California
This location is an innovation centre where ideas are born, devices are created, new product introductions (NPI) are conducted and technology readiness (T.R. 1 through to 4) is achieved. It is home to the company's doctors and where new material process, for example PAEK, development occurs. Fremont works with large hospital networks such as UCSF (University of California San Francisco), Stanford, and medical innovators like CZ BioHub to collaboratively bring device concepts to market.

Addivation Medical
Chester, New Jersey
Staffed with former Zimmer, Stryker, and Biomed employees, this location serves the 'medical device technologist' role of taking new concepts through the FDA regulatory process.

Vertex Manufacturing
Cincinnati, Ohio
When PrinterPrezz was founded, this independent company was its exclusive post-processing partner. Today, it is the company's manufacturing arm, offering additive and traditional manufacturing. Beyond PrinterPrezz products, Vertex also serves as an AS9100D certified, ITAR registered contract manufacturer for non-medical products in industries such as aerospace and defence.

Upon completing the coming facility expansion, Vertex will become the first digital robotic facility in the US for medical and aerospace Additive Manufacturing production.

PrinterPrezz is technology and vendor agnostic so that it can pair the best solution with each application. Its stable of metal Additive Manufacturing technologies includes metal AM machines from Arcam (GE) and Concept Laser (GE), 3D Systems, EOS, Desktop Metal, Velo3D and Xerox. The company also has several high-temperature material polymer printers.

PrinterPrezz – Nanotech Lab
Boston, Massachusetts
After manufacturing, this advanced development facility applies nano-coatings or nano-etches (from the semiconductor world) to improve material performance in areas such as infection mitigation and bone growth.

PrinterPrezz SG
Singapore
Established before the global pandemic to support research and development projects coming from the national health clusters of Singapore, PrinterPrezz Singapore will be launching a full innovation centre this autumn to perform many of the same medical device development functions as the Fremont location, focusing specifically on the needs of the region.

PrinterPrezz headquarters in Fremont, California

Fig. 6 The company's FDA-cleared GAIA TPLIF lumbar cages incorporating exclusively licensed UCSF lattice (Courtesy PrinterPrezz)

Fig. 7 Large drill bit additively manufactured in Inconel 718 (Courtesy PrinterPrezz)

pendent lab testing, PrinterPrezz is poised to improve healing and bone growth through two semiconductor processes: nano etching and atomic layer deposition (coatings at nanoscale). Combined with latticed designs and the consideration of design and part orientation impact on surface quality, the company will deliver better outcomes for those that are surgical candidates and open the door to those that might otherwise be denied due to preexisting illness or comorbidities.

"Medical device innovation has traditionally focused on improving mechanical performance and improving surgeon or patient ergonomics," Alan said. "Nanotechnology adds the fundamental concept of helping patients heal after the surgery is done, without interrupting the clinical workflow."

What is PrinterPrezz doing now?

"New medical technologies are often introduced as high-end devices for the 3% of the world that already has access to advanced healthcare solutions. We are instead using our technology advantages to better serve the 97% that are underserved or ignored," Alan explained. "Because of our cost advantages, we can make a reasonable profit while impacting a lot of lives in areas that cannot afford current solutions."

PrinterPrezz is not going after custom, patient-specific medical devices. Instead, it focuses on high-volume production with a high product mix. Essentially, its definition of mass customisation is to build a multitude of variations of each medical device tailored for shape, size, and topology. Except for commodity items like screws and plates, everything that PrinterPrezz produces is made with Additive Manufacturing. The inherent batch-to-batch flexibility in the product mix is a critical piece of the company's plan to deliver a significant number of product variations.

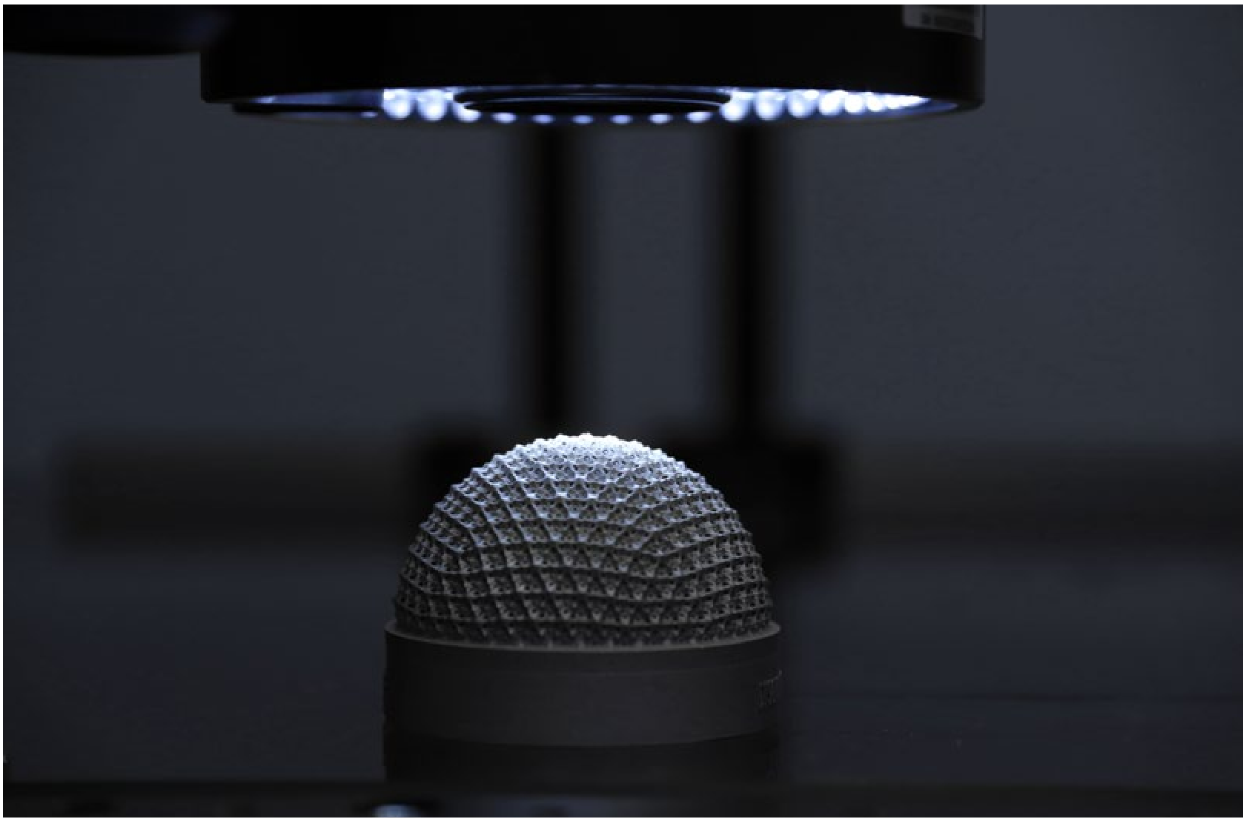


Fig. 8 Optical CMM measuring the topology of an implant's organic surface structure (Courtesy PrinterPrezz)

> *"We see the pathway to doing these custom devices being limited by the demand and the regulatory agencies in today's environment. Maybe there will be a valid customisation market in the future, but it will never be as big as the mass-customisation market."*

The limited impact potential of customised, patient-specific devices, based on the percentage of the population that can afford them, is a primary reason for PrinterPrezz to address the high-volume, high-mix opportunities. While some procedures require custom solutions, most are well-served by standardised devices that come in a wide range of sizes. A second reason is that processes that support patient-specific devices, in the areas of regulatory control and CT scanning to additively manufacturable models, are not as evolved as those for Additive Manufacturing and the materials and software that support it. Shetty said, "We see the pathway to doing these custom devices being limited by the demand and the regulatory agencies in today's environment. Maybe there will be a valid customisation market in the future, but it will never be as big as the mass-customisation market."

Presently, PrinterPrezz has six FDA-cleared spinal implants used in the lower back, a seventh FDA-cleared implant for the neck, and an additional nineteen devices in the pipeline. The company is also interested in expanding its added-value solutions to address surgical procedures for trauma and extremities.

Shetty stated, "3D printing is one piece of [our solution] that offers the customisation, and semiconductor is the piece that yields attractive costs. But both of them together, with the right people, give you products that can have real impact." Overlaying advanced digital technology and advanced manufacturing technology enables PrinterPrezz to be cost disruptive in the medical device market.

Fig. 9 The company's FDA-cleared GAIA PLIF lumbar cages (Courtesy PrinterPrezz)

Solutions for 6.7 billion people

"We see huge markets in the US and Asia that are very cost-competitive, and therefore, not targeted by those using advanced technologies. With our cost structure, we can be a disruptor," said Shetty. In Asia, he noted, 90% of the market does not have access to reasonably priced, FDA-approved devices, so they turn to knockoffs for an affordable alternative. Alan noted, "Today, we can deliver 'Made in the USA,' FDA-cleared devices at a lower cost than anything on the market globally. And we believe we can continue to drive that cost down."

Another consideration is that medical device companies have historically focused on serving the North American and Western European market, so the product designs are optimised for the typical North American bone structure. That means that the devices may not optimally fit the rest of the world. PrinterPrezz can design and manufacture for different global ethnicities by leveraging its high-volume, high-mix production capabilities.

Why the name PrinterPrezz?

The company had a vision from its onset to break down barriers to medical device access. That vision led to the company's name. It saw itself in a context aligned with Gutenberg and the advent of the movable-type printing press - hence *PrinterPrezz.*

Before Gutenberg, books were studied by the elite that could afford them, making knowledge a privilege that few could access. With the printing press, books were produced in greater numbers at far less expense and, as a result, the spread of knowledge, discoveries, and literacy swelled.

With the intent to offer lower cost solutions for medical devices produced in high volumes using a digital workflow, the company adopted the PrinterPrezz name.

Alan likened the high-mix capabilities to off-the-shelf shirts with various fits, sleeve lengths and collar sizes. "We can have a core design supported by a size matrix of hundreds of variables. These won't be manufactured on demand; rather, we will produce them in right-sized batches based on the demand from each region of the world." This global vision is the reason for the recently opened innovation centre in Singapore. Like the Fremont location, this facility collaborates with regional health clusters to bring solutions to market that address the problems faced by the medical industry and deliver medical devices that address the needs of patients and clinicians.

The use of Additive Manufacturing and semiconductor materials makes the global solution possible. But what makes it a reality is the company's digital backbone. "We can scale up globally. We aren't limited by physical assets and disjointed data flows. As we expanded into Southeast Asia, and as we expand into the Middle East or South America, we will be using the same digital backbone. In this way, we become more like Amazon or Uber and much less like a traditional contract manufacturer," said Shetty. As it expands, PrinterPrezz will add innovation centres, micro-factories and regulatory groups that can support the regional needs of countries beyond the US and Singapore.

Shetty stated, "PrinterPrezz is in a heavy expansion mode, and we are getting close to securing Series B funding to fuel that growth." However, he added, "We focus on the implants; we focus on the digital manufacturing; we focus on the globalisation. We focus on the devices and the customer." With operational structures, business processes and advanced technologies that support growth, the company can scale.

Shetty continued, "As we scale, we can cut our costs even further." For evidence, Shetty and Alan reference the flat-screen TV market. At scale and with efficient processes, what once cost $10,000 is now offered for $1,000 with the same or better profit margins. Shetty explained,

Fig. 10 The company's FDA-cleared GAIA ALIF lumbar cages (Courtesy PrinterPrezz)

"By combining everything we have assembled, PrinterPrezz can take life changing medical devices to market while reducing cost exponentially... that opens large markets, both in the US and internationally."

Conclusion

The PrinterPrezz story is impressive in many ways, but, in our conversations, it was shared with humility and without hyperbole or conjecture. As Alan said, "We under promise and over deliver. Our focus today is delivering state-of-the-art medical implants at an affordable cost, leveraging already proven methods from semiconductor manufacturing and e-commerce. Our nanotechnology programme is an investment for the future of hypermaterials, is built upon decades of science related to surface energy, and has already been evaluated by an independent third party lab in a large animal study. Lastly, our aerospace additive expertise and operational confidentiality is likely among the Top 3 in the industry. We have seen tremendous growth this year and additively manufacture for some of the biggest household names in that industry."

This is a company to watch as it innovates, disrupts and opens new markets for medical devices.

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Anatomy of an AM part failure: Lessons for managers, designers and producers from 2021's Olympic bike crash

In the men's track cycling team pursuit qualifying at the 2020 Olympics, broadcast live to a global audience, a handlebar part produced by metal Additive Manufacturing failed with catastrophic consequences for the rider, Australia's Alex Porter. Six months later, a forensic analysis of the incident was published as a 170-page report. The good news is that the company that made the AM part, along with the technology itself, were cleared of blame. So: what went wrong, and what lessons can be learned? Robin Weston digs into the details.

It's a dangerous business when things go wrong in the public eye. I'm not talking about the physical danger of an accident in elite track cycling, although that certainly is hazardous; without a doubt, a crash at 70 km/h is severe, especially when surrounded by other bikes travelling at the same speed. No, the danger to which I refer is the danger inherent in the speculation and blame game that inevitably follow a public mishap, and that can lead to unintended consequences if rumour and supposition take hold without a full understanding of the facts.

There is something about us humans; it is all too easy to play the blame game and, sometimes, see fortune in the misfortune of others. The Germans even have a word for it: Schadenfreude, 'pleasure derived from another person's misfortune,' a portmanteau based on the German words *Schaden* (harm) and *Freude* (joy).

I don't mind admitting that when I first heard about the failure of the additively manufactured titanium handlebars experienced by Alex Porter in the Australian Men's Team Pursuit race at the Tokyo 2020 Olympics (held in 2021), I had two initial thoughts: "That must have hurt," and – you guessed it – "I wonder which metal AM machine they were manufactured on?" The footage is quite shocking and Porter was fortunate not to have sustained much more serious injuries. He was also angry, and it certainly prevented AusCycling (a new organisation created in November 2020 out of a merger of Cycling Australia with two other cycling bodies) from achieving anything

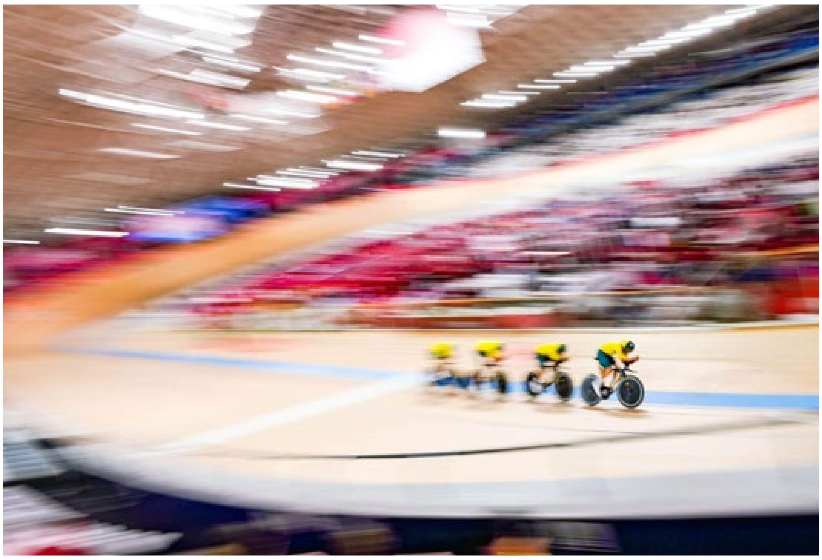

Fig. 1 Team Australia's Kelland O'Brien, Sam Welsford, Leigh Howard, and Alexander Porter pictured during the qualifying round of the Men's Team Pursuit at the Tokyo 2020 Olympic Games (Photo credit Shutaro Mochizuki/ AFLO/Alamy Live News)

Fig. 2 Replicas of Graeme Obree's Old Faithful on display at the Riverside Museum, Glasgow, February 2012 (Photo credit Ed Webster / Flicker / CC BY 2.0)

better than a bronze medal in the Team Pursuit. And nobody trains for a bronze medal.

Of course, I was utterly wrong. I was wrong to jump to conclusions without knowing the facts; I was also wrong to immediately associate the failure with a metal AM machine of a particular type and infer that some devices are materially better than others. In my experience, most metal AM machines can be persuaded to work well; it is often the demands placed on the user's know-how that are the most critical factor in the outcome.

Having absorbed the excellent 170-page report commissioned by AusCycling, freely available to download (see end of article), I will endeavour to provide a more balanced overview and try and seek out the useful lessons for our still relatively young – but increasingly professional – industry.

"Due to the strict timing of events and the drive to discover and implement performance gains quickly, advanced engineering, delivered to the point of need as fast as possible, is paramount. Then, the performance benefits can be assessed and further design iterations executed."

Elite sports and the performance race

There is a lot at stake in elite sport: vast sums of money, the pride of nations, the hard work of the athletes and support staff, and the expectation of medals. Teams compete for funding for each discipline, and cash is often directly tied to medal performance. So, the better each team does in its chosen sport, the more likely it will receive funding to invest in the latest equipment, coaching and sports science, which ultimately should advance its performance to achieve an even better medal tally next time. But the more you get, the more the expectation rises, and so the pressure increases. This causes teams to seek out every possible (legal) performance gain available. When it comes to equipment, this usually involves advanced engineering. Due to the strict timing of events and the drive to discover and implement performance gains quickly, advanced engineering, delivered to the point of need as fast

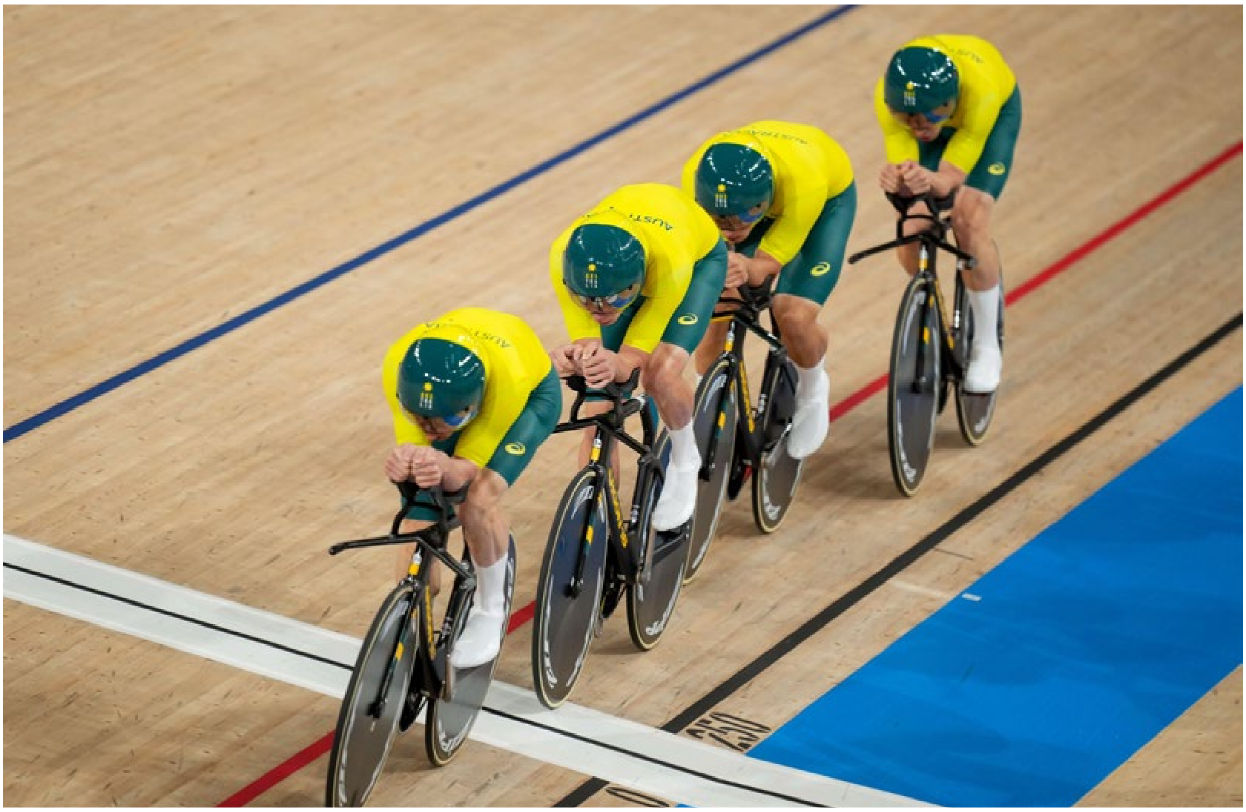

Fig. 3 Alexander Porter, Leigh Howard, Sam Welsford, and Kelland O'Brien compete during the Tokyo 2020 Olympic Games Tokyo, Japan (Photo credit Yannick Verhoeven/Orange Pictures)

as possible, is paramount. Then, the performance benefits can be assessed and further design iterations executed.

It's hard to imagine a more high-pressure scenario outside of critical infrastructure, defence, aviation and emergency healthcare. And, as I'm sure we can all attest, from our own experience, it doesn't matter if it's not important to anyone else; if it's important to us, then it's our prime focus.

For reasons of balance and to get a perspective on just how far equipment in elite sport has come, I'm going to reference something that might astonish our younger readers and jog the memories of those in advancing years like myself, at least if you followed cycling or the newspapers at the time. Back in the early 1990s, there was a Scottish cyclist called Graeme Obree, known in the press as The Flying Scotsman. He won two track cycling world championships and contested and beat the Hour Record held for about eight years by Francesco Moser, where riders cycle as far as possible in one hour. He broke the record a second time, surpassing a new record set by Moser, in 1994.

Graeme was not one to follow convention. Besides being an amazing athlete who could push himself to and beyond the limit, he was a disrupter in bike technology. He was also willing to test the competition rules to the limit. He hit the headlines having designed his own bike, produced in his own small workshop, without finite element analysis or CAD. He used the bearing from a washing machine drum to allow a narrower profile to the crank and chainrings, and very quirky handlebars that tucked the rider's arms and elbows underneath the torso, thus creating as low a profile aerodynamic form as possible. The bike almost looked like a throwback to the velocipedes of the early 1800s. Looks were deceiving, though, and the performance gains achieved resulted in a ban for this style of bike, with later designs after the ban ultimately resulting in the rules set in place by the UCI (cycling's governing body) today, which strictly govern the rider's position.

Why am I telling you all of this? Well, I guess, for a few reasons. If Obree's bike had failed on television when he rode in (and won) the individual pursuit at the 1995 world championships, most people would have put it down to its homemade nature. There probably would not have been an extensive report, because it would have been clear where the fault most likely lay. Obree would have gone home, scratched his head and quietly resolved the issues; that's the advantage of a small team. Besides, Graeme was looking for a great leap forward, so he wasn't so much pushing engineering boundaries as he was pushing the boundaries of convention, so the engineering could be robust. At the time, many other riders saw Obree as an outsider, and did not take so kindly to his maverick

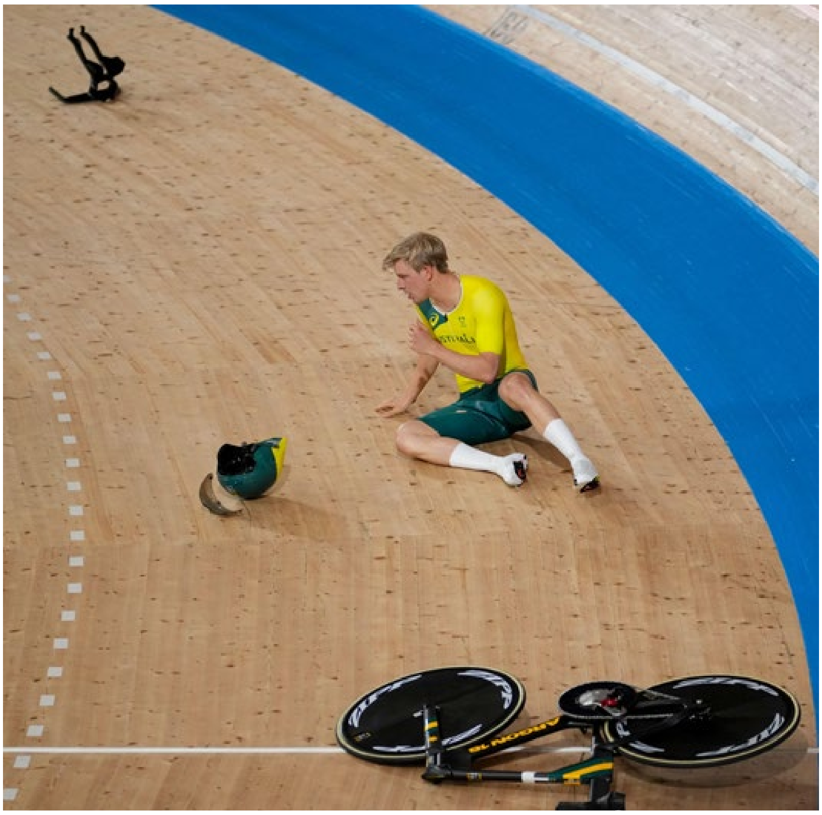

Fig. 4 Alexander Porter following the crash resulting from the bike failure (Photo by Yannick Verhoeven/Orange Pictures)

nature; opinions were divided on where he got his performance from: was it him or his rule-breaking bike? The answer? Have a dig around on YouTube for the video 'Graeme Obree - Athlete or Genius.'

There are no such issues today, with the rules around the bike design tightly governed by the UCI. In many ways, this means that today's teams must search much deeper and look far harder for the performance gains that will give them a competitive edge. Innovations and advancements, in today's world, tend to be incremental, rather than seismic. This means a highly data-driven approach; larger teams; more management; tighter product specifications; and marginal changes to shave off a hundredth of a second here and there. It also means lots of iterations, which piles on the time pressure, especially when it comes to hardware development. On the face of it, this sounds like the perfect opportunity for a flexible, digitally driven manufacturing technology, capable of producing parts that are nominally the same, but with minor geometric tweaks to improve performance. That'll be industrial metal Additive Manufacturing, then.

The emergence of AM for bikes

There is no doubt that when Rapid Prototyping first emerged in the mid-1980s, its primary application was to accelerate product development. Still, it would be more than a decade before anything remotely structural could be produced. Even then, nothing that would withstand significant forces, such as those at play in track cycling. The closest the technology got to manufacturing bike components was making cores for a conventional investment casting process, which might then be used to produce handlebars.

The first metal AM technologies started to hit the market at the turn of the century and the first glimmer of flexible on-demand manufacturing for one-off or small batches of end-use AM parts emerged. The three words 'metal Additive Manufacturing' don't fall into wider use until around 2006/7. The point is that it's still early days for a relatively new technology, but, as with many aspects of our world, the pace of technology adoption is accelerating. Metal AM is now firmly in use to produce aerospace components and medical implants, two highly regulated industries that have spent at least fifteen years climbing the adoption curve and now have whole factories dedicated to metal AM production. Surely it's possible to make some bike components?

The most distinct aspects of the aerospace and medical sectors are that they are highly regulated, high value, large scale, and highly experienced in controlled manufacturing. Significant constraints are placed around all processes. While speed to market for new innovations is an attractive feature of AM, it is generally not the primary motivator in these sectors. Instead, these industries are adopting metal AM to unlock performance enhancements in the component, reduce inventory by part consolidation, or perhaps exploit the geometric freedom offered by the process, maybe even process a challenging material that is too expensive to form by other means. Generally, they are not just using metal AM as a shortcut to get a product significantly faster than via a conventional route.

The demands of regulated sectors actively prevent the rash use of any technology, instead demanding rigour from fear of litigation and/or serious commercial penalties, either imposed or delivered by an unfavourable market response. Nobody wants to go through the trauma and reputational damage caused by a product recall, so companies develop systematic ways of working and follow international standards to safeguard against this as far as possible.

While I'm not suggesting that the field of elite sports plays fast and loose with how it uses technology, I imagine the perspective is different from that of the high-value manu-

Fig. 5 Alexander Porter walks along the track after falling during the race (Photo credit Reuters/Kacper Pempel)

facturing sector. Problem-solving is perhaps more centred around the human physiology of the athletes – "What do they need to perform better?" – rather than "How do we build a robust business using manufacturing technology to produce advanced products to serve a market and make a profit?"

So it's understandable, especially when market adoption of metal AM technologies in regulated advanced manufacturing companies is relatively high profile, that elite sports teams should want to embrace such a flexible and increasingly well-proven technology; one that can make parts that fly into space and on commercial airliners, and are implanted into people's bodies. But without the deep pockets and prospect of an ongoing commercial return, how can elite sports teams benefit from the potential of metal AM without running the risk of an engineering overhead that is too great a burden to bear?

"...it's understandable, especially when market adoption of metal AM technologies in regulated advanced manufacturing companies is relatively high profile, that elite sports teams should want to embrace such a flexible and increasingly well-proven technology..."

So what led to the catastrophic failure in Tokyo?

It's probably worth setting out precisely what happened to AusCycling, and the chain of events leading up to the upsetting scenes at the Izu velodrome in Tokyo, before we go into the why. At this point, I want to note that the report precludes selective quoting, so I will do my best to avoid this and, as far as possible, paraphrase the events and findings. I'll also focus on the most relevant findings for readers of *Metal AM* magazine, rather than list every nuanced point made in the 170-page report, which is available in full online for anyone wishing to take a deeper dive. *Metal AM* is a publication whose remit is to be a positive force for the development and promotion of AM technology worldwide. The aim is to provide a balanced view of the report's findings, give credit to all those involved

Fig. 6 A press image of the Argon 18 bike as released by Cycling Australia in February 2020. The photo shows the original handlebars as supplied by Argon 18, not the modified handlebars used at the 2020 Olympics (Photo Hikari Media/www.australiancyclingteam.com)

and highlight learnings that apply to all companies and organisations seeking to adopt metal AM.

COVID-19 in the mix

Like many competitive teams, Cycling Australia will evaluate several high-performance equipment suppliers for their elite riders. In the case of the Olympic cycling team, they settled on a Canadian manufacturer, Argon 18. The bikes were designed in carbon fibre specifically for Cycling Australia and custom built for each rider; the frames were manufactured in Asia. Carbon fibre is a process that generally requires tooling and carries a specific lead time that can become challenging if late changes are needed. At this point, it's also worth mentioning that the pandemic was to have an effect later in the programme, in multiple ways. First, the delay to the Olympics, disruption to supply chains and international travel ban further hampered both progress and potentially decision making, not to mention training and performance advancement; the incremental gains I talked of earlier.

I can imagine it was a less than perfect environment to develop and organise a team to challenge at the highest level. Whilst I know all the teams were in the same situation, it's not unreasonable to think that the disruption led to an overall increase in risk that would most likely appear somewhere in one of the teams; still nominally a level playing field, but perhaps a bumpier one.

With long lead times on the frames, the trigger for production and the end of the frame design phase came around two years ahead of the original schedule for the games in 2020. After this point, changes to the bike would need to be accommodated somewhere other than the frame.

The human form factor

In parallel to the equipment development, which also involved changes to the frame to reduce its size and aid aerodynamics, the coaching team worked on the starting technique. This involves the rider using the inertia in his body to lunge forward, effectively catapulting the bike below them forwards and setting it in motion. This technique places significant loads on the frame, and the handlebars in particular. Back in Obree's day, the starts were very different, with a slow build-up to wind up the massive gear needed for speed. This development in the starting technique revealed a problem with Porter's knees hitting the lower part of the handlebars, the base bars, and a request was made to increase the handlebar clearance.

This left the team with limited options except to change the handlebars to introduce additional clearance. Using the original handlebars, which had been in use for some time in 'standard' form without any issues, the design was modified to alleviate the knee clash and a trial polymer AM part from a non-structural material was produced to check form and fit. So far, so good;

Fig. 7 Press images of the Argon 18 bike's handlebars, as released by Cycling Australia in February 2020, showing the original handlebars as supplied by Argon 18, not the modified handlebars used at the 2020 Olympics (Photo Hikari Media/www.australiancyclingteam.com)

and the Olympics were still scheduled for July 24, 2020. The games were around fourteen months away; it seemed like there was plenty of time. The announcement that the games would be postponed did not come until about March 24, 2020.

Timing, and the attraction of AM's speed to accommodate late design changes

In parallel to the Olympic build-up, AusCycling had already worked with Bastion Cycles in Melbourne, which had developed significant expertise in the metal Additive Manufacturing of high-performance structural cycle frames and components to their own designs. AusCycling was using Bastion components for its training bikes, so it was engaged in designing and producing the revised handlebar design.

It's unclear why, but there was a six-month delay from making the additively manufactured model to check clearances before the final handlebars were ordered from Bastion. The report makes clear that the timing and sequence of the events leading up to the accident were contributing factors in the failure of the handlebars. Further analysis of the email communication reveals that the problem with the knee clash had been known for more than a year prior to ordering the replacement modified handlebars from Bastion. So, why was production not progressed as soon as the knee clash was identified?

"One aspect of AM is the genuine benefit of responding to late changes in designs; indeed, it is one of the many advantages marketed by AM companies... So, it's perhaps understandable that an assumption may have been made that it was OK to postpone producing the new design due to the quick nature of metal AM."

One aspect of AM is the genuine benefit of responding to late changes in designs; indeed, it is one of the many advantages marketed by AM companies. I know this, as I have peddled this idea myself. So, it's perhaps understandable that an assumption may have been made that it was OK to postpone producing the new design due to the quick nature of metal AM. However, this overlooks the other discoveries that can be made once the parts have been tested. In

Fig. 8 The broken handlebars, showing the point of failure, being carried off the track in Tokyo (Photo credit Reuters/Kacper Pempel)

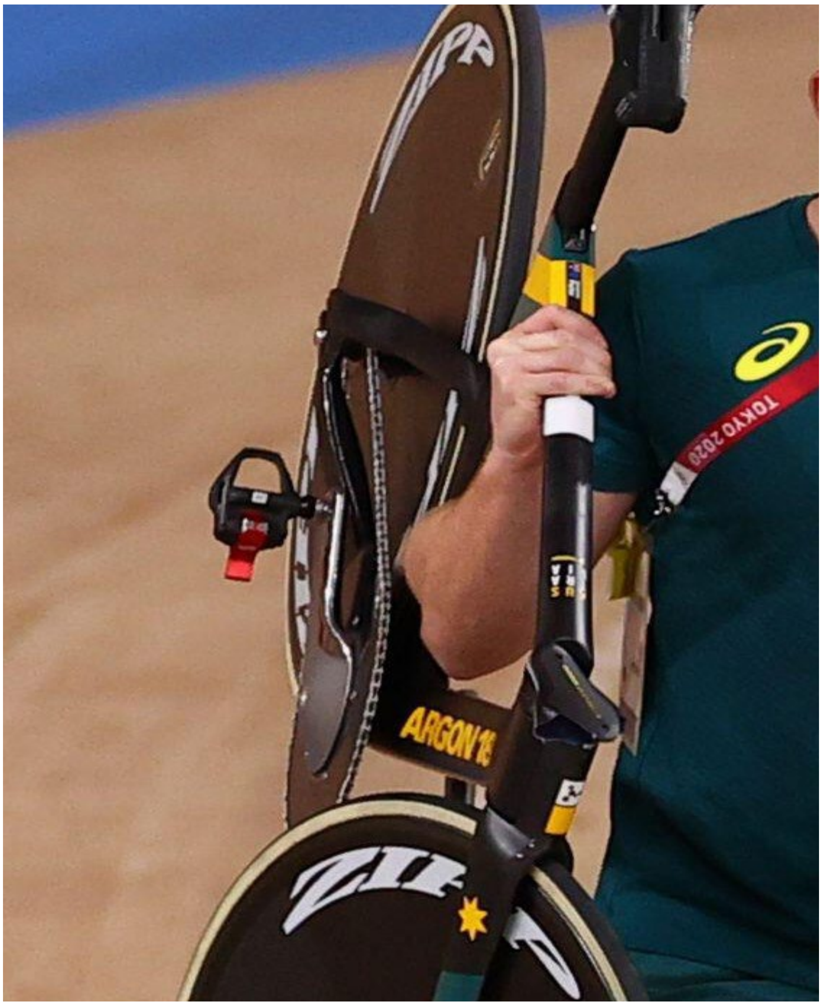

Fig. 9 The Argon 18 bike showing the point of failure (Photo credit Reuters/Kacper Pempel)

the case of AusCycling, this delay in production had the knock-on effect of reducing the time available for thorough durability testing.

Material and design changes

The report talks about two other critical aspects of the project: the choice of materials and the modification of the existing handlebars, specifically the precise specification of the revised handlebar design. Having read the report in some detail, it's unclear precisely what material was used for the original handlebar design from Argon 18. The report notes that an attempt was made to revise the handlebar design with Argon 18. However, this was impossible due to China's production constraints, indicating that the original material was not AM titanium; most likely, given the production route, the actual material was carbon fibre.

This is perhaps where things start to unravel a little, although I can imagine, at the time, it probably didn't seem like a tipping point. It's only with the benefit of hindsight that the potential impact of each event becomes clearer. Once it was decided that a different route was needed to manufacture the modified handlebars, this should have led to a complete re-evaluation of the design requirements; taking in the specifics of the geometry, the loads and forces, the manufacturing process, the available materials, and the time available for production, post-processing and testing.

I can see how the actual events may have unfolded from reading and absorbing the report. The report picks up on issues that initially seem relatively trivial (or perhaps a better description would be incidental). There are a couple of more serious issues, but I can see how it would be possible to 'sleepwalk' into them if the chain of events was disrupted – say, by a pandemic, or a change of management structure. Both occurred in the run-up to the Olympics.

Before producing the non-structural polymer AM test handlebars, a request had been made to the

Australian Institute of Sport for the extended design to be additively manufactured in titanium. For some reason, this did not happen; instead, the non-structural polymer AM handlebars were made and tested for rider position. Six months passed before the project was picked up again and an order was placed with Bastion. Unfortunately, Bastion was unaware that the detailed FEA and load calculations that governed the first design had not been revised for the second design. However, considering the nature and relative infancy of metal AM, Bastion did build several coupons to verify the values used in the FEA modelling to validate the actual mechanical properties of the coupons for the design calculations, demonstrating a thorough approach.

The cut-and-shut redesign to extend the base bar handlebar positions forward by 35 mm was adequate for the fit and form tests used to establish that the additional clearance was satisfactory. However, they were not sufficient for the structural part. In addition, the approach taken did not account for the change of material, and the new and significantly altered load conditions the new handlebars introduced due to the increase in the moment of force on the handlebars.

While a presentation capturing the design requirements shared with the Australian Institute for Sport featured the original request for titanium AM handlebars, this information was not shared with Bastion, perhaps because of the time lag or the potential change of management. Instead, the model data (the report calls this a skin-only drawing) used for the non-structural polymer AM part was used as the basis for the redesigned/remanufactured extended handlebars. As with most AM processes, this skin-only data is most likely STL data, although the report is not specific.

Maintaining continuity is challenging in all organisations, and can generally only be achieved with good documentation and rigour; often resource-heavy and requiring a particular mindset. The report refers to a culture within the AusCycling technical development team that was not fully aligned with the level of rigour necessary to effectively control and impart information.

"A crucial opportunity had been missed in not evaluating the new load conditions and change in material. In particular, the report references the fact that, while titanium is around four times stronger than steel, its behaviour under cyclical loads is limited by its lack of ductility, loads such as those at play on a bicycle."

Evaluating the impact of load, combined with the unique properties of titanium

A crucial opportunity had been missed in not evaluating the new load conditions and change in material. In particular, the report references the fact that, while titanium is around four times stronger than steel, its behaviour under cyclical loads is limited by its lack of ductility, loads such as those at play on a bicycle (there is a clue there, I think). In engineering terms, this reduced resilience to fatigue or lack of ductility must be accounted for in the design calculations and the subsequent testing.

In addition, a greater factor of safety can be designed in. The fatigue properties of titanium were discussed within the engineering team at AusCycling, and testing to appropriate standards was specified in the purchase order to Bastion. A suitable test rig was designed to apply both static and dynamic loads to the handlebars, and a static force of 1000 N – called for in ISO 4210-5; 2014 – was used, with the handlebars passing this test.

But this was not representative of the in-service conditions for the handlebars, so the test called for specific conditions and a number of cycles for the dynamic test, which is designed to replicate actual riding conditions more precisely. ISO 4210-5; 2014 calls for 200,000 cycles at a specific force and the automated test rig controls the frequency and conditions. I can only imagine that time was running short at this point, because a decision was taken by AusCycling to reduce the number of cycles from 200,000 to 50,000. The premise was that the 75% shortfall in fatigue testing cycles would be somewhat mitigated by rider testing, which could, presumably, commence sooner than if the total number of fatigue cycles had been completed. The inference is that the rider would uncover any lack of durability in track testing.

While this might be an acceptable method for a more ductile material that may show tell-tale signs of deformation before failing, titanium's known lack of ductility and durability results in catastrophic failure with little warning. This also points back to the need to clearly understand the choice of materials early in the design process so that appropriate tests and test rigs can be considered as part of the design-for-production case.

While the properties of AM Ti6Al4V were understood by Bastion, and an appropriate heat treatment cycle to ensure the mechanical properties was undertaken, further data was gathered from heat-treated coupons that indicated little difference between highly oxidised coupons and mildly oxidised coupons. Oxidation takes the form of discolouration to the material's surface, with mild oxidations showing up as a straw colour and heavier oxida-

"The report shows record keeping at Bastion was very thorough, particularly around machine checks and machine monitoring. Whilst not the state of the art when compared to the latest generation of AM machines, the best of which can gather vast amounts of data, the record-keeping at Bastion required user discipline and manual data entry. However, it is robust, and no corners were cut."

tion a deeper blue. This minimal difference in the ductility of the highly oxidised samples versus the mildly oxidised samples is somewhat surprising. However, from my experience working in Laser Beam Powder Bed Fusion, I know that ductility in Ti6Al4V can be significantly improved by reducing oxidation and choosing the right heat treatment conditions and temperature profile. Understanding this is a must for anyone working in titanium.

The report clearly outlines that the reduction in testing and the incomplete and inadequate design specification were probably the two most significant factors in the unexpected failure of the handlebars in the competition. Of course, there is no guarantee that the failure would have been initiated had the full 200,000 cycles been completed and the handlebars all passed static and dynamic tests. This also raises the question of the expected performance life for components at the edge of their design capabilities. The report found comprehensive record-keeping about the lifecycle of each set of handlebars was lacking, and, with designs at the extremes of capability, record keeping becomes paramount.

When considering the structural requirements for the handlebars, precise rider conditions and forces need to be established. In the case of AusCycling, this was achieved by using force meters within the cranks, which measured both the forces applied in the downward pedal stroke and the upward pedal stroke, with the upward force accounting for around 20% and the downward force around 80%. The upward force was subtracted from the downward force, and the rider's weight subtracted from this value. The result was the opposing force that the rider would exert when pulling up on the handlebars. These values were gathered from multiple riders. In the ISO tests, the force used was 1,000 N. Following the failure and further analysis, the original specification provided by AusCycling proved to be incorrect for the modified handlebars; the correct value for the upward force was, in fact, 1,411 N.

When considered as a safety factor, a value of one is regarded as the minimum required; with the revised calculations, this resulted in an unacceptable value of 0.65 under fatigue conditions, effectively only 65% as strong as needed. The report analysed how the mathematical model had been constructed and established that some of the factors affecting the calculation were not correctly accounted for. Neither had been appropriately checked, ultimately resulting in under-reported values for the forces on the revised handlebar design.

Learnings

It's commendable that AusCycling has been so open with its findings, and the report does not pull any punches about where things went wrong and how improvements can be made. Elite sport at this level is generally funded from the public purse, and a duty is owed to all those involved to ensure integrity and to allow others to benefit from the report's outcomes. The accident could have been much more severe, and Porter was lucky to escape with relatively minor injuries. With better oversight of engineering decision making and more robust processes in place, the risk of a failure of this type – and the accident that resulted – could have been significantly reduced or prevented.

Metal AM demands the same levels of rigour as other manufacturing processes

Companies considering implementing metal AM must recognise that it is a process that requires *at least* the same levels of rigour as other manufacturing processes. It cannot be used as an easy gap filler or a quick fix, particularly in structural applications. Metal AM is one of the most flexible manufacturing processes available, but many process variables need to be understood and controlled in a comprehensive specification.

The report shows record keeping at Bastion was very thorough, particularly around machine checks and machine monitoring. Whilst not the state of the art when compared to the latest generation of AM machines, the best of which can gather vast amounts of data, the record-keeping at Bastion required user discipline and manual data entry. However, it is robust, and no corners were cut. The report also praises Bastion for its openness and engagement with the report's author. The company's desire to learn from the experience and improve its own processes shone through.

When an incident with such a high profile happens, especially in the public eye on TV, it is human nature to speculate about the cause. I know not everyone watches the Olympics, and this incident may have passed many people by, but a thorough post-event evaluation and report provides invaluable learning to those interested in cycling or sports technology development and the wider application of metal AM. Identifying the influencing factors and the root causes has many benefits. Most importantly, it protects the athletes – i.e. the end-users of the equipment that failed. When new technologies are used, it provides valuable insight into how these technologies and processes are used to the best effect, and highlights the pitfalls that can often only come with experience. It also demands that those involved are robust enough as individuals to put themselves under the spotlight. The cultures they operate in must therefore be open, honest, and forgiving enough to make it safe for their employees to come forward and contribute.

"If you think health and safety is expensive, try having an accident"

This phrase is attributed to Stelios Haji-Ioannou, the EasyJet founder, "if you think health and safety is expensive, try having an accident." Safety is, increasingly, part of our culture, and I suspect that, if this accident resulted in more serious injuries, it would have attracted the attention of the governing authorities in Australia, as it would have done in many countries. That really is the kind of attention organisations don't need.

I know from personal experience, and I suspect this was potentially an aspect of the failure at AusCycling; just defining the tests or completing the risk assessments is only part of the process of minimising hazards. The level of rigour in applying the tests or mitigations is what matters most. AusCycling defined the tests and procedures, but made flawed decisions when applying them, which lacked rigour and a deeper consideration of the consequences of those decisions. I'm sure that it *felt* as if they had done everything right, and this perhaps led to a false sense of security.

Report

An Investigation into the Handlebar Failure that Occurred in the Australian Men's Team Pursuit race at the Tokyo 2020 Olympics

Date of Incident: 2nd August 2021

Location: Izu Velodrome, Tokyo, Japan

This report has been prepared for AusCycling Limited under Contract which precludes selective quoting from this Report.

This report was prepared by John Baker, AM
For Its Not Your Fault Pty Ltd

Fig. 10 The full 170 page report, "An Investigation into the Handlebar Failure that Occurred in the Australian Men's Team Pursuit race at the Tokyo 2020 Olympics, prepared by John Baker, AM, For Its Not Your Fault Pty Ltd, is available to download from https://bit.ly/3PV59r9

Last thoughts

If there is a lesson here, it is to continue questioning throughout the progress of each project, particularly at inflexion points such as a change of strategy. When looking at the images of the original and modified handlebars in the report, there is an obvious visual difference: a clue. I've no idea if the two designs ever sat side by side in the workshop; had they, I'm sure it would have raised the question, "Are they still OK?" Relying on numbers when the mathematical model is incorrect will not give the correct answer, but it's also much harder to see the difference in numbers than real life parts. Hence, a blend of data and eyeballs is, perhaps, a more prudent approach.

Metal AM and its widening adoption will provide many more companies with the opportunity to benefit from its valuable attributes. However, the challenge of understanding its performance envelope, and how to apply it safely and to the best effect, demands respect. AM is not a magic bullet or a quick fix; one can't just throw parts onto the machine and expect to get the best results. The key is to neither underestimate it, nor overestimate it. Strive to understand it before you ask it to fly to the moon or win a gold medal.

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What Xerox's aluminium liquid metal AM offers for supply chain resiliency

It is too easy to look at metal Additive Manufacturing technologies as neatly fitting into a small number of convenient process categories. The risk, in doing so, is that the best solution could be overlooked. One AM process that does not fit into such neat boxes is Xerox's Liquid Metal Jetting. Whilst it falls, broadly, under the ISO/ASTM 52900:2015 category of Material Jetting, it is unique among metal AM processes. Here, Bender Kutub considers where it fits into the drive for supply chain resilience, and explores its market potential.

Additive Manufacturing gets all the media attention, but is it truly production ready? It's difficult to say, because there are so many options available on the market, some exaggerated claims made, and no standard ways currently exist to qualify all of the different AM processes. Today, AM accounts for a tiny sliver – less than 1% – of the manufacturing market, and countless government and commercial organisations are investing heavily to identify the right technology platforms to reduce lead times, get to market faster and solve the supply chain crisis through which we are currently living.

While AM will no doubt continue to thrive in niche applications, can it be the game changer everyone hopes for when it comes to supply chain resiliency? After two decades of development, why hasn't metal AM become more of a mainstream manufacturing consideration?

Simply put, metal Additive Manufacturing is just too expensive to replace conventional processes like high-speed machining, sheet metal forming and casting. Throughput rates are the number one driver of cost and currently most metal AM technologies are just too slow. Raw materials, such as metal powders, are not only costly but can be difficult to procure and challenging to handle. The need for secondary processes to finish parts, such as Hot Isostatic Pressing (HIP), also adds cost to the bottom line. There are many factors, but part cost is just too high to create a compelling case.

Then there is the question of knowledge. Depending on who you ask, the casting industry dates to 3300–4000 BC, so it's obvious that we've learned a few things during that time. AM is still in its infancy, so the tribal knowledge associated with this

Fig. 1 The ElemX AM machine, capable of >99% dense aluminium parts using wire feedstock (Courtesy Xerox)

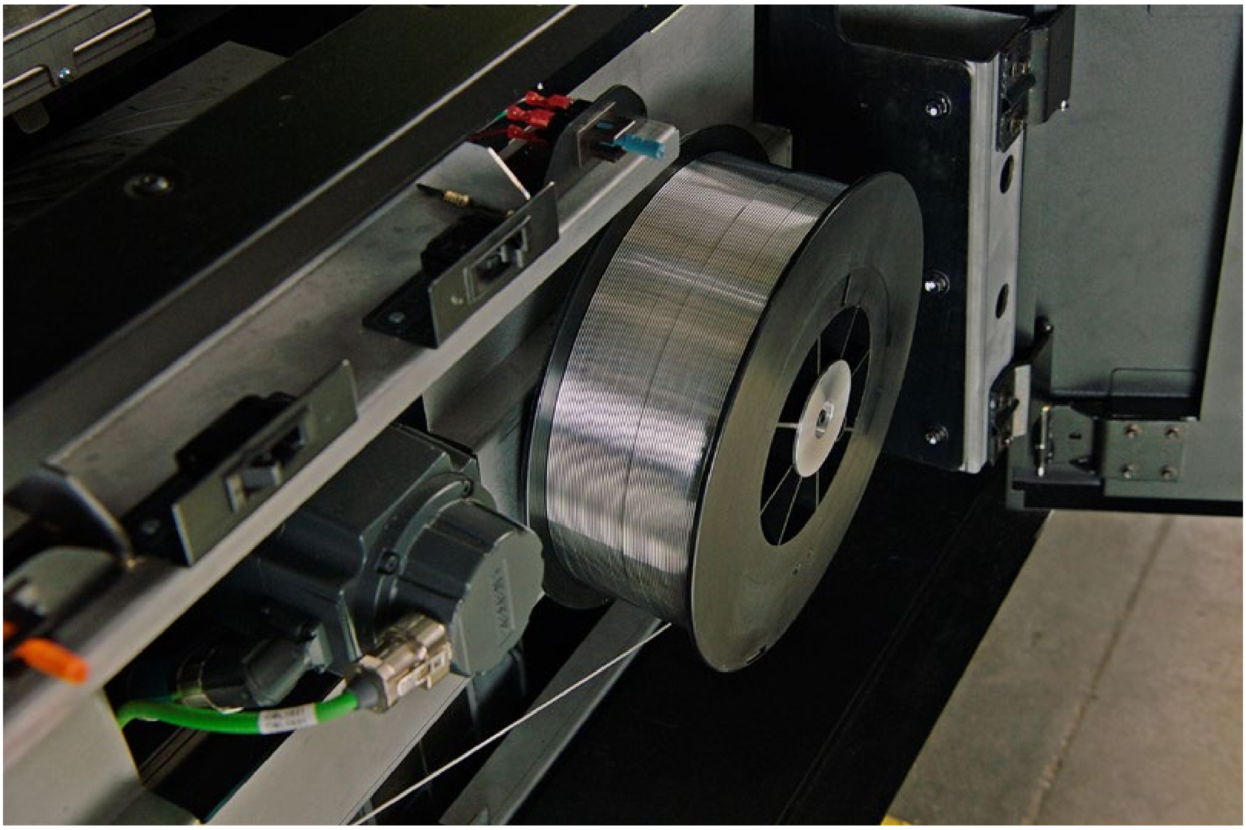

Fig. 2 The ElemX machine uses widely available wire as the process feedstock (Courtesy Xerox)

technology makes it tough to learn and adopt. However, this is evolving, and we are beginning to see more college classrooms introducing metal additive curriculums.

Finally, there is the challenge of qualification. For non-production applications, such as prototypes or some manufacturing aids, AM is an attractive alternative to traditional processes. However, for production parts, spares, and repairs, the industry requires a set of unified standards to reduce the costly one-off qualification needed for each AM technology, and, in many cases, each individual application produced.

Now that we understand the challenges associated with metal AM, it's time to explore a new technology that aims to bridge these gaps and present new solutions for production-ready, tangible manufacturing solutions. When it comes to supply chain resiliency, speed is the ultimate priority, and the scalability of the technology must be considered for application and usage. For the sake of this paper, scalability is defined by access, throughput, and availability.

Xerox's ElemX Liquid Metal Jetting (LMJ) platform is engineered to bring speed, simplicity and safety to the forefront of metal AM. It is designed as a process that is safer and much easier to implement for operators with varying technical competencies, and deployable for all locations, from airports and military bases to small machine shops. We argue that supply chain resiliency with AM relies on accessibility and, if we're being honest, a truly distributed and decentralised manufacturing approach that produces parts on-demand, when and where they're needed.

What is Liquid Metal Jetting?

ElemX Liquid Metal Jetting Additive Manufacturing utilises magnetohydrodynamics (MHD) to jet molten metal droplets at a specific rate and a specific mass. This method of Additive Manufacturing was developed by Vader Systems, which was acquired by Xerox in 2019. Since the acquisition, Xerox has matured the technology by leveraging its strong ink jetting expertise to refine the process, enabling the production of casting-like parts, both in properties and in feature capability.

Widely available aluminium welding wire is the primary feedstock for the ElemX (Fig. 2). The wire is fed into the machine and up to the jet nozzle, which converts the wire into a molten pool through induction heating. The nozzle assembly consists of multiple parts, including a one-piece upper and lower pump. Using MHD Lorenz forces, the molten metal is jetted through the nozzle (lower pump) and deposited in precise, sequential droplets onto a heated build plate (Fig. 3). The placement of each droplet is predetermined by a toolpath which is generated from the ElemX Slicer software. Each droplet solidifies when deposited, overlapping with the previous droplet to create a solid line of material.

The overall process is relatively simple and straightforward, however the true art of the process is in being able to place droplets exactly where you want them, when you want them and with a very precise mass. The thermal dynamics between the part and the drops are critical. In order to achieve the desired mechanical properties and feature resolution, the droplets and layers being formed must adhere in the right thermal processing window. The combination of these elements results in a technology capable of producing parts with attractive part attributes at high throughputs.

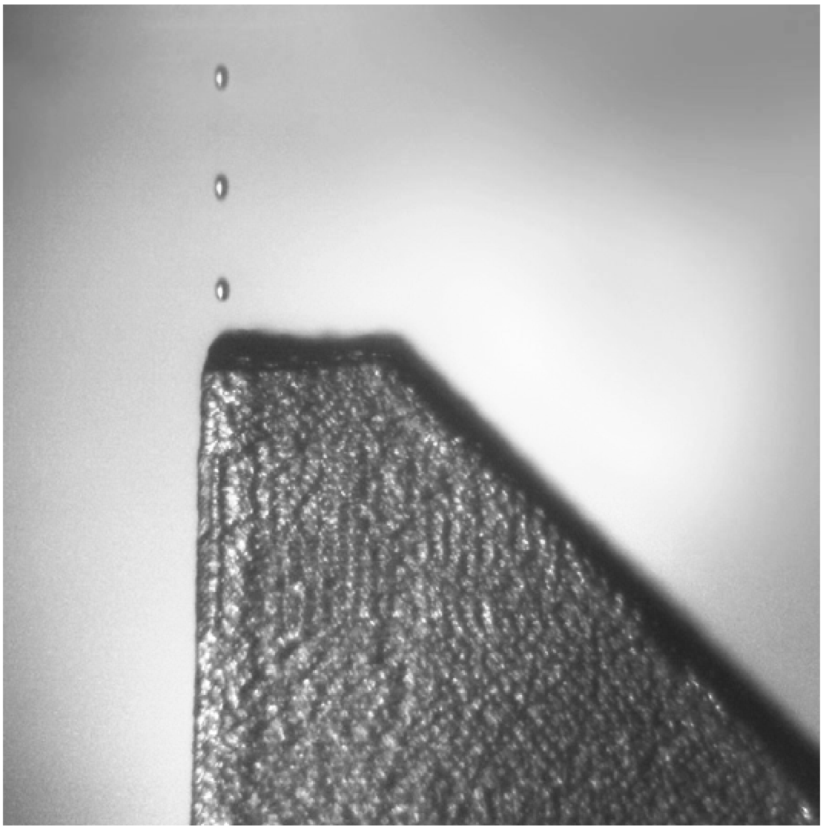

Fig. 3 An in-process image showing the release of multiple droplets of molten material (Courtesy Xerox)

Time to first part vs part complexity: a look at competing AM processes

In the metal AM industry, there is a wide range of technologies, all with different pros and cons when it comes to the value of parts that are produced. Evaluation typically includes throughput, design freedom, alloy availability and cost, ease of use, and safety. One can spend endless amounts of time generating comparisons between the exhaustive lists of metrics and extrapolate many different conclusions on why one technology is superior to the other. Our intent here is not to replicate that work, but instead to take a lens using a couple of key metrics to help highlight where Liquid Metal Jetting sits in the metal AM landscape.

The truth about metal AM technology is that there is no one-size-fits-all solution. To understand where LMJ technology stands in the metal AM landscape, we examine time to first part vs part complexity. When looking at various methods for cost modelling, throughput is one of the highest – if not the highest – lever to pull to determine the true production cost per part. Simply put, the higher the throughput, the lower the cost is to produce the part. Additionally, the time it takes to produce the first part is a critical indicator for the reaction time a process has when subjected to an unforeseen demand for a one-off spare part in a time-critical situation.

> *"When looking at various methods for cost modelling, throughput is one of the highest – if not the highest – lever to pull to determine the true production cost per part. Simply put, the higher the throughput, the lower the cost is to produce the part."*

Next, part complexity is key in determining the size of the addressable application space a process can meet. Part complexity is perhaps one of the biggest levers in determining the technical feasibility of a process for a specific application. When coupled with feature resolution, part complexity can provide a really good indicator if you can use the part directly after it's been built, or if you need to do some sort of post machining to achieve the desired end-part.

Powder Bed Fusion (PBF)
Powder Bed Fusion machines are the most widely adopted metal AM technologies in the industry. High part complexity and resolution, moderate throughput rates, and high-performance materials enable engineers

Fig. 4 A fluid distribution nozzle weighing 194 g, with a 4:30 build time and dimensions of 91 x 91 x 120 mm (Courtesy Xerox)

to use this technology for a variety of applications. However, Laser Beam Powder Bed Fusion (PBF-LB) can quickly become costly when high throughput rates require multi-laser machines. Additionally, PBF-LB still requires significant post-processing steps, from build plate and support removal to thermal processing, machining and, where necessary, Hot Isostatic Pressing.

Cold Spray

Cold Spray has one of the highest throughput rates compared to other AM technologies. Often, Cold Spray OEMs claim the ability to produce parts in minutes, which, in many cases, is not an understatement. This makes CS technology very attractive and an ideal candidate for lower cost, less critical spare parts applications.

The limitation of Cold Spray is the part complexity and feature resolution that can be achieved in an 'as-built' part. Parts produced using Cold Spray technology are most often considered to be 'near-net shape', particularly for complex and intricate geometries.

Directed Energy Deposition (DED)

Directed Energy Deposition is a process in which focused thermal energy is used to fuse materials, either powder or wire, by melting as they are being deposited. The energy source can be laser, electron beam or plasma arc. As with Cold Spray, part complexity and feature resolution that can be achieved from an 'as-built' part are limiting factors, however the process's speed, cost and ability to build at large scale are resulting in high levels of interest.

Binder Jetting (BJT)

Binder Jetting is one of the fastest metal AM technologies for the production of high volumes of small parts. Part complexity and resolution enable intricate and complex geometries. For moderately high volumes of small parts, BJT is an ideal technology – however, the sintering and shrinkage challenges the technology brings make it a poor choice for one-offs or medium-to-larger sized parts.

Material Extrusion (MEX)

Material Extrusion, using filaments or pellets containing a combination of metal powders and polymeric binders, can produce feature resolution and geometry complexity to satisfy a large application space, though it does not reach the complexities and resolutions achievable with Binder Jetting and PBF. The primary limitation for this type of technology is in the post-processing steps required to achieve the final part. Similar to Binder Jetting, the MEX of metal-containing feedstocks requires additional debinding and sintering steps, which may limit throughput as well as delivery time.

Liquid Metal Jetting

LMJ occupies an interesting spot in the AM portfolio when looked at through the lens of time to first part and part complexity. It exists in a similar realm as Cold Spray and DED in that it is high on the 'time to first part' scale and lower on the part complexity scale. The throughput is considerably higher than metal MEX, which begs the question: How does LMJ achieve this?

The key lies in the total time to part in hand. In its purist form, the LMJ process has the highest build time to overall throughput ratios of any technology considered. That means most of the overall throughput time for the LMJ process is actual build time, or material deposition time. When the build is finished, the part and plate are removed while still at temperature and rapidly cooled in a water tank. The part then 'pops' from the build plate, while simultaneously being cooled to a temperature that can be easily managed. The part is then ready for use.

What about the final part resolution? Although the part resolution and achievable complexity of LMJ pales in comparison to PBF, it is still considerably better than that offered by Cold Spray and DED. The best analogy to the output of the LMJ machine is a sandcast. This means that the LMJ process, in the as-built resolution, presents a viable solution for a considerable application space without the need for secondary machining. Taking this into account, we can more clearly see LMJ's space in the metal AM landscape: as a technology with the ability to provide reasonably high throughput while maintaining enough feature resolution and complexity to satisfy a sizable application space.

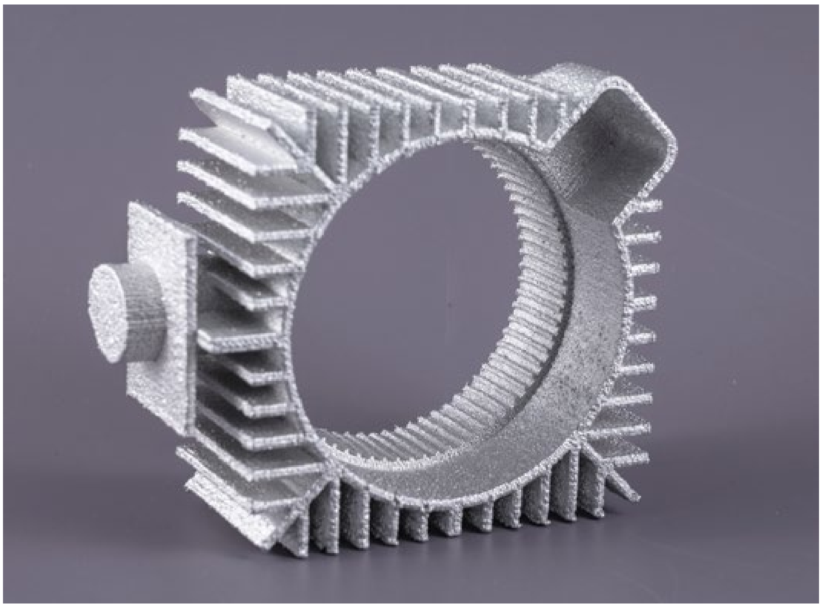

Fig. 5 A heat Sink weighing 434 g with a 6:22 build time and dimensions of 136 x 113 x 50 mm (Courtesy Xerox)

LMJ as a supply chain solution

So where do we see a need for a high throughput, medium resolution solution that can produce cost-effective parts in a short amount of time, with minimal secondary processing? Besides the obvious – prototyping, manufacturing aids, and pre-sampling – it is the spares and repairs market.

LMJ is well-suited for spare parts that are typically made using sand casting, which makes it a highly applicable option to solve the supply chain challenge, thanks to its functionality and immediacy. The lead time for sand cast replacement spares is notoriously long. Utilising LMJ over sand casting can generate lead time savings of up to 98%, or hours instead of weeks, and cost savings for one-off parts of between 85–95%.

The 'elephant in the room' in all of these calculations is the current global macroeconomic state of industrial manufacturing. It is estimated that 94% of Fortune 1000 companies experienced supply chain disruptions during the COVID-19 pandemic. 75% of companies have seen a negative or strongly negative

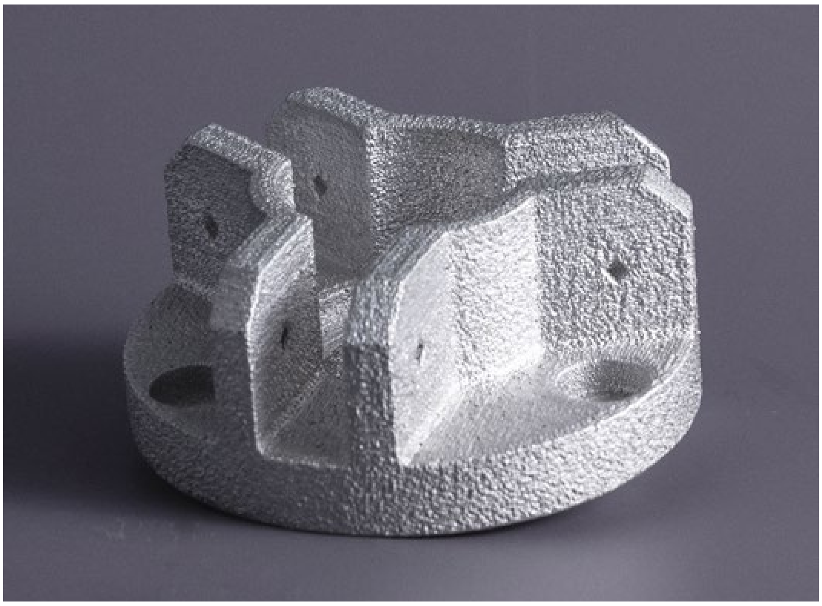

Fig. 6 A multi axis loaded bracket weighing 86 g, a 1:16 build time and dimensions of 62 x 62 x 27 mm (Courtesy Xerox)

"Utilising Liquid Metal Jetting over sand casting can generate lead time savings of up to 98%, or hours instead of weeks, and cost savings for one-off parts of between 85–95%."

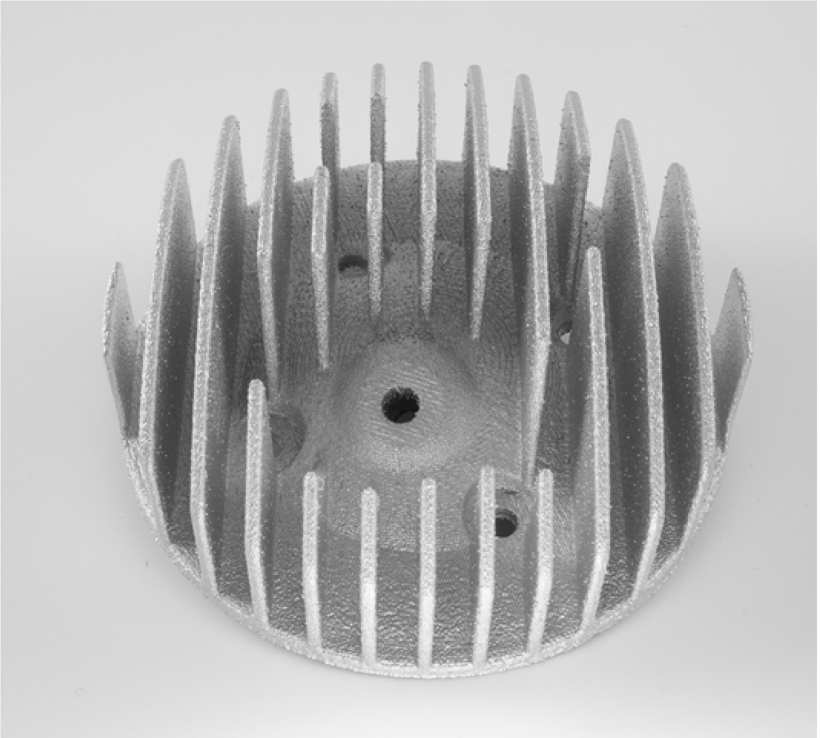

Fig. 7 A heat transfer cylinder head weighing 563 g with a 8:16 build time and dimensions of 139 x 140 x 61 mm (Courtesy Xerox)

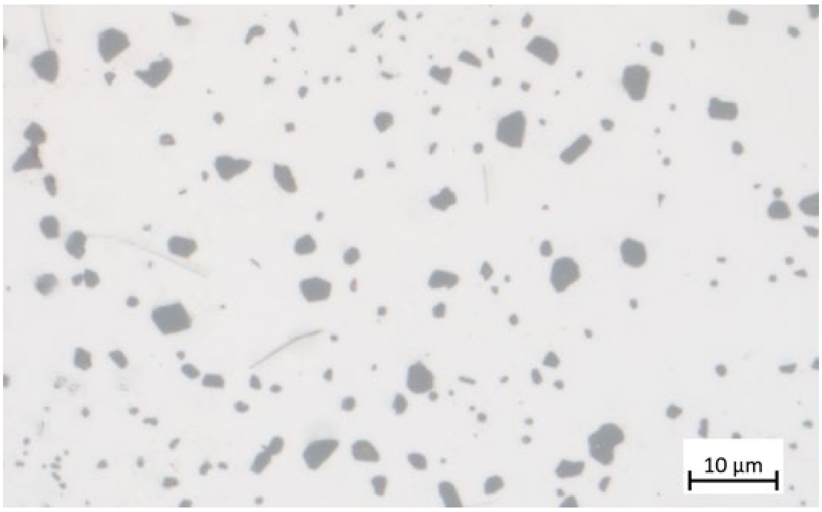

Fig. 8 Micrograph of solution annealed 4008 aluminium alloy produced on the ElemX (Courtesy Xerox)

"...if we now open the application space up to lower-value applications, where cost and schedule are critical, we can identify a major unexploited opportunity in the form of aluminium alloys."

impact on their business, and 55% of companies plan on downgrading their growth projections based solely on supply chain disruptions. The pain felt by industrial manufacturing in all industries – from aerospace and defence to automotive, heavy equipment to oil & gas – is centred around supply chain disruptions, leading to equipment downtime, unhappy customers, and an overall reduction in productivity. This not only caused a temporary setback for these industries, but contributed to wider economic damage that is expected to get worse before it gets better.

The reaction to this tide of uncertainty has been an all-hands-on-deck push by executive leadership in these industries to identify disruptive ways to derisk their supply chains. They cannot continue to operate as they previously have, because the impact on their business is too high. This, in turn, has created an opportunity to invest in new technologies that can benefit supply chain resiliency, such as AM. It is no exaggeration to say that companies will sink or swim depending on the actions taken now.

Why aluminium?

Now that we have identified LMJ as an ideal candidate for a supply chain spare parts solution, it is worth taking a look at what materials are most attractive for the LMJ process. Metal AM has traditionally found a lot of success processing high-strength alloys such as titanium, Inconel, and stainless steels. This can be tied back, in large part, to the application spaces that metal AM has been successful in, which are high-value, high-performance lightweighting applications, where one-off solutions are needed, and performance is prized over cost. However, if we now open the application space up to lower-value applications, where cost and schedule are critical, we can identify a major unexploited opportunity in the form of aluminium alloys.

Fig. 9 Major Stephen Strieby with an ElemX machine installed at the Naval Postgraduate School (NPS), Monterey, California, USA (Photo Javier Chagoya)

The aluminium spare parts market was estimated at $92.2 billion in 2020 and forecast to grow at 4.4% CAGR between 2020 and 2027. Coupled with the supply chain disruptions of the past couple of years, there is huge potential for metal AM to address aluminium spare parts supply chain disruptions. A closer look at these numbers unveils large application spaces for aluminium spares across industry segments. The aerospace and defence MRO market is expected to grow at CAGR of 4.7% from 2020 to 2025, reaching $95.6 billion.

Metal AM applications in this segment continue to move away from prototyping and jigs and fixtures, with an estimated 73% of applications to be end-use parts and spares by 2025. The aluminium spare parts market in the automotive industry is also expected to grow at a steady 4.1% CAGR from 2020 through 2030. The biggest application space for aluminium in this segment is cast parts, including applications such as heat exchangers, valves, brackets, and general engine components. The spares market for industrial heavy equipment is expected to grow from $85 billion in 2020 to $111 billion by 2027, with aluminium comprising the second highest material volumes at 23% of the total material consumed. Application spaces in the heavy equipment segment include valves, electronic enclosures, heat sinks, brackets and motor/spindle casings.

> *"The first question companies must ask when it comes to transitioning a part to AM is 'Can I additively manufacture it?' Quickly followed by 'Should I additively manufacture it?'"*

Adoption factors for distributed manufacturing

The are several reasons why industrial manufacturers have not already adopted AM into their supply chain. One relatively common barrier is a lack of knowledge of what's possible with technology and where it can be applied. The first question companies must ask when it comes to transitioning a part to AM is "Can I additively manufacture it?" Quickly followed by "Should I additively manufacture it?"

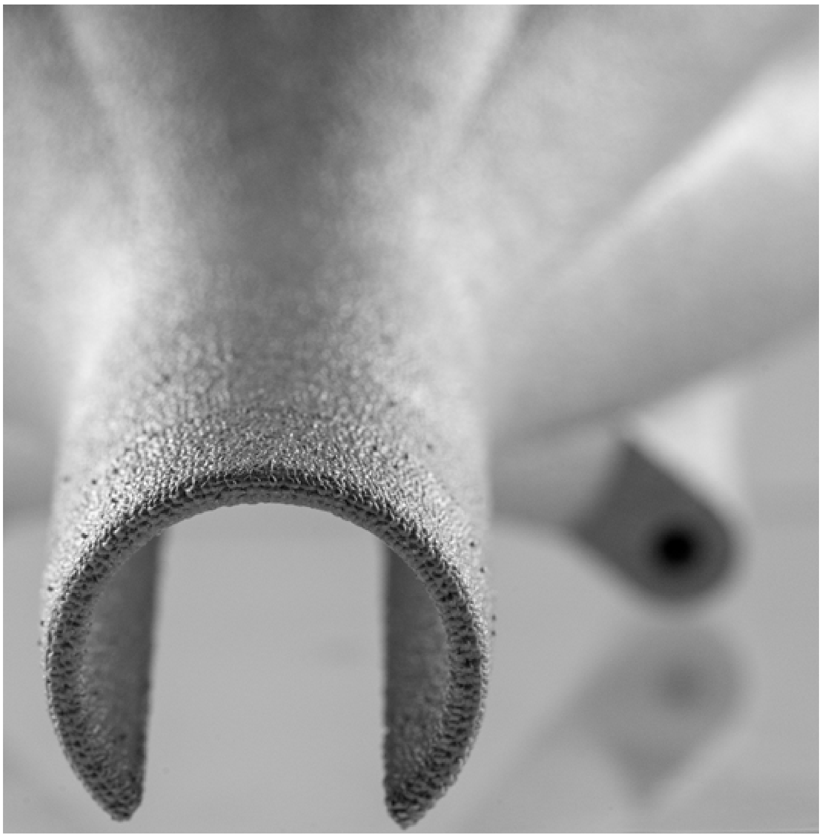

Fig. 10 Detail showing typical as-built surface finish. Droplets are ~240 µm and are jetted at up to 400 droplets per second (Courtesy Xerox)

> *"If a technology is difficult to use and requires a lot of training with a high degree of process expertise, it will struggle to gain adoption, particularly in a distributed manufacturing model."*

The first question must consider the technical feasibility of the application, and this is the first gate in evaluating a new manufacturing solution. Design parameters must be met for the part to be considered. Once this gate is passed, the next logical step is to determine what time, quality, or cost benefits come with AM. If AM can make the part quickly, at the lowest cost, and still meet the technical criteria necessary, then it is the clear winner. Unfortunately, it's never that easy.

Additional factors include ease of use and safety. If a technology is difficult to use and requires a lot of training with a high degree of process expertise, it will struggle to gain adoption, particularly in a distributed manufacturing model. Furthermore, the solution needs to be safe and deployable in a variety of industrial and non-industrial environments. While PBF continues to be the unquestioned leader in the metal AM space, the safety and facility requirements it brings with it limit it from full-scale adoption.

If we now look back at the AM landscapes and start to evaluate the different technologies against these criteria, we can see LMJ arise as a clear front runner. The technology has a reasonable application space, with good as-built design properties, which answers the question of 'Can I additively manufacture it?' The throughput possible answers the cost and time question of "Should I additively manufacture it?" and the lack of secondary processing and powders answers the questions of ease of use and safety. When we go from practice to practical, we find ourselves asking instead, 'Can liquid metal jetting solve supply chain challenges?'

What does the future of LMJ look like?

The future of LMJ looks promising: with this technology, onsite manufacturing of spares on-demand looks more realistic than ever. Checking the simplicity and safety boxes makes this a technology worth considering for a wide range of applications. Regarded as one of the most scalable technologies, aluminium LMJ is highly attractive because of its throughput and deployability. But (and there is always a but) Liquid Metal Jetting is first generation technology, and nothing is perfect first time. At Xerox Elem Additive, we are not naïve to this, but we are certainly excited about the potential. Already adopted by several contract manufacturers and industrial users, the ElemX is quickly advancing into more and more applications.

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Additive Manufacturing for oil, gas and maritime: An evaluation of capabilities and potential

In 2018, a consortium of twenty-three companies, managed by DNV and Berenschot, started a project, ProGRAM JIP, to produce a guideline formulating the necessary requirements to introduce components made by Additive Manufacturing into the oil, gas and maritime industry. This was followed, in May 2020, by ProGRAM JIP Phase II, again managed by DNV and supported by Berenschot. The participants in Phase II spanned the entire value chain, from end-users and OEMs to service providers, material suppliers and testing companies. Here, DNV's Sastry Yagnanna Kandukuri and Berenschot's Onno Ponfoort present the consortium's preliminary Phase II findings.

In 2018, a consortium of twenty-three companies, managed by DNV and Berenschot, started a project, ProGRAM JIP, to produce a guideline formulating requirements necessary to introduce components made by Additive Manufacturing into the oil, gas and maritime industry. The guideline established a practice for qualification and production of parts using two AM technologies: Laser Beam Powder Bed Fusion (PBF-LB), and electric arc-based wire Directed Energy Deposition (DED-arc) [1]. The guideline was translated into a standard issued by DNV (DNV ST-B203) [2].

In May 2020, a group of twenty companies formed a new consortium, ProGRAM JIP Phase II, managed by DNV and supported by Berenschot. The companies participating in Phase II spanned the entire value chain, from end-users and OEMs to service providers, material suppliers and testing companies. The consortium partners included: Saudi Aramco, Equinor, Siemens Energy, Kongsberg Maritime, K-Ferrotech, Voestalpine, Eifeler, Sandvik, Aperam, Imphytek, Intertek, Guaranteed, Addilan, FIT AG – Additive Manufacturing Group, BMT aerospace, IMI-Critical, ExOne, XDM3D, Howco and NMIS - Strathclyde University.

The goal was to extend standard DNV-ST-B203 with three additional AM technologies: Laser Beam Directed Energy Deposition (DED-LB), Electron Beam Powder Bed Fusion (PBF-EB), and metal Binder Jetting (BJT). As well as focusing on building new parts with these technologies, the consortium also looked at hybrid production, repairing or remanufacturing parts using AM. To this end, using Directed Energy Deposition to build features on an existing substrate was included in the project.

Fig. 1 Finished impellers manufactured by PBF-EB, one of several metal AM technologies evaluated in Phase II (Courtesy Eureka)

DED-arc: crank disc (Kongsberg Maritime)	DED-LB: wear ring (Saudi Aramco)	PBF-EB: impeller (Equinor)	BJT: fuel swirler (Siemens Energy)
			
This is a component in a controllable pitch propeller. Conventional crank discs are made in forged steel. Reasons for selecting AM: • Reduce cost • Reduce lead time • Improve sustainability • Improve possibilities for repair	The ring delivers wear and galling resistance and corrosion prevention. Conventional rings are machined from bar stock. Reasons for selecting AM: • Eliminate need to store various sizes for bars • Reduce material waste • Reduce manufacturing time	Part of a centrifugal pump. Compared to traditional manufacturing (casting), AM is selected to: • Reduce lead time • Rerate/customise existing pumps • Reduce stock levels • Improve quality	The fuel swirler is part of a fuel system for a turbine. It is a highly loaded critical part with a complex geometry. Reasons for selecting AM: • Lower cost alternative for current PBF-LB technology

Table 1 Overview of the technologies evaluated and the applications used

"The guideline DNV developed includes the end-to-end process from design, material and build process qualification, up to production, post-processing and part qualification."

The project delivered new insights into the capabilities of AM for the production of high-quality spare parts for the energy and maritime industries. The project also showed that hybrid production, as well as conducting repairs with AM, is a realistic, cost-effective and environmentally friendly manufacturing option. The results from the joint industry project will be incorporated in a new edition of DNV's standard for the Additive Manufacturing of metal parts, DNV-ST-B203, which is due to be published later this year.

ProGRAM JIP Phase II: Project set up

Similar to the setup of Phase 1, ProGRAM JIP Phase 2 organised a series of practical production cases where the companies manufactured parts to ensure the quality, completeness, and practicality of the developed guideline, before being incorporated into an extension of standard ST-B203. An overview of parts and their users is given in Table 1, showing the technologies involved and the initial reason for selecting AM to manufacture the parts.

The guideline DNV developed includes the end-to-end process from design, material and build process qualification, up to production, post-processing and part qualification. The standard gives the user a framework with guidance notes for ensuring a high-quality process. In the project, all these steps are carried out to ensure the practical viability of the established requirements, and to capture valuable insight that can be included as guidance in the standard. Over the following pages the most significant learnings are highlighted.

Design and production set-up

Electric Arc Directed Energy Deposition (DED-arc), often referred to as WAAM

With regards to the DED-arc process, a dramatic cost reduction was experienced when applying as a hybrid solution for the production

Fig. 2 The completed DED-LB wear ring, with the as-built ring shown inset (Courtesy NMIS and Eifeler - Voestalpine)

of a crank disc (Table 1, column 1). Conventional crank discs consist of a disc with a pin on top, manufactured through the forging and machining of often relatively expensive steels or alloy. Additionally the conventional process is complex and creates waste, which is reflected in the price of the product. When taking a low cost, readily available steel base plate, and using DED-arc to add the critical feature (the pin), the use of high-cost material, and material waste, was reduced.

As a best practice it is recommended that the transition zone between the base material and added feature should be moved outside the high loaded area. Using low-cost, normal-grade steel in the low loaded part, and using high-grade material only in the loaded part delivered by hybrid design, DED-arc technology was capable of manufacturing efficiently and cost effectively, provided that a good metallurgical compatibility exists between the substrate, an AM feature that needs special attention.

In this project, we used two different DED-arc production technologies: metal inert gas (MIG) and plasma arc welding (PAW). In terms of the deposition strategy, it was found that oscillated strategies reduced production time. The thickness of the base material is a factor to be accounted for with regards to the deposition strategy and the qualification process. However, good quality levels were realised for both technologies. The technology should be selected based on the type of application and material used, e.g. MIG allows for better accessibility for repair applications.

Repair and remanufacturing with DED-arc/WAAM was also subject to investigation during the project. It was found that different parameters are demanded for the repair process than for a new part build process, due to variation of base material. Omnidirectional trajectories make programming easier for repair application. See also the box at the end of this article for the benefits of DED-arc for repair.

Laser Beam Directed Energy Deposition (DED-LB)

The wear ring with hard overlay, made by DED-LB, has a simple part geometry without complex features (Fig. 2 and Table 1, 2nd column). Despite this simplicity, several iterations were needed to produce a sound, semi-near-net shape geometry. Additional layers had to be added to provide machining allowance. A near-net shape approach proved to be difficult to build as a first-time-right production, as this technology is prone to produce drop-offs from the desired end-contour.

The round geometry and limited thickness required detailed process parameters along the build height. Build process trails were developed using an integrated 3 + 2 axis hybrid DED-LB machine. The use of high-quality material also proved to be of utmost importance. Plasma atomised, spherical morphology 45–150 µm PSD Inconel 625 powder was required to obtain the desired process parameters.

Electron Beam Powder Bed Fusion (PBF-EB)

The experience gained in ProGRAM JIP I, where the same impeller was manufactured using Laser Beam Powder Bed Fusion (PBF-LB), proved to be very useful. Using this experience, first-time-right, cost-effective design and production of the impeller was achieved using PBF-EB (Table 3, 3rd column).

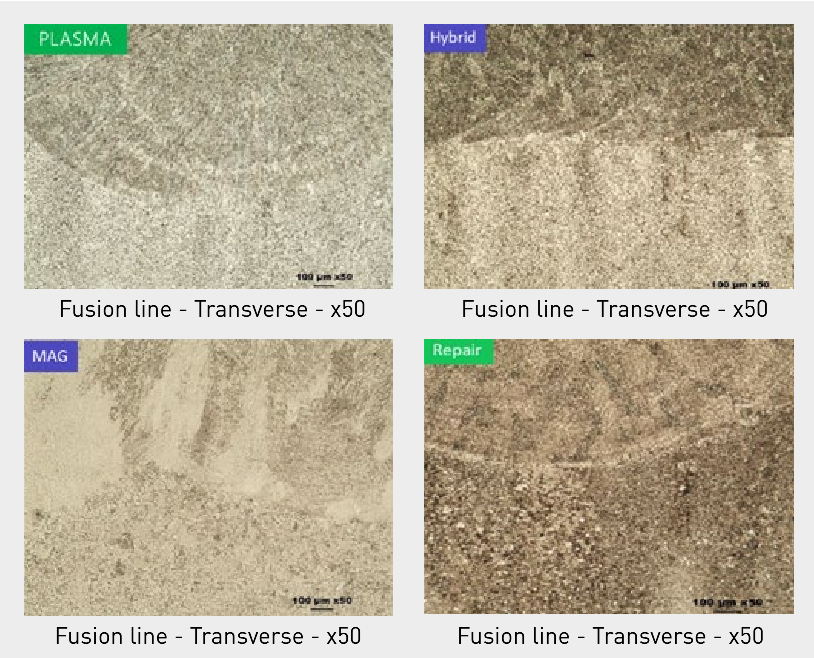

Fig. 3 Fusion results, on the left from Addilian and on the right from Guaranteed. Both DED technologies were able to produce hybrid new parts and repaired parts with excellent quality, meeting all specified criteria (Courtesy Addilan & Guaranteed)

For the design and production process, it was found that it is practical to build the test specimens and the final parts simultaneously in the same build envelope. In the case of small series, or when slightly adjusting the features of the part, this is considered to be quite convenient for end-users.

Binder Jetting (BJT)

The original design of the swirler for production by PBF-LB proved to be inappropriate for manufacturing via the BJT process, and attempts to use this design with BJT resulted in cracking/chipping during powder removal. Therefore, a significant redesign was required to meet the specifications set by Siemens in terms of functionality and mechanical properties (Table 1, 4th column).

Binder Jetting requires multiple process steps, including sintering and machining, for the component to exhibit the desired metallic properties. Thus, for qualification of the production set-up, this full process, including post-processing and machining, needed to be qualified. Compared to the other three AM technologies in this project (DED, PBF-LB and PBF-EB) this proved to be a more elaborate and time-consuming qualification process in this project.

Conclusions on design and production set-up

To achieve good results with Additive Manufacturing, the design and the build parameters need to be designed for the part and the build process. Selecting the correct technology in view of the application foreseen is fundamental, and even seemingly simple geometries demand for close monitoring of the design and build strategy. Finally, near-net shape is not always possible without careful optimisation of parameters, and extra layers for robustness and machining may add flexibility to the process.

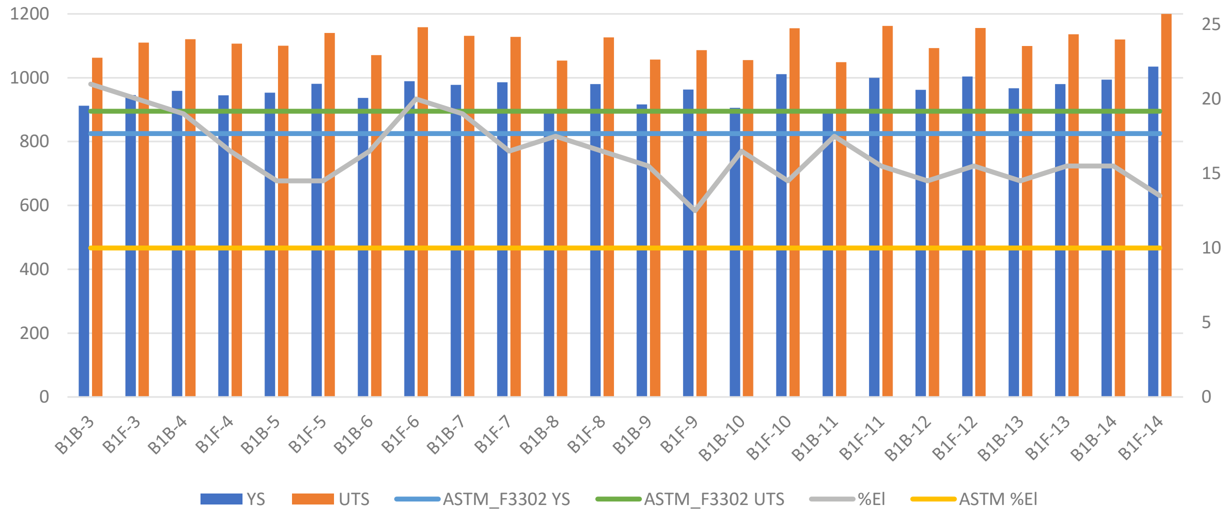

Fig. 4 Static tensile tests for the PBF-EB impeller meeting all ASTM F3302 requirements

Production and post processing

Some of the main learnings of the DED-arc and PBF-EB technologies are detailed here. The production and post processing for DED-LB and BJT is still work in progress at the time of writing of this article.

DED-arc

The main variables to control in the wire and arc DED process are the heat input, the wire feed speed and the inter-pass cooling temperature, which could be controlled using a pyrometer.

This technology was tried in a new build production case and a part repair case. The set-up time for the new part and the repair case were similar, and the execution time and heat treatment were quite similar in both applications. However, this may not always be the case, depending on the degree of machining, surface preparation and post-processing needed. An issue in need of extra attention is the mass of the feature compared to the mass of the build plate. As in this case the feature (the pin) was quite small, there was a large heat sink effect to deal with. For CNC-based systems, MIG offers less production time than plasma, thanks to its higher deposition speed and bidirectional deposition possibilities. Robot-based plasma systems would also allow for bidirectionality.

Two partners in the JIP (Guaranteed and Addilan) had DED-arc technology installed in house and took part in the production case studies. The achieved results showed that both DED-arc/PAW and DED-arc/MIG technology was able to produce hybrid new parts and repaired parts with excellent quality, meeting all specified criteria. Good fusion was observed, and no cracks were detected in the fusion zone (Fig. 3).

PBF-EB

Regarding the impeller, dimensional tolerances are critical to meet functional tests. After PBF-EB production, a slight warping and some pores were found, leading to small deviations on the openings of the flanges. They had no impact on pump performance, but were of a cosmetic nature. All mechanical properties resulting from PBF-EB conformed the requirements in ASTM F3302 standards, despite the high oxygen content in the initial powder material (0.3 wt.%) (Fig. 4). Hot Isostatic Pressing (HIPing) proved to be the perfect solution to reduce porosity and improve mechanical properties. Another learning was to rethink the set-up of support structures.

Although the part's geometry was quite complex (Fig. 5), there were no significant issues with powder removal or part placement in the build. Due to the geometry of the part (the limited key slot openings), the partners elected to use 5-axis machining instead of turning for the final machining of the part.

During the post-processing, the effect of various finishing procedures was tested (as-built, sand blasting, chemical finishing and hirtisation) to smoothen the surfaces and the edges. The finishing applied did not result in dramatic performance differences. This leads to the conclusion that as-produced parts might be good enough to be taken into production, which could lower manufacturing costs considerably.

Fig. 5 Finished PBF-EB impeller (Courtesy Equinor, BMT and Eureka)

"The achieved results showed that both DED-arc/PAW and DED-arc/MIG technology was able to produce hybrid new parts and repaired parts with excellent quality, meeting all specified criteria."

Using AM for repair in oil & gas

Findings from Guaranteed and Kongsberg

Repairing or remanufacturing parts is an alternative with both economic and sustainability benefits: less material is needed and thus less material is wasted, compared to shredding the old part and completely building a new part. Environmental friendliness is one of the original promises of AM.

In this project, the real life possibility of repair by AM was proven, and the variance of the environmental impact between a conventionally made part, a hybrid DED-produced part and a DED-repaired part assessed. Hybrid DED means the crank disk was produced using a standard disk, machining away some material and building up the pin on the disk using DED-wire. Repair took place by taking a damaged crank disk that was supplied by Kongsberg, machining away the damaged part, filling cracks and pores and building a pin on top.

The group produced two new crank disks (one at Addilan, one at Guaranteed) and repaired two used crank disks (one by Addilan, one by Guaranteed). The results presented are based on the Guaranteed build jobs and Kongsberg Maritime information on the conventionally produced parts.

In terms of part quality, both new builds and repaired parts showed good results. With regards to sustainability, the Hybrid DED-wire process is already beneficial compared to conventional production:

- Hybrid DED allows a reduction in energy consumption of approx. 50%
- Hybrid DED allows a reduction in CO_2 emissions of approx. 33%

But when comparing the repair by DED-wire to conventional production, the benefits are even more significant:

- DED repair allows a reduction in energy consumption of approx. 95%
- DED repair allows a reduction in CO_2 emissions of approx. 90%

Economic benefits can be obtained on many aspects: less material, reduced lead times, less energy and fuel costs, lower distribution, and warehousing costs. Cost benefits are highly part and volume specific and could range from 20–70%. The significantly reduced climate impact of the repaired parts, compared to conventional and DED new-build parts, together with the economic benefits, makes repairing or remanufacturing parts a realistic option (Fig. 6).

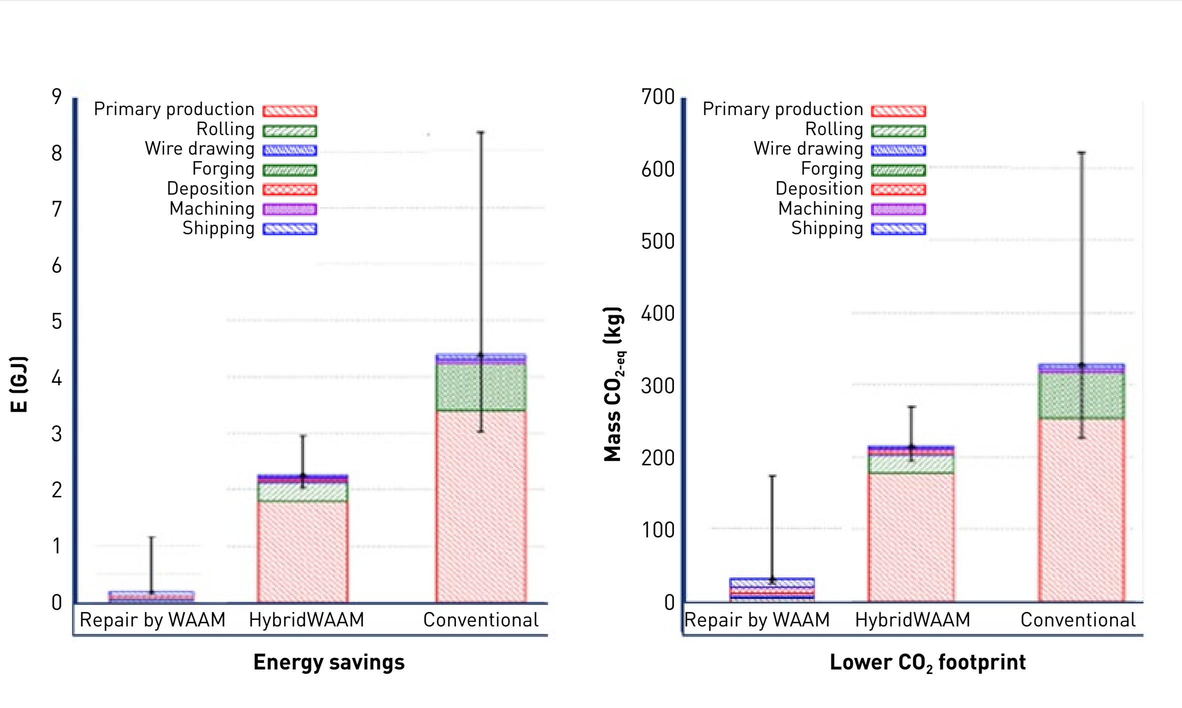

Fig. 6 Life cycle sustainability assessment of repair through wire and arc DED for the hybrid crank disk. Note that the figures above use the term WAAM (Wire Arc Additive Manufacturing), known as DED-arc in ISO/ASTM terminology (Courtesy Guaranteed)

Overall conclusions on production and post processing

Temperature management in production (DED-wire) and heat treatment during post-processing (PBF-EB) have a large impact on the final quality of the parts produced. A high number of parameters determine the final quality of the part, but starting material quality is also a decisive factor for the final quality of the part.

Conclusions

The ProGRAM JIP Phase II was launched to expand and improve DNV-ST-B203 with the incorporation of four additional AM technologies into the standard. This effort is designed to support companies in the energy and maritime sectors that want to make use of AM as a flexible, cost-effective and environmentally friendly production method. The guidelines developed in this JIP will be incorporated into an extension of the standard, which DNV expected to make available by summer 2022.

Furthermore, based on the results of this project, it can be concluded that two AM technologies (wire and arc DED and PBF-EB) are ready to be used for the manufacture of high-quality parts, be they spare parts on demand or production parts. The case studies related to the two other technologies (laser beam DED, BJT) are still ongoing. Wire and arc DED also proves to be an excellent option for hybrid production, as well as the repairing or remanufacturing of parts.

When looking at wire and arc DED, the project partners observed that this technology can produce high-quality, low-cost spare parts or perform repairs or remanufacturing in a short period of time. This presents a potentially very beneficial business case, with considerable energy savings as compared to conventional manufacturing.

PBF-EB proves to deliver similar or even better quality as compared to conventional manufacturing techniques such as casting. Where it is possible to build more than one part in the same build envelope, PBF-EB delivers lower cost parts while shortening the lead time by at least 10–30%. In our case, the lead time was reduced even further, from twenty-four weeks to just four weeks. PBF-EB, then, is a true competitor to conventional manufacturing and asks for further investigation using new use-cases.

Laser beam DED can be a flexible and cost-effective technology, also for repair purposes. But the design used in this project's case studies, a round geometry with a hard overlay, presented some challenges for this technology. In general, laser beam DED is recognised as a suitable technology for more straightforward repair activities.

BJT involves a more complex workflow that required a fundamental redesign of the part for the process to ensure the best functionality and mechanical properties. The design for BJT should take into account the full production cycle next to the build strategy, including the post-process steps (sintering and machining).

In mid-2022, DNV will follow up on the findings and looks to further expand the scope of standard ST-B203, with a new project: ProGRAM JIP Phase III. This project will focus on further improvement of the guidelines for the already included technologies and establish the tools need for using AM parts in relevant design applications in the energy and maritime industry, to further enable adoption of AM for a leaner and greener future.

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Future participation

If you want to be at the forefront of AM, do not hesitate to touch base with us. We invite you to participate in our efforts to make AM widely available as a high-quality manufacturing technology, that lives up to its environment friendly promise.

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Multi-material metal parts by Powder Bed Fusion: New application opportunities

As product developers become more and more aware of the possibilities of metal Additive Manufacturing and the design freedom it offers, metal Laser Beam Powder Bed Fusion (PBF-LB/M) has established itself for series applications in numerous industries. One novel capability of PBF-LB/M which has yet to be fully explored is the production of multi-material metal parts, which would offer huge new potential for designers in many industries. Prof Dr-Ing Christian Seidel looks at methods and solutions for the AM of parts consisting of two arbitrarily distributed metal alloys and presents use cases with the potential for series production by multi-material PBF-LB/M in the near future.

Additive Manufacturing has become increasingly important for production technology in recent years. In particular, metal Laser Beam Powder Bed Fusion (PBF-LB/M) has already made it into series production in industries such as aerospace, medical, and tool making, as well as general mechanical and plant engineering. Product developers appreciate the possibilities of Additive Manufacturing processes because of the high degree of design freedom they offer – for instance, the topology of a component in the force flow can be optimised according to the loads that occur, and the result can be additively manufactured more or less directly. A well-known example of this is the AM of titanium alloy brackets for aircraft. The possibility of function integration has also been exploited in numerous industries, since solid-state joints or porous structures can be manufactured in a targeted manner. Until now, however, these components have always been made from a single material.

A closer look at the industrial use of Additive Manufacturing reveals that series production has typically been realised in high-tech applications. This is not only because maximum design freedom is desirable in high-tech fields to achieve optimised device performance, but also because higher manufacturing costs are more likely be acceptable in such applications. The reason for this is that production costs can be compensated for, or even overcompensated, in a short time due to the ongoing savings achieved during the use of the component. Hence, a return-on-investment calculation becomes possible in which the increased cost of producing a component is exceeded by the saving achieved in a few years, months or even days. If, for example, a valve block is not manufactured conventionally by means of milling and drilling, but flow-optimised via Design for AM (DfAM), flow losses can

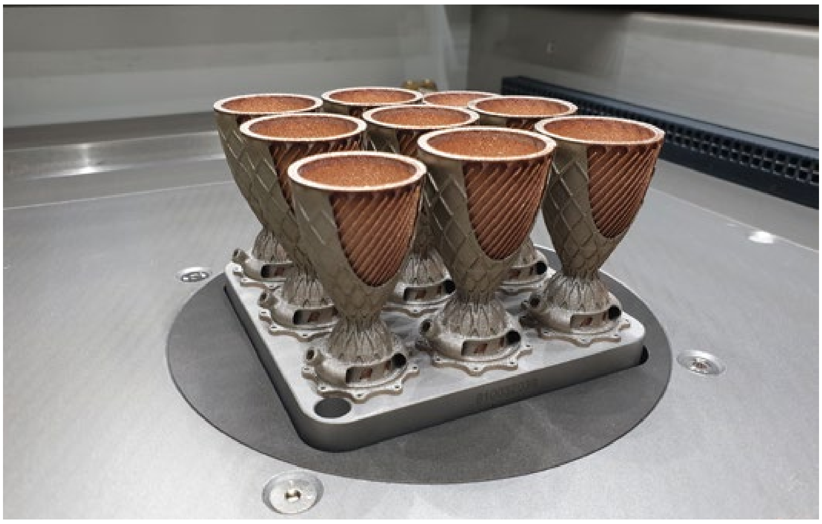

Fig. 1 Nickel-copper combustion chamber demonstrator parts on the build platform (Courtesy Fraunhofer IGCV)

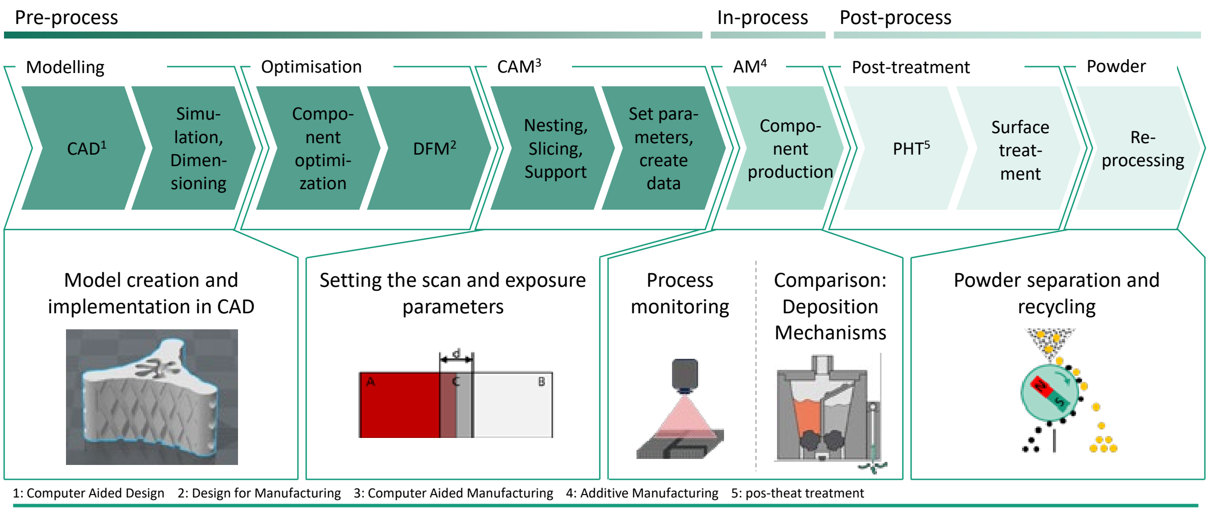

Fig. 2 Challenges of multi-material processing along a process chain (d = width of transition area)

be reduced. This may allow the use of a smaller pump in operation, thus saving not only on the investment but also ongoing energy costs. In view of the new possibilities we have seen these high-tech fields achieve using AM, it seems clear that these same fields would benefit from multi-material Additive Manufacturing.

As defined by ISO/ASTM TR 52912 [4], a multi-material component is characterised by the presence of at least two different materials that are firmly bonded together. The production of 2D multi-material components, in which a material change takes place in the direction of the build process between successive layers, can already be carried out today on most commercially available PBF-LB/M machines. To do this, a component is additively manufactured with 'material 1' up to the desired height for this material. Then the remaining material 1 powder is removed from the machine and, if necessary, the filter in the protective gas flow and the corresponding seal changed to fit 'material 2.' After this cleaning and setup process, Additive Manufacturing continues with material 2, with the previously manufactured part structure serving as the base body and replacing the typical build platform. In summary, additively manufacturing 2D multi-material parts in the improved manner described is comparatively time consuming, but it is possible on typical PBF-LB/M machines thanks to a manual material change. For the manufacturing of a 3D multi-material component, state-of-the-art PBF-LB/M machines cannot be used, because both materials must be present within one layer. Accordingly, a 3D multi-material component is characterised by the fact that the material can be randomly distributed in the volume.

From mono-material to 3D multi-material PBF-LB/M

For the production of 3D multi-material components by means of PBF-LB/M, it is necessary to push the capabilities of commercially available PBF-LB/M machines on the software and hardware side and to adjust the typical process chain in every step, as shown in Fig. 2.

Pre-process

Firstly, the material distribution needs to be defined by the designer. This can be done either by applying the designer's own expertise or using simulation tools (although a state-of-the-art review has revealed that the optimisation of material distribution within a part is not a standard feature of established Computer Aided Design [CAD] tools). Once the desired material distribution is known, three sub-models of the part need to be generated for the AM process, as shown in Fig. 3. For each material section, a separate model (sub-model) is needed in order to allow for a suitable parameterisation for solidification within PBF-LB/M. Fig. 3 shows a part containing a tool steel (1.2709) and a copper alloy (CuCr1Zr).

In addition to the sub-model generated per material, a third is required that geometrically describes the transition zone between materials. For each of these partial models, specific parameters are usually required for the build process in order to ensure that the materials produced are of sufficient quality. This means that, for example, laser power, scan velocity and hatch distance might vary for each material region in order to obtain high relative density values and crack-free material. This is due to the presence of different material characteristics in terms of powder properties, conductivity and absorptivity, amongst other factors. Furthermore, differences in part quality may be found depending on the exposure sequence; Fig. 4 shows an example for the material combination of tool steel (1.2709) and copper alloy (CuCr1Zr) shown in Fig. 3.

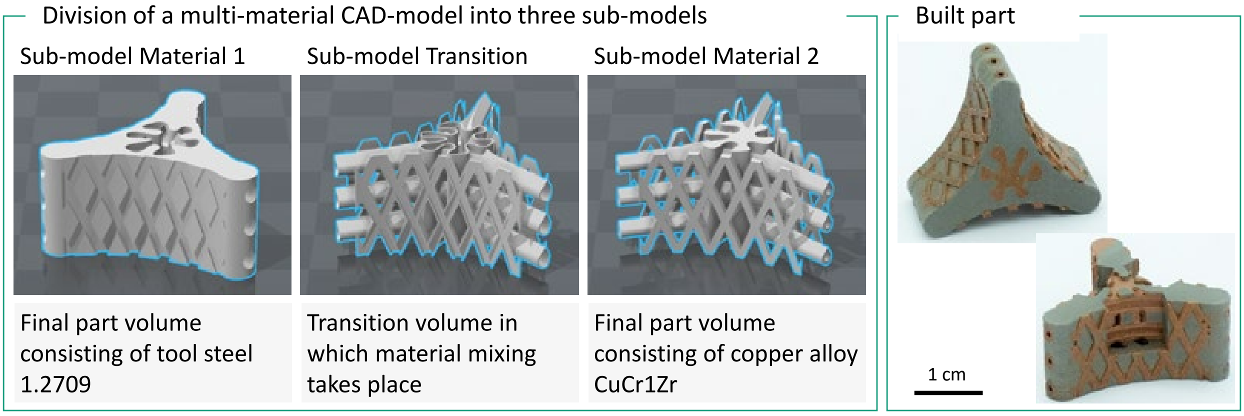

Fig. 3 Part modelling for multi-material PBF-LB/M: each material section requires its own sub-model to allow subsequent assignment of parameters

In-process

The most significant challenge in the multi-material PBF-LB/M process is to implement powder recoating for multiple materials. Typical recoating mechanisms do not provide for the application of two powder materials within one build job. For that reason, both the machine software and hardware need to be modified in order to enable recoating with multiple powders. Fig. 5 provides a view inside the build chamber of an SLM Solutions SLM® 280 2.0 machine at the Fraunhofer IGCV laboratory in Augsburg, Germany, that is capable of producing multi-material parts. The mechanism used within this machine follows the principle developed by Fraunhofer IGCV [1]. In short, a double-chamber recoater is used to provide two powder materials within one build job. In addition, the coating axes are equipped with a suction unit, which is able to remove a number of powder layers. The multi-material cycle thus follows these steps:

1. Material A is applied in layer n and solidified according to its CAD design
2. Unsolidified powder material A is removed by the suction unit
3. Material B is coated in layer n and solidified according to its CAD design, unsolidified powder material B remains in the build chamber
4. The build platform is lowered by one layer height and step 1 is repeated for layer n+1

Following the described principle in steps 1–4, material B remains in the build chamber whereas material A is constantly extracted by the suction unit.

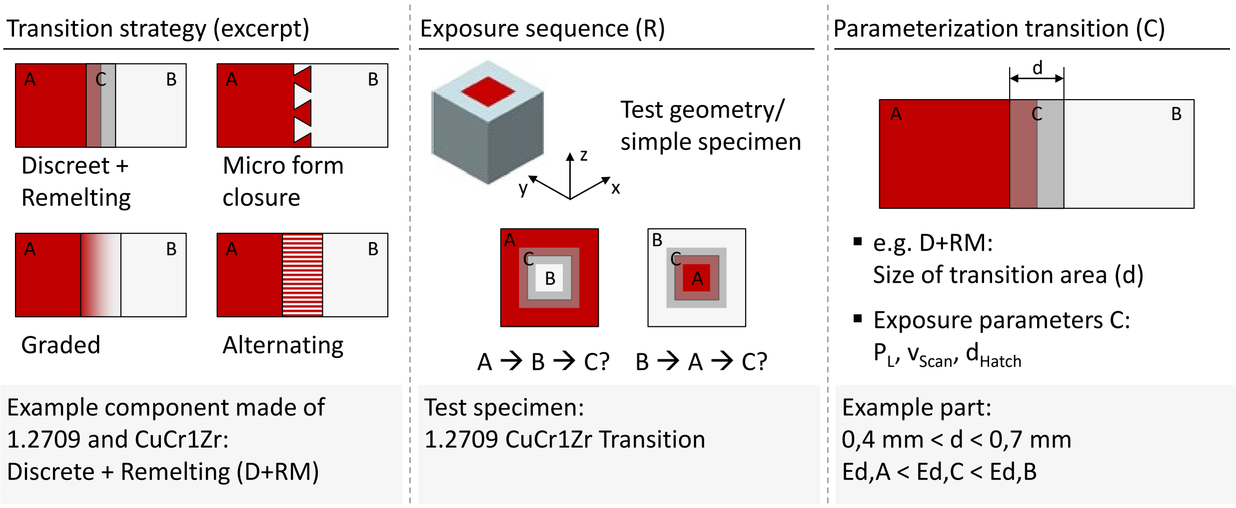

Fig. 4 Parametrisation of multi-material parts with a focus on the transition zone (C) between two specific materials A and B. Key: Ed = Energy density, P_L = Laser Power, v_{scan} = Scan velocity, d_{Hatch} = Hatch distance

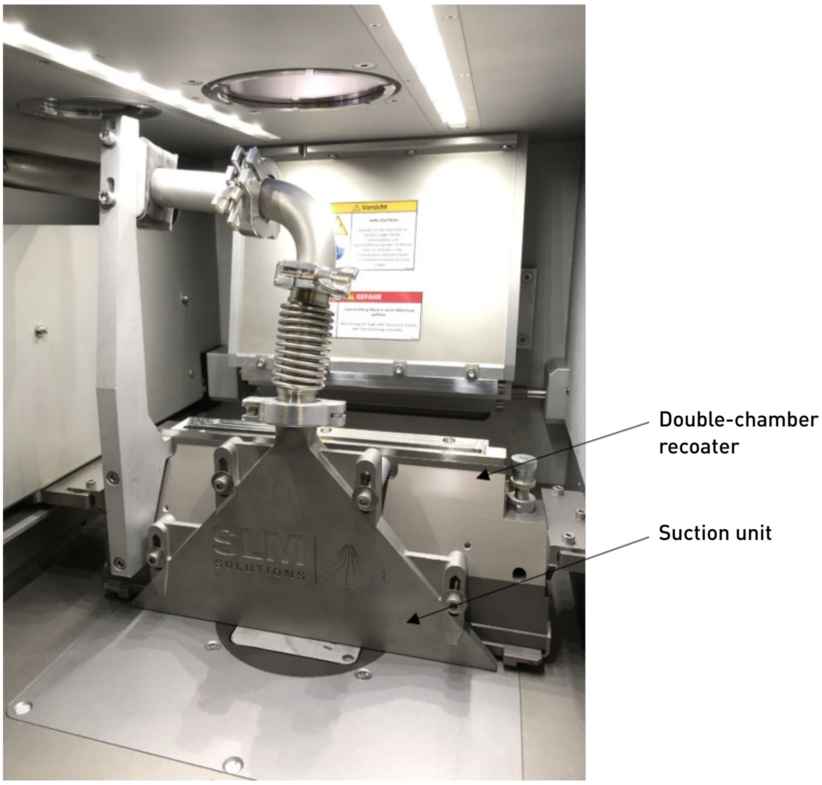

Fig. 5 View inside a multi-material-capable SLM® 280 2.0 machine at Fraunhofer IGCV laboratory Augsburg (Courtesy Fraunhofer IGCV)

Theoretically, it is sufficient to remove exactly one layer of powder. This would completely remove material A from the build chamber and only material B would be left. Also, only material A would be left in the suction device. However, it was found that the current state of the art does not allow powder layers to be removed so accurately. The particle size distribution of the powder and the resulting particle masses, as well as the achievable uniformity of the suction device, limit accuracy and mean that, usually, three or more layer heights are suctioned to avoid contamination. Therefore, research was carried out into general principles that enable the recycling of powder mixtures, as shown in Fig. 6. Various principles are known depending on the characteristics of the utilised powder materials. For example, if one powder material has magnetic properties, but the second powder material does not, magnetic powder separation can be used. If it is possible to process the powders in different and overlap-free particle size distributions, separation can also be carried out downstream by this difference using sieves. In addition, other physical principles are available (Fig. 6), but their current suitability for Additive Manufacturing is still significantly lower than that of magnetic separation or sieving [2]. As

Post-processing

Besides the challenges already familiar in mono-material processing, such as loose powder removal from the part or support structure removal, the separation of powder mixtures is the key additional challenge that comes with multi-material processing. Within the described coating process in steps 1–4, a mixing of the two powder materials cannot be avoided. This is a result of step 2, the removal of unsolidified powder material A using the suction unit.

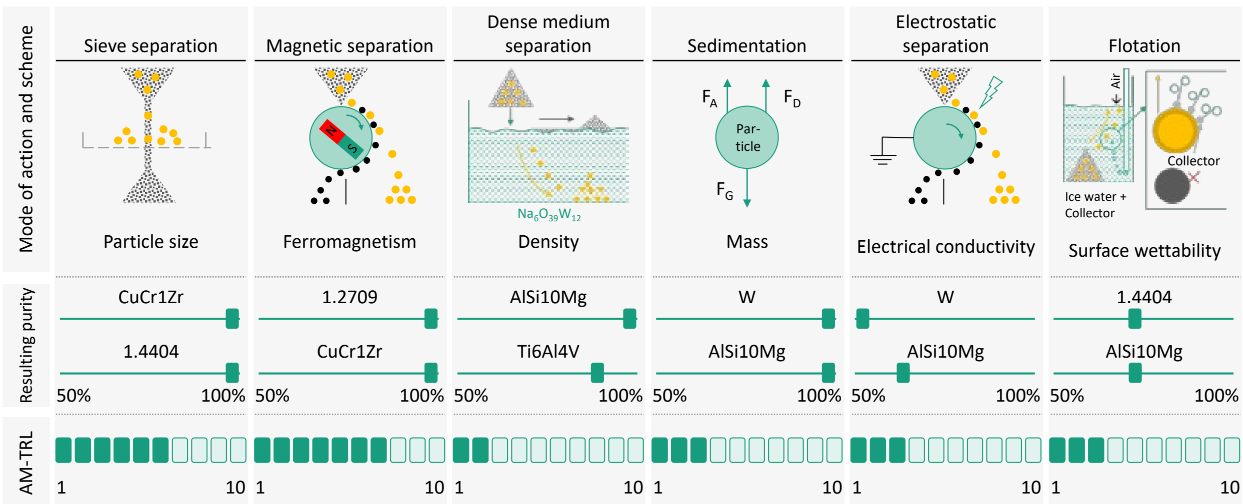

Fig. 6 Identified principles for recycling of powder mixtures (AM-TRL: Technology Readiness Level for Additive Manufacturing Application)

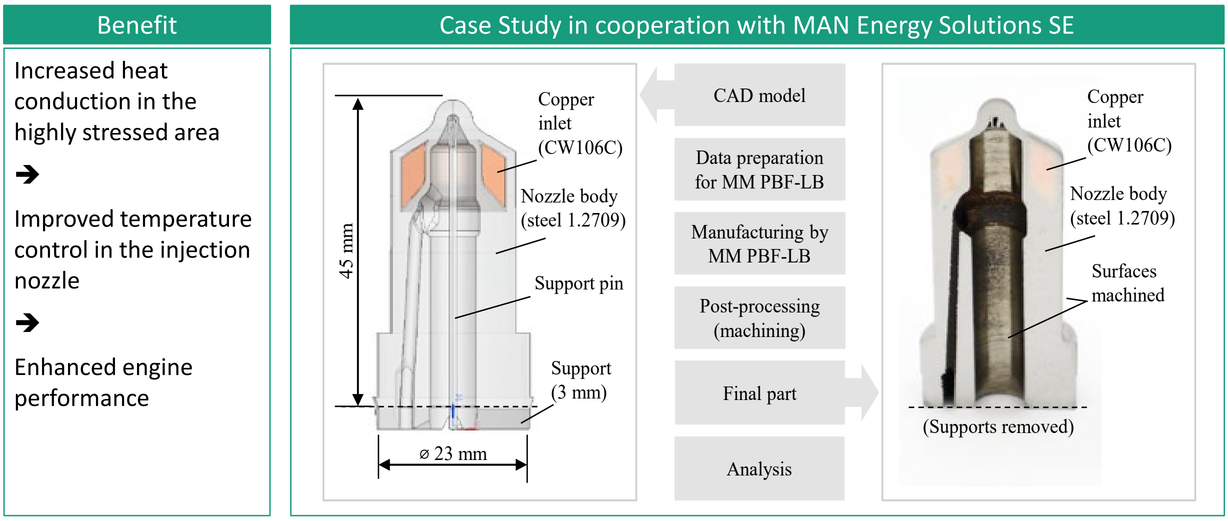

Fig. 7 Industrial use case on multi-material metal Powder Bed Fusion, an injection nozzle for large bore engines, investigated in cooperation with MAN Energy Solutions SE

demonstrated by [3], it is not always necessary to aim for a 100% separation of the powder materials in order to be able to reuse them again. The required level of purity is highly dependent on the material combination.

Industrial potential and examples of multi-material parts

Multi-material components make it possible to make optimum use of material-specific advantages depending on the component requirements. For example, a wear- and heat-resistant steel can be combined with a copper alloy with good thermal conductivity for a large bore engine application. Fig. 7 shows a use case of an injection nozzle jointly investigated by Fraunhofer IGCV and MAN Energy Solutions SE. The multi-material design foresees a copper core in the highly stressed area leading to improved temperature control in the injection nozzle and in consequence enhanced engine performance. The shown part was additively manufactured following the procedure described above.

Fig. 8 shows a section of a gear wheel consisting of two steels. The procedure was as described in steps 1–4. In this case, material 2 was a powder mixture and was deposited in layers in the peripheral area of the gear. In material 2 powder, the carbon content (C content) was increased in advance by means of a graphite admixture. This resulted in a C content of approx. 0.2 wt.% in the interior of the component (material 1,

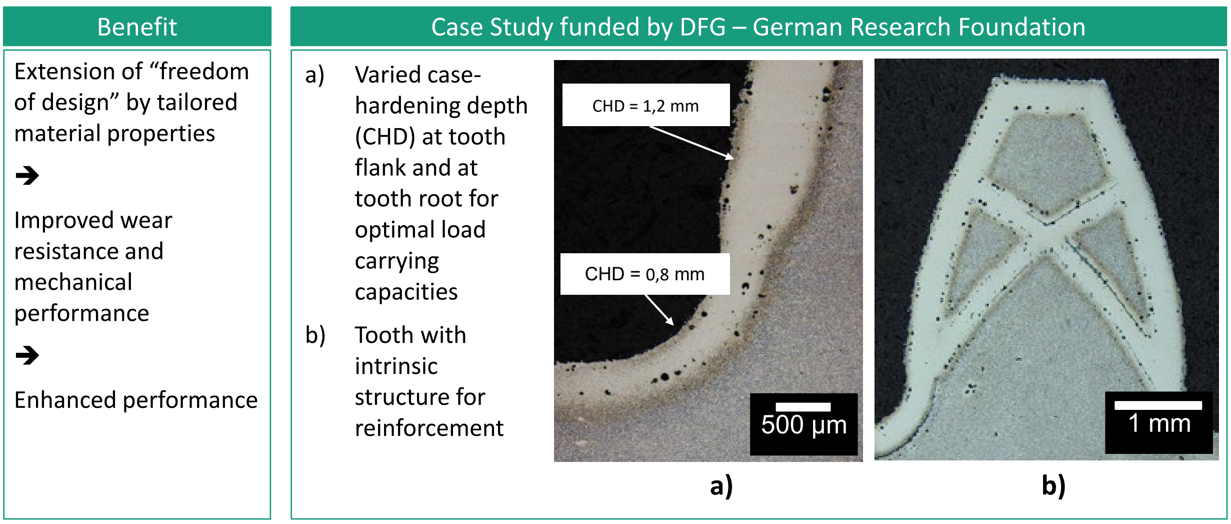

Fig. 8 Industrial use case of a gear wheel consisting of two steels, produced using multi-material metal Powder Bed Fusion, investigated in cooperation with DFG - German Research Foundation

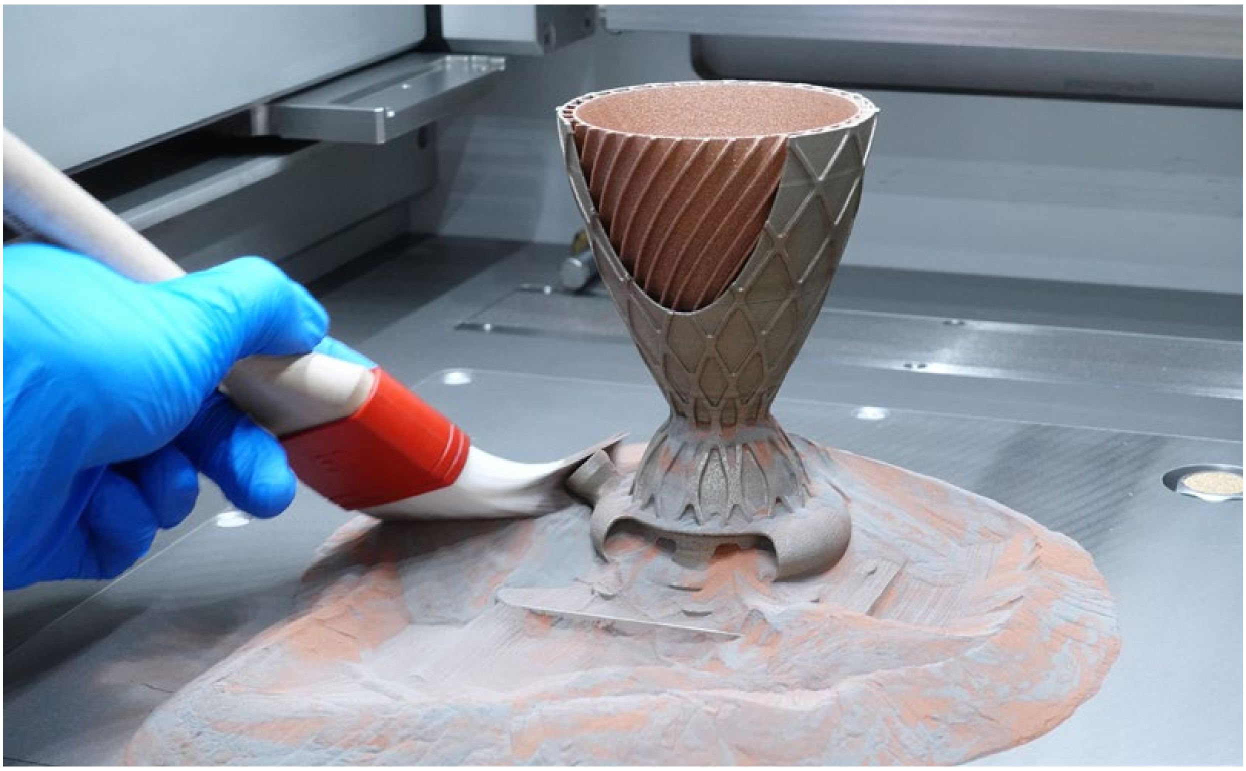

Fig. 9 Demonstrator model of a nickel-copper combustion chamber for space application during depowdering (Courtesy Fraunhofer IGCV)

1.2344, H13) and 0.8 wt.% in the rim. The diffusion of the carbon during melting and heating as a result of laser exposure led to a graded transition between the two areas. The process used allows the thickness of the edge layer to be selectively set and adjusted. This makes it possible, for example, to produce an optimum hardness profile at the tooth flank and at the same time a hardness profile in the tooth root that is optimised for load-bearing capacity. In addition, the procedure shown here can be used to create struts inside the component (Fig. 8b). Subsequent case hardening is not necessary. Only heating and quenching is required to produce a complete martensitic surface layer. The result shown here, therefore, has potential for gear manufacturing.

"This makes it possible, for example, to produce an optimum hardness profile at the tooth flank and at the same time a hardness profile in the tooth root that is optimised for load-bearing capacity. In addition, the procedure shown here can be used to create struts inside the component."

Fig. 9 is an example from the space industry. Combustion chambers are faced with high thermal loads, but also need to be as light as possible. The more performant a chamber can be built, the better for the rocket. The less mass is needed for the required thruster chamber, the more pay load can be sold to customers for the transportation to space. Therefore, increased manufacturing costs can be overcompensated by more load that can be brought to space. For these reasons, space is one of the core industries for Additive Manufacturing in general, and multi-material Additive Manufacturing in particular. In the example shown, a nickel-base alloy would serve as the heat-resistant base body of the chamber and copper-based regions are foreseen to increase heat transfer.

However, the potential for multi-material components is by no means fully described with the components shown in this article. For example, for an injection moulding application, an abrasion-resistant tool steel can be combined with a copper alloy with good thermal conductivity, significantly reducing cycle times in the production of plastic components with high aspect ratios. The combination of aluminium and copper alloys offers opportunities for cost savings in electric motor manufacturing. Furthermore, the advantage of combining a titanium alloy with tantalum can improve dental implants.

In summary, the current state of multi-material processing is mature enough to investigate industrial applications. It is now well known what can and cannot work. For example, it has become apparent that the technological readiness for certain material pairings, such as copper and steel, is sufficient to enable industrial applications. This is due to the fact that the Additive Manufacturing process itself can be mastered. Equally relevant is that with this material pairing, it has been shown that the powder materials mixed in the build-up process can subsequently be sorted with a purity of almost 100% by utilising magnetic separation. In contrast to the material combination steel-copper, the current state of the art makes it difficult to combine materials that are very similar in all respects (e.g., density, magnetisability, grain size distribution). In this case, powder separation is difficult and multi-material processing is therefore not very economical as the reusability of the powders is usually regarded as a central criterion for the economic efficiency. At the same time, however, it is reasonable to ask what advantage multi-material processing would offer in this scenario, since if materials are very similar, synergy effects are limited. The combination of metal alloys with technical ceramics also does not seem to make much sense at present, since the quality of laser-based processed ceramics (e.g., Al_2O_3) do not meet the typical requirements and processing is not very stable. However, the suitability could be demonstrated for electrically insulating (thin) structures in metal components.

Conclusion

As expected, the technology readiness level of multi-material PBF-LB/M is still lower today than that of mono-material PBF-LB/M. Nevertheless, the example of various industrial applications has shown that now is the time to transfer the topic from research to the targeted development of commercial applications. The basic feasibility has been demonstrated in all areas of the additive process chain and first industrial machinery is available on the market. For a broad industrial application, it is now necessary to address product-specific requirements. In most cases, the foundations for this are available via scientific publications. For this reason, it can be summarised that multi-material processing provides companies, especially in the high-tech segment, with an excellent opportunity for a market advantage in future series products.

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Findings from *Wohlers Report 2022*: Taking a chance on new technologies and the evolving materials mix

Getting to grips with what is really happening in our industry can be a tricky business. Thankfully market analysis is available from a number of expert sources, with the longest established being the *Wohlers Report*. Here, Noah Mostow, Olaf Diegel, and Terry Wohlers share insight from the recently published 2022 edition, including an overview of machine sales, the acceptance of a new breed of technology suppliers, the growth of service companies, and the evolving metal AM material mix.

Metal Additive Manufacturing is relatively new compared to polymer AM, but has seen consistent growth and adoption over the past decade. New applications have developed in the aerospace, automotive, health-care, and dental industries, to name just a few. Interesting application examples include heat exchangers, fuel nozzles, and tooling with performance-enhancing conformal cooling channels.

Over the past twenty-seven years, the annual *Wohlers Report* has offered insight into the state of the AM industry. The report comprises quantitative and qualitative analysis of the industry and technology for users, machine manufacturers, and material producers. For *Wohlers Report 2022*, 117 service providers, 114 AM machine manufacturers, and twenty-nine third-party producers of materials provided information and data on the AM industry. During the data gathering process for *Wohlers Report 2022*, companies were approached for information about their experiences in the 2021 calendar year.

The information gathered included growth/decline figures, information on sectors adopting AM, and a wide breadth and depth of other detailed information.

For this article, the principal authors of *Wohlers Report 2022* have highlighted some of the key takeaways from the report. Among them are the fact that 'hot' sales of metal AM machines have cooled to an extent over the past three years. The number of metal powder producers has also grown, while buying trends have shifted.

Metal AM machines level off

Research for *Wohlers Report 2022* indicates that the number of metal AM machines sold every year has plateaued since 2018. Fig. 1 shows the number of such machines sold each year by companies around the world. Wohlers Associates saw a decrease in the number of machines sold in 2020, inevitably due to the impact of the COVID-19 pandemic. However, from 2018 to 2021, the average number of

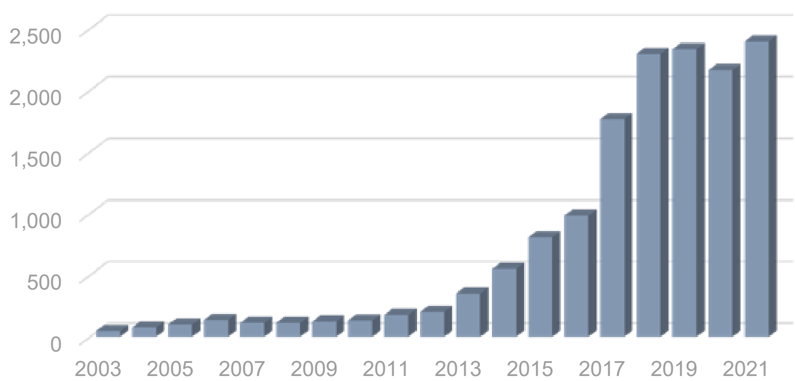

Fig. 1 Number of metal AM machines sold worldwide from 2003 to 2021 (Wohlers Report 2022)

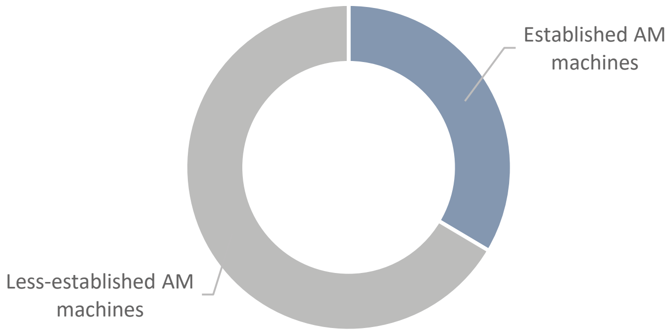

Fig. 2 Segmentation of 2021 AM machine purchases from established or less-established companies (Courtesy Wohlers Report 2022)

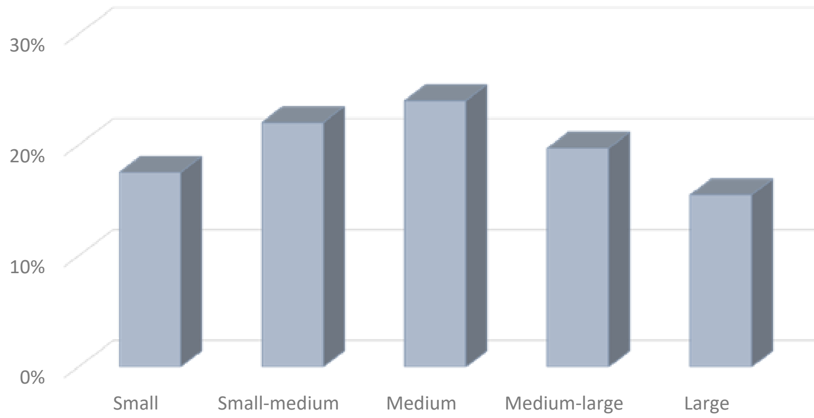

Fig. 3 Revenue growth of service providers in 2021 segmented by number of employees (Courtesy Wohlers Report 2022)

metal AM machines sold has been in the range of 2,350 units per year. The effect of the pandemic may, of course, have continued to impact sales growth 2021.

The metal AM industry is strong and growing, a primary factor driving the development and commercialisation of new metal AM machines. Even so, these efforts do not appear to have contributed to an increase in the number of machines sold. This may well change as the industry continues to rebound and government initiatives focus on creating robust supply chains with the help of AM.

For companies entering the metal AM industry, research for *Wohlers Report 2022* shows that many are purchasing machines from less-established machine manufacturers. These machine manufacturers are typically relatively new to the AM industry, and some are startups. Established companies include 3D Systems, EOS, Renishaw, GE Additive, SLM Solutions, and others. Fig. 2 shows the percentage of metal and polymer AM machines purchased from established versus less established machine manufacturers by 117 service providers worldwide.

This is the second consecutive year in which service providers purchased more machines from less-established machine manufacturers. It suggests they are willing to accept some risk by buying less developed platforms. Potential benefits include lower cost machines with features they may not otherwise get if buying a similarly priced alternative from an established manufacturer. Metal AM machines are typically expensive, so buying from new manufacturers shows an increasing level of trust in AM.

Growth is not uniform

The AM industry is made up of varying sizes of companies. In preparing *Wohlers Report 2022* the authors asked companies, for the first time, for the number of employees they have. Focusing specifically on the 117 service providers who responded, the initial hypothesis was that AM service provider growth would be uniform regardless of size. Surprisingly, as seen in Fig. 3, small companies of less than twenty and and large companies greater than 250 grew the least. Medium-sized companies (50–100 employees) had the largest growth average of 24%.

As companies grow larger, they become more bureaucratic with structures that can make them slower to react and innovate. When reviewing the number of new products introduced each year by large companies, they are roughly the same number as for a company of 20-100 people in size. It is all too easy for large companies to be hindered in the development process by bigger teams and additional bureaucracy, limiting their ability to move quickly.

Growing powder product lines

For metal Powder Bed Fusion (PBF) in particular, powder production can be expected to grow in step with the number of machines sold. As of May 2022, Wohlers Associates was tracking sixty-nine active third-party producers of metal powders. This excludes AM machine manufacturers selling their own branded powder. By comparison, Wohlers Associates was tracking forty-six producers in 2018.

A growing number of producers of metal powders is good for the industry. Competition often brings new or more efficient ways of producing quality powders while lowering prices. Currently, the cost of powders for metal AM can be many times higher than a similar metal produced for conventional manufacturing.

One surprising finding from *Wohlers Report 2022* is the shift in the types of alloys that are profitable among service providers. Fig. 4 shows the most profitable materials in 2020 and 2021, according to service providers. In 2021, 17-4PH stainless steel saw the largest growth as the most profitable material.

In the two charts, nickel alloys include Inconel 625 and 718. The growth in nickel alloys may be attributed in part to the aerospace industry, which has been adopting this material for launch vehicles. For example, Launcher, a California startup, is using the material to produce propellant tanks. Other specialised alloys not shown in the chart include copper alloys, with one example being copper-chromium-niobium, classified as GRCop-42 by NASA, and developed specifically for aerospace applications.

Post-processing costs

Post-processing represents the steps taken after the completion of an AM build to achieve the desired final properties and tolerances. This includes powder/support material removal, heat treatment, machining, and surface finishing. Wohlers Associates has been tracking the breakdown of how much companies spend on pre- and post-processing as well as the building of parts. Fig. 5 shows the historical trend of metal AM since 2017.

Many would assume that with time, and an increased understanding of the process, combined with advancing technology, the cost of post-processing would decline. It has not. The increasing cost could be

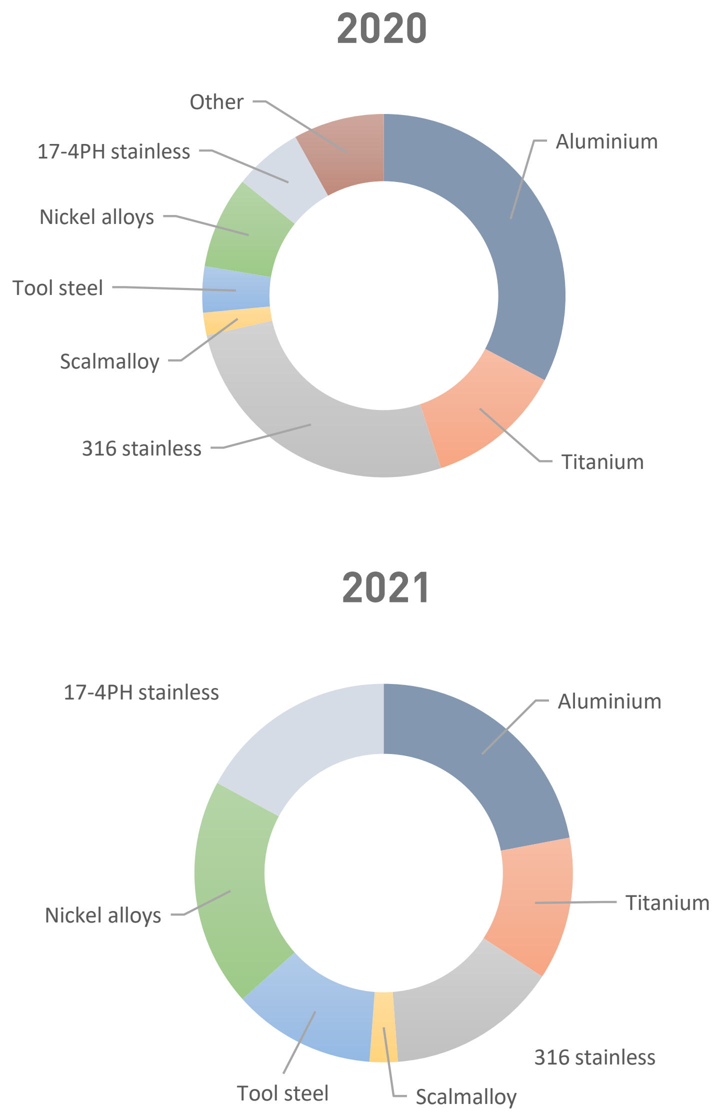

Fig. 4 Most profitable materials in 2020 (top) and 2021 (bottom) among service providers (Courtesy Wohlers Report 2022)

"One surprising finding from Wohlers Report 2022 is the shift in the types of alloys that are profitable among service providers. Fig. 4 shows the most profitable materials in 2020 and 2021, according to service providers. In 2021, 17-4PH stainless steel saw the largest growth as the most profitable material."

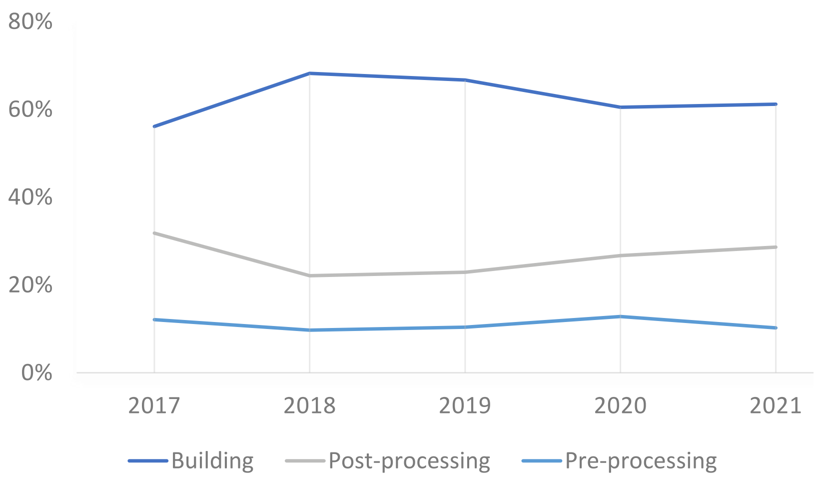

Fig. 5 Cost breakdown evolution in 2021 of metal AM parts by build, and pre- and post-processing (Courtesy Wohlers Report 2022)

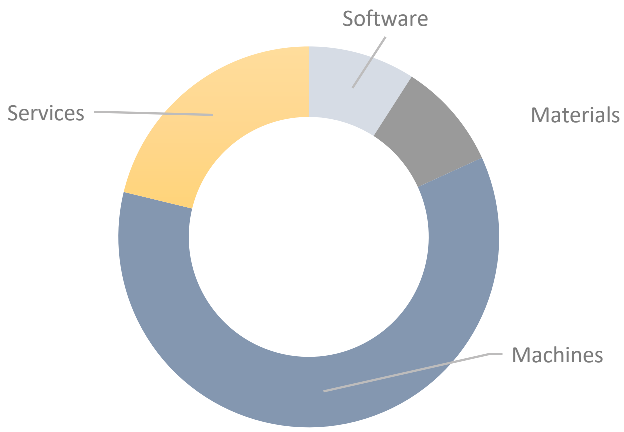

Fig. 6 Investments in AM in 2021 segmented by company type (Courtesy Wohlers Report 2022)

due to additional requirements in the aerospace, defence, healthcare and energy sectors. The removal of powder and support material and the need for high-quality surfaces add to the expense.

As more automation methods and hardware solutions enter the market, we may see the cost of post-processing decline for some applications. This would be a welcomed change, especially as production quantities increase. A reduction of manual labour while increasing standardisation could help more than anything.

Increase in investments

Wohlers Report 2022 tracks companies that receive funding, whether through private or public investments. In 2021, metal AM companies including 3D Metalforge and Freemelt raised millions of dollars in initial public offerings. Titomic, an Australian company, raised $6.6 million through a secondary offering on the Australian stock exchange. A large player within AM's aerospace sector, Velo3D, raised $274 million by going public through a merger with a special purpose acquisition company (SPAC) and a private investment in a public entity.

The investments in the wider AM industry include AM machines, services, software, and materials. Fig. 6 shows that AM machines accounted for the most investment by far. The AM industry will benefit the most if all four areas receive strong investment and development over the coming years.

Conclusion

The metal AM industry continues to develop impressively. Even so, it faces challenges, such as reducing costs and increasing adoption in the automotive sector. New companies entering the metal AM market see the opportunities but also understand that they face fierce competition. The technology produces parts that create opportunities that were previously impractical or impossible. Investments in AM continue to expand, with an interesting number of companies going public in 2021. With so much activity and compelling use cases, Wohlers Associates sees a great future for metal AM.

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The challenge of grain size: X-ray powder diffraction analysis of parts made by metal AM

X-ray powder diffraction (XRPD) has long been a powerful tool in metallurgy, but its unsuitability for parts with large grain sizes has made its use for the analysis of metal additively manufactured parts a challenge. In this article, Dr Scott Speakman, Malvern Panalytical, reports on a study in which specimens of soft magnetic Fe-Si steel were made by PBF-LB using a variety of raster and annealing strategies to produce specimens with large grain sizes. The X-ray diffraction data collected illustrates the tell-tale signs of poor crystallite sampling statistics. Speakman presents some strategies for recovering data fidelity with conventionally available options.

X-ray powder diffraction (XRPD) has been a powerful tool in metallurgy for over 100 years [1,2]. Despite the misleading name, X-ray powder diffraction is used for analysis of more than just powder: it is routinely used for the non-destructive analysis of metal sheet, wire, and parts. XRPD is a well-established method for production control using phase identification, phase quantification (such as retained Austenite), texture and residual stress analysis of manufactured parts. Given its credentials as an established non-destructive characterisation method, XRPD should be a powerful solution for the process development, optimisation of parts, and certification of production machines that is needed for the widespread commercialisation of Additive Manufacturing [3].

X-ray powder diffraction has been used for research studies for analysis of additively manufactured parts, primarily for phase identification during alloy development and residual stress analysis [4, 5,10]. However, this method is not universally used in process studies or commercialisation strategies because Additive Manufacturing can routinely produce parts with grain sizes 100 µm and larger [6]. The ideal specimen for XRPD analysis has a crystallite size less than 1 µm. Therefore, the large grain sizes that can be produced by Additive Manufacturing limit the use of XRPD as a process optimisation and control tool.

For this study, specimens of soft magnetic Fe-Si steel were made by Laser Beam Powder Bed Fusion (PBF-LB) using a variety of raster and annealing strategies. These processes produced specimens with large grain sizes from 100 to > 500 µm. Such grain sizes are unfavourable for X-ray powder diffraction

Fig. 1 Malvern Panalytical's Empyrean range was the X-ray diffractometer platform used in this study

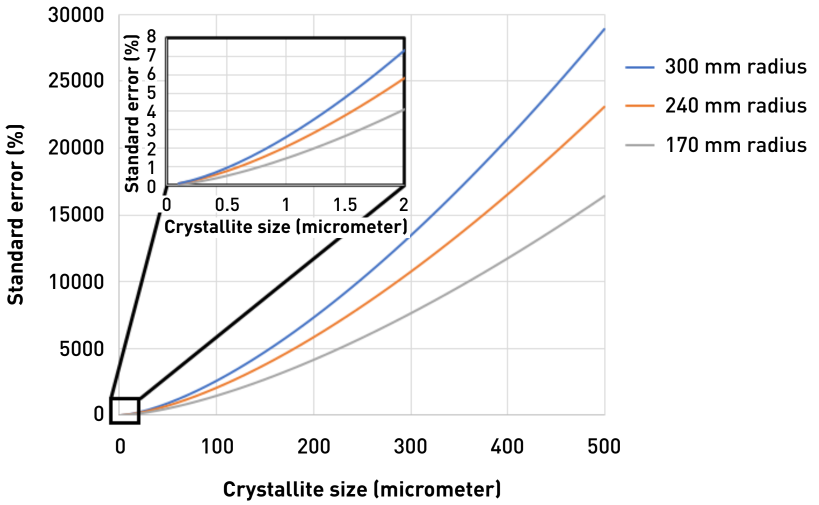

Fig. 2 Standard error as a function of crystallite size calculated for instruments with different goniometer radii

analysis, which works best with specimens that have < 10 µm grain sizes. X-ray diffraction data were collected using several different strategies to illustrate the signs of poor crystallite sampling statistics, and some strategies for recovering data fidelity with conventionally available options were explored.

Understanding the problem

The problem of large grain sizes is well-known in XRPD analysis. It is often called 'particle statistics' [7], though the term 'crystallite statistics' is more accurate [8]. X-ray powder diffraction assumes that a statistically sufficient number of crystallites are irradiated by the X-ray beam to produce an accurate measurement of diffracted intensity and a smooth diffraction peak that can be fit and analysed by software. Achieving adequate crystallite statistics is difficult because only a small fraction of crystallites in a specimen will be properly oriented to diffract. A sample with 1 µm average crystallite size will have 38,200,000,000 crystallites within the irradiated volume; but only 38,000 (i.e. 0.0001%) of the crystallites will be properly oriented to diffract at any given Bragg angle [8].

Poor crystallite statistics will affect the precision and accuracy of intensity measurements, the precision of peak position measurements, and the precision of peak width measurements.

Fig. 2 shows the standard error in intensity calculated as a function of crystallite size for diffractometers with differing goniometer radii (ie the distance from the source-to-sample and the distance from sample-to-detector). The standard error is calculated as $2.3\sigma = 2.3 \sqrt{N_s}/N_s *100$, where N_s is the number of diffracting crystallites for a given diffraction peak [8]. The fraction of crystallites contributing to the measured intensity, N_s, is calculated using equations derived by Jenkins and Snyder [15]. Amongst various factors, N_s depends on goniometer radius, the take-off angle of the incident X-rays, and the size of the receiving slit aperture.

As seen in Fig. 2, even a specimen with 1 µm crystallite size will produce > 1% standard error. As calculated by Davis *et al* [8], there should be ~53,000 diffracting crystallites in a specimen in order to produce standard error less than 1% for the intensity of a given diffraction peak. A specimen with 1 µm crystallite size will contain only 38,000 diffracting crystallites in the standard irradiated volume. This is still much better than a specimen with a 40 µm crystallite size, which will contain only twelve diffracting crystallites and can produce a > 100% standard error in the measured peak intensity.

Fig. 2 not only illustrates that standard error increase quickly with crystallite size, but also that a longer goniometer radius also increases the standard errors in measuring peak intensity. While a shorter radius will improve crystallite statistics, it must be balanced against the optics and detector to maintain suitable angular resolution at that radius.

Poor crystallite statistics can also produce inaccurate peak intensity measurements because XRPD assumes that every diffraction peak is the product of diffraction from a statistically equivalent number of crystallites. This assumption is not valid in a specimen with poor crystallite statistics [11,12]. Consequently, any analysis that relies on accurate peak intensities – such as phase quantification and texture analysis – will fail.

The above numbers are calculated for a 20 mm^3 irradiated volume that is produced by a conventional powder diffractometer using a half degree fixed divergence slit and 13 mm beam width to analyse a SiO_2 material. It has become popular to analyse manufactured parts with microfocus sources that produce ≤ 0.4 mm diameter X-ray beam. While these sources provide improved spatial resolution, the number of irradiated grains is significantly diminished. The crystallite statistics can be improved by combining a large area detector with the microfocus source, which increases the fraction of the Debye diffraction ring observed, effectively increasing the receiving slit aperture [9]. However, when the grain size is 40 µm the maximum number of crystallites irradiated is still limited to ~375, which will not produce sufficient crystallite statistics for accurate analysis.

The effect of poor crystallite statistics on peak intensity is well-documented [11,12]. Less well-documented is how poor crystallite statistics also compromise the accuracy of peak position measurements, which will produce errors in lattice parameter and residual stress calculations. This problem is illustrated in Fig. 3, which compares the 2D and 1D diffraction patterns of SiO_2 specimens with 8 and 27 µm average crystallite size. The 2D diffraction pattern shows a segment of the Debye diffraction ring. The ideal powder specimen produces a Debye diffraction ring that appears as an arc of continuous and even intensity. The 2D diffraction pattern from a specimen with large crystallite size shows individual diffraction spots, rather than an arc of intensity. Each spot in the 2D diffraction pattern essentially represents diffraction from a crystallite. The 2D diffraction pattern can be converted into an equivalent 1D diffraction pattern by integrating the data in arcs corresponding to Debye rings.

Even though the spots seen in the diffraction rings in Fig. 3 are all produced by diffraction from a single Bragg angle, the diffraction spots appear to be distributed across a range of 2theta values. This occurs because the X-ray beam footprint has a finite length on the sample. This footprint is imaged by the position sensitive detector, as illustrated in Fig. 4. Crystallites in different positions of the footprint will appear to diffract at different 2theta values. The divergence of the incident X-ray beam will also contribute to the peak width and may be affected by the distribution of diffracting crystallites at different rocking angles within the irradiated volume. This effect can be reduced by using a smaller incident X-ray beam, which will adversely affect the crystallite statistics. It can also be reduced by using a parallel-plate collimator with small angular aperture.

The specimen with 8 µm crystallite size produces a diffraction ring of overlapping spots in the 2D diffraction pattern. When the 2D pattern is integrated into an equivalent 1D diffraction pattern, it produces a diffraction peak with a standard and easily characterized shape. The spread of the intensity distribution across a 2theta range is well-

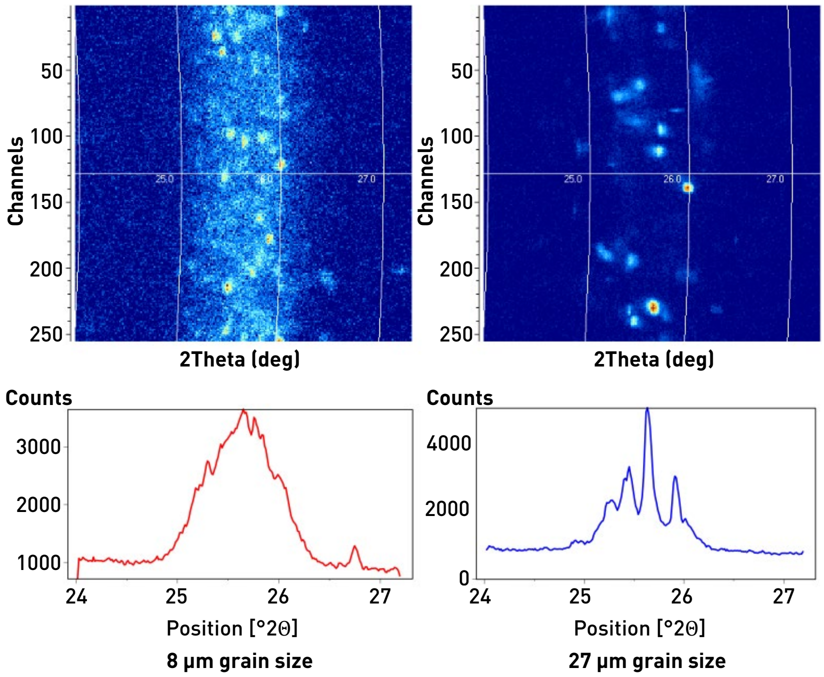

Fig. 3 Comparison of 2D XRPD diffraction patterns (top) between sand specimens with 8 and 27 µm crystallite size. The 1D XRPD patterns (bottom) were produced from the 2D diffraction patterns by integrating the intensity along arcs in 0.02° increments

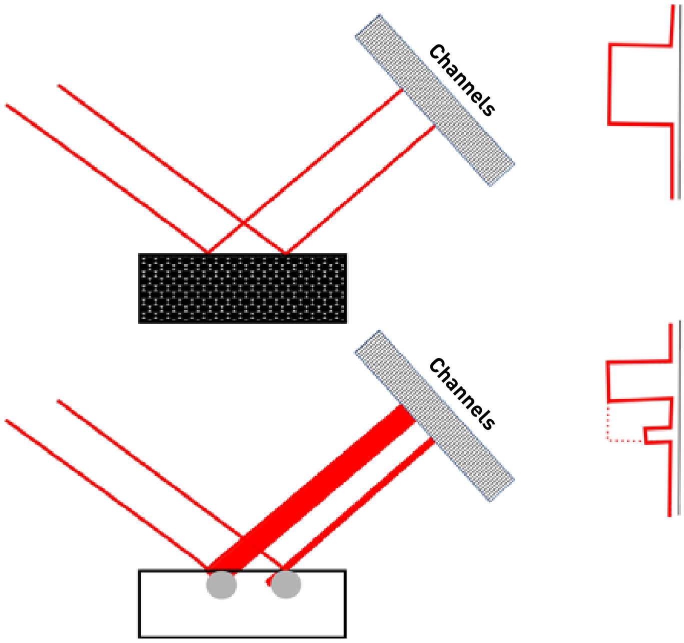

Fig. 4 The distribution of diffracting crystallites creates the appearance of diffraction peaks at different 2theta values. The different channels in the detector are each assigned a different 2theta value during a measurement. Crystallites diffracting at the same Bragg angle, but from different positions in the beam footprint, will be detected at different channels, which will be converted into a range of 2theta values. When the crystallite size is small, the distribution of intensity across the detector channels will be uniform and observed as a single broadened peak (top illustration); when the crystallite size is large, only a portion of the beam footprint will be diffracted and this will appear as separate peaks on the detector (bottom illustration)

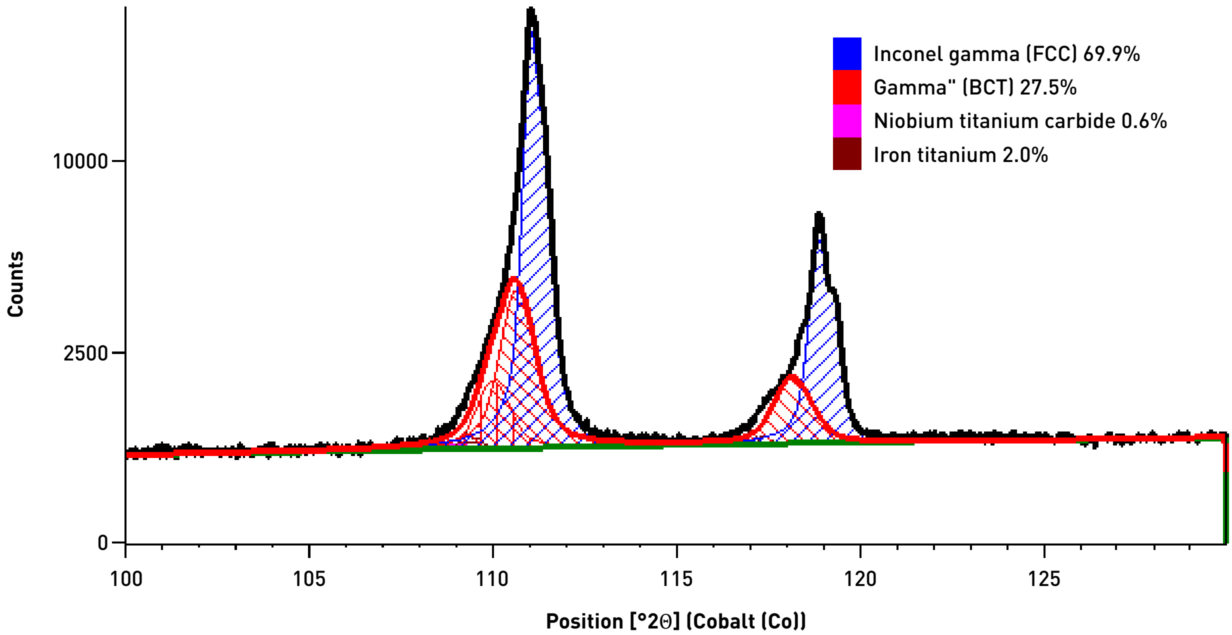

Fig. 5 The measured diffraction data (black) from as-received powder was modelled as a combination of the diffraction profiles of γ (blue) and γ'' (red) diffraction peaks. Trace amounts of (Nb,Ti)C and Fe_2Ti were quantified based on diffraction peaks observed in the 40 to 60° 2theta range (not pictured)

understood and readily modelled with profile fitting software [13], allowing the peak position to be accurately determined to be 25.67° 2theta. In contrast, the specimen with 27 µm crystallite size produces discrete diffraction spots spread over a 2theta range. Each different crystallite within the beam footprint and with a different orientation produces a spot at a slightly different angle because of the divergence of the X-ray beam. When this 'spotty' diffraction pattern is converted into an equivalent 1D pattern, a series of sharp spikes of intensity is produced. It is impossible to calculate an accurate diffraction peak position from these data.

Current solutions

Despite the challenges of crystallite statistics, XRPD has been successfully used as a research tool for analysis of additively manufactured (AM) parts, such as the determination of γ' and γ'' precipitates in Inconel 718 [4, 5]. In a previous study [10], XRPD was used to study the variation of phase composition in feed powder and parts as excess powder was recovered and recycled into the powder hopper between successive builds. As shown in Fig. 5, XRPD was able to clearly distinguish the diffraction peaks of the face-centred cubic (FCC) Inconel 718 gamma phase and the body-centered tetragonal (BCT) γ'' phase. While XRF analysis indicated that chemical composition did not vary, quantitative XRPD analysis revealed that parts had significantly more γ'' phase than the powder and that the phase composition of both the recovered powder and parts varied slightly between builds. This study was successful partially because the grain size of the Inconel 718 was sufficiently small to provide adequate particle statistics.

Traditional methods to improve crystallite statistics of a powder sample include grinding the specimen to a small particle size, sieving the sample with 325 or better mesh, and repacking and remeasuring the powder specimen multiple times [11]. None of these techniques are suitable for AM parts. Spinning or oscillating the specimen during data collection can also improve crystallite statistics, but this is not suitable for many AM parts that are large or have complex shapes.

Other conventional techniques, available on most diffractometer platforms, that can be successful in improving particles statistics, include:

1. Using a wider divergence slit to increase the irradiated area and the rocking angle of crystallites that will diffract (though Davis *et al* argue that the take-off angle is more important than the divergence slit in determining the rocking angle) [8]
2. Wobbling the sample, using a wobble scan mode, or using the linear (1D) or area (2D) detector in scanning mode to bring more crystallites into diffraction orientation [8]
3. Using a smaller wavelength of X-rays, such as using a Mo anode X-ray tube instead of a Cu anode X-ray tube, to increase the penetration depth and therefore the irradiated volume [11]

To demonstrate the effectiveness and limitations of these approaches, XRPD data were collected from coupons of Fe-3 wt.% Si soft magnetic steel built using Laser Beam Powder Bed Fusion. Details of the scan strategies and microstructure analysis were published by Haines *et al* [14]. XRPD data were collected using a Malvern Panalytical Empyrean diffractometer with Co anode X-ray tube, Bragg-Brentano HD incident-beam optic, and GaliPIX detector. Fig. 6 compares the diffraction patterns of Fe-3 wt.% Si specimens additively manufactured with the longitudinal raster scan strategy as-fabricated, annealed in flowing argon at 1000°C for 5 min and for 1 h, and annealed in H_2 at 1000°C for 4 h. The as-fabricated sample shows a single diffraction peak, consistent with ferritic BCC phase. Note that, as with most powder diffractometers, each diffraction peak actually consists of a peak doublet due to the presence of characteristic K-alpha1 and K-alpha2 wavelength X-rays. The samples annealed in Ar show two diffraction peaks, indicating phase separation or another effect.

All samples have a grain size that is larger than optimal. The as-fabricated sample has ~ 100 µm average grain size, the samples annealed in Ar have ~ 200 µm average grain size, and the sample annealed in H_2 has a > 500 µm average grain size. These data were collected using two different X-ray beam sizes: a small beam utilizing 1/16° divergence slit and 2 mm mask, which produces an irradiated footprint of 0.5 x 9 mm; and a large beam using a half degree divergence slit and 20 mm mask that produces an irradiated footprint of 4.5 x 27 mm. Data from both configurations were collected with the detector in stationary mode. The benefits of the larger X-ray beam can be quantified when the diffraction data are profile fit using a pseudo-Voigt peak shape. Table 1 compares several parameters that evaluate the goodness of the fit, such as the weight residual of the fit and the estimated standard deviation (ESD) of the peak position and intensity. While these parameters do not provide the true precision of the measurement, they are a useful tool for evaluating how

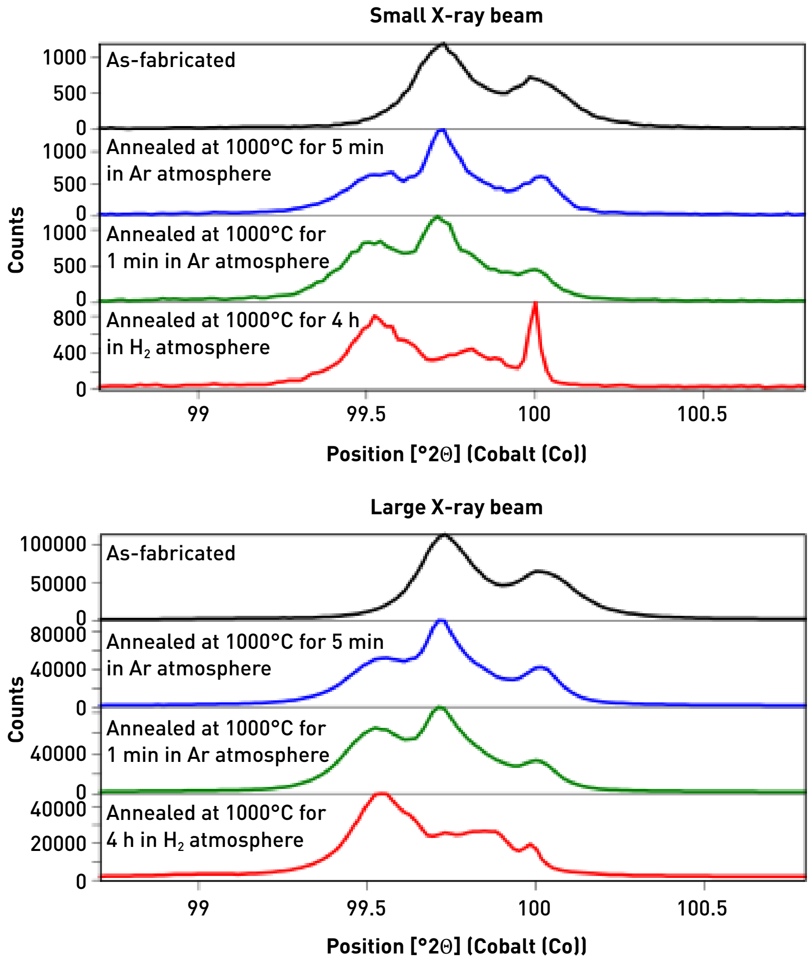

Fig. 6 XRPD data collected from Fe-3 wt.% Si using a small X-ray beam, i.e. 1/16° divergence slit and 0.5 mm x 9 mm footprint (top) and a large X-ray beam, i.e. a half degree divergence slit and 4.5 x 27 mm footprint (bottom). The most significant difference between data collected with the two different configurations is the improved peak shape when using a larger X-ray beam to measure the specimen annealed at 1000°C for 4 h in H_2

		As-fabricated	Annealed for 5 min in Ar	Annealed for 1 h in Ar	Annealed for 4 h in H_2
wRp (%)	Small beam	7.5	4.7	9.0	NA
	Large beam	5.1	2.1	3.3	6.5
ESD of peak position	Small beam	0.00002	0.00002	0.00004	NA
	Large beam	0.0000004	0.0000007	0.0000009	0.000001
ESD of peak area	Small beam	0.05	0.2	0.2	NA
	Large beam	0.05	0.2	0.2	0.2
ESD of peak width	Small beam	0.00007	0.00007	0.00009	NA
	Large Beam	0.000001	0.000002	0.000002	0.00003

Table 1 Goodness of fit parameters that can be used to evaluate how well the measured diffraction data conform to peak shapes that can be modelled and fit using standard profile fit functions. For all parameters, a smaller value represents a better fit and more precise analysis.

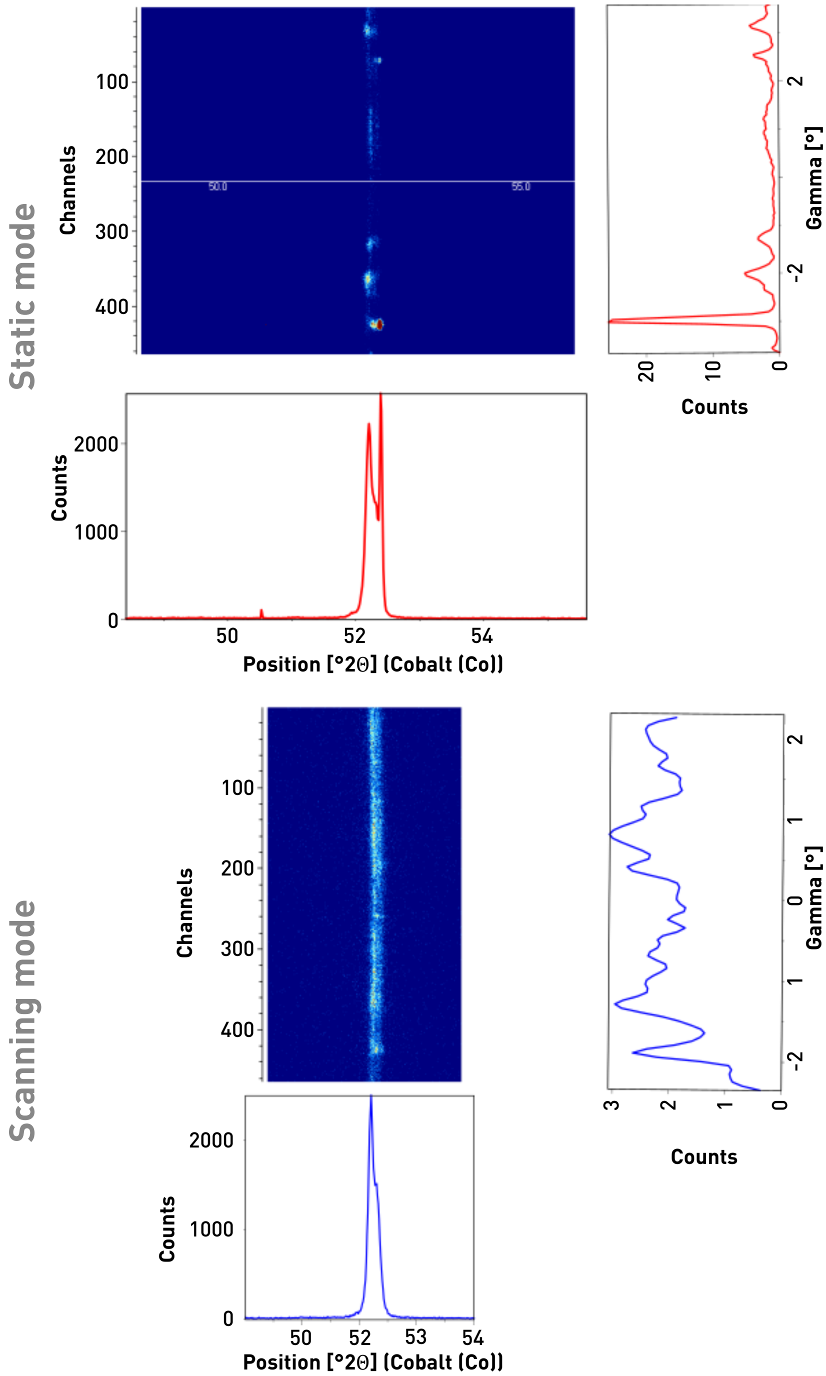

Fig. 7 Comparison of data collected using static (top) and scanning (bottom) 2D detector to measure Fe-3 wt.% Si annealed at 1000°C in H_2 for 4 h, which has average grain size > 500 µm. 1D plots show intensity integration along 2theta and gamma directions

well the diffraction data conform to the standard peak models. Data collected with the larger X-ray beam consistently provide better residuals and ESDs.

The improvement is most readily noticeable in data from the specimen annealed in H_2. When analysed with a small X-ray beam, the diffraction data exhibits the 'spotty' peak error associated with poor crystallite statistics. This error makes it difficult, possibly impossible, to accurately analyse the data. When the same specimen is measured using the large X-ray beam, the diffraction peaks are still non-ideal but can now be fit and semi-quantitatively analysed.

The larger X-ray beam improves the crystallite statistics and resulting data; but a larger X-ray beam is not always a viable solution, especially when analysis requires spatial resolution of regions of interest. In cases where the X-ray beam must be smaller, then a scanning detector mode can also be used to improve the crystallite statistics.

When a linear (1D) or area (2D) position sensitive detector is used in scanning mode, then the effective crystallite rocking angle is increased, substantially increasing the number of crystallites contributing to the diffraction peak. This is effectively using the rocking (i.e. wobble) strategy recommended by Davis *et al* [8].

Fig. 7 compares the static and scanning 2D diffraction measurements of the (110) peak and integrated 1D scans for Fe-3 wt.% Si produced using the rotated raster direction and then annealed at 1000°C for 1 h in H_2. In the static 2D measurement, the diffraction pattern is dominated by a single diffraction spot at 52.4° 2theta; whereas in the scanning 2D measurement the diffraction intensity is distributed amongst many spots more closely approaching an ideal diffraction ring. This is highlighted in the integrated intensity vs gamma plot, which shows how intensity is distributed along the arc of the Debye diffraction ring. In the static measurement, a peak at -3° gamma dominates the plot. In the scanning measurement, intensity is broadly distributed across the full observed gamma range. The scanning measurement does not match an ideal powder specimen, which would have a smooth and constant intensity at all gamma values; but the scanning measurement clearly represents data more closely approaching ideal crystallite statistics.

When a large X-ray beam and scanning mode data collection are combined, the crystallite statistics can be considerably improved.

Fig. 8 compares data for all longitudinal specimens using a scanning 1D mode with a large X-ray beam using a half degree divergence slit and 20 mm mask that produces an irradiated footprint of 4.5 x 27 mm when measuring the (211) peak at 99.5° 2theta. The scanning 1D mode discards some of the microstructural information that can be derived from a 2D scan, but the scanning 1D mode allows a much larger X-ray beam to be used.

The as-fabricated specimen is purely BCC Fe, as indicated by the single (211) diffraction peak at 99.8° 2theta, while the annealed samples contain varying amounts of a secondary phase indicated by a diffraction peak at 99.5° 2theta. Phase analysis and whole pattern fitting was performed on data from the as-fabricated sample and from the specimen annealed in Ar for 1 h, which exhibited the strongest peaks of the secondary phase. This specimen was also the only one to exhibit a third phase, as shown in Fig. 9.

Whole pattern fitting of data from the as-fabricated specimen indicates a BCC Fe phase with lattice parameter a= 2.8633 A. This lattice parameter is consistent with reported values for Si-doped Fe [16], which is slightly smaller than pure Fe. The fitting also indicated a slight <001> texture.

The specimen annealed at 1000°C in Ar for 1 h contained two BCC Fe phases and ~ 20 wt.% Fe_2SiO_4. The two BCC Fe phases had lattice parameters of 2.8635 and 2.8673 A. The first value is again consistent with other lattice parameters reported for Si-doped Fe, while the second value is more consistent with pure Fe. This suggests that, as grains grew during annealing, some grains became Si-rich while others became Si-deficient. This result is not entirely consistent with EBSD analysis reported for these samples [14], so further analysis may be warranted. Whole pattern fitting also indicated that the texture of the two Fe species differed. The Si-rich phase had a pronounced <001> texture, while the Si-deficient phase had a <111> texture.

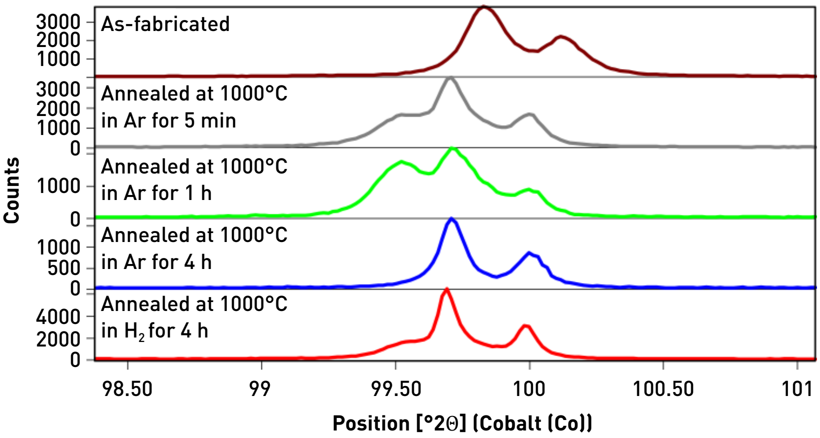

Fig. 8 Diffraction data collected in scanning 1D mode from Fe-3 wt.% Si additively manufactured using the longitudinal raster pattern, as fabricated, as annealed at 1000°C in flowing Ar for 5 min, 1 h and 4 h; and annealed at 1000°C in flowing H_2 for 4 h

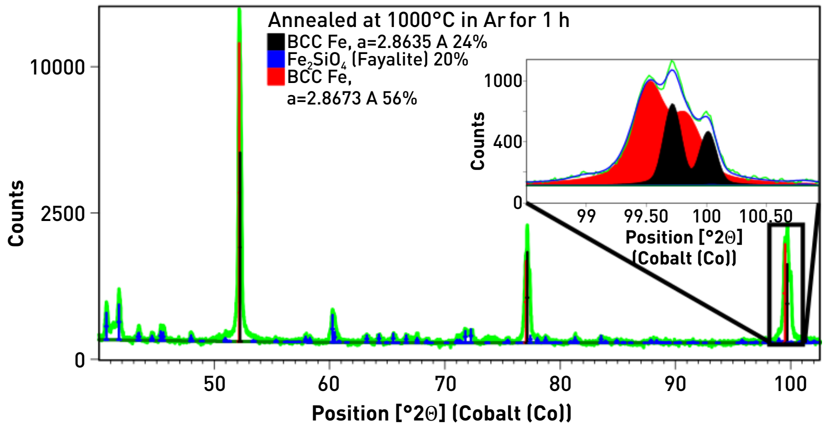

Fig. 9 Phase analysis of specimen Fe-3 wt.% Si annealed at 1000°C in Ar for 1 h. The inset shows a section of the whole pattern fitting used to quantify the Fe-based phases in the specimen

One final qualitative observation can be added to this discussion. The XRPD data are not as 'spotty' as would be expected for the grain sizes reported based on EBSD analysis of these specimens [14]. This qualitatively indicates that the crystallite statistics are not as poor as expected. This discrepancy can be understood by distinguishing between particle, grain, and crystallite size. A crystallite is a unit volume where the atomic structure is undistorted, producing continuous crystallographic planes with uniform lattice spacing. Anything that disrupts the uniform lattice spacing and orientation will form a boundary for the crystallite. This may be a grain or particle boundary, but may also be a dislocation wall, antiphase domain boundary, or similar distortion of the atomic structure. A grain is a unit volume where the crystallographic planes are generally parallel. A grain boundary is created by a change in the direction of the crystallographic planes that maintains some atomic bonding across the grain boundary. A particle is a discrete unit volume that does not share atomic bonding across the boundary with neighbouring particles. As such, a particle may contain multiple grains, and a grain may contain multiple crystallites. EBSD will most often quantify grain size and the misorientation angle between neighbouring grains. However, samples with high concentrations of dislocations, stacking faults, and other crystallographic defects may have a crystallite size that is smaller than the grain size measured by EBSD and other techniques. Given that the XRPD data show better-than-expected crystallite statistics and that EBSD indicates a high concentration of geometrically necessary dislocations (GNDs), it seems reasonable to conclude that the crystallite size of the Fe-3 wt.% Si samples was smaller than the grain size.

Summary

Parts made by Additive Manufacturing often have crystallite sizes that are challenging for precise and accurate measurement by X-ray powder diffraction (XRPD). The error produced in peak intensities may complicate phase analysis and may compromise quantitative phase analysis and texture analysis. The error produced in peak position will compromise lattice parameter and residual stress analysis. Collecting data with a scanning position sensitive detector instead of a static position sensitive detector or point detector can improve the crystallite statistics. A larger X-ray beam footprint will also improve crystallite statistics, though this may compromise spatial resolution on the specimen. Care must also be taken to preserve sufficient angular resolution of the diffraction data when using a larger X-ray beam.

Other strategies for improving XRPD analysis, not explored in this article, include using shorter wavelength X-rays (such as from a Mo anode X-ray tube) to increase the irradiated volume and the number of diffraction peaks observed in a measurement; and using parallel-beam or high-resolution optics to improve the accuracy of peak position measurements.

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Industry events

2022

Additive Manufacturing Forum Berlin
July 5–6, Berlin, Germany
www.am-forum.eu

PMTi2022
August 29–31, Montréal, QC, Canada
www.pmti2022.org

AM Summit 2022
September 7, Copenhagen, Denmark
www.amsummit.dk

13th International Conference on Hot Isostatic Pressing
September 11–14, Columbus, OH, USA
www.hip2022.com

Sinter-based Additive Manufacturing Workshop – Fraunhofer IFAM
September 14–15, Bremen, Germany
www.ifam.fraunhofer.de

Formnext + PM South China 2022
September 14–16, Shenzhen, China
www.formnext-pm.com

Metal Additive Manufacturing Conference 2022
September 26–28, Graz, Austria
www.mamc2022.org

World PM2022
October 9–13, Lyon, France
www.worldpm2022.com

AMTC - Advanced Manufacturing Technology Conference
October 11–12, Munich, Germany
www.amtc.community/amtc/en/

***Metal AM* magazine is dedicated to driving awareness and development of metal Additive Manufacturing and its related technologies. Key to this aim is our support of a range of international partner conferences and exhibitions. View our complete events listing on www.metal-am.com**

EuroBLECH 2022
October 26–28, Hannover, Germany
www.euroblech.com

ICAM2022 International Conference on Additive Manufacturing
October 31–November 4, Orlando, FL, USA
www.amcoe.org/icam2022

PM China 2022
November 4–6, Shanghai, China
www.pmexchina.com

Formnext
November 15–18, Frankfurt, Germany
www.formnext.com

Space Tech Expo Europe 2022
November 15–17, Bremen, Germany
www.spacetechexpo.eu

If you would like to see your Metal Additive Manufacturing related event listed in this magazine and on our websites, please contact Kim Hayes:
kim@inovar-communications.com

2023

MIM2023
February 27–March 1, Costa Mesa, CA, USA
www.mim2023.org

Fraunhofer Direct Digital Manufacturing Conference (DDMC) 2023
March 15–16, Berlin, Germany
www.ddmc-fraunhofer.de

AMUG 2023
March 19–23, Chicago, IL, USA
www.amug.com

EBAM 2023 – International Conference on Electron Beam Additive Manufacturing
March 22–24, Erlangen, Germany
www.ebam.fau.de

Hannover Messe 2023
April 17–21, Hannover, Germany
www.hannovermesse.de

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