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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

ATHERTON BIKES
NASA & REM: SURFACE FINISHING
AM OF HARDMETALS

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METAL ADDITIVE MANUFACTURING

Hardmetals: an unexpected opportunity for AM?

One of the benefits of following the metal Additive Manufacturing industry is seeing the constant flow of new applications and opportunities, many of which may simply have been 'off the radar' for many years.

One such application area that is now starting to be explored more intensively is that of hardmetal parts production. Also widely known as cemented carbides, hardmetals have been in commercial production for wear resistant parts and cutting tools for close to a hundred years. As it happens, hardmetals were also one of the early materials explored – at the time, unsuccessfully – for 'AM' production at the USA's MIT in the mid-1990s.

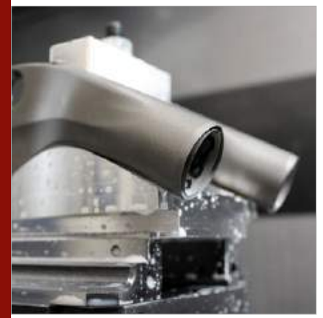
Now an industry sector with sales in excess of $20 billion a year, if AM can take just a small percentage of hardmetal production from conventional processes such as 'press and sinter' Powder Metallurgy and, more recently, Powder Injection Moulding, the rewards will be significant.

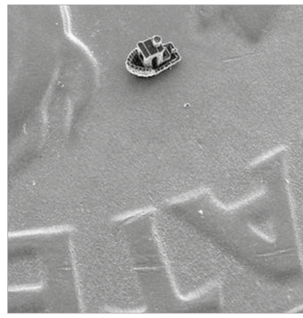
In contrast to instances where the use of AM requires an entirely new application, or a revolution in an existing application's design or function, the use of AM in the world of hardmetals is potentially more immediate and far less of a leap of faith.

The hardmetals industry already relies on sintering as one of its manufacturing steps, so the added benefits of tool-free production, new and unique shapes, innovative and functionally graded materials and, of course, part customisation, will inevitably be attractive. In this issue of *Metal Additive Manufacturing* magazine, we publish a review of research to date on the viability of AM processes for hardmetal production (page 155).

Nick Williams
Managing Director

Cover image
Gee Atherton putting the Atherton Bikes frame, made using lugs manufactured by Laser Beam Powder Bed Fusion, through its paces (Courtesy Moonhead Media)





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BAE plans to produce 30% of Tempest fighter jet parts by AM

BAE has informed UK suppliers of its target to additively manufacture 30% of the parts for its Tempest fighter jet (Courtesy BAE Systems)

BAE Systems has given its UK suppliers notice of its plans to produce a targeted 30% of parts for its Tempest fighter jet by Additive Manufacturing. BAE's announcement comes as the UK aerospace supply chain feels the impact of a sharp downturn in demand for civilian aircraft due to the coronavirus (COVID-19) crisis. It is expected that BAE's suppliers will have to adapt to meet the Tempest programme's aim to cut the cost and time needed to produce a complex combat aircraft in half.

The BAE team working on Tempest has already reportedly reduced the production time of one large part, located in the rear fuselage of the aircraft, from about two years to two months using Additive Manufacturing. In the future, instead of ordering some components from suppliers, BAE may additively manufacture the parts in-house.

Charles Woodburn, BAE Chief Executive, stated, "To stay at the forefront of this strategically important industry, we have to radically change the way we design and build combat air systems."

David Holmes, BAE Manufacturing Director, explained that he expects new suppliers to join the Tempest programme, potentially from outside the aerospace industry, as a result of the new production targets. "You may see traditional suppliers start to disappear," he noted in an interview with the *Financial Times*. BAE is working with hundreds of suppliers on the Tempest programme.

AM was used to produce less than 1% of the parts on the Typhoon combat jet. BAE has also set a target of assembling 50% of the Tempest using robots, while no automation was used in the production of the Typhoon.

The manufacturing technologies identified for Tempest are reportedly being spun out into the Typhoon programme to prove their effectiveness. Early results are believed to have given BAE confidence that the target of halving the cost of Tempest's development can be met, as long as the company has 'an end-to-end supply chain' that is fit for purpose.

www.baesystems.com

Looking for AM technology, materials or parts?

Check out our new Advertiser's Index / Buyer's Guide on pages 210-214. Here you will find companies listed under key product categories, as well as alphabetically, helping you to easily find suppliers of powders, AM machines, as well as part manufacturing partners and everything else in between.

Desktop Metal to be publicly listed following investment from Trine

Desktop Metal, Burlington, Massachusetts, USA, has announced that it will become a publicly listed company during the fourth quarter of 2020. The company has signed a definitive business combination agreement with Trine Acquisition Corp., an acquisition company led by Leo Hindery, Jr., and HPS Investment Partners, a global credit investment firm.

It was reported that Desktop Metal's existing shareholders will hold approximately 74% of the issued and outstanding shares of common stock immediately following the closing of the business combination. The resulting operating company will be named Desktop Metal, Inc. and will continue to be listed on the New York Stock Exchange and trade under the ticker symbol DM.

"We are at a major inflexion point in the adoption of Additive Manufacturing, and Desktop Metal is leading the way in this transformation," stated Ric Fulop, co-founder, chairman & CEO of Desktop Metal. "We are energised to make our debut as a publicly-traded company and begin our partnership with Trine, which will provide the resources to accelerate our go-to-market efforts and enhance our relentless efforts in R&D."

Desktop Metal's Production System (Courtesy Desktop Metal)

Trine , which currently holds $300 million in cash in trust, will combine with Desktop Metal at an estimated $2.5 billion pro forma equity value. Leo Hindery, Jr., Chairman & CEO of Trine, added, "After evaluating more than 100 companies, we identified Desktop Metal as the most unique and compelling opportunity, a company that we believe is primed to be the leader in a rapidly growing industry thanks to their substantial technology moat, deep customer relationships across diverse end markets, and impressive, recurring unit economics."

"Ric has put together an exceptional team and board of directors with whom we are excited to partner to create the only publicly traded pure-play Additive Manufacturing 2.0 company," continued Hindery, Jr.

The boards of directors of both Desktop Metal and Trine have unanimously approved the proposed transaction. Completion of the proposed transaction is subject to the approval of Trine and Desktop Metal stockholders and other closing conditions, including a registration statement being declared effective by the Securities and Exchange Commission.

Tom Wasserman, Director of Trine and Managing Director of HPS Investment Partners, concluded, "Thanks to its tremendous team, we believe Desktop Metal has incredible potential for future growth, which will only be accelerated by the extensive financial resources provided by this transaction."

www.desktopmetal.com

Altana to expand its Eckart business following acquisition of TLS and AMT

Speciality chemicals group Altana AG, headquartered in Wesel, Germany, is to acquire TLS Technik GmbH & Co. Spezialpulver KG, Bitterfeld-Wolfen, Germany, a leading manufacturer of metal powders for Additive Manufacturing, as well as Aluminium Materials Technologies Ltd. (AMT), Worcester, UK, developer of the patented special alloy A20X, in order to expand its Eckart division.

"By acquiring the TLS business, we are expanding our portfolio in 3D printing for industrial Additive Manufacturing and positioning ourselves in a technology market of the future," stated Martin Babilas, CEO of Altana AG. "With this step, we are continuing to implement Altana's strategy of generating value-creating growth through targeted acquisitions, even in difficult economic times."

With twenty-five years of experience, TLS is regarded as a leading specialist in the production of high-quality metal powders for industrial Additive Manufacturing, explains Altana.

"TLS' expertise in the production of metal powders and alloys for metallic 3D printing complements Eckart's strengths as a specialist in the atomisation of metals," notes Dr Wolfgang Schütt, head of Altana's Eckart Division. "We are also strengthening ourselves in a targeted manner for functional applications."

The transaction is expected to take place in the fourth quarter of 2020, when Eckart will take over the production facility in Bitterfeld and its forty or so employees.

AMT developed the A20X special alloy for Additive Manufacturing, which is said to enable the manufacturing of significantly lighter components with outstanding mechanical properties.

Dr Schütt added, "AMT and its A20X alloy complement TLS' capabilities, enabling us to offer users even more high-performance materials in the future, including in the aerospace industry, a key market for metallic 3D printing."

www.tls-technik.de
www.a20x.com
www.altana.com

Sandvik Additive Manufacturing joins GE Additive's binder jet programme

GE Additive reports that Sandvik Additive Manufacturing, a division of Sandvik AB, headquartered in Stockholm, Sweden, has joined its binder jet beta partner programme. Sandvik has one of the widest alloy ranges for Additive Manufacturing, marketed under its Osprey® brand.

Sandvik will work closely with GE Additive to become a certified powder supplier for a range of Osprey alloys that complement GE Additive and AP&C's own materials portfolio, and will reportedly also use GE Additive's H2 Binder Jet beta machine to support its internal and external customers.

GE Additive explains that its binder jet beta partner programme hopes to leverage its strength in industrialising Additive Manufacturing technology with strong technical and innovative partners to rapidly grow its Binder Jetting technology. The first phase will encompass the development of the beta H2 system into pilot lines, before moving into a commercially-available factory solution in 2021.

"Our approach to binder jet is making additive mass production a reality in every industry," stated Jacob Brunsberg, Binder Jet Product Line Leader, GE Additive. "And while it would be relatively easier to launch individual machines, we continue to hear from customers, especially in the automotive industry, that they need a complete solution that can scale."

"Attracting partners like Sandvik – with know-how in industrialising innovation, deep materials knowledge, and a shared vision for the potential for additive technology – remains a cornerstone of our binder jet commercialisation strategy," added Brunsberg.

Kristian Egeberg, president of Sandvik Additive Manufacturing, commented, "Sandvik is a leading expert in gas-atomised Additive Manufacturing powders, as well as in optimising the materials to customers' specific print processes and applications. The materials collaboration with GE Additive offers great opportunities to qualify our wide range of Osprey metal powders for their new binder jet platform, to enhance end-customer productivity and product performance."

www.ge.com/additive
www.additive.sandvik

SMS Group to supply Outokumpu's new stainless steel AM powder atomisation plant under subscription contract

SMS Group will supply Outokumpu with an atomisation plant through a subscription (Courtesy SMS Group)

SMS Group, Düsseldorf, Germany, reports that it is to supply global stainless steels manufacturer, Outokumpu, headquartered in Helsinki, Finland, with an atomisation plant through a new subscription contract. The new facility will be used for the production of stainless steel powder used in Additive Manufacturing.

SMS Group states that this is the first ever facility the group will have supplied under a subscription contract, with the agreement representing a new business model for both companies. According to the SMS Group, the subscription contract agreement will see the group remain the owner of the powder atomisation plant, while Outokumpu will be its operator. Outokumpu will pay SMS Group pro rata for the quantity of stainless steel powder produced.

The powder atomisation plant will include an induction melter, atomiser, two cyclones and filter elements, and will be designed to enable the complete process to take place in an inert atmosphere. This enables temperature measurements, sample taking and material feeding to be performed without causing any atmospheric variations. The atomisation plant is scheduled to become operational in early 2022, and will be designed for an annual production of up to 330 tons of stainless steel powder.

"Right from the beginning, the whole project has been sailing under the flag of partnership," stated Tobias Brune, SMS Group Head of Additive Manufacturing & Powder Metallurgy. "The subscription contract provides for both companies to concentrate on their respective core competencies to be successful in the market."

Philip Salfeld, Outokumpu Manager Strategic Investments, added, "As the inventors of stainless steel, we are aiming to continuously advance innovation in general, and the development and distribution of this highly versatile and sustainable material. In so doing, we are always looking out for innovative applications that will attract new customer segments to our products. Metal powder is one such innovative business field. And we are looking very much forward to developing it jointly with SMS Group."

www.sms-group.com
www.outokumpu.com

Rena acquires Hirtenberger Engineered Surfaces and its Hirtisation AM surface finishing technology

Rena Technologies GmbH, headquartered in Gütenbach, Germany, acquired Austria-based Hirtenberger Engineered Surfaces (HES) on July 27, 2020, and has since rebranded it as Rena Technologies Austria, establishing a new Additive Manufacturing hub for the group.

HES is known for its development of the Hirtisation technology, a high-performance tool for post-processing metal additively manufactured parts. The automated process is said to be precise and suitable for mass production in metal Additive Manufacturing, offering an alternative to conventional post-processing methods. The existing HES team and its Hirtisation technology will be integrated into the Rena corporate structure.

"The outstanding expertise and efficient implementation of modern production machinery designed to respond to customer needs immediately impressed us," stated Peter Schneidewind, Rena's CEO. "Hirtisation technology complements perfectly Rena's product portfolio."

Rena has acquired Hirtenberger Engineered Surfaces and its Hirtisation technology (Courtesy Rena Technologies)

As Rena Technologies Austria, the site will operate as a hub for the groups Additive Manufacturing activities. It will also function as a technology and development centre for all aspects of electrochemical surface finishing.

"We are looking forward enthusiastically to working with our new colleagues at Rena because we can exploit Rena's worldwide network as a launching pad for marketing our technology globally," stated Wolfgang Hansal, Managing Director of HES and designated Managing Director of Rena AT.

"The first industrial machines have already been successfully introduced to the market," added Michael Escher, Managing Director of the new Rena AT. "Together with Rena we can speed up the establishment of our cutting-edge technology. Additive Manufacturing is becoming a building block of industrial production chains. With Rena Additive Manufacturing we can shape this process actively and gear up for growth."

Schneidewind added, "The innovative segment opens a new and promising chapter with tremendous growth potential for Rena."

www.rena.com

Novamet acquires Rhode Island metal powder atomisation facility

Ultra Fine Specialty Products, LLC, a division of Novamet Specialty Products Corporation, Inc, Lebanon, Tennessee, USA, has acquired a high-purity, fine metal powder atomising facility, located in Woonsocket, Rhode Island, USA. The facility was formerly owned by Carpenter Powder Products, Inc., a subsidiary of Carpenter Technology Corporation.

The company explains that Ultra Fine will now focus on refining and expanding the capabilities of the atomising facility to produce high-quality metal powders in the finest range of sizes available through gas atomisation. The process used by Ultra Fine to produce powders is said to be unique, enabling powders in the size range of under 30 µm.

Ultra Fine was formed by Jeffrey Peterson, Novamet CEO; John Torbic, Novamet president; and Novamet General Counsel Michael Hinchion, to locate and acquire technically-oriented production assets to support the advancement of metal powder technologies and their use in aerospace, electronics, batteries, industrial parts and other markets in the US and around the world.

Novamet was formed in 1976 to apply its technology for the development of nickel-base powders and technologies into different morphologies, shapes and sizes for various industrial uses, focusing on nickel powders produced by its then-parent company, Inco. The company was acquired by investors in 2010 and after nearly forty years in Bergen County, New Jersey, USA, moved its headquarters and manufacturing facilities to Lebanon, Tennessee. Novamet currently processes and distributes various metal powders and coated products for the Metal Injection Moulding, aerospace, automotive, coatings and electronic materials markets.

"Novamet has a strong record of working with the types of powders this facility can produce, and we see even more potential for growth as Novamet and Ultra Fine combine their technical strengths and manufacturing skill sets," Torbic added.

www.novametcorp.com

Sandvik achieves ISO medical certification for its Osprey titanium powders

Sandvik Additive Manufacturing, a division of Sandvik AB, headquartered in Stockholm, Sweden, reports that its new titanium powder plant in Sandviken, Sweden, has received ISO 13485:2016 medical certification for its Osprey titanium powders. This means its titanium powder is approved for use in the Additive Manufacturing of medical applications.

The company's titanium powder plant was inaugurated at the end of 2019, and since then, Sandvik states that extensive work has been ongoing to ramp-up the highly automated plant. This has included fine tuning the process and optimising the powder to ensure the best possible consistency, morphology and quality required for AM. Earlier this year, the powder plant also achieved the AS9100D aerospace certification.

"Achieving the ISO 13485:2016 medical certification will allow our medical customers to complete the necessary regulatory supplier approvals when bringing a medical application to market, utilising Osprey titanium powders from Sandvik," stated Keith Murray, VP and Head of Global Sales at Sandvik Additive Manufacturing.

Sandvik's titanium powder production facility in Sandviken, Sweden (Courtesy Sandvik Additive Manufacturing)

According to the company, the properties of the metal powders used directly impact the reliability of the performance of the AM process, as well as the quality and performance of the finished product. The medical certification ensures that best practices and continuous improvement techniques – including the company's development, manufacturing, and testing capabilities – are leveraged during all stages of the powder lifecycle, resulting in a safer medical device.

Murray added, "In Additive Manufacturing it is essential to use high-quality metal powders with consistent quality, adapted to the different Additive Manufacturing processes. Sandvik's highly automated manufacturing process ensures excellent consistency."

Product traceability is especially important in the medical industry and Sandvik explains that it offers complete traceability for its titanium powder, made possible by having the full supply chain in-house – from titanium sponge to finished powder. The new titanium powder process uses advanced electrode induction melting inert gas atomisation technology to produce highly consistent and repeatable titanium powder with low oxygen and nitrogen levels. The production facility also includes dedicated downstream sieving, blending and packing facilities – integrated through the use of industrial robotics.

The powder plant is located next to Sandvik's Additive Manufacturing facility in Sandviken, Sweden, which includes all relevant metal AM processes. This means that Sandvik can tailor the powder to different Additive Manufacturing processes on the same site. The first two powders produced at the plant will be Osprey Ti-6Al-4V Grade 5 and Osprey Ti-6Al-4V Grade 23.

"Now we are one of few metal powder and Additive Manufacturing companies that holds both the AS9100D quality certification for aerospace and the ISO 13485:2016 certification for medical. This will facilitate many customer collaborations going forward. Imagine what 158 years of leading materials expertise can do for your additive process," Murray concluded.

www.additive.sandvik

Wayland Additive to launch its NeuBeam metal AM machine Calibur 3 in January 2021

Wayland Additive, Huddersfield, UK, reports that it will commercially launch Calibur 3, its first NeuBeam® process metal Additive Manufacturing on January 27, 2021, and expects to start shipping later that year.

Developed in house, the NeuBeam metal AM process is said to be an entirely new Powder Bed Fusion (PBF) process, claiming to provide the best of both laser- and electron-beam PBF systems.

Although EBM and NeuBeam are both PBF processes, using an electron beam as the heat source to melt the metal powder, it is stated that two processes are fundamentally different. Unlike the conventional Electron Beam PBF process, the charging issues that can make it unstable are said to have been fully neutralised with NeuBeam using core physics principles developed in the demanding semi-conductor industry.

Moreover, NeuBeam is a hot part process rather than a hot bed process. This is said to create parts that are free of residual stresses, because the high temperatures are only applied to the part and not the bed, ensuring free-flowing powder post-build (no sinter cake) and stress-free parts with reduced energy consumption.

The NeuBeam process is capable of producing fully dense parts in a wide range of materials, many of which are not compatible with traditional electron or laser beam processes, such as refractory metals and highly reflective alloys. Designed specifically for production applications, the Calibur 3 incorporates fully embedded in-process monitoring capabilities that can provide full oversight during every build, said to ensure full traceability.

Peter Hansford, Director of Business Development at Wayland Additive, commented, "We are very happy to confirm the launch date for the Calibur 3 On 27th January next year we will be unveiling the full specs of the machine to our early adopters and partners as well as to the press at a dedicated event."

"Currently the plan is to bring people in to see it in action for themselves if we are able to with COVID-19 restrictions, but we will also be live-streaming the event for interested parties that may not be able to attend. 2020 has been an unprecedented year in many ways and the global pandemic has caused a great deal of disruption and uncertainty," Hansford continued.

"At Wayland, however, we have been able to navigate through these difficulties and keep our focus on the development of our system. Talking to industrial users of metal AM throughout, it is clear that despite the disruptions, many companies are still making medium and long-term plans, and we look forward to serving them with our ground-breaking technology."

Will Richardson, CEO at Wayland Additive, stated, "Save the date in your diary now. We are in the process of curating an impressive in-person and on-line event which will be of huge interest to industrial sectors that use or are planning to use metal AM for production applications. January 27 2021, will be a pivotal day for Wayland, but also a pivotal day for industry as they get a first clear view of the opportunities that exist through the use of our NeuBeam technology."

www.waylandadditive.com

The Calibur 3, Wayland Additive's first metal AM machine developed with its NeuBeam process (Courtesy Wayland Additive)

Tinkerine to develop metal powder Additive Manufacturing machine

Tinkerine Studios Ltd., based in Delta, British Columbia, Canada, has announced plans to expand into the metal AM sector, with the development of a 'Made in Canada' metal powder based AM machine.

Established in 2012, Tinkerine is a leading Canadian manufacturer of PLA and composite-based filament AM machines. The company states that its mission is to provide a foundational understanding of applied design driven by Additive Manufacturing, and its range of AM products and educational resources aims to equip future generations with innovative tools and products.

According to the company, metal AM is seen as the AM technology that can have the highest amount of impact on production, due to materials used for the industrial, aerospace and automotive industries.

"Through applied design and the knowledge gained in the 3D Additive Manufacturing space, Tinkerine believes there is a significant opportunity to be a leading player in the metal powder space. Design has been initiated for the development of systems for a powder-based unit," stated Eugene Suyu, CEO of Tinkerine Studios Ltd. "Our aim is to produce a machine with the capacity to process materials including aluminium to titanium powder."

www.tinkerine.com

New steel powders from Mitsubishi Steel qualified for MIM and AM feedstocks

Hong Kong-based GC Advanced Material Solutions Ltd (GCAMS) has announced the recent evaluation, and subsequent qualification, of gas-atomised steel powders from Mitsubishi Steel Mfg. Co., Ltd., Tokyo, Japan, for the preparation of MIM and AM feedstocks.

Mitsubishi Steel's 316L, 17-4PH and D11 powders are said to offer exceptionally high and reproducible tap density values, and have been qualified for the GCAMS Medpimould® and AmbientPrint™ feedstocks.

The steel powders are considered to be especially suitable as raw material for manufacturers using Material Extrusion (MEX)-based AM, or what GCAMS refers to as a Bound Material Powder Deposition process. The powder solids loading obtained with these powders is said to be measured consistently at 70+ vol.% for the wax-base and at 60+ vol.% for the solvent-base feedstocks, which results in a low shrinkage on sintering.

According to Dr Robert Pompe, company CEO, the Bound Material Powder Deposition technology, involving direct nozzle extrusion, is gaining traction, as companies in the AM field intensify development of real-world value chains for additively manufactured series products.

"The starting material cost adds significantly to the total cost of AM-based production. Our business is to sell licenses at a low cost, comparable to the one or two-month salary of a qualified R&D worker," added Pompe, "to make it possible for many companies to turn the potential benefits of AM into a successful industrial or end-user product. Part manufacturers can now use these and other MIM/CIM powders on the market and convert them into printable feedstocks."

The licenses are specifically designed for and sold with the AM machines manufactured by Metallic3D, Inc., Stuart, Florida, USA. Complete packages are marketed by 3D Dragon Printing Technology Co., Ltd., Hong Kong, in southeast Asia, China and other dedicated markets.

www.3ddragontech.wixsite.com
www.gcamsltd.wixsite.com
www.metallic3d.com

Desktop Metal previews its new Live Sinter software to mitigate sintering distortion

In the latest issue of *PIM International*, Desktop Metal shared details of its upcoming sintering simulation tool, Live Sinter™. Andy Roberts, VP Software at Desktop Metal and the inventor of Live Parts™, the company's generative design software, presented the new simulation software along with a number of case studies illustrating its capabilities.

Sintering distortion is a fact of life in the Metal Injection Moulding industry. However, through the combination of an experienced eye, the 'trial and error' iteration of a part's design, and the use of sintering supports when needed, stable high-volume production is achieved.

With the growth of sinter-based Additive Manufacturing processes such as metal Binder Jetting, however, the need to manufacture a much wider range of parts at lower production volumes and in a shorter time frame means that a more efficient and streamlined approach is required.

Desktop Metal's Live Sinter simulation tool is said to enable users to simulate, in minutes, the deformation parts undergo as they sinter, allowing them to predict how parts will change shape as they densify. The software uses iterative simulation operations to create 'negative offsets', proactively deforming parts by specific amounts in specific directions that allow them to achieve their intended shape as they sinter.

Learn more about the science behind Live Sinter and how it can help engineers to address the challenges of sinter-based manufacturing in the new issue of *PIM International*, available to read for free online.

www.pim-international.com

Tekna's powder qualified by Boeing

Tekna, a subsidiary of Arendals Fossekompani ASA, headquartered in Sherbrooke, Canada, has successfully completed metal powder qualifications for Additive Manufacturing with aircraft manufacturer Boeing.

The company states that it is the first worldwide supplier to be qualified by Boeing for the production of Boeing Material Specification (BMS) titanium alloy powders and BMS aluminium alloy powders for AM. Tekna states this further positions the company as a key powder supplier for aerospace OEMs and their related AM service.

"Tekna is proud to meet Boeing's demanding BMS specification and to be its first qualified powder manufacturer for BMS Titanium (Ti64) and BMS Aluminum (AlSi10Mg)," stated Luc Dionne, CEO at Tekna. "Furthermore, Tekna manages a robust supply chain, from ingot to packaged spherical powders, thus ensuring reliable supply and material traceability."

www.tekna.com

Honeywell flight-critical AM engine part achieves certification

Honeywell Aerospace, headquartered in Phoenix, Arizona, USA, reports that it has produced and installed its first certified, flight-critical engine part built using Additive Manufacturing. Known as the #4/5 bearing housing, the part is a major structural component in the ATF3-6 turbofan engine used on the Dassault Falcon 20G maritime patrol aircraft.

In service with the French Navy for patrol and search-and-rescue missions, there are reportedly only about a dozen ATF3-6 engines still flying. Designed by Garrett in the early 1960s and certified in 1967, there are sourcing and supply chain challenges for operators of these aircraft.

In addition, the #4/5 bearing housing is said to be a complicated part to manufacture – making it extremely costly for operators to replace due to the low quantity of orders placed. This challenge is combined with the high cost of tools needed to produce parts with traditional casting methods. With Additive Manufacturing, these parts can be built more quickly and in smaller quantities without the need for expensive tools.

"Though there aren't many in service, Honeywell is responsible for supporting and maintaining these engines," stated Jon Hobgood, VP of Manufacturing Engineering, Honeywell Aerospace. "We had to find a way to address these supply chain issues and keep these aircraft flying. We were able to use our expertise in Additive Manufacturing to produce the qualified part much faster, reducing our lead time from approximately two years to two weeks."

Parts such as the #4/5 bearing housing are considered safety-critical or flight-critical by regulatory bodies, meaning they must always function properly. Malfunction or failure of these parts would pose a major threat to passenger and crew safety and could cause significant damage to an aircraft. Safety-critical parts face increased scrutiny and must be approved by regulatory organisations such as the Federal Aviation Administration (FAA), which makes the process from development to qualification a lengthy one.

Honeywell has been working closely with the FAA on the development and certification of multiple AM components and its efforts have enabled the bearing housing to be the first component approved under the normal FAA delegated authority.

"This is a major milestone for Honeywell because it demonstrates the maturity of our Additive Manufacturing operations and paves the way for us to print more certified, flight-critical parts in the future. It also is a major win for the additive industry, as flight-critical parts face heavy scrutiny and high standards for qualification and installation on aircraft, but this shows it can be done," Hobgood added.

www.aerospace.honeywell.com

Honeywell has achieved certification for an additively manufactured flight-critical bearing housing used in the ATF3-6 turbofan engine (Courtesy Honeywell Aerospace)

MELD releases new L3 Additive Manufacturing machine

MELD Manufacturing Corporation, Christiansburg, Virginia, USA, has released the L3 MELD machine, the latest in its range of metal Additive Manufacturing machines. The L3 has a build volume of 114 x 58 x 58 cm (45 x 23 x 23 in) and a table size of 130 cm x 58 cm (51 in x 23 in).

The L3 machine sits between the larger MELD K2 model, with a build volume of 210 x 110 x 100 cm (83 x 43 x 39 in), and the smaller B8 model, offering a build volume of 91 x 30 x 30 (36 x 12 x 12 in).

The open-air operation of the MELD machine is said to make it unique, with simplified requirements for material, usability and operating costs. MELD states that this simplicity extends to safety, only requiring standard manufacturing protective equipment.

"When we look at our customers and what they want to do with the technology it was clear that there needed to be a machine with a platform perfect for both part fabrication and repair," commented Dr Chase Cox, MELD Manufacturing Corporation Director of Technology.

"The L3 serves that need, offering a tremendous increase in production capability without requiring a larger footprint on the manufacturing floor."

www.meldmanufacturing.com

World's fastest fan-driven HIP from Quintus Technologies supports AM post-production at PRES-X

Quintus Technologies, Västerås, Sweden, has delivered what is claimed to be the world's fastest fan-driven Hot Isostatic Press (HIP) to PRES-X, a startup established to meet the post-production needs of metal additively manufactured components, based in Reggio Emilia, in Northern Italy.

Installation of the QIH 60 M URC® press has resulted in PRES-X being the first company in the world to deploy the special fan-driven HIP, specifically designed for the AM industry. The QIH 60's High Pressure Heat Treatment (HPHT) capability makes it possible to eliminate several operations in the AM production line, creating a more cost-effective process.

With Quintus' proprietary Uniform Rapid Cooling (URC®) technology, a cooling rate of 1500K/minute can be achieved while minimising thermal distortion and non-uniform grain growth, producing finished AM parts with optimal material properties.

The combination of HIP and in-process heat treatment is said to align with the PRES-X strategy to shorten the AM production cycle and key operations, performing them in a single production site. The setup offers process efficiency with a significant reduction in time and cost, as well as a favourable impact on sustainability.

"Our vision is to become the innovation leader within HIP," commented Andrea Scanavini, PRES-X CEO and founder. "We need a technical partner that shares our mission to be at the forefront, and Quintus is a perfect match. They have the same approach to introducing disruptive innovations in the field of HIP and HT, in the critical phases of post-processing AM parts."

The model QIH 60 press features a hot zone of 410 x 1000 mm (16.14 x 39.37 in) and operates at a maximum temperature of 1,400°C (2,552°F) and maximum pressure of 207 MPa (30,000 psi). It has a maximum workload weight of 600 kg (1,322 lb).

"The QIH 60's innovative capabilities have already prompted customers to review their parts production methods, even in application areas that have long used more traditional techniques," added Scanavini. "This is allowing us to see new project starts and growth in orders and revenue despite a very challenging global market situation."

Jan Söderström, CEO of Quintus Technologies, stated, "Quintus Technologies has developed solutions targeted specifically at AM products and projects in these areas. With the QIH 60 HIP, PRES-X is well positioned to satisfy the needs of the market today, where there is exceptional interest in new approaches that improve quality, lower cost, and reduce environmental impacts. We are very pleased to be working as a strategic partner to help PRES-X play a leading role in this innovation."

www.quintustechnologies.com
www.pres-x.com

A QIH 60 M URC HIP press has been installed at PRES-X (Courtesy Quintus Technologies)

ExOne announces new InnoventPro metal Binder Jetting machine and binder system

The ExOne Company, North Huntingdon, Pennsylvania, USA, has released details of its InnoventPro concept, said to be the most advanced entry-level model for metal Binder Jetting. The InnoventPro will be deployed with ExOne's NanoFuse binders, a new range of inkjet-printable nanoparticle suspensions.

According to the company, the InnoventPro represents a major upgrade to the Innovent+, which ExOne released in 2016. It will offer two new build sizes, a three litre and a five litre version, with build speeds topping 700 cm³/hour.

The new AM machine is said to be aimed at academics, researchers, and a full spectrum of manufacturers, from machine and MIM shops to high-volume producers, who want to produce metal parts quickly, affordably and sustainably.

"Customers around the world already love the Innovent+, and based on their feedback, we're going to give them an updated entry-level system that's bigger, faster and smarter than ever," stated John Hartner, ExOne CEO.

The InnoventPro will feature the same recirculating print head modules used on the X1 25Pro® and X1 160Pro™ metal Binder Jetting Additive Manufacturing machines, allowing users to easily scale up from R&D to high-volume production, explains the company.

The recirculating print head reportedly also enables ExOne to offer particulate binders as an option on a commercial Binder Jetting system. According to the company, its research team has been additively manufacturing a variety of nanoparticles suspended in its binders for years.

A new class of NanoFuse binders

The all-new class of NanoFuse binders, first patented in 2018 with related patents pending globally, is said to advance the field of binder jet Additive Manufacturing in critical ways. The company explains that, because nanoparticles fill in the interstices between powder bed particles and can bond at lower temperatures, they enable stronger green parts.

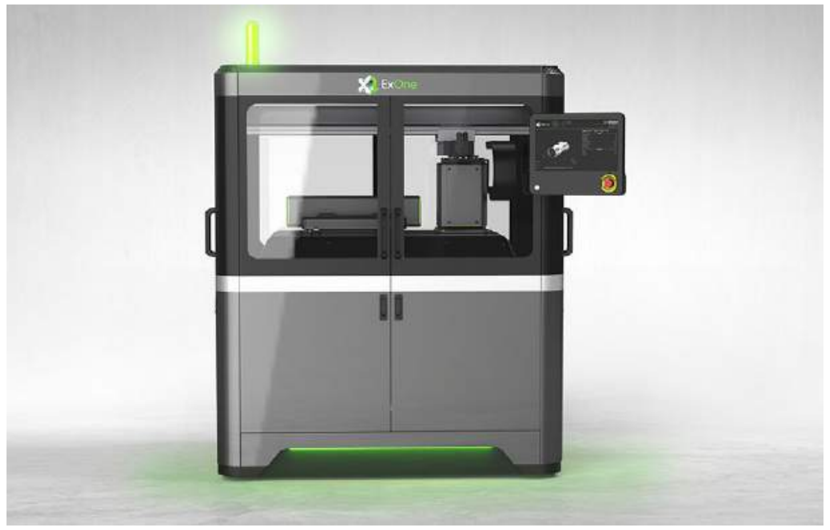
In turn, this enables the Additive Manufacturing of larger parts and finer features, delivering sharper corners and edges. These new binders are said to also improve the resolution and sinterability of high-demand metals, such as copper and aluminium.

Rick Lucas, ExOne CTO and VP, New Markets, commented, "Just as the current Innovent+ served as the proving ground for our patented Triple ACT system, which now delivers industry-leading quality in metal Binder Jetting, the InnoventPro will offer groundbreaking new features in a commercial system. Our patented approach to 3D printing particulate inks in a print bed is opening new doors in Binder Jetting."

ExOne's patented Triple ACT is a critical advanced compaction technology that, depending on the material, delivers final part density of 97+%, dimensional tolerances in the range of < 1% - 2.5%, and high consistency, with part variation of just 0.3% across the print-bed.

The company explains that Triple ACT has been so effective that it has also sped up ExOne's qualification of new materials. ExOne binder jet systems now process more than twenty metal, ceramic and composite materials, with single-alloy metals making up more than half of those offerings. NanoFuse binders are expected to expand that material range and improve sintering dynamics.

www.exone.com



ExOne's InnoventPro is a new entry-level Binder Jetting system for additively manufacturing metals, ceramics and composites (Courtesy The ExOne Company)

Submitting news...

Submitting news to *Metal AM* is free of charge. Contact Paul Whittaker: paul@inovar-communications.com

Carnegie Mellon University researchers develop sensor to detect COVID-19 antibodies using Optomec's Aerosol Jet process

Optomec, headquartered in Albuquerque, New Mexico, USA, reports that researchers from Carnegie Mellon University (CMU) located in Pittsburgh, Pennsylvania, USA, have utilised its Aerosol Jet process to develop a low-cost sensor that is capable of identifying coronavirus (COVID-19) antibodies in approximately ten seconds.

The sensor is based on a special structure of tiny gold electrodes that are additively manufactured using the Optomec Aerosol Jet process. The CMU researchers believe that the sensor will allow clinicians to instantly and accurately detect COVID-19 antibodies due to the specific geometry and surface characteristics of the additively manufactured structure.

Optomec's Aerosol Jet technology is a production process capable of additively manufacturing extremely precise conductive and non-conductive materials with features as fine as 10 microns. It is used in advanced semiconductor packaging, 3D antenna and sensor production, medical device manufacturing, aerospace and other industries.

For the sensor developed by the CMU researchers, ink droplets containing nanoparticles were placed to build a matrix of 100 gold pillars in 2 mm square at high speed. The pillars were then coated with reduced graphene oxide, which binds the antibodies to the gold electrodes.

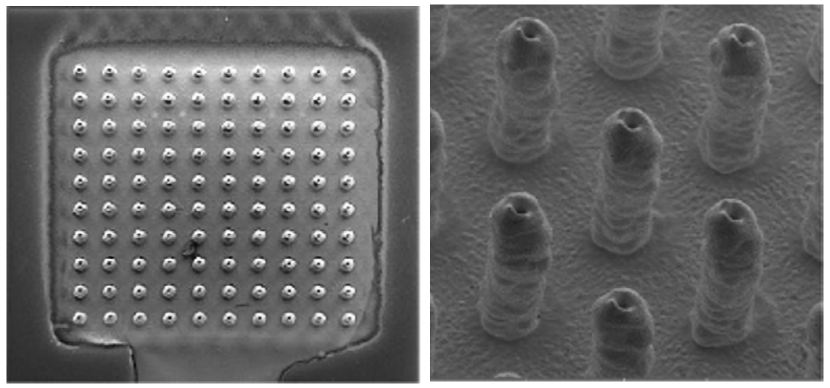
The test identifies two antibodies of the virus and is capable of detection even at very low concentrations through an electrochemical reaction sensed in the additively manufactured structure within a simple handheld device that interfaces with a smartphone. The CMU researchers have also begun research that will allow this platform to detect the active virus, in addition to its antibodies.

The sensor was developed by a team lead by Rahul Panat, Associate Professor of Mechanical Engineering at Carnegie Mellon University, who researches Additive Manufacturing techniques for producing biosensing devices and human-computer interfaces. Prof Panat also collaborated with Shou-Jiang Gao, leader of the Cancer Virology Program at UPMC Hillman Cancer Center and professor of microbiology and molecular genetics at the University of Pittsburgh.

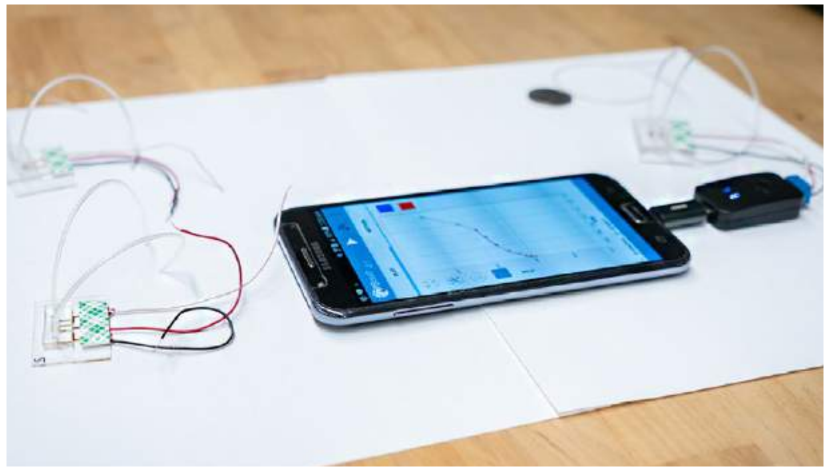
"My research team was working on 3D printed high-performance sensors to detect dopamine, a chemical in the brain, when we realised that we could adapt our work for COVID-19 testing," stated Prof Panat "We shifted our research to apply our expertise to combatting this devastating pandemic. The Aerosol Jet process was critical to producing a sensor with high sensitivity and speed."

The sensor has entered trials with COVID-19 patients and could prove to be a key tool in understanding the path and concentration of the current COVID-19 pandemic and could be a critical enabler in opening up certain parts of the economy. According to the researchers, the device has the potential to detect other viruses such as Zika, Ebola and HIV.

www.engineering.cmu.edu
www.optomec.com



The Aerosol Jet additively manufactured 100 gold micropillars (Courtesy Carnegie Mellon University)



An interface with a smartphone provides the results of the antibody test (Courtesy Carnegie Mellon University)

Prima Power Laserdyne introduces new hybrid AM machine

Prima Power Laserdyne, Champlin, Minnesota, USA, has introduced a new hybrid Additive Manufacturing machine which combines Directed Energy Deposition (DED) Additive Manufacturing, welding, drilling and cutting capabilities. The Laserdyne 811® serves as a replacement machine for the discontinued and obsolete Laserdyne® 780.

The Laserdyne 811 is said to employ the most current hardware and software components for flexible precision laser processing in an affordable compact platform. The combination of workstation, controller and laser in one machine is said to offer a cost-effective, high-speed, reliable solution for low- and high-throughput manufacturing, and takes full advantage of fibre laser technology.

The machine is said to have the necessary flexibility and precision to perform optimised laser processing on welding, drilling, cutting, and DED AM applications for small- to medium-size workpieces. Its working envelope is 1100 x 800 x 600 mm (41.5 x 31.5 x 24 in) for the X, Y, and Z axes, respectively. Each axis offers 50 m/sec velocity and acceleration of 1.2 g and is reportedly optimised for floor space efficiency.

Prima Power Laserdyne's new Laserdyne 811 machine combines DED AM, welding, drilling and cutting capabilities (Courtesy Prima Power Laserdyne)

When used for DED applications, the Laserdyne 811 is said to offer precise real-time control over powder deposition, laser power and shield gas delivery, enabling powders to be fused for the production of parts from scratch or to repair and rebuild metal surfaces, which are then machined to the OEM's specifications.

The Laserdyne 811 is designed to take advantage of the company's BeamDirector® technology. An additional two axes of motion (C and D) provide access to hard-to-reach places in the workpiece, precise beam placement, and a high degree of flexibility. The BeamDirector has 90 rpm rotational speed and control repeatability of 15 arcsecs. In addition, it supports laser processing from 90° (normal to the surface) to 10° off the surface of a part all the way along the axis of travel.

As with all Prima Power Laserdyne machines, the Laserdyne 811 is equipped with the latest standard software and supports Windows 10. This includes the full suite of SmartTechniques software to optimise the laser process and shorten cycle times, while improving process quality and consistency. The machine is also said to support the implementation of Industry 4.0 through the use of MTConnect™ real-time parameter and data streaming along with Prima Power Laserdyne developed SPC process data reporting and storage capability.

FastTrim and Fast Suite II CAD/CAM software, which support full six-axis interpolation, are also optionally available with the Laserdyne 811. The CAD/CAM option offered with the DED Additive Manufacturing machine is AMExpress, with CAM manufacturing software to produce part programmes.

www.primapowerlaserdyne.com

Lincotek Additive completes Additive Production Center for medical devices

Additive Manufacturing solutions provider Lincotek Additive, Trento, Italy, reports that it has completed development of its state-of-the-art Additive Production Center for medical devices at its Trento facility. The centre was completed with the addition of a high-vacuum furnace and validated heat treatment process designed specifically for the post-processing of titanium additively manufactured parts, expected to triple the capacity for thermal treatment at the site.

Lincotek reports that it has been working to improve its AM processes for fifteen years, drawing on the expertise of a team said to have a deep understanding of metallurgy, AM design and processing. Reactive metals such as titanium pose specific challenges, and the high-temperature heat treating of AM parts involves a great deal of complexity, but Lincotek Additive stated that it is mastering these challenges and has achieved very good scrap rates and high reliability in its production.

The company's investments in its new Additive Production Center are said to have resulted in a reduction in lead times as well as a robust back-up strategy, both of which are expected to benefit the company's customers. The company also stated that it is continuously innovating, in collaboration with its customers, in the field of heat treatments designed to improve material properties.

In addition to its significant investment in heat treatment at the centre, Lincotek Additive has added a range of instruments to its Trento Laboratory which it states are essential to understanding and mastering AM Powder Metallurgy. This expansion of its laboratory capabilities is expected to boost new project development and validation capability to support the company's global expansion.

"We're delighted that so many OEMs are now taking advantage of our complete additive service offer," stated Winfried Schaller, Lincotek Group CEO. "Our outstanding performance is based on a profound technical mastery of the AM process, building on R&D and validation capability, led by additive experts who support the OEMs in their serial AM needs."

"Today, we're globalising our reach, by having invested in an AM facility in our plant in Memphis, Tennessee [USA] to best support our US medical customers," he continued. "In 2019 we have moved to the next step, by opening an Additive Innovation Center in Switzerland, Europe, focused on the IGT and aviation market. We are already working on the next step of growth, looking at expanding our AM capability in China too."

www.lincotek.com/additive

A vacuum furnace (left) and EOS metal Additive Manufacturing machines (right) at Lincotek Additive's Additive Production Center (Courtesy Lincotek Additive)

Linde offers gas for optimal sintering in the Desktop Metal Studio System

Linde, a global industrial gas specialist headquartered in Guildford, Surrey, UK, has launched ADDvance® Sinter250, a new gas mixture said to deliver optimal atmospheric conditions in sintering furnaces as part of Desktop Metal's Additive Manufacturing process. The argon/hydrogen gas mixture has reportedly been developed for Desktop Metal's European customers, for use with the company's Studio System™.

Linde states that it will also supply customised installation kits to simplify the implementation of the Studio System, allowing for faster start times, as well as consultancy services to advise on gas supply options and best practice for cylinder storage.

According to Linde, the tailored argon/hydrogen mix of ADDvance Sinter250 is for use on parts made from stainless steel powders, but the company states that it will also supply a pure argon 5.0 gas for the manufacture of parts made from low alloy steel and tool steel powders.

"Linde has long been a pioneer in the development of innovative gas mixtures to optimise manufacturing processes," stated Pierre Forêt, Senior Expert Additive Manufacturing, Linde. "In this rapidly developing world of Additive Manufacturing, we are delighted to be collaborating with an innovator in the space such as Desktop Metal to supply this gas mixture to their customers."

Arjun Aggarwal, VP of Business Development & Product, Desktop Metal, commented, "Linde has developed a standard gas offering optimised for Studio System and is able to offer this streamlined solution to our European Desktop Metal customers. This enables us to expand our horizons and bring added value to our business."

www.linde.com
www.desktopmetal.com

NASA looks to large-scale DED Additive Manufacturing for future rocket engines

Blown powder Directed Energy Deposition can produce large structures such as these engine nozzles (Courtesy NASA)

NASA reports that it is seeking to incorporate large-scale metal Additive Manufacturing in the design and manufacture of its future rocket engines, through its Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) project. By using a blown powder Directed Energy Deposition (DED) process, NASA hopes to reduce costs and lead times for producing large, complex engine components such as nozzles and combustion chambers.

"This technology advancement is significant, as it allows us to produce the most difficult and expensive rocket engine parts for a lower price tag than in the past," stated Drew Hope, Manager of NASA's Game Changing Development Program, which funds the RAMPT project. "Further, it will allow companies within and outside of the aerospace industry to do the same and apply this manufacturing technology to the medical, transportation, and infrastructure industries."

The DED Additive Manufacturing method injects metal powder into a laser-heated pool of molten metal, or melt pool. The blown powder nozzle and laser optics are integrated into a build-head. The build-head is attached to a robot and moves in a pattern determined by a computer, building one layer at a time. The fabrication method has many advantages, including the ability to produce very large pieces, states NASA. It can also be used to additively manufacture very complex parts, including engine nozzles with internal coolant channels. Rocket engine nozzles that contain internal coolant channels run cryogenic propellant through the channels to help keep the nozzle at safe temperatures.

"It's a challenging process to manufacture the nozzles traditionally, and it can take a very long time," commented Paul Gradl, RAMPT Co-Principal Investigator at NASA's Marshall Space Flight Center in Huntsville, Alabama, USA. "Blown powder Directed Energy Deposition Additive Manufacturing allows us to create very large-scale components with complex internal features that were not previously possible. We're able to significantly reduce the time and the cost associated with the fabrication of channel-cooled nozzles and other critical rocket components."

The RAMPT team recently used the technique to produce one of the largest nozzles NASA has additively manufactured, measuring 102 cm (40 in) in diameter and standing 97 cm (38 in) tall, with fully integrated cooling channels. This nozzle was fabricated in a record time of just thirty days, compared with nearly one-year using traditional welding methods, and completion occurred a year earlier than scheduled due to the technology advancing rapidly.

The RAMPT project's success has garnered the attention of NASA's Space Launch System (SLS) rocket team. NASA's SLS, along with the Orion spacecraft, are reported to be the backbone to its deep space exploration plans, including sending the first woman and next man to the Moon in 2024 and establishing sustainable exploration by the end of the decade. The SLS Program is investing in RAMPT's blown powder Directed Energy Deposition fabrication process with the goal of certifying it for spaceflight. Together with RAMPT, the team is using the technique to build and evaluate a channel-cooled nozzle that is up to 142 cm (5 ft) in diameter and almost 213 cm (7 ft) tall.

"Producing channel wall nozzles and other components using this new type of Additive Manufacturing would enable us to make the SLS engines at the scale required with a reduced schedule and reduced cost," said Johnny Heflin, Liquid Engines Office Manager for the SLS Program.

Through a series of rigorous hot fire tests, engineers will subject a subscale version of the nozzle to the same 6,000-degree combustion temperatures and sustained pressures it would face during launch to demonstrate the durability and performance of the new DED technology.

NASA's investments in blown powder DED fabrication technology and materials development is expected to play a critical role in enabling the agency's most ambitious exploration missions. The technology may also play critical roles in many other industries, including commercial space.

RAMPT includes partners from across the agency, including NASA's Glenn Research Center in Cleveland, NASA's Ames Research Center in Silicon Valley, California, industry, and academia.

www.nasa.gov

Fathom acquires metal AM provider GPI

Private equity firm Core Industrial Partners, headquartered in Chicago, Illinois, USA, reports that its portfolio company Fathom has acquired the metal Additive Manufacturing company GPI Prototype & Manufacturing Services, LLC (GPI), Lake Bluff, Illinois, USA.

Core acquired Midwest Composite Technologies in 2018, and Fathom and ICOMold in 2019. All four companies will be moving forward under the Fathom brand.

GPI was founded in 2007 and was reportedly one of the first metal AM services providers in the country. The company uses Laser Beam Powder Bed Fusion (PBF-LB) to additively manufacture parts with complex geometries for on-demand manufacturing applications. It utilises a variety of metal powders, including aluminium, stainless steel, tool steel, titanium, Inconel and cobalt chrome and holds ISO 9001, ISO 13485, and AS9100D certifications.

"GPI's ability to leverage metal Additive Manufacturing accelerates both design cycles and time to market and further enhances Fathom's existing metal additive capabilities and our unique customer value proposition," stated Ryan Martin, CEO of Fathom. "We're excited to work closely with GPI's customers as a turnkey partner for on-demand manufacturing, providing a broad array of complementary services and an unparalleled customer experience."

Matthew Puglisi, partner at Core, commented, "DMLS is one of the fastest-growing Additive Manufacturing technologies, both at Fathom and broadly across the industry, and an important strategic focus as we seek to further strengthen Fathom's position as a leading on-demand manufacturer.

"GPI is widely respected as one of the original metal Additive Manufacturing services providers, and we believe the combination with Fathom will be highly synergistic," continued Puglisi.

Adam Galloway, president of GPI, reported, "Since its founding over a decade ago, GPI has been on the cutting-edge of the revolutionary metal Additive Manufacturing space. This partnership with Fathom will further benefit our valued customers through an enhanced suite of manufacturing capabilities accompanied by the same excellent customer service, quality and metallurgical expertise for which we're known."

www.coreipfund.com
www.gpiprototype.com
www.studiofathom.com

Teamziereis adds dry electropolishing system for dental AM

Teamziereis GmbH, a dental products and services specialist based in Engelsbrand, Germany, has announced its recent investment in an innovative dry electropolishing system from DLyte, Barcelona, Spain.

The DLyte 10D system allows the automatic polishing of components produced by Additive Manufacturing and hybrid manufacturing. It is said to result in an excellent polished finish on removable partials, dental crowns and products for orthodontic treatments.

Ralph Ziereis, General Manager of Teamziereis, explained how he found the dry electropolishing system, "A customer told us about the innovative DLyte polishing method. Subsequently we informed ourselves about this technology and its possibilities at the AM Solutions booth during the 2019 formnext show."

Teamziereis produces removable partials, dental crowns and components for orthodontic treatments, for example, filigreed wires, from cobalt chrome alloys with a Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing system. After they were built, these components had to be manually polished. This costly operation usually took place in dental labs, explains Ziereis. "To relieve our customers from this time consuming and expensive operation and to be able to offer another service, we had been looking for a suitable mechanical polishing method and with the DLyte technology we finally found it."

"This system saves our customers not only a lot of money and time, but it also produces absolutely repeatable, high-quality polishing results," added Ziereis. By using the DLyte 10D, processing time can be reduced by up to 80% compared to manual work, depending on the application. Furthermore, several parts can be processed simultaneously.

www.teamziereis.de
www.dlyte.es

Teamziereis produces dental components via metal Additive Manufacturing (Courtesy Teamziereis GmbH)

Ralph Ziereis, General Manager of Teamziereis, with the new DLyte electropolishing system (Courtesy Teamziereis GmbH)

Materials producer 5N Plus enters metal AM market

5N Plus Inc., Montréal, Québec, Canada, a producer of speciality chemicals and engineered materials, has entered the Additive Manufacturing market as a supplier of high-performance engineered powders, beginning with the launch of a broad portfolio of metal powder products. The company began its engineered powder activities in 2014 and has continued to invest in process technologies. As a new entrant to the market, 5N Plus elected to initially focus on the technologically challenging and smaller markets within micro-electronics and semiconductor applications.

The company's new portfolio of engineered powders is produced using proprietary process technologies based on copper and copper-based alloys. These engineered materials are said to offer optimised morphology, controlled oxygen content, ultra-high purity, surface oxide thickness uniformity and controlled particle size distribution.

Between the company's internal developments and products currently under acquisition, 5N Plus' portfolio of engineered powders is expected to span two dozen different metal alloy compositions, with melting points ranging from 60°C to well over 2600°C. An area of particular focus at 5N Plus is cold spray AM technology. The company reports that it has been co-developing engineered powders with leading Canadian stakeholders in this area. It is currently collaborating with McGill University, Montréal researchers to engineer and test powders based on copper alloys.

The company is also collaborating with key industrial partners to develop tailor-made, cost-effective solutions based on the cold spray application of copper alloys to provide sustainable and safe isolation of nuclear waste over prolonged periods.

www.5NPlus.com

ExOne releases X1D1 automated guided vehicle concept

The ExOne Company, North Huntingdon, Pennsylvania, USA, has released a concept rendering of its new X1D1 Automated Guided Vehicle (AGV), designed to enable efficient transport of build boxes through the Binder Jetting process.

The X1D1 will initially be offered as an option for customers of ExOne's new X1 160Pro™ production metal Additive Manufacturing machine, which will begin shipping later this year. The 160Pro will be offered with either a standard conveyance system or the new X1D1, providing manufacturers with greater layout flexibility and efficiency options.

The X1D1 AGV will lock into place at the front of the 160Pro, and will be able to roll a build box into and out of the machine. With a build volume of 160 litres, a full build box of metal powder will often weigh more than 700 kg (1,500 lb). After the build process, the X1D1 will transport the build box to a curing oven where the parts are dried, before moving to an automated depowdering and cleaning station, and lastly to sintering.

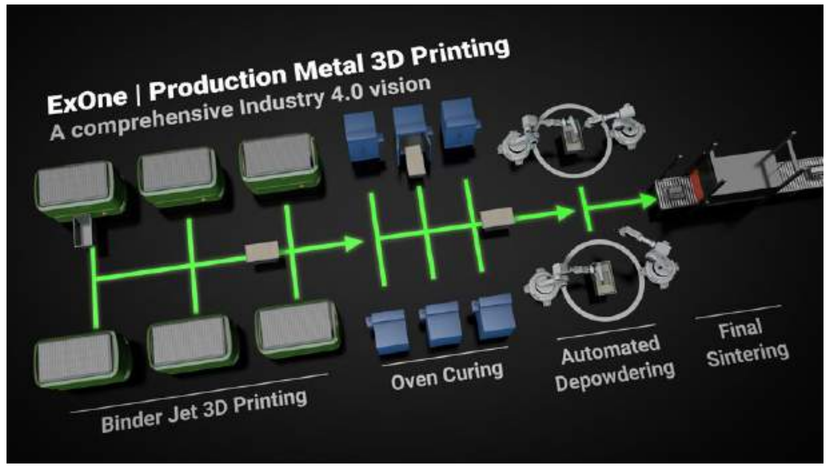
"As part of our discussion with manufacturers, we've updated our vision for the production Binder Jetting work cell, developing an option that provides high-volume manufacturers with more intelligent flexibility and better use of factory space," stated John Hartner, ExOne CEO.

ExOne's X1D1 Automated Guided Vehicle enables efficient transport of build boxes (Courtesy The ExOne Company)

According to ExOne, the AGV is said to be able to support multiple AM machines and processes efficiently, thus reducing the total footprint of the machine and simplifying timed movements between processes.

"While ExOne's production metal 3D printers will remain the centrepiece of our digital manufacturing vision, we're looking to streamline the entire sequence of processes around our systems with automation, software and remote monitoring and controls," Hartner concluded.

www.exone.com



The AGV will enable automated and efficient Industry 4.0 transport of AM build boxes through the Binder Jetting process (Courtesy The ExOne Company)

nTopology raises $40 million in latest funding round

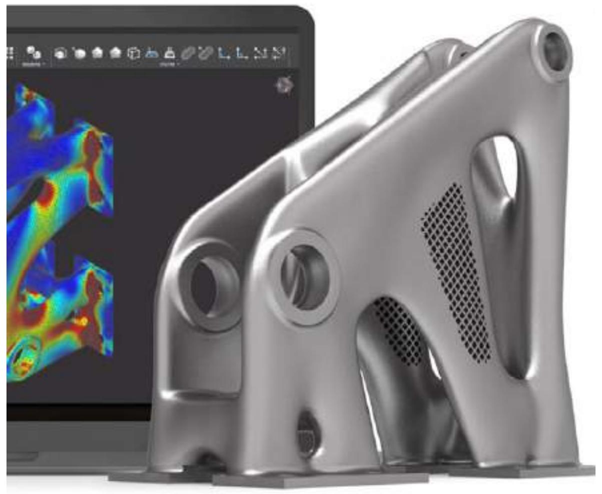
Engineering software company nTopology Inc., headquartered in New York City, New York, USA, reports that it has raised $40 million in its latest Series C funding round. The funding round was led by global venture capital and private equity firm Insight Partners, based in New York City, New York, USA, and nTopology's existing venture partners Root, Canaan, DCVC, & Haystack. The company states that Josh Fredberg of Insight Partners will join nToplogy's board of directors along with Carl Bass, the former CEO of Autodesk.

Launched in 2019, the company's nTop Platform empowers engineers to design revolutionary products and the software is said to be used at hundreds of engineering companies by thousands of engineers on their most advanced projects in the aerospace, automotive, medical, and consumer industries.

nTopology stated in a press release, "nTop Platform is our contribution to the engineering world. We're relentlessly pursuing our goal to build the most powerful engineering software, eliminate bottlenecks in traditional modelling technology, and empower engineers to design transformative products."

"Engineers from the aerospace and medical industries are currently leading the adoption and deployment of advanced manufacturing, so they were the first to realise the need of the powerful design tools offered by nTop Platform. We're also seeing rapid adoption of our tools in the automotive, consumer, and manufacturing tooling industries. Closing this new round of funding will help make the most advanced engineering software accessible to all."

www.ntopology.com



nTopology's latest funding round will allow the company to further advance its engineering software (Courtesy nTopology Inc)

AML3D ships AM stainless steel 'showpiece' propeller to consultancy firm 3D Printing Corporation

AML3D Limited, Edinburgh, Australia, reports that it has shipped a 316L stainless steel additively manufactured propeller to 3D Printing Corporation (3DPC) based in Yokohama, Kanagawa Prefecture, Japan.

3DPC is a consultancy firm that focuses on identifying innovative technologies capable of enhancing the manufacturing capabilities of its clients.

The additively manufactured propeller will reportedly be made available to 3DPC's marine sector clients as a 'showpiece' to demonstrate the advantages of AML3D's WAM® (Wire Additive Manufacturing) technology over the traditional casting methods.

AML3D states that the relationship with 3DPC provides a significant opportunity to capitalise on the growing global market for propellers that is anticipated to reach US$5.4 billion by 2022, with considerable demand coming from the APAC region.

The purchase order for the additively manufactured propeller is valued at $10,000 and it is anticipated that successful validation may lead to significant commercial contracts with various 3DPC clients, explains AML3D.

Andrew Sales, AML3D's Managing Director, commented, "We are proud to be able to deliver a complex propeller blade trial piece and look forward to expanding our presence in both the Asia Pacific region and global marine sector with the support of 3DPC."

www.aml3d.com

www.3dpc.co.jp

AML3D has shipped this additively manufactured propeller to 3D Printing Corporation to demonstrate benefits of its WAM® (Wire Additive Manufacturing) technology (Courtesy AML3D Limited)

Alloyed and Taniobis collaborate to develop advanced titanium and refractory alloy metal powders

Metal powder development company, Alloyed, London, UK, and Taniobis, based in Goslar, Germany, have announced a collaboration to identify, develop, produce, and implement innovative high-quality titanium and refractory alloy metal powders for use in advanced manufacturing applications, including AM.

The partnership is said to enable a full end-to-end solution for the material development process, including analysis and qualification, production, component design and performance, and into pilot production. "At Alloyed we are very happy to be working with the global team at Taniobis to progress innovations with new titanium and refractory alloys for AM," stated Michael Holmes, Managing Director of Alloyed. "The Alloys By Design (ABD) platform, coupled with Taniobis' long-standing and world-leading expertise with tantalum and niobium materials has the potential to open up some new and very exciting application areas for advanced manufacturing applications."

Katarzyna Kosowski, who heads Corporate Business Development & Communication at Taniobis added, "There is great synergy between Taniobis and Alloyed that I believe will serve our clients in limitless ways when it comes to providing end-to-end solutions for new and greatly improved applications with metal AM technologies. By collaborating with the experts at Alloyed and their exceptional ABD platform, we are extending our reach and capabilities into new and innovative areas for advanced manufacturing and particularly for Additive Manufacturing. The opportunities that AM affords has been well documented, but unlocking new materials for AM remains a constant goal. Together with Alloyed, we at Taniobis hold one of the keys."

www.alloyed.com
www.taniobis.com

Alloyed and Taniobis will develop titanium and refractory metal powders (Courtesy Taniobis)

Blackstone develops and tests additively manufactured solid-state battery prototypes

Blackstone Resources AG, headquartered in Baar, Switzerland, reports that it has achieved a series of milestones for its proprietary AM technology to additively manufacture lithium ion solid-state batteries.

The company explains that it has been investing in the next generation of battery technology through its subsidiary German-based Blackstone Technology GmbH. This includes patented Additive Manufacturing techniques and research into the mass production of batteries, which has been shown to offer greater energy density and a higher number of charging cycles.

According to Blackstone Technology, its AM process offers substantial advantages over conventional battery cell design that use liquid electrolytes. These advantages are said to include:

- Significantly lower costs
- A higher level of production flexibility when it comes to the format of the cell
- A 20% increase in energy density

In addition, the company states that by using this technology, the amount of materials that do not store energy, i.e. copper and aluminium, could be reduced by up to 10%. These advantages can be achieved independently of the electrode chemistry.

Having developed and tested this technology, Blackstone Technology states that to achieve the highest efficiency from its AM technology, it plans to produce additively manufactured solid-state battery cells.

An automated Additive Manufacturing production process could reportedly save up to 70% of the traditional Capex used to produce solid-state batteries. Solid-state batteries are also said to be safer as they do not use flammable liquid electrolytes which are also more harmful to the environment.

The first solid-state battery prototypes developed by Blackstone Technology have already been tested and the company is now developing the AM technology required to additively manufacture these solid-state battery cells for mass production. Following the conclusion of an extensive development contract with Germany's Fraunhofer Institute, the first AM prototypes will be tested in Q1 2021.

Holger Gritzka, CEO of Blackstone Technology GmbH, commented, "Together with the developments we have made in 3D-printing battery technology to date, this development paves the way for the mass production of solid-state battery cells. In addition to major markets such as the automotive industry, marine applications and new 5G wireless networks would benefit from the advantages that 3D-printed solid-state cells can offer."

www.blackstoneresources.ch

AML3D to implement Industrial Internet of Things technology into its WAAM machines

Australian-based AML3D Limited has entered into a Memorandum of Understanding (MoU) with the Advanced Manufacturing Growth Centre (AMGC) and Dematec Automation Pty Ltd (Dematec) to co-develop Industrial Internet of Things (IIoT) solutions for AML3D's Adelaide Production machine modules and Arcemy® Wire-Arc Additive Manufacturing (WAAM) units.

The project aims to deliver a solution that enables AML3D's distributed manufacturing business model strategy, enabling the deployment of Arcemy units close to customer sites globally. AML3D's engineers and technicians will then be able to centralise control of deployed Arcemy models via 'printing module dashboards' to allow local production of parts manufacturing on demand for its customers.

This initiative includes enabling an artificial intelligence capability in line with AML3D's product development roadmap to enable smarter machines in line with the market's anticipated development over the next three to five years.


AML3D Managing Director Andrew Sales with Dematec Automation Managing Director David Hart at AML3D's new facility in Edinburgh Parks, Adelaide, Australia (Courtesy Roy VanDerVegt / AML3D Limited)

AML3D intends to use these technologies to drive efficiencies internally and externally to deliver a fully integrated customer service solution, capable of:

- Centralised remote operation of Arcemy units deployed globally based on customer location demand
- Deployment of a future 'virtual warehouse' of parts for customers
- Enabling artificial intelligence interfaces as part of the AML3D product development roadmap to optimise the build process

Andrew Sales, AML3D's Managing Director, commented, "We're eager to embark on this program with two highly regarded innovation partners. The enhanced capabilities of the proposed platform will provide us with complete oversight of all production units globally."

"A greater level of live insight is key to driving efficiencies, both internally and externally," he continued. "Once integrated, the platform will only further imbed our technologies within our clients' operations, solidifying AML3D as a core advanced manufacturing partner."

David Hart, Dematec CEO, commented, "At Dematec, we're focused on pushing the Australian manufacturing sector to the forefront of innovation. AML3D is a great example of Australian ingenuity, and we're excited to embark on a co-development program that will only further enhance their offering."

www.aml3d.com
www.amgc.org.au
www.dematec.com.au

Freemelt introduces ProHeat for pre-heating AM machines

Freemelt AB, Mölndal, Sweden, a developer of Electron Beam Powder Bed Fusion (PBF-EB) Additive Manufacturing technologies, has introduced ProHeat, a new solution to enable preheating of the powder bed in PBF-EB AM machines. According to the company, ProHeat is based on heating by electromagnetic radiation from a heating device positioned over the powder bed. The radiation sinters each powder layer smoothly, with zero risk of powder charging or so-called smoke events. It is said to provide a number of benefits over existing PBF-EB preheating solutions. Benefits include:

- Fast and efficient heating, preserving all unique advantages of a hot and stress-relieved AM process
- Preheating without interaction with electrons – eliminating charging of the powder
- Highest vacuum purity and optimum beam quality maintained at all times
- Zero consumption of costly, high-purity inert gas (helium or argon)
- Uniform sintering of the powder bed, resulting in smoother melting and less spatter.

ProHeat is expected to be implemented in future versions of Freemelt's AM machines. "We are very optimistic about this innovation," stated Ulric Ljungblad, Freemelt CEO. "ProHeat is an enabler for robust, efficient processing and expands the potential of E-PBF to new classes of materials that are difficult or even impossible to process in E-PBF systems as of today."

Ulf Ackelid, senior scientist at Freemelt, added, "ProHeat will speed up development of new E-PBF materials since it eliminates the time-consuming optimisation of preheating parameters."

www.freemelt.com

Porsche tests metal AM pistons in its 911 GT2 RS engine

Porsche, in cooperation with its partners Mahle, Trumpf and Zeiss, recently used metal Additive Manufacturing to produce a series of aluminium pistons for the high-performance engine of its 911 flagship model, the GT2 RS sports car.

The automaker already uses Additive Manufacturing technology for prototypes and in the manufacture of spare parts for classic sports cars, as well as in some other areas. Using Laser Beam Powder Bed Fusion (PBF-LB) technology from Trumpf to produce the GT2 RS pistons, Porsche believes it is establishing a new milestone in the use of AM for highly-stressed drive components.

The use of AM allowed the pistons to be manufactured with a structure optimised for the loads acting on them. As a result, the additively manufactured pistons weigh 10% less than the forged pistons which Porsche has conventionally used. In addition, the pistons have an integrated and closed cooling duct in the crown which could not have been produced by forging.

"Thanks to the new, lighter pistons, we can increase the engine speed, lower the temperature load on the pistons and optimise combustion," stated Frank Ickinger, from the Advance Drive Development Department at Porsche. "This makes it possible to get up to 30 PS more power from the 700 PS biturbo engine, while at the same time improving efficiency."

The aluminium additively manufactured pistons have now been successfully tested on the engine test bench for the GT2 RS. Their quality and performance capability was validated using measurement technology from Zeiss.

www.porsche.com

The AM pistons were developed at Mahle (Courtesy Porsche)

An aluminium AM piston is installed for testing on the engine test bench for Porsche's 911 GT2 RS sports car (Courtesy Porsche)

Additive Industries and Sigma Labs qualify MetalFAB1 'PrintRite3D Ready'

Additive Industries, Eindhoven, the Netherlands, and Sigma Labs, Inc., Santa Fe, New Mexico, USA, have announced that the MetalFAB1 AM machine is now qualified as 'PrintRite3D® Ready'. The effort to qualify the machine was undertaken as part of a partnership between the companies' engineering teams.

The qualification for use with Sigma Labs' PrintRite3D software will allow the MetalFAB1 AM machine to be equipped with a meltpool monitoring solution. Able to monitor up to four full-field lasers and offering real-time multi-laser visualisations, the PrintRite3D Melt-Pool Monitoring solution is a valuable integration into the MetalFAB1, according to Additive Industries. Real-time visualisation can be viewed in 2D or 3D; potential anomalies in the part will be highlighted.

"Our engineering teams have truly accomplished a remarkable milestone in 3D metal printing by designing and building a high-performance computer platform that processes sensor data and produces a near real-time visualisation for a quad-laser printer," stated Mark K Ruport, president and CEO of Sigma.

"We are very pleased to be working with an industry leader such as Additive Industries to accelerate the industrialisation of 3D metal printing," he continued. "The MetalFAB1 is a remarkable printer and it's a privilege to have it certified as PrintRite3D Ready."

Mark Vaes, CEO and CTO of Additive Industries, commented, "The integration of the PrintRite3D Melt-Pool Monitoring solution in our MetalFAB1 is an important addition to our product portfolio. The PrintRite3D solution matches very well with our focus on quality and reproducibility, allowing our customers to benefit from reduced post-processing cost, and faster part qualification. We are very pleased with the strong partnership with Sigma Labs, and are proud to be working with their industry-leading PrintRite3D solution."

The MetalFAB1 has been qualified as 'PrintRite3D Ready' as part of Additive Industries and Sigma Labs' partnership (Courtesy Additive Industries)

www.additiveindustries.com

www.sigmalabsinc.com

Authentise and Addiguru integrate in-process monitoring into AM workflow

Authentise, a developer of data-driven workflow tools for Additive Manufacturing founded in San Francisco, California, USA, with offices in London, UK; Kiev, Ukraine and Philadelphia, Pennsylvania, USA; and Addiguru, a provider of real-time monitoring solutions for AM based in Los Angeles, California, USA, have collaborated to extend the Authentise Manufacturing Execution System (AMES) to include real-time process monitoring based on computer vision and artificial intelligence (AI).

The companies explained that the integration of Authentise with Addiguru will provide a seamless experience for users who are seeking to gain practical use from their AM monitoring systems. In the integrated solution, alerts from Addiguru algorithms create real-time notifications within the Authentise web interface and app, display images highlighting potential issues, and visually spotlight the alert within the full workflow view.

The full data suite of images and findings is said to be automatically added to the real-time traceability alert and in a new analytics section for each machine and build. This includes the ability to overlay detected anomalies with sensor data taken from Authentise's access to machine data. Each user can also use this data to create custom alerts, reports and dashboards.

"Existing in-process monitoring tools either require the user to have spent days setting up trial prints or to click through every image to detect potential flaws," stated Shuchi Khurana, CEO of Addiguru. "The combination of our AI-driven insight and Authentise's workflow tools enables the user to gain practical benefit in a system they love by having all data and notifications in one place. This initiative with Authentise also moves us closer to our goal of an open architecture framework."

Andre Wegner, CEO of Authentise, commented, "The collaboration with Addiguru is a success because each party brings unique skills: Authentise provides coherent control of the digital thread and access to machine data, to which Addiguru can add visual inspection and intelligent analysis."

"Our collaboration with Addiguru is testament to both Authentise's openness and the continued inventiveness of the startup community," he continued. "While incumbent providers try to develop everything in-house, we work with the brightest minds to ensure that critical, cutting-edge solutions enter the market rapidly."

"Addiguru joins a variety of partner modules in areas such as geometric search, mesh healing, or quoting. Their integration into our MES makes ground-breaking solutions accessible, affordable and seamless. We are proud to guarantee our clients that they will always have access to best-in-class solutions."

www.authentise.com

www.addiguru.com

DoD awards Desktop Metal $2.45 million project for high-volume AM of cobalt-free hardmetals

Desktop Metal, Burlington, Massachusetts, USA, has been awarded Phase I of a three-year $2.45 million project by the US Department of Defense (DoD) to develop an Additive Manufacturing process that is capable of mass-producing cobalt-free hardmetals, developed by the US Army. The company's Production System™ with Single Pass Jetting (SPJ), a proprietary technology developed by Desktop Metal, will reportedly enable the mass-manufacturing of complex-shaped cobalt-free hardmetal parts without tooling. The project is expected to lead to the development of a dual-use technology with numerous applications in defence as well as in the civilian sector.

Desktop Metal stated that its new process has the potential to "change the landscape of the carbide hardmetals market," which is projected to grow to $24 billion by 2024. Applications for hardmetals include cutting tools; abrasion and chemical-resistant nozzles; parts for the oil and gas sector; parts for the chemical and textile industry; tools used in agriculture and mining, the steel industry, consumer goods and sporting goods; parts for off-road transportation; parts for the aerospace and defence sector; parts for construction; and tools and dies for chipless material forming.

The project is issued to Desktop Metal by the US Army Contracting Command – Aberdeen, Research Triangle Park, on behalf of the US Army Research Laboratory (ARL) to the National Center for Manufacturing Sciences (NCMS) Advanced Manufacturing, Materials & Processes (AMMP) Consortium. Successful investigations by the US Army in developing a novel iron-based nanomaterial as the matrix in WC-based hardmetals, replacing cobalt, has reportedly resulted in the development of patented, novel Co-free WC-(Fe-Ni-Zr)-based hardmetals.

In alignment with the creation of the new material for commercial and DoD applications, the ARL has been in search of a cost-effective, high-volume process capable of manufacturing the new Co-free hardmetals into complex, net or near-net shape parts without the use of any tooling.

The three-year project will include the development of a feedstock and binder system for a novel cobalt-free hardmetal. The project will seek to use the Desktop Metal SPJ process to build a sufficient quantity of components, with at least 200,000 parts in one day from a single machine. It will also deliver a cost analysis for scaling up the advanced SPJ Binder Jetting technique to successfully manufacture at least 500,000 prototype pieces.

"The novel Co-free hardmetal grade is expected to yield a high-strength, high-toughness, high-hardness, and high-wear resistance material," stated Dr Nicholas Ku, Materials Engineer, CCDC Army Research Laboratory. "We believe combining this novel material with Desktop Metal's Single Pass Jetting technology will have major applications not only in the defence sector but also in the commercial sector."

Ku added, "Further, we believe this combined method will dramatically improve sustainability, reduce the use of a conflict mineral and provide an environmentally-friendly process to mass-produce parts with superior properties."

Whereas typical Binder Jetting processes use multiple carriages and passes over a build box to complete the steps required to build each layer, bi-directional SPJ on the Production System consolidates these steps into the motion of a single print carriage, dramatically reducing build time and removing wasted motions during AM to increase mechanical efficiency.

Dr Animesh Bose, vice president of Special Projects for Desktop Metal, who will serve as principal investigator of the three-year project, stated, "The success in this project will not only provide the hardmetal community with their eagerly desired Co-free hardmetal solution but also result in the development of a tool-free processing technique capable of fabricating this class of materials into extremely complex-shaped parts at speeds that can rival most other high-volume manufacturing techniques, opening up new horizons in the area of hardmetals and its applications."

Lisa Strama, NCMS' CEO, reported, "This effort exemplifies the ability of NCMS and AMMP to link cutting-edge technologies of non-traditional defence contractors with government agencies to meet existing needs and requirements. We look forward to the lasting impact this initiative will have within AMMP, the Army, and the broader community driving innovative Co-free hardmetal solutions across the services and industry at large."

www.desktopmetal.com

Desktop Metal's Production System, with Single Pass Jetting, will be used to mass manufacture complex-shaped Co-free hardmetal parts as part of the project (Courtesy Desktop Metal)

On-demand manufacturing marketplace Xometry announces $75 million equity round

Xometry, headquartered in Gaithersburg, Maryland, USA, has completed a $75 million equity round, led by funds and accounts advised by T. Rowe Price Associates, Inc. Following a $55 million Series D in 2019, this new funding round brings Xometry to $193 million in total funding since its founding in 2013. Durable Capital Partners LP and ArrowMark Partners also participated in the round, along with previous venture and strategic investors BMW i Ventures, Greenspring Associates, Dell Technologies Capital, Robert Bosch Venture Capital, Foundry Group, Highland Capital Partners, and Almaz Capital.

Xometry also announced the appointment of Jim Rallo as its Chief Financial Officer. Rallo previously served as CFO and president of Liquidity Services.

"Xometry is focused on helping manufacturers navigate the current disruption associated with supply chain flexibility, reshoring and shift to digital manufacturing," stated Randy Altschuler, Xometry CEO. "We're thrilled to be working with T. Rowe Price, Durable Capital Partners and ArrowMark Partners as we build on our strong growth."

"This funding will enable us to continue to accelerate our business through investments in our software platform, new products, and other initiatives," he added.

"The adoption of distributed manufacturing across industries is accelerating," commented Andrew Davis, Director of Private Investments at T. Rowe Price Associates, Inc.

"Xometry's agile digital marketplace helps both the Fortune 500 and smaller businesses meet their production requirements," he continued. "Xometry has the right team, the right technology at the right time to build a strong, global scale manufacturing business."

Xometry's on-demand manufacturing marketplace offers a wide range of manufacturing capabilities, including more than sixty metal and plastic Additive Manufacturing materials, CNC machining, injection moulding and sheet metal manufacturing, through a network of over 5,000 manufacturers.

The company has seen its revenue double each year over the past five years. Xometry also acquired Shift, Munich, Germany, in December 2019.

www.xometry.com

Creaform introduces new suite of automated dimensional quality control solutions

Creaform, a 3D measurement solutions provider based in Lévis, Québec, Canada, has announced the latest release in its R-Series™ line, including its new MetraSCAN 3D-R BLACK|Elite™ as well as the addition of four different models in its CUBE-R 3D scanning measuring machine. Creaform also launched its VXscan-R™ digital twin environment software module, which completes the company's turnkey automated quality control solution suite.

Designed for automated quality control applications, the R-Series 3D scanning solutions are said to enable manufacturing companies to increase productivity by measuring more dimensions on more parts, without compromising on accuracy.

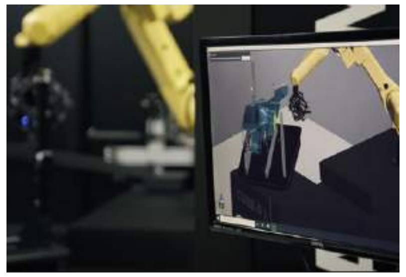
The MetraSCAN 3D-R is a robot-mounted optical CMM scanner that can be seamlessly integrated into automated quality control processes for at-line inspection in mass production.

The CUBE-R is said to leverage the power of the MetraSCAN 3D-R in a high-productivity industrial measuring cell designed to be integrated into factories for at-line inspections. Compared to traditional CMMs, the CUBE-R is reportedly faster, providing improved productivity and efficiency.

"Manufacturers need to achieve fast, accurate and repeatable output – now more than ever before. With Creaform's automated quality control solutions, manufacturers can increase their productivity," stated Jérôme-Alexandre Lavoie, Product Manager at Creaform.

"By detecting and addressing quality issues faster based on statistical analyses, corrective measures can be more proactively implemented to mitigate total quality costs (TQC) and unprofitable recalls," concluded Lavoie.

www.creaform3d.com



Creaform's 3D measurement solutions offer fast and accurate scanning for automated quality control (Courtesy Creaform)

ULT highlights the importance of air handling technology for PBF-LB Additive Manufacturing

Additive Manufacturing offers many benefits compared to conventional production processes, but the technology involves some special challenges with regards to extraction and filtration technology, particularly during Laser Beam Powder Bed Fusion (PBF-LB) metal Additive Manufacturing.

PBF-LB AM takes place in an enclosed build area under an inert gas atmosphere, usually comprised of nitrogen or argon. The process results in the production of fume and fine dust in the build area, which partly consists of extremely tiny nanoparticles.

Boris Frühauf, Key Account Manager Laser Technology for ULT AG, headquartered in Löbau, Germany, spoke to *Metal AM* to explain the importance of air handling technology, and the research yet to be done in the area to ensure the safe disposal of fume and particulates generated during PBF-LB.

ULT has been a vendor of fume extraction technology for Additive Manufacturing processes for some years, providing a wide range of experience and technical expertise in this area. "One could say that we are the pioneers in this field, constantly enhancing our technology," Frühauf commented.

"To guarantee a stable construction process, the entire system must be designed to enable a uniform laminar flow over the powder bed, capturing fume and particulates but not the powder bed material," explains Frühauf. "Finally, airborne pollutants are collected in a filter. This is definitely a technical challenge."

Safe disposal of highly reactive dust

ULT's gas flow systems use specially developed cartridge filters, in which particles are retained on the surface of the filter elements. At programmable intervals, supported by sensors, the cartridges are cleaned with a compressed air counter-flush and the dust is completely gathered in dust collectors. Afterwards, the filters can resume their work. This guarantees, among other benefits, suitability for long build jobs and a long filter life.

ULT attaches great importance to occupational health and safety – for employees, machinery and products. Due to its small particle sizes, the dust produced in PBF-LB can be highly reactive and inflammable. As a result, safety precautions must be taken and safety guidelines followed. It is also important that filters are able to be exchanged without contamination - or at least with a low level of contamination.

However, there are not currently any uniform standards or rules on correct dust disposal for PBF-LB. That might be why so many metal Additive Manufacturing users struggle to find the right disposal company, one with sufficient experience in that area, which knows how to deal with reactive materials. "ULT has compiled special passivation opportunities and disposal options," explained Frühauf.

In filtration technology, there are two basic techniques: cartridge filters, which can be dedusted, and storage filters, which at some point become saturated and must be disposed of. Storage filter disposal also requires correct handling, as dust may ignite through exposure to the air or the vibration of the cartridge. This can be prevented by passivation.

Cartridge filter solutions are used commonly in the industry because of the equipment's longer lifespan, which can be some months depending on the materials being processed. Furthermore, ULT fume extraction systems are equipped with differential pressure sensors; these measure pressure differences and recognise saturated or maximum-loaded filters. Required filter exchanges are then signalled in time to prevent system stops.

Post-processing and powder handling

Fume extraction technology is not only utilised in Additive Manufacturing machines; it is essential for the entire workflow. Solutions for post-processing steps such as removing support structures and for powder drying are also required. In addition to portable solutions, stationary units can be utilised.

A view inside the Laser Beam Powder Bed Fusion (PBF-LB) machine (Courtesy ULT AG)

"We are constantly striving to meet the requirements of Additive Manufacturing by continuously enhancing our modular systems," Frühauf stated. "'Extraction. Filtration. Persistence.' is ULT's corporate motto. In this instance, 'persistence' means knowledge on the latest technologies, which we have successfully implemented in various solutions for laser processing, for example. That requires high commitment to research and development."

During material exchange, the entire construction chamber must be cleaned. For instance: if the production of a stainless steel component follows the production of an aluminium component, the machine must not contain any aluminium particles when the stainless steel build begins. Mobile fume extraction systems or wet separators are used to capture and bind residual material from the process, but in the case of non-oxidised aluminium, there is the danger of reaction with water, which can produce hydrogen. If hydrogen gas escapes and comes into contact with a spark, it may explode.

"So far, there is little experience with that matter. Yet, the first Additive Manufacturing companies have begun to measure the hydrogen content in an attempt to determine the critical explosion magnitude and force ventilation or waste air outlet to the outside," Frühauf explained.

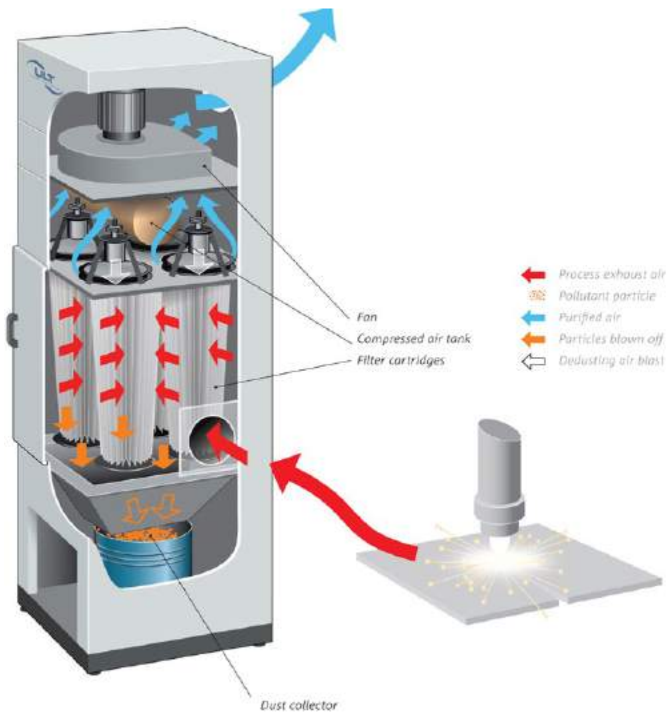
The extraction of residual material is not the final link in the disposal process chain. The exhaust systems must also be cleaned; to do this, contaminated water is poured into containers, in which the particles slowly sediment. The remaining metal sludge must then be disposed of at regular intervals. Today, these containers are partly positioned within the production facilities. "The risk here is that the hydrogen content in these halls increases. Therefore, ULT recommends placing the containers outside to enable an outward degassing. At this point, much educational work is needed," Frühauf commented.

Many potential scenarios in Additive Manufacturing are not yet determined. There are many technical challenges, and even more where new powder types and materials are used. Many standards for Additive Manufacturing are still in development, for example on health and safety, emissions and powder handling. There is, as yet, no information available on material mixture reactions on the nanoscale. Additionally, there are no numbers available on the explosivitiy of nanoscale materials < 0.5 µm.

Material classification – whether related to hazardous goods or not – and disposal are hard to determine for system operators. Each disposal company places different values on hydrogen generation of powder in combination with water; this area is little studied.

In conclusion, Frühauf stated, "That is why ULT works on solutions together with other companies, institutions and associations within a large research network. Our goal is creating standards within Additive Manufacturing."

www.ult.de



The basic principle of a cartridge filter system (Courtesy ULT AG)


Air cleaning in post-processing (Courtesy ULT AG)

Kolibri powder drying system to minimise cracking in AM parts

Kolibri Metals GmbH, Amtzell, Germany, has launched the ATACAMA powder drying system, a machine which dries metal powder to a moisture content of less than 4% to increase the buildability of tool steels with carbon contents, such as H11 and H13.

Moisture is a significant factor in the formation of cracks in these materials when processed by Laser Beam Powder Bed Fusion (PBF-LB), as well as the formation of 'zebra-patterns' in materials, annealing colours, poor component surfaces, inhomogeneities in structure, poor flowability and ultimately a fluctuating service life and component quality.

Kolibri is reported to be highly experienced in the Additive Manufacturing of high-carbon tool steels and metal matrix composites by PBF-LB.

For these materials, extremely low levels of moisture are essential. However, in its series production of extremely high-strength components out of tool steel, in conjunction with carbides or diamond powder, Kolibri found that there was no solution on the market which would enable it to achieve the level of powder dryness and process stability required for these applications.

In response to this need, the company developed the ATACAMA system, said to dry metal powders in a standardised and simple manner. The machine is expected to enable users to correct the fluctuating quality of powder shipped from powder manufacturers, significantly improves powder flowability, and can be used for all inorganic powder materials.

Kolibri Metals GmbH, Amtzell, Germany, has launched the ATACAMA metal powder drying system

Three models are available in the range, with the ATACAMA 10 offering a drying speed of 10 kg every few hours, the ATACAMA 10 K, able to dry 10 kg of powder in under an hour and the ATACAMA 10 KA/10A, which offers the additional option to preserve dried powders in an argon atmosphere.

www.kolibri.de.com

Purdue receives funding from US Dept of Energy to accelerate adoption of metal AM microreactors

The U.S. Department of Energy has awarded an $800,000 grant to Purdue University's College of Engineering in West Lafayette, Indiana, USA, for a project to accelerate the introduction of its metal additively manufactured microreactor – a new type of nuclear reactor said to have the flexibility and versatility needed for many current energy applications.

The Nuclear Energy University Program funding will enable Purdue to serve as a key contributor to the Transformational Challenge Reactor Demonstration Program, in which the Department of Energy's Oak Ridge National Laboratory (ORNL) is working to build the first AM micro-reactor by 2023. The microreactor will be the first advanced reactor to operate in the US in more than forty years.

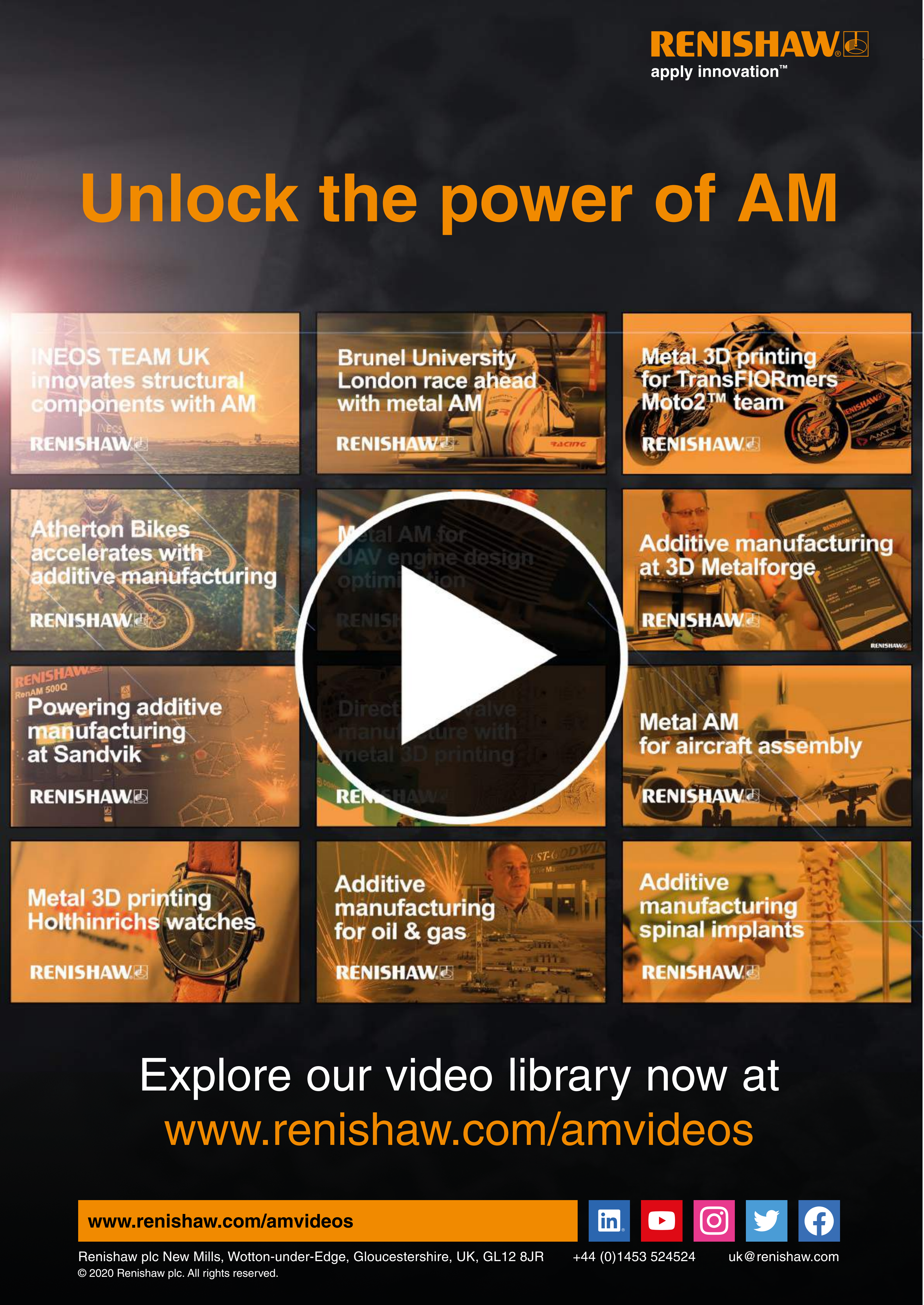
The Purdue project is intended to drive the use of Additive Manufacturing, computation materials modelling, and AI concepts in creating nuclear reactor components. The goal of all these technologies is to significantly reduce manufacturing costs and development time, and to realistically estimate safety risks while offering reliability and convenient access to nuclear power.

"Microreactors introduce a transformational trend to the nuclear industry – a trend that enables more streamlined construction and deployment processes to address the nation's energy challenges, that cannot be overcome solely with large-scale nuclear reactors," stated Hany Abdel-Khalik, Technical Lead for the project and Associate Professor of Nuclear Engineering.

"Purdue will fill a technological gap in the nuclear industry, reflecting a broader trend of applying AI strategies to support Additive Manufacturing," explained Abdel-Khalik. "AM enables designs to be adjusted during manufacturing, greatly decreasing production cost and time. Our work is aimed at driving widespread adoption of additively manufactured reactor components using an AI-powered software system to ensure safety and reliability."

"Synchronised application of Additive Manufacturing and artificial intelligence techniques are key to providing the most data-rich and cost-effective nuclear component qualification process. This is one of the key goals of DOE-NE's TCR programme: using modern technology to deliver a new and better way to deploy nuclear energy," stated Kurt Terrani, director of the TCR programme at ORNL. "The programme is engaging the industry, the regulator and, in this case, universities in order to ensure an optimal approach is developed and adopted in widespread fashion," he continued.

www.purdue.edu



Pandemic reinforces focus on Additive Manufacturing at DMG Mori

DMG Mori's Lasertec 30 Dual SLM machine, a Laser Powder Bed Fusion machine (Courtesy DMG Mori)

DMG Mori, headquartered in Bielefeld, Germany, has reported its financial results for the first half of 2020. The group is one of the largest producers of cutting machine tools globally, as well as a developer of Directed Energy Deposition (DED), Laser Beam Powder Bed Fusion (PBF-LB) and hybrid metal Additive Manufacturing technologies.

Like most companies, DMG Mori stated that it had felt the effects of the coronavirus (COVID-19) pandemic, and a corresponding decline in the global demand for machine tools. Order intake, sales revenues and earnings for the first half of 2020 were significantly below the high figures of 2019.

The company reported order intake of €784 million for the first half of the year, down from €1,412.3 million in 2019. Sales revenues were €838 million (2019: €1,276.4 million), with an EBIT figure of €33.2 million (2019: €103.4 million) and an EBIT margin of 4% (2019: 8.1%).

Responding to the results, Christian Thönes, Chairman of the Executive Board, stated that the coronavirus had accelerated many of the company's customers' transitions to the digital factory model, reinforcing the group's focus on its advanced and digital technology offerings.

"This strengthens our intention to further expand our future fields of automation, digitisation and Additive Manufacturing," he commented. "Investing in innovations, and especially in digitisation, is the only way out of the crisis. The economic situation is and remains challenging. But we are well-positioned and will continue to have positive results."

Recognising the importance of digital manufacturing solutions, including Additive Manufacturing, to aid in the manufacturing industry's recovery, the group noted that in the financial year 2020 it will present thirty-five new innovations, including three automation solutions, twenty 'digital innovations' and two new DMG Mori components.

Looking ahead to the second half of 2020, the company reflected that the global market for machine tools will decline sharply. In their April forecasts, the German Association of Machine Tool Builders (VDW) and the British economic research institute, Oxford Economics, forecast growth in global consumption to fall significantly by 28.3% to €52.3 billion.

Due to the complete change in global economic conditions, DMG Mori stated that it expects a sharp decline in order intake, sales revenues, earnings and free cash flow over the full financial year 2020.

Despite these challenging conditions, the company believes that its cost reduction and flexibilisation measures, initiated early in all areas, will support its performance and profitability. These measures, in addition to the further expansion of its Additive Manufacturing, automation, and digitisation efforts, are expected to grant DMG Mori resilience against the ongoing situation.

www.dmgmori-ag.com

Freeman Technology releases application note on preparation and storage of AM feedstocks

Freeman Technology, a Micromeritics company based in Tewkesbury, Gloucestershire, UK, has released a new application note: 'Preparation Techniques and Storage Conditions on the Flow Properties of Additive Manufacturing (AM) Feedstocks'.

The company explains that AM is rapidly gaining acceptance in a wide range of industries due to its ability to manufacture complex components quickly and precisely.

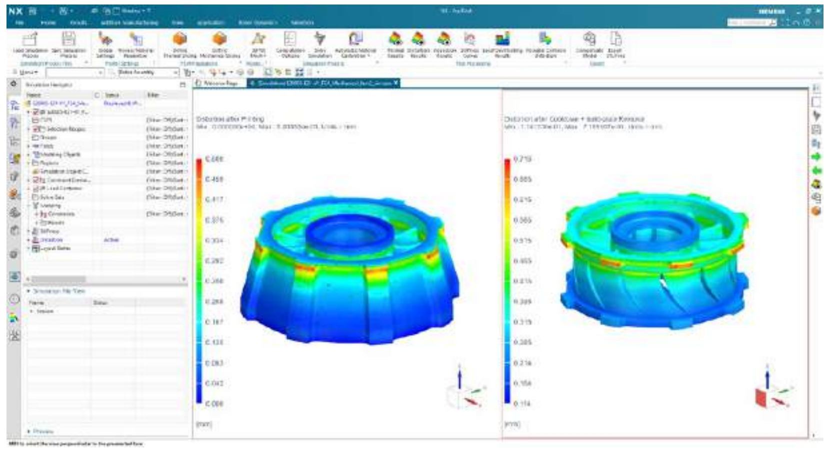
As industrial implementation of the technology increases, so does the diversity of environmental and storage conditions to which feedstocks are subjected to. This can significantly impact process performance and product quality states Freeman.

The new application note investigates the relationships between the flow properties of two batches of a stainless steel powder with varying particle sizes, and their preparation process and subsequent storage conditions.

According to Freeman, the results demonstrate how different baking processes can influence flow properties that are known to affect Additive Manufacturing performance and also highlight how powders with different particle sizes respond differently to the same preparation and storage conditions.

www.freemantech.co.uk

Sintavia and Siemens to collaborate on end-to-end AM software solution



Simulation designed by Sintavia of an aerospace nozzle guide vane ring, both with and without supports, using Siemens Xcelerator™ simulation software (Courtesy Sintavia/Siemens)

Sintavia LLC, Hollywood, Florida, USA, has entered into an agreement to collaborate with Siemens Digital Industries Software on the development of an end-to-end Additive Manufacturing software solution as part of Siemens' Xcelerator™ portfolio.

Sintavia will provide testing and technical feedback on pre-released software that will be part of future AM solutions. In exchange, the company will become a preferred AM partner of Siemens and gain access to the software in advance of the market, along with technical support for its implementation.

"We're excited to be collaborating with Siemens to help make industrialised Additive Manufacturing a reality," stated Brian Neff, Sintavia CEO. "The end-to-end solution that Siemens has been developing is absolutely essential to making additive a viable manufacturing process."

Neff noted that the value of the Siemens AM solution goes beyond digitally connecting the various phases of the AM process. He continued, "We've developed a lot of tribal knowledge on how to deliver quality 3D printed metal parts. But we recognise that we can't just rely on individual expertise to meet the accelerating demand in aerospace for additive manufacturing. We need software to codify the processes we undertake, and not just connect them in a digital thread, but automate them, take our know-how and have it drive activities in the background, so we can achieve optimal efficiency."

Aaron Frankel, vice president of the AM Program for Siemens Digital Industries Software, commented, "The collaboration with Sintavia is vital to our efforts to develop an automated end-to-end solution that spans the entire AM lifecycle – from designing an optimised part, preparing it 3D printing and simulating its build, to planning serial production, executing on the shop floor, and delivering a qualified part."

"With their depth of experience and track record in the market, Sintavia can provide the kind of technical feedback we need to build AM know-how into our digital twin and make the system the expert as opposed to the user. This is a critical step to making additive more widely embraced for volume production."

"Unlike traditional manufacturing, additive is a process where we don't have decades of established knowledge that is readily communicated, whether in software or through technical education. Companies can't afford to make everyone in the AM process an expert; they need the software to automate some tasks, work in the background, and make additive more of a push-button process," Frankel added.

As part of the three-year agreement, the two companies will collaborate on joint sales and marketing activities, and plan to organise events at Sintavia's facility that will showcase Siemens' AM solution in an industrialised AM production environment.

The companies have reportedly agreed that sustainability will be a focus area for their marketing collaboration. In November 2019, Sintavia co-founded the Additive Manufacturer Green Trade Association (AMGTA), a global, non-commercial, unaffiliated non-profit organisation open to any additive manufacturer or industry stakeholder that meets certain criteria relating to sustainability of production. Siemens joined AMGTA in 2020.

"Siemens has a strong commitment to sustainability – it is a key part of the Siemens 2020+ vision. Siemens' Additive Manufacturing software contributes to greener Additive Manufacturing production not just by streamlining designs and reducing material usage, but also by leveraging simulation to help enable first-time-right 3D printing and optimise AM factory efficiency to eliminate waste. We're excited to join the AMGTA and work closely with Sintavia to help promote the green benefits of Additive Manufacturing," Frankel concluded.

www.sintavia.com
www.sw.siemens.com

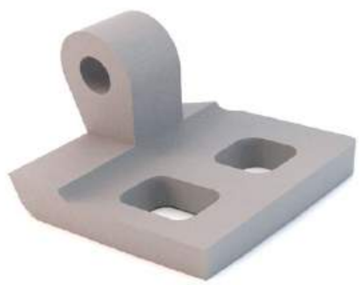
Simufact introduces Binder Jetting module to simulate sintering distortion

Simufact Engineering GmbH, Hamburg, Germany, part of the Manufacturing Intelligence division of Sweden's Hexagon AB, has introduced its metal Binder Jetting (BJT) module for a Simufact Additive simulation software, which enables manufacturers to predict and prevent the distortion that sintering processes can have on parts during design.

The company states that its new simulation tool marks a significant step forward for Additive Manufacturing because it helps manufacturers achieve the high quality they require while exploiting the unique benefits BJT offers for volume production. Simufact explains that one key challenge in metal Binder Jetting has been predicting changes during the sintering process. A part can shrink as much as 35% during sintering, and the simple shrinkage models used for other processes cannot predict this distortion for AM. Until now, costly physical trials were required to perfect the Additive Manufacturing of each part, preventing many manufacturers from realising the low cost and flexibility BJT offers, states the company.

The new simulation tool, which was made available to existing Simufact Additive customers in August 2020, extends the software's capabilities for BJT processes. Manufacturers can predict the shrinkage caused by factors such as the thermal strain, friction, and gravity during sintering without specialist simulation knowledge.

By compensating for these changes, parts can be additively manufactured as they are designed,



A hinge part simulated with the Metal Binder Jetting module in Simufact Additive, rendered to look like the real part (Courtesy Simufact)

and production teams can significantly reduce the proportion of parts that must be scrapped or reprocessed.

Sintering-induced mechanical stress is also predicted before the build, indicating where defects might occur. Manufacturers can use this information to make changes earlier in their product development and reduce the need for redesign.

Designed for busy manufacturing professionals, the simulation tool can automate the model setup, preparing the CAD or CAE file for manufacturing simulation and simulations can also be automated through Python scripts. To validate the sintering compensation and increase confidence in quality, the optimised geometry from the tool can be compared immediately to both the initial design (CAD) geometry and a metrology scan of a manufactured part within the user interface.

www.simufact.com
www.hexagonmi.com

Three phases of automated optimisation show compensation for distortion using the metal Binder Jetting module in Simufact Additive. The results show the deviation between the simulated part and its initial CAD geometry – blue/red = bad; green = good (Courtesy Simufact)

Optomec receives US Air Force contract for metal AM system to repair engines

Optomec, headquartered in Albuquerque, New Mexico, USA, has been awarded a $1 million contract by the US Air Force to deliver a high-volume production metal Additive Manufacturing machine for refurbishing turbine engine components, including titanium parts. The equipment will include an automation system for batch processing, an oxygen-free controlled atmosphere, and an adaptive vision system. This automated additive repair system is said to be capable of processing tens of thousands of repairs per year, with an initial focus on tip refurbishment for turbine blades.

The company states that it will also assist the US Air Force in developing optimal process parameters for a range of target repairs. The solution will be installed at Tinker Air Force Base, Oklahoma City, Oklahoma, USA, which already hosts a comprehensive aircraft engine overhaul capability.

According to Optomec, the US Air Force spends billions of dollars annually for the maintenance, repair and overhaul (MRO) of engines for its military aircraft. More broadly, there is reported to be a $50 billion a year global market for aircraft engine MRO across all commercial and military aviation combined.

www.optomec.com

3D Systems reports Q2 results and plans for reorganisation and restructuring

3D Systems Corporation, Rock Hill, South Carolina, USA, has announced its financial results for the second quarter ended June 30, 2020. The company also announced plans for restructuring and reorganisation to focus on its Healthcare and Industrial offerings. 3D Systems reported revenues of $112.1 million for Q2 2020, compared to $157.3 million in Q2 2019. An operating loss of $33.9 million was reported, compared to $19.2 million in Q2 2019. The gross profit margin in Q2 2020 was 31.4%, compared to 46.6% in Q2 2019. For the six months ended June 30, the company reported revenues of $246.8 million, down from $309.3 million in 2019. A six-month operating loss of $52.1 million was recorded, compared to $40.5 million in 2019.

"Our results in the second quarter reflect continued impact from the COVID-19 pandemic; however, the pandemic has also demonstrated a clear role for flexible supply chain enabled by Additive Manufacturing, particularly in the medical field," stated Dr Jeffery Graves, president and CEO. "Redirecting the company is intended to bring us back to a sharp application focus on key markets that are growing. With a clear statement of purpose and a return to the ideals we were founded on, I believe 3D Systems will be successful."

The company stated that it expects its resizing efforts, in conjunction with other measures, to reduce annualised costs by approximately $100 million by the end of next year, enabling it to be profitable at current revenue levels, and be well positioned to leverage the sales growth as it returns. Cost reduction efforts include reducing the number of its facilities and examining every aspect of its manufacturing and operating costs. 3D Systems will incur a cash charge in the range of $25–30 million for severance, facility closing and other costs, primarily in the second half of this year.

The company added that it may incur additional charges in 2021 as it finalises all the actions to be taken. 3D Systems is also evaluating the divestiture of parts of the business that do not align with this strategic focus.

"In the two months since I joined 3D Systems, I have held many reviews and discussions with our employees and key customers to understand the value we deliver and the markets that we serve. This has enabled us to state a clear purpose for our company moving forward – one that builds on our unique history and core strengths [...] We are the leaders in enabling AM solutions for applications in growing markets that demand high-reliability products," added Graves.

www.3dsystems.com

Optomec customers surpass 10 million turbine blade repairs using metal AM

Optomec, headquartered in Albuquerque, New Mexico, USA, reports that over 10 million turbine blades have now been repaired using its metal Additive Manufacturing machines. The impressive figure was calculated following a survey of over a hundred of Optomec's customers using the company's various systems for gas turbine component repair.

The company is reported to have metal additive repair machines installed at all leading gas turbine OEMs, in both the aviation market for aircraft engines and the energy market for power generation.

In addition, many of the third party Maintenance Repair and Overhaul (MRO) shops also use Optomec systems. The solutions include Optomec's Huffman brand 5-axis Laser Cladders and its LENS brand metal AM machines – both based on Directed Energy Deposition (DED) technology.

Common production applications include the repair of turbine blade tips, seals and wear surfaces; compressor blades, including titanium alloys; vanes, shrouds and other high-value components.

According to Optomec, its automated solution typically replaces manual operations, such as Tungsten Inert Gas (TIG) welding, and reduces the cost of routine maintenance. The ROI of Optomec's machinery has been recently calculated to be in excess of 180%. Additionally, Optomec's laser-based processing provides superior mechanical performance due to its optimal metallurgy and minimal heat input, compared to manual operations.

"We are really excited to reach this important milestone for both the Additive Manufacturing segment and, more important, for our gas turbine customers," stated Mike Dean, Marketing Director at Optomec.

Optomec's laser cladding systems are said to be the most widely adopted in the industry and are approved for aviation maintenance in fifteen countries.

Dean added, "Chances are that if you fly much, you've probably flown with an engine that was maintained with an Optomec laser cladder."

www.optomec.com

Optomec's customers have repaired over 10 million turbine blades using its DED AM machines (Courtesy Optomec)

AM post-processing training cell added to Rock Island Arsenal

Phillips Federal, a division of Phillips Corporation, Hannover, Maryland, USA, has added post-processing technologies from Bel Air Finishing, North Kingstown, Rhode Island, USA, to support its Public Private Partnership (P3) and Additive Manufacturing programmes at the Rock Island Arsenal (RIA) Innovation Center, Rock Island, Illinois, USA.

Bel Air and Phillips Federal partnered to install a fully-operational training cell that will develop expertise in the post-processing of metal and plastic additively manufactured components. The training cell will be available for use by the US Federal Government and qualified Department of Defense contractors involved in Additive Manufacturing at the RIA.

Steve Alviti, Bel Air Finishing, stated, "The Bel Air team is very excited to combine with Phillips Federal to teach the various technologies of post-processing, which is mostly overlooked in the AM process. The training facility will make printing efforts more efficient along with more effective products by bringing the level of printed surfaces to meet or exceed traditional subtractive surfaces."

The training cell includes automated build removal capabilities, surface grinding, polishing, cleaning, and its own closed loop water feed system. Bel Air personnel will reportedly present a number of Phillips Federal-scheduled training workshop presentations.

John Harrison of Phillips Federal commented, "Additive Manufacturing typically doesn't stop with the print. The addition of Bel Air Systems to the innovation centre will add automated finishing know-how from the leaders in additive post-processing."

www.phillipscorp.com
www.belairfinishing.com

3YOURMIND raises $5.5 million in Series A+ funding round

Additive Manufacturing software provider 3YOURMIND, Berlin, Germany, has raised $5.5 million in a Series A+ funding round led by EnBW New Ventures GmbH (ENV), the venture unit of EnBW, a major renewable energies company and operator of extensive infrastructure in Germany and throughout Europe.

The funding round also included 3YOURMIND's existing investors UVC Partners, AM Ventures, Trumpf Venture and coparion. The funds raised are expected to support the company's further growth in sectors such as aerospace, automotive and engineering, and also strengthens its position in the energy and infrastructure maintenance industries. The company states that it has secured contracts with over fifty enterprise customers in various industries, helping them to produce thousands of AM parts per day.

EnBW explains that, similarly, to other energy providers, it operates power plants of different types and age, as well as an extensive delivery infrastructure. To supply its six million customers and remain operational it must find efficient ways to maintain outdated equipment; Additive Manufacturing has reportedly proven to be a viable solution.

3YOURMIND's proprietary Additive Manufacturing workflow software is designed to help users optimise their value chain and achieve up to 40% cost reduction, as well as 18% shorter lead times. Agile manufacturing, which is defined by flexible, automated and distributive production, is possible with 3YOURMIND and will equip enterprises with the ability to redefine the next generation of manufacturing.

Primarily used as a streamlined communication tool for many different industries, this workflow software has reportedly also become an integral solution for those who are producing spare parts on-demand, replacing outdated machinery and transitioning to a digital warehouse.

Although most of its customers are already heavy users of Additive Manufacturing, 3YOURMIND's software is also said to provide an ideal entry point for those that want to identify AM use cases and understand the impact that agile manufacturing can provide to their business.

"The current macro situation forces companies to focus on supply chain resilience," stated Aleksander Ciszek, co-founder and CEO of 3YOURMIND. "Our customers benefit from the distributed manufacturing software we are providing as the increased flexibility in their supply networks secures and generates value. We are happy that ENV and our existing investors support that vision."

"The promise of Industry 4.0 relies on Additive Manufacturing," commented Crispin Leick, Managing Director at ENV. "The 3YOURMIND offering enables companies to easily implement AM into their production process which supports the sustainability of many manufacturing and MRO (Maintenance, Repair, & Operations) applications. We are excited to invest in 3YOURMIND, a company that is shaping the future of manufacturing."

Stephan Kühr, 3YOURMIND CEO, reported, "Even during these unprecedented times, we expect to double our annual sales for the third straight year. This investment by ENV and our existing investors UVC Partners, AM Ventures, Trumpf Venture and coparion will enable us to strengthen our expansion efforts in Europe and North America."

www.3yourmind.com
www.env.vc

Waygate Technologies launches Phoenix V|tome|x S240 CT system

Waygate Technologies, a global provider of non-destructive testing solutions and a division of Baker Hughes Digital Solutions, has launched the next generation of its industrial 2D radiography and 3D CT systems, the Phoenix V|tome|x S240. The new system is said to cover a wide range of CT applications in research institutes and industrial quality labs, including internal defect analysis, 3D quantitative porosity analysis, materials structure analysis, assembly control, and coordinate measurement tasks such as CAD data nom/act comparison.

With an option to combine both a nanofocus and microfocus X-ray tube, the new system is equipped with the Dynamic 41|200p+ detector technology that allows for higher resolution and image quality at much faster scan times. This proprietary device is well established with the premium system V|tome|x M. It doubles CT throughput at the same quality level as conventional DXR detectors by combining increased detector sensitivity and a larger imaging area, with faster frame rates and adaptive imaging modes.

By concentrating more power on a smaller focal spot, the optional High-flux|target offered by Waygate Technologies doubles resolution or scan speed. Production throughput can thus be increased even further without compromising on accuracy and precision, the company states.

The Phoenix V|tome|x S240 is capable of helical (spiral) scanning with the sample moving upwards in the X-ray beam, thereby enabling faster scans of longer parts, and eliminating the need to stitch several partial scan results together afterwards. This acquisition technique is claimed to generate significantly better results by eliminating artifacts on horizontal surfaces and in the stitching areas. The system is equipped with CT scanning software for fully automated data acquisition and volume processing. The entire CT scanning and evaluation process chain can be initiated, with 3D failure analysis or 3D metrology tasks executed automatically.

www.waygate-tech.com

The V|tome|x S240 covers a wide range of CT applications (Courtesy Waygate Technologies)

Aniwaa launches new AM comparison platform

Aniwaa Pte. Ltd., headquartered in Singapore, reports that it has launched its new Additive Manufacturing machine comparison platform. The company, which was established in 2013 to help professional users research, evaluate and purchase AM equipment, states that it has built the most comprehensive database yet of Additive Manufacturing machines.

The release is also said to mark the company's transition to a platform model, with Aniwaa capable of not only allowing its users to identify the right products but also connecting potential buyers with trusted resellers from its global network to finalise their purchases.

In addition, Aniwaa has developed efficient marketing and selling solutions, tailored to help AM brands connect with a qualified audience of professional buyers while they are researching their next purchase on the platform.

According to the company, information about industrial Additive Manufacturing machines is scattered across the internet, with few reliable and user-friendly tools available to guide professional buyers. Thus, researching and comparing products in the fast-changing AM landscape can be a daunting task.

Addressing this issue, Aniwaa explains that its completely redesigned comparison engine indexes over 2,100 products, encompassing the full spectrum of AM machines. The tool includes a range of unique filtering and comparison options designed to help users easily narrow down their selection. They can also benchmark up to four AM machines at a time, side by side, and receive a comprehensive overview of the products that interest them.

"3D printers are a fast-growing category; we're seeing many professional applications reaching maturity and a strong untapped potential overall," stated Pierre-Antoine Arrighi, Aniwaa's co-founder. "New hardware is being released frequently, which is creating a very fragmented market space and making it difficult for potential buyers to make an informed choice. That's why we're constantly improving our tools to help our users find the best AM hardware for their needs and budget."

Martin Lansard, Aniwaa's CEO and co-founder, commented, "I'm really proud of what we've achieved. With the COVID-19 situation, physical trade shows are declining sharply while the product discovery and comparison phases are moving online."

Lansard added, "This new release strengthens Aniwaa's position as the go-to Additive Manufacturing platform, helping not only buyers but also suppliers – from manufacturers aiming to build their brands to resellers looking for qualified leads. We're all excited by what's ahead and look forward to supporting the growth of our industry and helping 3D printing companies thrive."

www.aniwaa.com

ORNL researchers additively manufacture aluminium device for capturing carbon dioxide

Researchers from the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL), Tennessee, USA, have designed and additively manufactured what they describe as a first-of-its-kind aluminium device that enhances the capture of carbon dioxide emitted from fossil fuel plants and other industrial processes.

Solutions for reducing global emissions of heat-trapping greenhouse gases such as CO_2 address the continued use of low-cost, domestic fossil fuel resources while mitigating potential climate impacts. ORNL's device focuses on a key challenge in conventional absorption of carbon using solvents: the process typically produces heat, which can limit its overall efficiency.

By using Additive Manufacturing, the researchers were able to custom design a multifunctional device that greatly improves the process efficiency by removing excess heat while keeping costs low. Absorption, which is one of the most commonly used and economical methods for capturing CO_2, places a flue-gas stream from smokestacks in contact with a solvent, such as monoethanolamine, known as MEA, or other amine solutions that can react with the gas.

The research team tested the novel circular device, which integrates a heat exchanger with a mass-exchanging contactor, inside a 1 m tall x 20 cm wide absorption column consisting of seven commercial stainless steel packing elements. The AM device was installed in the top half of the column between the packing elements. "We call the device intensified because it enables enhanced mass transfer (the amount of CO_2 transferred from a gas to a liquid state) through in-situ cooling," stated Costas Tsouris, one of ORNL's lead researchers on the project. "Controlling the temperature of absorption is critical to capturing carbon dioxide."

When CO_2 interacts with the solvent, it produces heat that can diminish the capability of the solvent to react with CO_2. Reducing this localised temperature spike in the column through cooling channels helps increase the efficiency of CO_2 capture.

Xin Sun, the project's principal investigator, commented, "Prior to the design of our 3D printed device, it was difficult to implement a heat exchanger concept into the CO_2 absorption column because of the complex geometry of the column's packing elements. With 3D printing, the mass exchanger and heat exchanger can co-exist within a single multifunctional, intensified device."

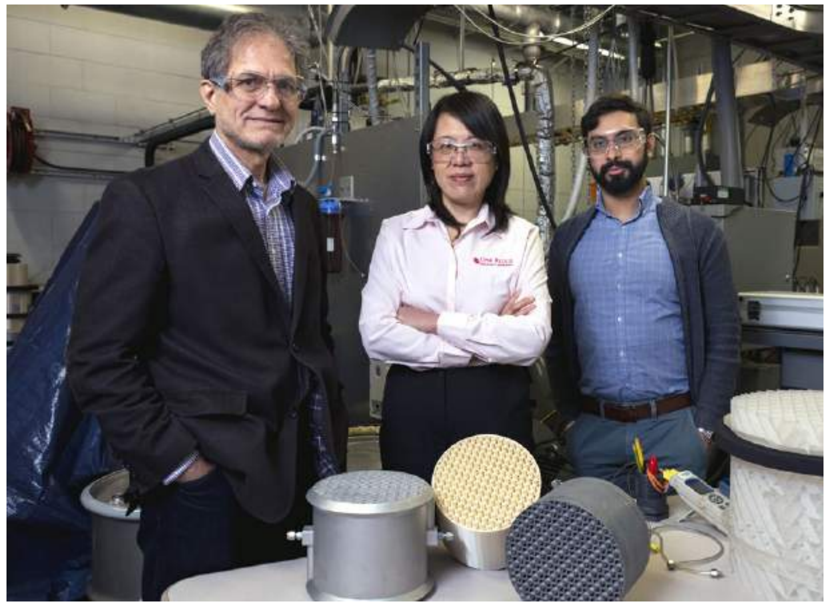
Embedded coolant channels were added inside the packing element's corrugated sheets to allow for heat exchange capabilities. The final aluminium prototype measured 20.3 cm in diameter, 14.6 cm in height, with a total fluid volume capacity of 0.6 l. "The device can also be manufactured using other materials, such as emerging high thermal conductivity polymers and metals," explained Lonnie Love, a lead manufacturing researcher at ORNL, who designed the intensified device.

In results published in the *AIChE Journal*, the ORNL researchers conducted two experiments – one that varied the CO_2-containing gas flow rate and one that varied the MEA solvent flow rate. The experiments aimed to determine which operating conditions would produce the greatest benefit to carbon capture efficiency. Both experiments produced substantial improvements in the carbon capture rate and demonstrated that the magnitude of the capture consistently depended on the gas flow rates. The study also showed a peak in capture at 20% of carbon dioxide concentration, with percent of increase in capture rate ranging from 2.2% to 15.5% depending on the operating conditions.

Future research is expected to focus on optimising operating conditions and device geometry to produce additional improvements in the carbon capture absorption process. This research project was sponsored by DOE's Office of Fossil Energy.

www.ornl.gov

www.energy.gov



ORNL's Costas Tsouris, Xin Sun and Eduardo Miramontes demonstrated that the additively manufactured device enhanced carbon dioxide capture efficiency (Courtesy ORNL/Carlos Jones)

RAM3D partners with Renishaw to develop its AM capabilities

Rapid Advanced Manufacturing Ltd (RAM3D), based in New Zealand, has partnered with Renishaw PLC, Wotton-under-Edge, Gloucestershire, UK, to establish high-quality volume metal Additive Manufacturing capabilities. RAM3D, said to be the Southern Hemisphere's largest independent metal AM service, provides solutions for a range of global industry sectors, including aerospace, marine, and food processing. Warwick Downing, CEO and co-founder of RAM3D, stated, "In a way, RAM3D's origins and success reflect the New Zealand culture. A culture where people aren't afraid to try new things and try different approaches in order to overcome difficult challenges."

Downing continued, "In our first couple of years, we had to learn very fast and while, to a certain extent, we were being told what machines we were going to need, we were quick to understand the real impact of operating costs and the need for a more flexible manufacturing platform."

"We realised early on that those extra 'bells and whistles' on an AM machine weren't necessarily a good thing," he explained. "Very often, they were in fact the things that would cause a machine to break down or underperform. The most important thing to us was assuring production process integrity, high-quality and reliability, and ensuring cost-efficiency and effectiveness."

Using its suite of Renishaw AM machines, RAM3D additively manufactures metal parts in a complete range of metal powders, including stainless steel 15-5ph, stainless steel 316, inconel 718 and titanium 64, and is currently looking to add maraging tool steel to its product portfolio. In the five years since purchasing its first Renishaw AM machine, RAM3D has grown its metal AM business from a prototyping service to a fully-fledged volume production service. The company is able to serve customers throughout the world as well as in its Australasian home territory.

Since partnering with Renishaw, RAM3D has seen customer part volumes increase exponentially and has been running the machines for twenty-four hours a day for at least six days a week. The company explains that while demand is very much sector- and product-specific, it has seen production run volumes rise from 3,000–4,000, up to 12,000 per year, and expects them to reach 20,000 per year over the next few years. Currently, RAM3D's operating plant in Tauranga, New Zealand, houses eight metal Additive Manufacturing machines.

www.rapidman.co.nz
www.renishaw.com

HP to utilise Dyndrite Kernel for its digital manufacturing solutions

Dyndrite Corporation, headquartered in Seattle, Washington, USA, reports that HP Inc. plans to use the Dyndrite Kernel to help power its next-generation cloud and edge-based digital manufacturing solutions.

According to Dyndrite, this collaboration is expected to bring higher performance, efficiency, automation, and extensibility to HP's growing portfolio of digital manufacturing products, including its Binder Jetting (BJT) metal Additive Manufacturing machine the HP Metal Jet.

The Dyndrite Kernel is designed to enable the development of high-performance, scalable Additive Manufacturing hardware and software solutions. It features a multi-threaded and GPU-powered hybrid geometry core, a scalable modern computation architecture, and an accessible Python programming interface. Dyndrite's built-in extensibility also enables a variety of plug-ins for simulation, MES, OEM toolpath development, and more.

"From the very beginning, HP recognised the potential of Dyndrite's kernel technology," stated Ryan Palmer, Global Head of Software, Data and Automation, HP 3D Printing & Digital Manufacturing. "As the first member of the Dyndrite Development Council, we quickly identified areas where Dyndrite's innovative technology could be applied to solve the larger challenges facing the AM industry."

Palmer added, "We are committed to advancing our digital manufacturing platform capabilities and this strategic collaboration with Dyndrite is an exciting next step on the journey."

Harshil Goel, founder and CEO of Dyndrite, commented, "The promise of AM is to deliver customised, personalised, and on-demand 3D printed parts, on an industrial scale. For this to happen the AM software industry must evolve. Dyndrite's mission has been to accelerate this change."

Goel added, "Our collaboration with HP is intended to dramatically scale the impact our technology will have in the AM and DM industries. We appreciate the confidence they have placed in us and are energised by their vision."

www.dyndrite.com

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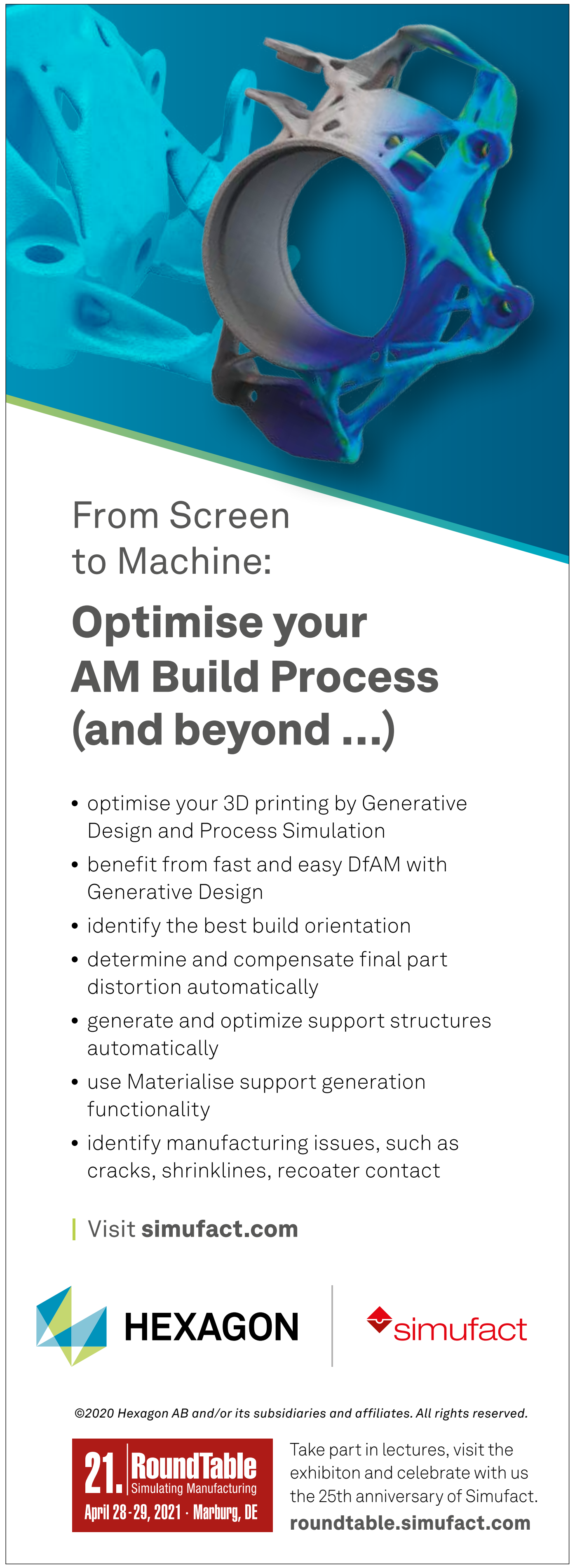


3Diligent opens beta programme for new ProdEX and Shopsight Connect software

3Diligent, a digital manufacturing services provider headquartered in El Segundo, California, USA, reports that it has successfully concluded a closed beta round of its new ProdEX Connect and Shopsight Connect applications. Based on the success of the pilot, the company has now opened the beta programme to all qualified users.

ProdEX Connect is a service platform for companies seeking custom manufactured parts on-demand, including technologies such as Additive Manufacturing, CNC machining, Sheet Metal Forming, Casting, and Injection Moulding. The Shopsight Connect software helps job shops, machine shops, and service bureaus manufacture and deliver custom parts through a collection of quoting, project management, and quality assurance tools.

3Diligent explains that central to its new offerings are two key components which include, firstly, job opportunities facilitated between ProdEX and Shopsight users utilising the company's team and proprietary matching algorithms, and secondly, enhanced connectivity throughout the product development cycle using integrated sharing tools, including Zoom video conferencing.

"Connect represents an exciting step forward for our ProdEX and Shopsight applications," stated Cullen Hilkene, 3Diligent CEO. "In our current economy, it is crucial that people in purchasing or product development can still stay connected to their contract manufacturing partners. ProdEX Connect and Shopsight Connect increase that connectivity to levels surpassing even pre-pandemic times."

3Diligent offers a range of solutions to help realise on-demand manufacturing (Courtesy 3Diligent)

Users of ProdEX may now choose to submit RFQs in one of three ways: request a 'ProdEX Auto' instant quote for rapid prototyping, request a 'ProdEX PM' quote for well-defined products in which the ProdEX team will serve as project managers, or request a 'ProdEX Connect' quote.

According to the company, users that choose to submit their RFQ through ProdEX Connect will have the opportunity to release their request directly to their preferred suppliers through the portal at no charge. Users can also request introductions to qualified suppliers in the ProdEX production network for a fee. Those submitting requests to suppliers that are not in the ProdEX network will be able to grant their manufacturing partners free extended trials of the Shopsight software as part of the Connect workflow.

After submitting requests, customers can engage with their suppliers using the communication and data management tools embedded in the ProdEX application. Their suppliers, in turn, can engage via the Shopsight management portal. The tools embedded in each application include video communication and screen sharing powered by Zoom, as well as RFQ/order tracking from request to delivery.

www.3diligent.com

Verder Scientific acquires Porotec GmbH

Verder Scientific, a division of Verder Group headquartered in Haan, Germany, has acquired Porotec GmbH, located near Frankfurt am Main, Germany, in order to further expand its particle characterisation business.

Porotec develops and sells particle and porosity measurement instruments and operates as a dealer for Microtrac MRB, which Verder Scientific acquired in 2019, who also specialises in particle characterisation.

Verder Scientific explains that with the acquisition of Porotec, Microtrac MRB enhances its expertise and market position in gas adsorption, porosimetry and density measurement, while strengthening its German team in the areas of application, sales and service. Porotec contributes relevant technical experience and in-depth knowledge of the market.

Microtrac MRB was established in 2020 by uniting the companies Microtrac Inc., MicrotracBEL Corp., and Retsch Technology GmbH and is said to provide the world's widest product offering for particle characterisation.

www.verder-scientific.com
www.porotec.de

Authentise releases digital powder tracking tool to reduce waste and cost

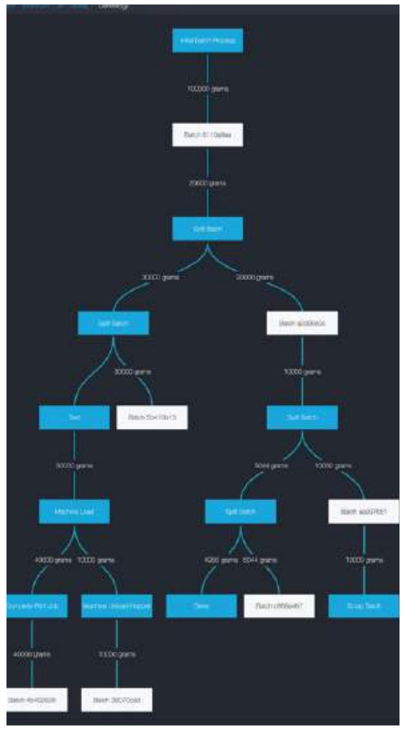
Authentise, a developer of data-driven workflow tools for Additive Manufacturing based in Philadelphia, Pennsylvania, USA, has released Material Management, a new addition to the Authentise Manufacturing Execution System (AMES) to simplify the digital tracking of metal powders in the Additive Manufacturing process.

Material Management enables customers to track all actions associated with a material, such as sieving, blending, testing or Additive Manufacturing, to provide a full digital thread of the material. Operators can update the status seamlessly using apps on handheld devices, while full reports and details, such as a full material genealogy tree, can be viewed in the browser.

The company explains that tight integration with AMES associates the material traceability report with any part additively manufactured on the machine it was loaded into. This is said to enable a detailed end-to-end digital thread that accounts not only for the full material history but also operator actions, machine data, and more.

"Digital Material Management is the missing piece of the puzzle for us," stated Miguel Zavala, project leader in Laser Additive Manufacturing at TWI Ltd, UK. "As a certified Lloyds Register lab, we have to prove that we're following the right process at all times."

Zavala continued, "The combination of AMES with a seamless material tracking tool delivers full digital traceability of not only what we've done but everything that has happened to the part. We can use that data to improve our processes, provide automated reports to clients and work with our partners to develop better machines, materials, processes and designs."



Example of the workflow genealogy tree (Courtesy Authentise)

Batch	Batch Event	Batch Details	Batch Event Quality	Date
8110a9aa	Machine Unload Hopper	New batch created 38070cdd	10000.0 grams	09-15-20 15:50 UTC
8110a9aa	Machine Unload Chamber	New batch created 4b402626	40000.0 grams	09-15-20 15:47 UTC
8110a9aa	Machine Load		50000.0 grams	09-15-20 15:46 UTC
8110a9aa	Test		0.0 grams	09-15-20 15:45 UTC
8110a9aa	Split Batch	New batch created 5b410b13	30000.0 grams	09-15-20 15:44 UTC
8110a9aa	Split Batch	New batch created a2d96e0c	20000.0 grams	09-15-20 15:43 UTC
8110a9aa (Selected Batch)	Create Initial Batch	Deliver lot 2abadd05	10000.0 grams	09-15-20 15:43 UTC

An example of a Material Traceability Report produced by Authentise's new Material Management feature (Courtesy Authentise)

Andre Wegner, CEO of Authentise, commented, "We're excited to be the only independent provider with an end-to-end digital material and part traceability solution. There's still so much we don't know about the additive process: How do storage conditions affect end part quality? How many times can we recycle, under what conditions? As a result, too much money is wasted as we default to the most secure and expensive options."

"Too many parts still end up being printed with virgin powder unnecessarily. The integration of our unique ability to draw together data from machines, operators, testing and now materials finally gives us the tools to understand these processes fully, and explain them to our partners."

www.authentise.com

Cincinnati Incorporated partners with Multiax America for turnkey AM solutions

Cincinnati Incorporated (CI), a build-to-order machine tool manufacturer based in Harrison, Ohio, USA, has partnered with Multiax America, a custom designer of CNC machining centres, headquartered in Grandville, Michigan, USA. The partnership will allow each company to provide required products in the Additive Manufacturing market.

CI explains that in AM, components almost always have to be machined after they are additively manufactured. This secondary machining process gets the part to its final dimension and smooths the surface. Multiax America now offers CI's Big Area Additive Manufacturing (BAAM) machine, and CI in turn now offers the Multiax line of 5-axis routers. The result is said to be a turnkey solution for customers that saves time and opens up to the service and support of two manufacturing companies.

"Because an overwhelming majority of BAAM-printed parts require secondary machining, we've had a goal to partner with a leading CNC machine manufacturer for some time," stated Alex Riestenberg, Additive Manufacturing Product Manager at CI. "Multiax is that manufacturer. Our open-book relationship will make both of us stronger, and it will ultimately better serve the customer."

According to CI, the applications that see the most success with the BAAM machine are tooling and moulds for the aerospace, marine and automotive industries. All of these applications require CNC machining, and Multiax machines are said to be suited to those operations.

Ed Gauthier, CEO of Multiax America, commented, "Our partnership with Cincinnati Incorporated allows us to offer customers one of the finest 3D printing systems in the market today. We believe CI will have a similar advance with their customers and our Multiax CNC router systems." A Multiax P Series moving bridge machine will feature alongside the BAAM machine at the CI showroom in southwest Ohio, enabling customers to see how beneficial an additive turnkey can be.

Joe Bockrath, Strategic Sales & Marketing Specialist at Multiax America, reported, "The partnership will let both companies expand our customer bases and provide high-throughput 3D/AM production systems for the emerging advanced manufacturing sector."

www.multiaxamerica.com
www.e-ci.com

Ipsen to establish global Technology Excellence Centres

Ipsen offers a range of furnaces for heat treatment and sintering applications (Courtesy Ipsen)

Ipsen USA, Cherry Valley, Illinois, USA, reports that it is establishing Technology Excellence Centres, while further strengthening the company's offerings, in order to ensure it is addressing the market needs of its current and future customers.

The company's equipment manufacturing business will be driven by an Atmosphere Technology Excellence Center in Kleve, Germany, and a Vacuum Technology Excellence Center near Rockford, Illinois, USA. Ipsen explains that this focus on one field of technology will enable faster-paced innovation and a laser-focus on performance and quality.

As a result of this change, new furnace equipment will be manufactured at fewer locations globally with a focus on specialisation. The Ipsen Germany location will exclusively build Atmosphere Batch and Continuous Systems while the US location will exclusively build all types of Vacuum Furnaces.

In addition, Ipsen India will continue to build atmosphere furnaces for the India and Southeast Asia markets, noted the company. Its China and Japan locations will no longer manufacture new furnaces and will focus on customer service and the sale of new equipment from the Excellence Centres.

The company states that the customer relationship with Ipsen will remain unchanged and that it will continue to support its customers from all its global locations. All Ipsen plants remain open in all regions, as aftermarket support of its customers is said to be more than half of Ipsen's annual business. Activities such as upgrades, local inventory of parts and service are expected to continue to be fully supported on a local basis.

According to Ipsen, this consolidation of equipment manufacturing sites together with the uncertainty of the COVID-19 pandemic does result in a reduction of staff, which the company reports is a regrettable but necessary outcome from its carefully planned strategic step.

www.ipsenusa.com

Ampal and Loewy Institute complete Phase I project to optimise Al powder for Additive Manufacturing

Ampal, Inc., Palmerton, Pennsylvania, USA, a fully-owned subsidiary of U.S. Metal Powders, Inc., and Lehigh University's Loewy Institute, Bethlehem, Pennsylvania, USA, have completed a Phase I Ben Franklin project on the 'Optimization of Aluminium Alloy AA6061 powder for Selective Laser Melting Process'.

U.S. Metal Powders, Inc. has been supplying aluminium alloy powders produced by air and inert gas atomisation to the Additive Manufacturing industry for several years. The demand for aluminium alloys has been increasing, and AA6061 (Al-Mg-Si) is one of the most sought after alloy systems in the AM industry, with applications in several industries including the automotive and aerospace sectors.

However, the production of sound parts using AA6061 alloy powder in Laser Beam Powder Bed Fusion (PBF-LB), or Selective Laser Melting (SLM), has been challenging due to the powder's low flowability and high thermal conductivity.

As part of the project, AA6061 inert gas atomised aluminium powder grades were used to build 10 mm x 10 mm x 10 mm solid cube samples using lasers ranging from 200–400 W. The parts were built in a Renishaw AM400 unit with a reduced build volume (RBV) unit installed; this deposits powder using a mechanical feed piston system.

Several sets of sample parts were built using a Renishaw AM400 with variations in laser power, point distance, and exposure time. The density of each sample was determined using the Archimedes method and light optical microscopy. Metallographic analysis determined optimum build parameters, and characterised the meltpool boundaries (MPB) and porosity formed in the PBF-LB process.

Scanning Electron Microscopy (SEM) revealed a fine microstructure and precipitate formation through natural ageing. Micro hardness tests showed promising results comparable to previous literature, leading to high mechanical properties.

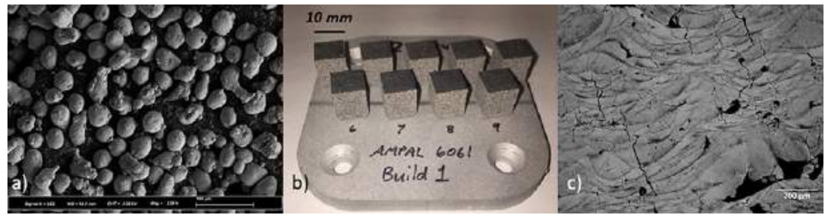
AA6061 parts were built to near-net density by the PBF-LB process at optimum conditions. The optimised process parameters yielded around 98% density for the alloy, with porosities reduced to the minimum by modifying processing parameters.

The Phase 2 project will target the optimisation of heat treated properties, further density improvement, and crack reduction to achieve a commercially viable PBF-LB process to make parts using optimised AA6061 alloy powder and processing parameters.

U.S. Metal Powders, Inc. is the largest aluminium powder producer in North America and global producer of aluminium and aluminium alloy powders, offering a full-range of coarse to fine aluminium powders from its manufacturing facilities Ampal, Inc., USA and Poudres Hermillon SARL, France.

Ben Franklin Technology Partners is an initiative of the Pennsylvania Department of Community and Economic Development and is funded by the Ben Franklin Technology Development Authority.

www.usmetalpowders.com
www.nep.benfranklin.org



AA6061 alloy as (a) powder, (b) as-built components, and (c) as shown in a light optical micrograph (Courtesy US Metal Powders Inc)

Tekna's powder manufacturing operations achieve AS9100 and ISO 9001 compliance

Tekna, a subsidiary of Arendals Fossekompani ASA with its headquarters in Sherbrooke, Québec, Canada, has announced that all of its powder manufacturing facilities are now in compliance with AS9100 and ISO 9001 quality management system requirements.

The announcement includes the company's recently-certified plant in France, where its nickel-base superalloy powders are produced, as well as its Canadian plant, whichproduces titanium and aluminium powders and was certified in 2017.

"This certification reinforces our position as a major player offering personalised client approach in the market. We are delivering on our commitment: Powder on time, every time, everywhere," stated Rémy Pontone, VP Sales & Marketing.

"This milestone is a major achievement for Tekna on its mission to consistently deliver high-quality plasma powders among the most regulated business segments in the world: aviation, space and defence," stated Luc Dionne, CEO at Tekna.

www.tekna.com

Purdue and ITAMCO receive $1 million grant for AM runway mat development

Researchers from Purdue University, West Lafayette, Indiana, USA, and Indiana Technology and Manufacturing Companies (ITAMCO), Plymouth, Indiana, USA, have received a $1 million SBIR Phase II grant from the U.S. Air Force which will help to fast-track the development of a new metal additively manufactured runway mat for temporary or expeditionary flight operations.

Pablo Zavattieri, the Jerry M and Lynda T Engelhardt Professor in Civil Engineering at Purdue University, is working with ITAMCO to develop the runway mat using metal AM.

"The objective of the research is to develop a robust sheet or roll technology that serves as an alternative to the AM-2 mat for temporary or expeditionary flight operations," stated Zavattieri. "AM-2 matting has served the US military well since the Vietnam War, but the materials and technology in the ITAMCO-led research project will offer many benefits over AM-2 matting."

The proposed matting solution is composed of an upper surface that mates with a lower surface and contains a type of architectured material called Phase Transforming Cellular Material (PXCM) geometry to mitigate anticipated loading and shear stresses.

Zavattieri explains that a portable and lightweight airfield mat must be easy to install and store, yet capable of withstanding the stresses of repeated takeoffs and landings of aircraft.

He continued, "Products made with PXCM geometry have the ability to change from one stable configuration to another stable or metastable configuration and back again."

"This means the new runway mat could potentially heal itself, resulting in a much longer life span than a runway made with AM-2 matting. Another benefit is that debris on the runway will not hamper the runway's performance with our technology."

In Phase II, the team will reportedly move into the prototype and testing stage. The prototype's ability to restore itself to its original contour and attain full operational capability thirty minutes after compaction and preparation of the final repair site will be tested.

www.purdue.edu
www.itamco.com

The $1 million SBIR Phase II grant from the U.S. Air Force will help to develop a new additively manufactured runway mat (Courtesy Purdue University)

Optisys additively manufactures largest monolithic metal antenna

Optisys, LLC, a metal Additive Manufacturing and RF design company headquartered in Salt Lake, Utah, USA, reports that it has completed the development and production of what it states is the world's largest single build, entirely metal additively manufactured antenna. The large, flat-panel slotted antenna tile is for use in sea, ground, aerospace and satellite applications. The metal antenna was built as one continuous piece using Laser Beam Powder Bed Fusion (PBF-LB).

"We have been developing ways we can increase the size and cost-efficiency of our large array offerings," stated Janos Opra, CEO of Optisys. "Today marks the conclusion of an incredible R&D effort to obtain this capability."

The company explains that the ultra-large tile can form the basis for a much larger array, made up of many of these building blocks, and is suitable for any application already covered by Optisys technology from sea to space. The flat panel slotted antenna was chosen as a development piece because of its reliance on flatness and tight tolerances, attributes which are said to be challenging to achieve on such a large scale using metal AM. According to Optisys, its successful production of this antenna and the information gained during the process, further extends its capability over legacy technology.

Michael Hollenbeck, CTO of Optisys, commented, "We have been able to produce any size antenna or radar array, using tiling, for a while now. However, this development brings a new level of cost-effectiveness and we have demonstrated our scalability to truly ground-breaking sizes."

www.optisys.tech

LLNL investigates microcrack formation in tungsten Additive Manufacturing

Lawrence Livermore National Laboratory (LLNL), Livermore, California, USA, has conducted a study using thermomechanical simulations and high-speed videos, taken during the Laser Beam Powder Bed Fusion (PBF-LB) metal Additive Manufacturing process, to characterise how and why microcracks form in the AM of tungsten.

Tungsten has the highest melting and boiling points of all known elements, making it a popular choice for applications involving extreme temperatures, including lightbulb filaments, arc welding, radiation shielding and, more recently, as a plasma-facing material in fusion reactors such as the ITER Tokamak.

However, tungsten's inherent brittleness, and the microcracking that occurs within the material during PBF-LB AM, currently pose challenges to its widespread adoption. Previous research into microcracking in tungsten has been limited to examining cracks post-build, but observing the build process in real-time allowed LLNL's scientists to observe how microcracks initiated and spread as the metal heated and cooled.

Thanks to this real-time perspective on the process, the team was able to correlate the microcracking phenomenon with variables such as residual stress, strain rate and temperature, and confirm that the ductile-to-brittle (DTB) transformation of the material was the cause of the cracking. The LLNL researches stated that the study, recently published in the journal *Acta Materialia*, uncovered the fundamental mechanisms behind cracking in AM tungsten and set a baseline for future efforts to produce crack-free parts from the metal.

"Because of its unique properties, tungsten has played a significant role in mission-specific applications for the Department of Energy and Department of Defense," stated co-principal investigator Manyalibo Matthews. "This work helps pave the way toward new Additive Manufacturing processing territory for tungsten that can have significant impact to these missions."

Through experimental observations and computational modelling performed using LLNL's Diablo finite element code, the researchers found that microcracking in tungsten occurs in a small window between 450 and 650 Kelvin and is dependent on strain rate, which is directly influenced by process parameters. They were also able to correlate the size of the crack-affected area and crack network morphology to local residual stresses.

Lawrence Fellow Bey Vrancken, the paper's lead author and co-principal investigator, designed and performed the experiments and also conducted most of the data analysis. The work was funded through the Laboratory Directed Research and Development programme, and LLNL engineer Rishi Ganeriwala performed the finite element model simulations and co-authored the paper

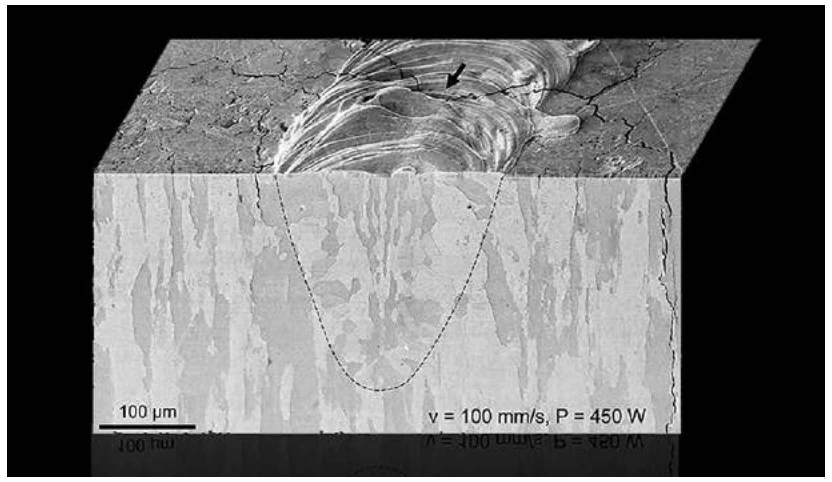
"I had hypothesised that there would be a delay in the cracking for tungsten, but the results greatly exceeded my expectations," Vrancken explained. "The thermomechanical model provided an explanation for all our experimental observations, and both were detailed enough to capture the strain rate dependence of the DBT. With this method, we have an excellent tool to determine the most effective strategies to eliminate cracking during the AM of tungsten."

The work is reported to provide a detailed, fundamental understanding of the influence of process parameters and melt geometry on crack formation and to show the impact material composition and preheating have on the structural integrity of parts printed with tungsten.

The team concluded that the addition of certain alloy elements could help reduce the DBT transition and strengthen the metal, while preheating could help mitigate microcracking. The team is using the results to evaluate existing crack-mitigation techniques, such as process and alloy modifications.

The findings, along with the diagnostics developed for the study, will be crucial to LLNL's ultimate goal of additively manufacturing crack-free tungsten parts that can withstand extreme environments.

www.llnl.gov



By combining simulations with high-speed videos taken during the PBF-LB build process, LLNL scientists were able to visualise the ductile-to-brittle transition in tungsten in real-time, allowing them to observe how microcracks initiated and spread in the metal (Courtesy Lawrence Livermore National Laboratory)

Australian Army deploys second field trial of WarpSPEE3D metal AM machine

SPEE3D, headquartered in Melbourne, Australia, reports that building on the success of its latest field trial with its WarpSPEE3D metal Additive Manufacturing machine, it has once again been deployed by the Australian Army, during a two-week field exercise in the Northern Territory.

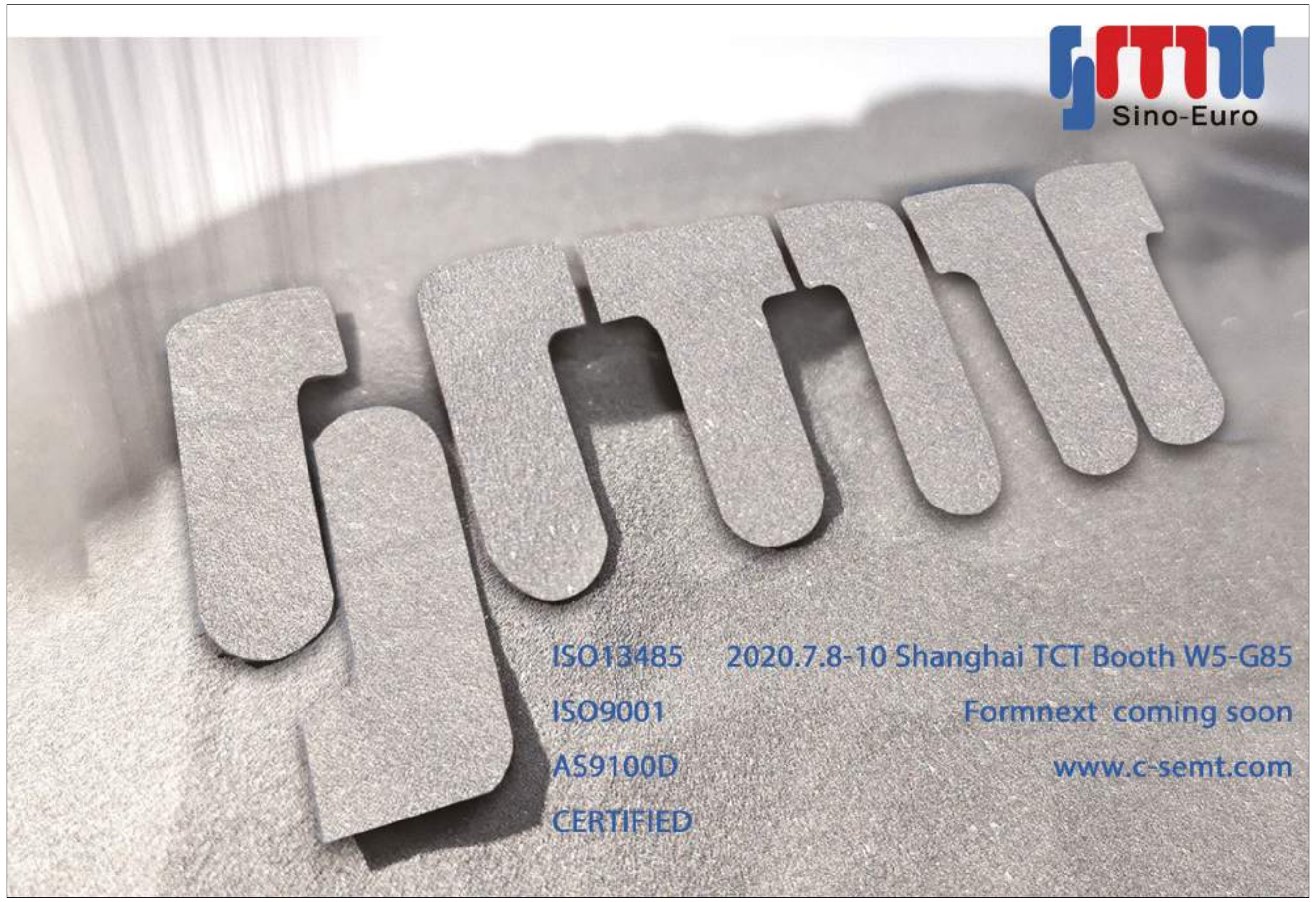
WarpSPEE3D offers large-format metal Additive Manufacturing, using the company's patented cold spray technology. According to SPEE3D, this enables significantly faster and more cost-effective metal part production than traditional manufacturing. It is capable of building metal parts up to 40 kg at a speed of 100 g per minute.

The Additive Manufacturing machine arrived in Darwin, Australia, in early June and has since received a number of upgrades and modifications in the two months since its first deployment. The WarpSPEE3D print cell deployed as part of the 1st Combat Service Support Battalion (1 CSSB)'s larger Brigade Support Group to various field locations in temperatures up to 37°C and 80% humidity, whilst additively manufacturing and machining genuine military metal parts.

The Australian Army announced a $1.5 million investment in a pilot of SPEE3D technology in February 2020, with a twelve-month trial designed to test the feasibility of deploying metal AM machines both on-base and in the field. SPEE3D states that it partnered with the Advanced Manufacturing Alliance (AMA) and Charles Darwin University (CDU) to deliver the programme with soldiers from the Australian Army 1st Brigade training in Additive Manufacturing at CDU since February. The programme aims to significantly increase the availability of unique parts to the army compared to what the regular supply chain can provide.

"This second field deployment proves our technology is a genuine solution for expeditionary metal 3D printing," stated Byron Kennedy, SPEE3D CEO. "This two-week trial demonstrates the WarpSPEE3D is a robust workhorse that is capable of printing real parts and solving real problems in the field. It also proves that soldiers can take control of the whole workflow of creating the spare parts they need, from design to printing and post-processing, right here where they need them."

www.spee3d.com
www.army.gov.au



Atlas Copco and Conflux conclude heat exchanger AM project

Atlas Copco, Nacka, Sweden, and Conflux Technology, Waurn Ponds, Victoria, Australia, have concluded an eighteen-month collaborative project on the Additive Manufacturing of heat exchangers. The project focused on parts consolidation and performance, with a corresponding business case evaluation.

Atlas Copco produces portable and stationary air compressor solutions. Conflux Technology's Additive Manufacturing business focuses solely on the design and development of heat exchangers. The company employs a team of scientists and engineers specialised in thermo- and fluid dynamics, engineering design and metal AM process optimisation.

To conduct the project, the company analysed an existing Atlas Copco product subsystem and designed an alternative solution that streamlined the system by consolidating multiple braised, welded and bolted parts into monolithic AM parts. The company then demonstrated the parts' performance improvement potential and carried out a business case analysis, providing input for future technology investment decisions within Atlas Copco.

"Efficiency gains in heat exchange requires substantial innovation," explained Luc de Beul, VP New Business Technologies, Atlas Copco. "In Conflux we found a highly inventive company that has expertise in fundamental thermophysical modelling, engineering design creativity and AM process know-how."

"Conflux conducted a highly professional programme and could cope with the risks that materialised during this challenging project," he commented. "A great deal of insight was gained that gives input to our AM roadmap."

"Conflux heat exchangers derive their performance from highly complex geometries that make use of the inherent freedoms afforded by Additive Manufacturing," added Michael Fuller, Conflux Technology Founder and CEO.

"Our team of scientists and engineers developed a highly innovative heat exchange application that improved fundamental thermal efficiencies whilst consolidating the system level bill of materials. I look forward to future collaborations with Atlas Copco as they continue on their journey with Additive Manufacturing."

www.confluxtechnology.com
www.atlascopcogroup.com

TWI recognised for its work on PBF AM for the NANOTUN3D Project

TWI Ltd, headquartered in Great Abington, Cambridge, UK, reports that the European Innovation Radar, a support initiative that focuses on the identification of high-potential innovations in H2020 projects, as well as the key businesses delivering these projects, has identified TWI and project partner APR Srl,Turin, Italy, as key innovators for the NANOTUN3D Project.

The NANOTUN3D Project, which worked to optimise Powder Bed Fusion (PBF) Additive Manufacturing for Ti-based nano-additive material, has been determined to be 'tech-ready' as well as addressing the needs of existing markets. The project will now join over 3,600 others on the European Commission's Innovation Radar platform.

The project took advantage of Additive Manufacturing alongside the development of a specially-tailored Ti-based nano-additive material to achieve dramatic improvements in structural parts for the aerospace, astrospace, mobility and equipment sectors.

"The project aims to deliver expected savings of between 40% and 50% for material in critical applications, in addition to inherent AM benefits such as a decrease in throughput times, toolless production and high buy-to-fly ratios," explained Miguel Zavala, TWI Additive Manufacturing expert.

"The project developed nano-modified Ti6Al4V alloy with enhanced structural performance compared to the standard alloy. The nano-modified material has been tested in Laser Beam Powder Bed Fusion (PBF-LB) and Electron Beam Powder Bed Fusion (PBF-EB) processes, with validated supply chain workflow and a health, safety and environmental management system for the manufacture of 'virtual demonstrators' from industrial sectors."

Zavala added, "The whole life cycle of the NANOTUN3D material has been designed with AM processability in mind. The aims of the project are only possible with efficient implementation of AM technologies."

www.ec.europa.eu/digital-single-market/en/innovation-radar

www.twi-global.com

www.apr.it

www.nanotun3d.eu

SLM Solutions reports 90% revenue growth in first half 2020

SLM Solutions Group AG, Lübeck, Germany, reported total sales of €31.2 million, an increase of 90% for the first half of the 2020 financial year. The company stated that 76% of that figure was derived from the sale of Additive Manufacturing machines. In the second quarter of 2020, SLM Solutions recorded revenue of €13.3 million and received orders amounting to €10.7 million.

Overall, the total order intake in the first half of 2020 was reported at €13.7 million (H1 2019: €20.8 million), slowing down compared to the previous year due to the significant restrictions caused by COVID-19 and the resulting global economic slowdown. However, the order backlog of €19.2 million as of 30 June 2020 was well above the previous year's level, increasing by 31% (30 June 2019: €14.6 million). EBITDA (earnings before interest, taxes, depreciation and amortisation) improved by €12.9 million to €–6.0 million for the reporting period (H1 2019: €–18.9 million).

A major driver was increased revenue. Additionally, measures from SLM Solutions' turnaround programme had a positive effect on costs. For example, the company stated that it had benefitted from a more efficient material cost management, leading to improved gross margins.

In addition, SLM Solutions recorded positive one-time effects of €1.2 million within personnel costs as it benefitted from the short-term work programme in Germany and the Paycheck Protection Program in the US. Furthermore, travel expenses decreased by €0.5 million compared to the previous year due to COVID-19.

Meddah Hadjar, CEO of SLM Solutions, commented, "The first half of 2020 was significantly burdened by the effects and uncertainties of the COVID-19 pandemic. Nevertheless, we have made good progress with our turnaround at SLM Solutions."

"This applies in particular to the development process for our next generation machine, which has progressed according to plan and will be launched in the week commencing 9 November 2020," he continued. "We strongly believe this machine will be a game changer for us and the entire metal additive industry."

Dirk Ackermann, CFO of SLM Solutions, added, "After a significant slowdown starting in March, we experienced an uptake of customer activities towards the end of the first half of the year. So far, this trend continued in the third quarter."

"For the remaining second half of 2020, we expect customer activities to intensify and our business to pick up further," he explained. "With the funds generated in July from the first tranche of our new convertible bond, we believe that we are currently well positioned to steer SLM Solutions through these challenging times and to continue our turnaround."

The Management Board stated that it expects a revenue increase of at least 20% compared to the previous year for the full year 2020 (revenue 2019: €49.0 million). This forecast is based on the assumption that there will be no significant deterioration of the COVID-19 situation with extensive lockdown measures in the company's key sales markets during the remainder of 2020.

www.slm-solutions.com

Elementum 3D white paper examines recycling of its RAM powders for use in Laser Beam PBF

Elementum 3D, Erie, Colorado, USA, has published a white paper on 'Powder Recycling in Laser Powder Bed Fusion: Improving Processing, Maintaining Quality'. The white paper explains how the company's blended materials can provide powder recycling benefits while maintaining particle size distribution, without component desegregation.

The findings presented in the white paper come from three different studies, with each study using a different material. Elementum states that the introduction of its patented Reactive Additive Manufacturing (RAM) technology allows for a wide variety of materials not typically additively manufacturable by Laser Beam Powder Bed Fusion (PBF-LB) to be processed.

Along with bringing new materials to the market, parts produced by RAM technology are said to have equivalent and improved mechanical properties compared to traditional wrought alloys.

RAM technology uses micron-scale additives blended into powder feedstock that react in-situ during Additive Manufacturing to form sub-micron inoculants. These inoculants lead to grain refinement, and reportedly contribute to eliminating defects like hot tearing in aluminium, a hurdle for many alloys in AM.

The reactive process of the RAM material, with dissolution of the reactive additives in the melt and reprecipitation of the products as sub-micron inoculants, occurs during Additive Manufacturing and encourages homogeneous distribution of constituents in the final product.

Elementum explains that it has seen interest from consumers in powder recycling, and using the company's alloy feedstocks for PBF-LB for multiple builds. In response, Elementum performed three studies on three different RAM materials.

Powder recycling is economically and environmentally beneficial, increasing the number of builds that can be performed with the same feedstock and reducing material wasted per build. Powder processing also allows the blending of multiple components for the production of materials like metal matrix composites (MMCs).

However, there are concerns about the physical and chemical changes that may occur under processing conditions in PBF-LB, along with concerns around components segregating during handling.

The PBF-LB build process involves thermal cycling that can lead to a loss in chemical composition, and changes in particle morphology can lead to variances in mechanical behaviour, while changes in particle size distribution can affect flowability and cause inhomogeneous powder distribution over the build platform.

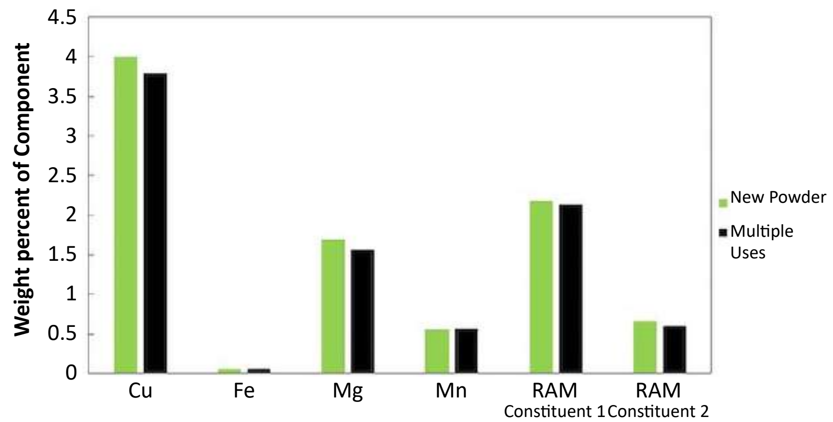
Further, improper powder handling can expose powders to moisture, oxidising particle surfaces and introducing impurities, altering the mechanical performance of a part.

Despite these concerns, many alloys have been shown to retain their chemistry, particle size, morphology and mechanical properties after multiple builds with the same powder. Powder processing also provides improved homogeneity in multi-component materials (e.g. MMCs) compared to liquid processing, where dendritic solidification and agglomeration of added particles encourages segregation.

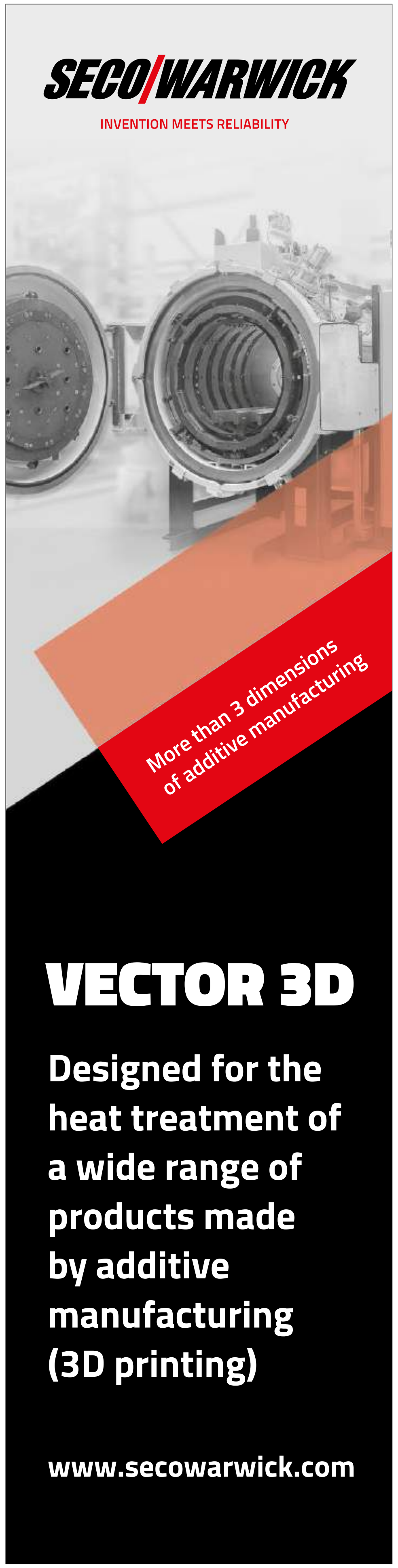
Elementum conducted three different studies of its A6061-RAM2, A2024-RAM2, and IN625-RAM2 materials, respectively, and reports that it was able to confirm that its materials "stand up to the challenge." The powder processing technique used by the company also allows for larger, safer particle sizes for storing and handling that form the beneficial sub-micron reinforcements during Additive Manufacturing.

Powder segregation in A6061-RAM2

For this study, the company emulated a 'worst-case scenario': segregated particle constituents. Smaller, higher-density particles tend to settle to the bottom with time or movement; for example, in a jar filled with material of varying sizes like sand, pebbles, and rocks, finer materials (sand) tend to settle at the bottom, while larger materials (pebbles and rocks) stay in relatively the same place.



The measured chemistry of Elementum's A2024-RAM2 new powder versus the same powder after multiple uses over five months and seventy sieving cycles with no new powder refreshment (Courtesy Elementum 3D)



While Elementum's multi-component powder mixtures aim to minimise this by using similar size matrix and additive particle sizes and relative densities, the company wanted to ensure segregation did not occur through multiple handling cycles and builds.

The company took used powder from a build and sieved it twenty times consecutively with no re-blending. Powder was consistently fed into the sieve from the bottom of a collection bin to maximise component segregation.

It performed two additional builds: one using the top of the final powder blend and another using the bottom half of the powder in the bin. This was then followed by tensile testing each part. The results showed consistent performance by Elementum's powder, even with handling that encourages component segregation.

Consistent particle chemistry & size distribution in A2024-RAM2

Along with a development partner, the company ensured the maintenance of particle size and chemistry after multiple builds in an SLM 280 Additive Manufacturing machine with a powder supply unit (PSV).

After multiple builds using A2024-RAM2 powder over five months and seventy sieving cycles, without refreshing with new powder, Elementum's material was said to have a similar particle size range to new powder, and preserved chemistry that was in-spec.

The company states that this confirmed its material's ability to maintain consistent strength and remain well-mixed over multiple builds, with the same particle characteristics as new powder.

Retaining mechanical performance in IN625-RAM2

Students at Colorado School of Mines (CSM), Colorado, USA, performed a study on Elementum 3D's Inconel 625 nickel alloy with 2% ceramic reinforcements (IN625-RAM2). Evaluation was based on tensile properties of bars and impact energy of Charpy specimens built with recycled powder.

Following the first build with new powder, the used powder was topped off with new powder to maintain 25 kg for each build. The mixture was tumbled for ten minutes to ensure proper blending. This was done for each of nine builds (eight reuses) performed on an EOS M290 PBF-LB Additive Manufacturing machine at Elementum 3D.

The resulting tensile properties of bars taken from the first, second, and eighth reuse (second, third, and final builds) showed consistent strength values above 1,225 MPa for ultimate tensile strength (UTS) and 850 MPa for yield strength (YS).

Both were higher than those reported for wrought plate of the same material according to the manufacturer's data sheet (827- 1103 MPa for UTS and 414-758 MPa for YS). Charpy specimens were also found to have similar impact energy up to the final (eighth) reuse.

These samples showed consistent values in both strength values across multiple builds. Each data point represents an average value for multiple specimens and the error bars shown represent one standard deviation for that sample set.

Study results

Each study conducted by Elementum 3D was said to have explored and confirmed the quality and performance of its powder feedstock over multiple builds. The resulting consistency of mechanical properties and powder characteristics helped the company to assure its customers of the resilience and reliability of its materials.

The reusability of Elementum 3D's feedstock reportedly stems from its use of reactive powder design using micron-scale reactive powders to achieve sub-micron products that act as grain refiners. The similar size and relative density of these additions and its matrix alloy powder are believed to prevent segregation even after multiple cycles of powder handling and sieving.

www.elementum3d.com

Dyndrite welcomes five new AM vendors to its Developer Council

Dyndrite Corporation, headquartered in Seattle, Washington, USA, has welcomed five new Additive Manufacturing vendors to its Developer Council, following the announcement of its first member, HP. The new members include Additive Industries, Open Additive, Trumpf, Photocentric and Currax. They join current Developer Council members which include 3D Systems, Aconity3D, Altair Engineering, AON3D, ANSYS, Aurora Labs, Desktop Metal, EOS, ExOne, HP, Impossible Objects, NVIDIA, Plural, Renishaw, and SLM Solutions.

The Dyndrite Developer Council is a central component of the Dyndrite Developer Program which provides tools, resources and community for original equipment manufacturers (OEMs), independent software vendors (ISVs), service providers and educators developing on the Dyndrite platform. The company states that the council was formed to develop the Dyndrite platform, industry standards, and create seamless customer experiences by cross-leveraging tools that elevate the industry as a whole.

"Open Additive and Dyndrite share a vision for a more open future for the AM industry, in which users have more accessible and powerful tools to accelerate innovation,' explained Ty Pollak, president, Open Additive. "We're excited by the potential impact of our complementary hardware and software capabilities to increase productivity and quality of metal AM parts."

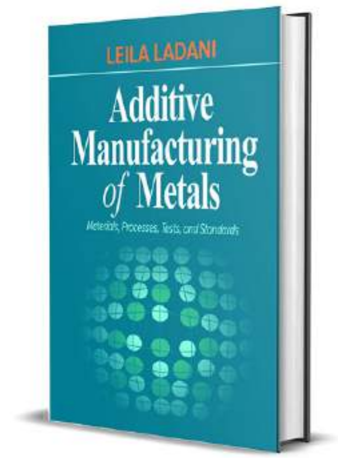
Mark Vaes, CEO/CTO of Additive Industries, commented, "A strong industry has to have modern, robust standards. As a provider of industrial solutions for metal additive manufacturing, we are joining the Dyndrite Developer Council in part to be active in creating a new set of standards that deliver the productivity, efficiency and automated workflows that our customers need."

Ilona Heurich, Head of R&D Software HMI, Trumpf, stated, "Trumpf is excited to join the Dyndrite Developer Council. As a pioneer in Additive Manufacturing as well as laser specialists we are always looking to implement the latest technologies."

Heurich added, "We are excited to see how the Dyndrite GPU accelerated geometry kernel can help to maximise process performance and further strengthen the power and scalability of the AM industry."

www.dyndrite.com

New book published on *Additive Manufacturing of Metals: Materials, Processes, Tests, and Standards*



DEStech Publications, Inc., has published a new Additive Manufacturing resource, *Additive Manufacturing of Metals: Materials, Processes, Tests, and Standards*, by Leila Ladani, PhD, Professor of Mechanical Engineering, Director, The Polytechnic School, Arizona State University.

This book serves as a technical introduction to metal Additive Manufacturing, with a focus on Powder Bed Fusion processes, providing the theory and industry-based practices to design, manufacture, and test metal components via AM.

The book explains the workings and physical limitations of Electron Beam Powder Bed Fusion (PBF-EB) and Laser Beam Powder Bed Fusion (PBF-LB) technologies in the manufacturing of parts using a variety of metal powders. The physics of powder melting is described, as well as the effects of temperature variables on the properties of a part.

The critical elements of how powder feedstock is chosen and formulated are explained. Processing methods are also described using original design and engineering parameters developed by the author. Further information is provided on current test methods available for metal parts produced by AM, as well as how to carry out quality control, monitor reliability and implement safety standards. A section is also dedicated to modelling for process design.

Intended as a resource for training and education in metal Additive Manufacturing, each chapter also includes a set of problems for students and practitioners.

The book can be purchased online as an ebook or ordered in its physical format via the DEStech Publications store.

www.destechpub.com

ExOne's X1 160Pro Metal Binder Jetting machine enters production

During The ExOne Company's recent quarterly financial results release, John Hartner, ExOne CEO, stated that the company's new X1 160Pro™ metal Binder Jetting (BJT) machine, announced in November 2019, is currently in production for its first customers.

"Recently, we won our first commitments for our X1 160 Pro, the industry's largest metal binder jet system, which we announced last November," Hartner stated. "This breakthrough system, our tenth metal printer to date, is well on its way to proving itself as a critical tool that will move metal 3D printing into high-volume production."

"Our team has already begun producing the first 160Pros for customers, and we remain on target with our release plans," he stated. "We continue to expect first shipments by the end of 2020."

The frame of an X1 160Pro machine in production (Courtesy The ExOne Company)

The X1 160Pro is built off the company's S-Print platform for sand Additive Manufacturing, originally launched in 2005. Designed for high-throughput and large-part production, it was stated at the machine's announcement that it will offer build dimensions of 800 x 500 x 400 mm and build speeds of up to 10,000 cm^3/hour.

The open material system is expected to be capable of building in six qualified metals, including the popular stainless steels 316L, 304L and 17-4PH, as well as in ceramic. The X1 160PRO will also feature Industry 4.0 cloud connectivity and process-linking capabilities enabled by Siemens MindSphere.

The new system also incorporates ExOne's patented Triple Advanced Compaction Technology (ACT) system, said to be critical to delivering consistent part density and repeatability across the entire build area in the Binder Jetting process. Triple ACT is reported to tackle the challenges associated with dispensing, spreading and uniformly compacting ultra-fine metal powders, with an average particle size, or D50, of 9 µm.

www.exone.com

AlphaSTAR wins DLA programme to study Grain Boundary Engineering in AM

Software developer AlphaSTAR Corporation (ASC), headquartered in Long Beach, California, USA, has been awarded a contract by the USA's Defense Logistics Agency to improve the mechanical properties and structural performance of metal additively manufactured parts by studying Grain Boundary Engineering in AM.

The contract was awarded to ASC in collaboration with General Electric Global Research Center, the University of Southern California (USC) Viterbi Center for Advanced Manufacturing, and the University of Michigan (UoM) Aerospace Engineering.

ASC explains that, as AM is a relatively new manufacturing technology, it has many hurdles to overcome before universal adoption as a replacement for conventional manufacturing technologies is possible. As such, the company states that there exists an ongoing challenge to provide out-of-production parts and maintain the mission readiness of various weapons system platforms.

During the award period, the team will reportedly establish material precursor screening, selection and improvement of AM driven legacy parts. According to ASC, these developments will apply to all DoD sectors looking to improve the quality and reliability of AM parts.

"Grain Boundary Engineering can improve mechanical strain, crack growth and fatigue properties of the AM part compared to current equiaxed-grain-boundaries in 'as-built' vs 'as-is' parts," commented Dr Rashid Miraj, Director of Technical Operations at AlphaSTAR.

"It will yield significant advancement for the design of DoD supply chain of AM components that are flexible, scalable, and capable of producing parts which are qualified and more reliable using the current AM practices," he concluded.

www.alphastarcorp.com

Xerion's Fusion Factory installed at Fraunhofer IFAM's facility in Dresden

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), Dresden, Germany, reports that it has installed a new Fusion Factory Additive Manufacturing system from Xerion Berlin Laboratories GmbH, Berlin, Germany, at its Innovation Centre Additive Manufacturing (ICAM).

Xerion's Fusion Factory has been installed at Fraunhofer IFAM's facility in Dresden (Courtesy Xerion Berlin Laboratories GmbH)

The Fusion Factory is a compact production line for the Additive Manufacturing of metal and ceramic components. It has three modules that combine the process steps of printing, debinding and sintering (the final heat treatment to produce a purely metal and dense component) into one plant. With additional AM modules, the system can be expanded for industrial series production.

The Fusion Factory was developed by Xerion with scientific support from Fraunhofer IFAM Dresden and brought to market maturity. Parts produced reportedly allow a particularly high degree of design freedom, as both open and closed porosity of the parts can be achieved in the printing stage.

IFAM explains that it plans to implement new filament materials and further develop the technology and the process chain for optimised industrial production.

www.ifam.fraunhofer.de
www.xerion.de

Jellypipe launches its online AM ecosystem in the UK and Ireland

Jellypipe AG, headquartered in Fislisbach, Switzerland, has launched its online B2B Additive Manufacturing platform in the UK and Ireland. The platform brings together manufacturers requiring additively manufactured parts and components with AM solutions providers that own and curate online 'shops' via Jellypipe.

"We are delighted to bring the Jellypipe 3D printing platform to the United Kingdom and Ireland," stated Georges Benz, president and co-founder of Jellypipe. "Since 2018, Jellypipe has been working in continental Europe, and this is an important step for us as we work towards our platform being used globally. The principle behind Jellypipe is very simple, but is made possible by some extremely complex and intricate software which is the engine that makes using our platform so intuitive and rewarding commercially for all parts of the 3D printing ecosystem we host."

"Users of Jellypipe can easily access a huge resource of knowledge, advice, and consultation to ensure that the correct materials, 3D printing technology, and finishing is selected, and then receive quotes from the most extensive network of 3D printing service providers based on speed of delivery or lowest cost," he continued. "It really couldn't be more powerful or more simple to engage."

Users of the Jellypipe platform can upload their 3D files directly for viewing by their chosen solutions provider. The solutions provider will liaise with the customer if necessary to optimise designs or advise on materials, and the job will then be put out to the service provider network for quotes. Quotes will come back for the quickest delivery and for the least expensive cost of production, and the customer can choose which is best, select, and have the parts shipped directly to their premises.

Scott Colman, Jellypipe representative for the UK and Ireland, commented, "It is the extent and the coherence of the Jellypipe platform that is so impressive. It overcomes many of the obstacles that stand between manufacturers and their use of 3D printing, key among which are a lack of understanding as to just what opportunities are available, and also an unwillingness to invest in what is often expensive and difficult to use technology. Jellypipe removes these hurdles and draws together 'virtual shop' owning 3D printing solutions providers with an extensive network of 3D printing service providers. The Jellypipe ecosystem means that manufacturers can tap into all the knowledge and expertise necessary to exploit 3D printing effectively for their requirements."

www.jellypipe.com

Oerlikon Group announces second quarter and half year results for 2020

Oerlikon Group, Pfäffikon, Schwyz, Switzerland, has announced its financial results for the second quarter and first six months of 2020. As a result of the coronavirus (COVID-19) pandemic, the group reported a decrease in order intake year-on-year of 10.1% to CHF 604 million for Q2 2020, and a reduction in group sales by 27.2% to CHF 510 million.

The group stated that the lock-downs imposed by governments had impacted supply chains and demand across regions and industries, significantly effecting the end markets of Oerlikon Surface Solutions, which includes its Additive Manufacturing segment Oerlikon AM. The most effected markets were aviation, automotive, tooling and general industries, power generation and oil & gas.

In the first half of 2020, the group's order intake declined by 20.1% year-on-year to CHF 1,081 million, and sales decreased by 21.5% to CHF 1,039 million. The net result for the first half of the year was CHF -32 million.

"We have accelerated our productivity programmes to mitigate the impacts from the pandemic and are ahead of schedule," commented Dr Roland Fischer, CEO Oerlikon Group. "We have significantly reduced cost and are putting in place a more flexible cost structure to strengthen our foundation."

"The Surface Solutions Segment experienced significant demand challenges due to the lockdowns," he explained. "Toward the end of the quarter, we saw some encouraging signs of moderate recovery in automotive and precision components in China and Germany. The recovery of the economy and markets remains uncertain."

The execution of comprehensive restructuring and productivity programmes across Oerlikon Group has been accelerated and extended to mitigate the impacts caused by the COVID-19 pandemic. In the first half of 2020, operating expenses were said to have been reduced by more than CHF 90 million and capital expenditure was reduced by CHF 18 million, compared to the preceding year.

The execution of the structural and cost-out programmes that were launched in 2019 has also been accelerated. These programmes include rightsizing Additive Manufacturing, optimising support functions and the global footprint, leveraging synergies in procurement and equipment business, and addressing market challenges.

www.oerlikon.com

Würth Industry North America signs distribution agreement with Markforged

Würth Industry North America (WINA), a division of the Würth Group and an industrial distributor of supply chain solutions for fasteners, MRO and safety equipment, has signed a national agreement with Markforged, Watertown, Massachusetts, USA, in order to better serve the needs of Würth Industry's customers in the general manufacturing market, as well as oil & gas, heavy equipment, and transportation.

According to the companies, the agreement to distribute Markforged's Additive Manufacturing solutions complements Würth Industry's strength as a provider of innovative supply chain solutions for original equipment manufacturers (OEMs). Würth Industry states that it now provides several additional cost-saving options to its customers, including metal additively manufactured parts and tools, rapid prototyping, and full-service digital Kanban solutions to better manage inventory.

Markforged's machines can be used to manufacture a wide range of metals, including copper, industrial tool steels and superalloys, making them suitable for application to a wide range of inventory solutions. The company also produces a range of AM machines for composite materials such as carbon fibre, Kevlar and more.

"We are thrilled to bring innovative digital supply chain solutions to our customers," stated Dan Hill, CEO of Würth Industry North America. "By integrating Markforged 3D Printing technology with our existing Kanban programmes, we are able to offer quicker time to market and lower inventory costs. We're able to cut out the sourcing, purchasing, and transportation costs and deliver the value directly to the customer."

Greg Mark, CEO and founder of Markforged, commented, "We're excited to expand the global reach of our solutions with Würth and continue to push the bounds of what's possible in Additive Manufacturing. This partnership truly opens up valuable potential for us, and for the industry. Markforged makes it easy to build anything you can imagine, and that capability will allow industrial manufacturers to lower inventory costs by printing production tools and parts – quickly and reliably."

www.wurthindustry.com
www.markforged.com

Classic car specialist turns to ExOne binder jet AM for vintage Ferrari part

HV3DWorks LLC, Sewickley, Pennsylvania, USA, recently used Binder Jetting (BJT) Additive Manufacturing technology from The ExOne Company, North Huntingdon, Pennsylvania, USA, to enable the reproduction of a carburettor for a vintage Ferrari. HV3DWorks specialises in the restoration of collector cars using AM parts.

The carburettor for a vintage Ferrari, reproduced using Binder Jetting (Courtesy The ExOne Company)

HV3DWorks' client approached the company for assistance in producing replacement parts for the top section of a Weber 40 DFI-6 carburettor for a 1969 Ferrari 365 GT 2+2 V-12 engine. The original carburettor had stripped threads and was leaking fuel, and attempts to source an original replacement part had proved unsuccessful.

The original carburettor top served as the design guide for the part, which was modelled and initially produced in plastic to confirm fit and finalise the design. Once the design was approved, the part was produced in 316 stainless steel infiltrated with bronze on an ExOne M-Flex metal Binder Jetting machine.

The overall production time for the part was twelve weeks, including CAD design, Additive Manufacturing, post-production impregnation and thread clean-up. While sourcing the original part would have cost HV3DWorks' client $2,500, the cost of the AM part was significantly lower at $1,200, a saving of $1,300.

www.exone.com
www.hv3Dworks.com

ExOne qualifies Inconel 718 for binder jet AM applications

The ExOne Company, North Huntingdon, Pennsylvania, USA, reports that the nickel-base alloy Inconel 718 has been certified as Third-Party Qualified, the company's highest designation of material readiness for its binder jet metal Additive Manufacturing machines.

Frequently used in the aerospace, energy and automotive industries, Inconel 718 is known for its high strength and hardness, with strong resistance to corrosion, chemicals and extreme temperatures ranging from sub-zero to 704°C. It also has outstanding welding characteristics and is often used for high-temperature applications such as jet engines and tooling, or corrosive environments, such as those featuring seawater or acids.

"Today's qualification of Inconel 718, following on the heels of M2 Tool Steel earlier this year, shows the ExOne R&D team is aggressively delivering new materials for binder jet 3D printing," stated Rick Lucas, ExOne CTO and VP, New Markets. "Our increasing pace of material qualifications is a testament to the strength of our new metal 3D printer systems equipped with Triple ACT, an advanced compaction technology that is essential for Binder Jetting metals and other materials at high speeds and densities."

The company explains that as is the case with Inconel 718, ExOne's patented Triple ACT enables the Additive Manufacturing of standard MIM powders, followed by the use of standard sintering profiles and heat treatments, that deliver high-density results consistent with wrought material. Independent testing verifies that Inconel 718 additively manufactured and sintered by ExOne meets ASTM standard B637-18.

Lucas added, "ExOne can now transition R&D materials to full qualification as demand increases." ExOne has three tiers of material qualification, used to signify the varying levels of readiness of materials for binder jet AM applications: R&D, Customer-Qualified and Third-Party Qualified.

Previously, the company had recognised Inconel 718 as an R&D material, which meant it had been deemed buildable for researchers, supported by ongoing development. The new Third-Party Qualified status means that the material has passed rigorous ExOne tests over multiple builds and has verified material property data from an independent third party.

Customer-Qualified materials are those that have been qualified by ExOne customers with their own standards and are currently being successfully additively manufactured for their own applications. However, they have not yet earned ExOne's highest level of qualification for general market readiness.

Currently, twenty-two metal, ceramic and composite materials are Third-Party or Customer-Qualified. In addition, more than two-dozen materials are recognised as R&D ready, including aluminium, which has been fast-tracked for qualification. ExOne believes the ability to additively manufacture aluminium at high speeds will have a transformative, sustainable effect on the automobile and aerospace industry.

The company explains that its proprietary CleanFuse binder was a critical component in the new qualification of Inconel 718. CleanFuse is a clean-burning binder for additively manufactured metals that are sensitive to carbon left behind by other binding agents during sintering.

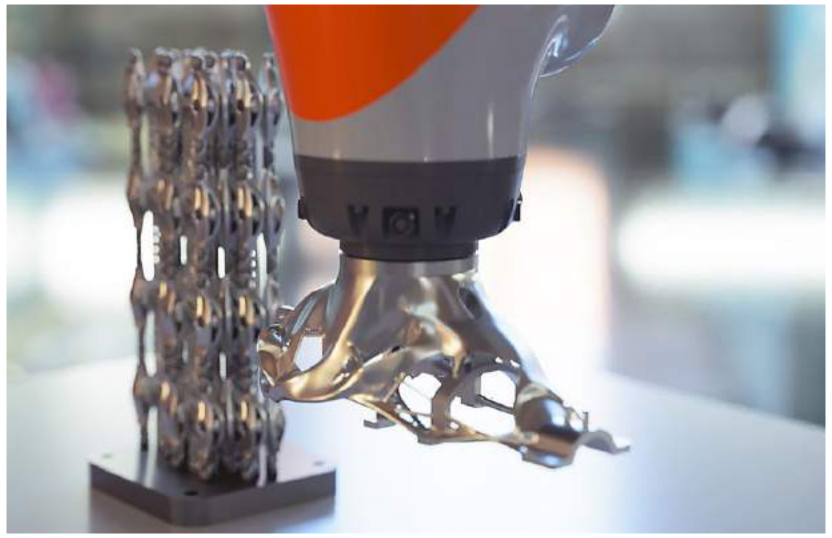
www.exone.com

Project to automate post-processing of additively manufactured parts

Renishaw, Wotton-under-Edge, Gloucestershire, UK, is collaborating with start-up Additive Automations, Sheffield, South Yorkshire, UK, as part of a project to automate the post-processing of metal additively manufactured parts by using collaborative robots (cobots) to perform support structure removal.

Additive Automations creates robotic systems specifically designed to automate Additive Manufacturing. After obtaining funding from UK and Canadian bodies, its founder and CEO, Robert Bush, collaborated with both Renishaw and the University of Sheffield's Advanced Manufacturing Research Centre (AMRC). Renishaw provided four examples of its AM builds to enable the start-up to demonstrate its support structure removal system. The four AM parts were designed for medical, oil and gas, automotive and mechanical engineering applications.

Testing its robotic system on parts already being used in industrial applications will help Additive Automations demonstrate the potential of its product. According to Renishaw, the project, Separation of Additive-Layer Supports by Automation (SALSA), could reduce the average cost per part by 25%, furthering AM's potential as a cost-effective option for large-volume production lines.



Post-processing of a metal additively manufactured part (Courtesy Renishaw)

SALSA aims to use robotics and deep learning to digitalise some of the few remaining manual processes left in AM. Cobots were chosen for their high payload-to-size ratio and integrated force sensors, which collect data to determine the geometry of AM parts. Software then analyses the data, using digital twin technology. The output is then used to determine where the support structures are so that they can be removed using an end-effector tool.

"Automating support removal and finishing in AM completely changes the economics when scaling up AM, and for the first time makes it feasible for manufacturers around the world to adopt this technology in rapid production," explained Bush.

"Improvements in post-processing could bring AM to the forefront of new applications in medical and aerospace applications," added Bryan Austin, Director of AM Sales at Renishaw. "An automated manufacturing process could make AM adoption more appealing to manufacturers operating large volume production lines."

www.renishaw.com

The Barnes Group Advisors becomes The Barnes Global Advisors

The Barnes Group Advisors (TBGA), headquartered in Pittsburgh, Pennsylvania, USA, has announced a change of name to The Barnes Global Advisors (TBGA). The name change is said to acknowledge that the consultancy's ADDvisor® team has provided consulting and training expertise to companies on six continents, with a clear mission to industrialise Additive Manufacturing globally.

The TBGA team provides extensive AM consultation across the industry, including in newer advanced manufacturing technologies such as Cold Spray Additive Manufacturing, Binder Jetting (BJT), Directed Energy Deposition (DED), and in the field of supply chain development.

"When TBGA started three years ago, we had a vision to bring people from around the world together from our connections to solve problems, link companies and generally help get from A to B," stated John Barnes, TBGA's founder & Managing Director. "In that time, we grew more than anticipated and have this great team with fantastic experience. In my mind, it took twenty-five years to create the team, but it also took twenty-five years to build the trust and integrity we have with our customers."

"I have always believed that we need to be part of the fabric of AM, and so TBGA is involved in many committees, mentoring and providing a linkage from the cutting-edge research with colleagues at RMIT in Melbourne, Australia, Carnegie Mellon University in Pittsburgh, Pennsylvania, USA, and the University of Waterloo outside Toronto, Canada," Barnes added.

www.barnesglobaladvisors.com

Link3D launches Post-Production Management app to streamline AM workflow

Link3D, Boulder, Colorado, USA, has launched its first mobile app: Post-Production Management. The company states that the new application will change the way companies and organisations manage their post-production processes and provide a streamlined workflow by allowing quick and efficient management of additively manufactured parts and creating a digital thread.

The company offers solutions for organisations to scale their Additive Manufacturing processes and enables workflow automation by connecting IT, hardware, and software technologies with APIs. With the ability to configure order forms and collect data in any language, facilities can accept, quote, and cost orders from anywhere in the world.

The Post-Production Management app is said to allow teams to maximise and optimise end-to-end processes in conjunction with the Production Dashboard that automatically keeps track of queued, completed and failed parts.

Link3D's app will enable its customers to:

- Locate parts by (1) scanning a QR code (2) filtering by tasks (3) Work Center hub
- Review and update the status at each step from 'Not Started' to 'Arrived,' 'In Progress,' 'Completed,' or 'Failed'
- Automatically route the parts through a series of Work Centers defined by the traveller
- Manage yield by tracking how many parts were completed successfully at each Work Center, and how many require rebuilding
- Track failure reasons for each Work Center to increase traceability of yield management on the production floor
- Track the labour and machine hours required to complete each post-process for different parts and Work Orders
- Complete pre- and post-checklists to ensure that the technician successfully followed all work instructions
- Upload and view documentation/images for traceability of happenings at each Work Center
- View additional order details to provide context for the full order including customer information and detailed production requirements for a given part

According to Link3D, as more companies begin to adopt AM processes, it will be critical that each job is as seamless and connected as possible. The company states that its new app gives companies control of their jobs and complete transparency of each step in the production process.

Lara Janse van Vuuren, Technical Program Manager at Link3D, commented, "We have seen the Post Production app streamline the post-processing steps and increase the traceability without adding overhead to every task. The paper trail is eliminated without losing the sign-offs and accountability for each step after the printing process."

https://am.link3d.co/

Sumitomo Corporation of Americas to increase investment in Sintavia

Sumitomo Corporation of Americas (SCOA), headquartered in New York City, New York, USA, the US division of Japan's Sumitomo Corporation, reports that it has entered into an agreement to increase its investment in metal Additive Manufacturer Sintavia LLC, Hollywood, Florida, USA.

The companies explain that the minority investment, which follows an initial investment by SCOA in 2018, will be used to fund Sintavia's growing business as a provider of additively manufactured parts to aerospace and space companies. The terms of the deal were not disclosed.

The investment will also reportedly help Sintavia scale its production capacity for flight-critical components produced via AM, while continuing to advance its technical capabilities. In addition to this financial investment, SCOA and Sintavia will continue to identify opportunities to apply Sintavia's Additive Manufacturing and design capabilities toward Sumitomo Corporation Group's global industrial activities.

The transaction is expected to close in the second half of 2020, following customary regulatory review.

"We truly value SCOA as a long-term partner for Sintavia and are excited to expand our existing relationship," stated Brian R Neff, Sintavia's CEO and managing partner of Neff Capital Management LLC, Sintavia's majority owner. "With this investment, we are further aligning ourselves with a global thought leader in Additive Manufacturing that is committed to supporting our continued growth."

Kevin Hyuga, SVP and General Manager of SCOA's Construction and Transportation Systems Group, commented, "Since our initial investment in 2018, we've been impressed by Sintavia's leadership and growth in such a short time."

He added, "We see continued synergies in the future through this partnership, and look forward to continuing to help Sintavia support the Aerospace and Space industry. Moreover, Sintavia is well-aligned with our company's sustainability goals. Through its technology, Sintavia is capable of reducing waste in the Additive Manufacturing production process, allowing end-stage products to fly lighter, ultimately reducing greenhouse gases and helping to create a more sustainable society."

www.sumitomocorp.com
www.sintavia.com

3DEO wins MPIF Design Excellence Award

3DEO's award-winning metal additively manufactured component, an anchor link (Courtesy 3DEO, Inc.)

3DEO, Inc., a metal Additive Manufacturing technology company based in Los Angeles, California, USA, received a Design Excellence Award for its metal additively manufactured production component, an anchor link, in the Metal Powder Industries Federation (MPIF)'s 2020 PM Design Excellence Awards. The company's process combines binder-based metal Additive Manufacturing with green-state milling.

The competition recognises distinguished examples of the efforts made in metal Additive Manufacturing to advance new technologies, designs, and commercial success.

According to 3DEO, the company is gaining high-volume, low-cost parts orders versus traditional manufacturing techniques such as CNC machining and Metal Injection Moulding. The company explained that it is breaking new ground in metal AM due to its differentiated technology and business model; rather than selling AM machines, the company sells parts and offers customers a 'one-stop-shop' for production-quality metal components.

"We are honoured to receive this award of distinction from MPIF," stated Payman Torabi, PhD, 3DEO's co-founder and CTO. "It is a terrific accomplishment for 3DEO that highlights the giant leaps we have made over the last eighteen months commercialising our technology."

Torabi also noted the potential of 3DEO, and Additive Manufacturing in general, to catalyse the next industrial revolution. He added, "3D printing is an incredible modern tool with a lot of advantages. You can't utilise all its potential powers with an outdated mindset or approach. We as engineers, designers, builders, and innovators need to start rethinking our methods so all of humanity can witness and benefit from a new industrial revolution."

Matt Petros, PhD, 3DEO's CEO, reported, "It is particularly exciting to me that the winning component is a high-volume production part, not a one-off prototype. We had to out-compete CNC machining to win the production order, and we did that with a lower piece price and the ability to seamlessly scale quantities into very high volumes. It was a 'win-win' for both 3DEO and our customer."

"With production customers in diverse industries and applications such as aerospace, defence, medical devices, and consumer products, 3DEO is well on its way to realising its vision to become a world-class metal parts supplier," continued Petros.

"The design award for such a high-volume production component is a terrific example of the tangible progress we are making. Thank you to MPIF for the recognition, and most importantly thank you to our customers for working side-by-side with us to change the world of manufacturing together."

www.3deo.co

Poly-Shape and Constellium to explore aluminium AM

Poly-Shape, an AddUp company, has signed a contract with Constellium, Paris, France, to research and develop innovative components made from aluminium powder. The components will be additively manufactured from the Aheadd® powders recently developed by Constellium.

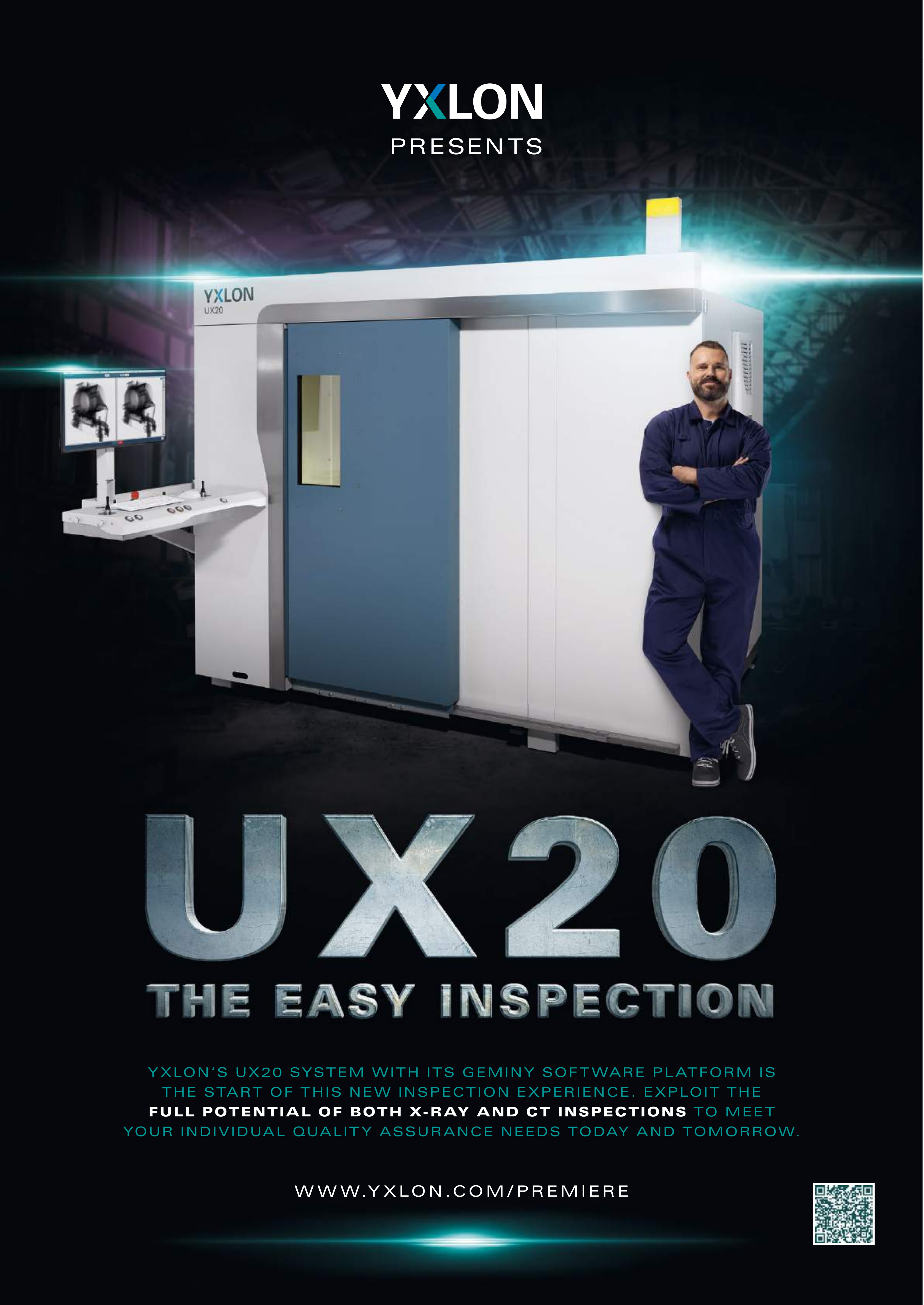
"This is the result of the flexibility of our structures, our reactivity and the high quality of our teams, in particular the research and development sector," stated Stephane Abed, CEO of Poly-Shape. "From the beginning, our strong culture of R&D places innovation at the centre of the company, to meet the expectations of the demanding high-tech industries in which we operate."

With experience as a provider of metal Additive Manufacturing services for industries such as aeronautical, motorsports and energy, Poly-Shape has an in-house R&D department and participates in numerous multinational industrial innovation projects. This includes projects to develop emerging processes to validate new materials and new design methods, improve manufacturing parameters for existing machines, and perform testing of future machines.

A research team is working to develop innovative additively manufactured components from aluminium powders (Courtesy P Urvoy/Poly-Shape)

The new collaboration is reported to be fully integrated into the overall AddUp R&D policy, which includes a joint-venture between France's Michelin and Fives.

www.poly-shape.com



Velo3D joins forces with Lam Research on metal AM for semiconductors

Velo3D, Campbell, California, USA, and semiconductor specialist Lam Research Corporation, Fremont, California, USA, will collaborate on novel materials and designs for metal Additive Manufacturing of applications in the semiconductor industry, as part of a joint development agreement.

Lam plans to significantly increase the volume of parts produced by AM in the semiconductor industry over the next five years, and Velo3D states that under the joint development agreement it will develop new metal alloys for processing on its Sapphire® metal AM machine, which uses Laser Beam Powder Bed Fusion (PBF-LB), that are said to be critical to Lam designs and technologies.

Lam Capital, a venture group of Lam Research Corporation, will also invest an undisclosed amount in Velo3D. Velo3D recently closed a $40 million round of funding, bringing total funding for the company to $150 million. This new investment is said to enable the company to expand its technology capabilities and reach profitability by mid-2022.

"Lam Research is leveraging Additive Manufacturing as a driver of the innovation that enables our customers to build smaller, faster, more powerful and power-efficient electronic devices for everyday use," commented Kevin Jennings, senior vice president of Global Operations at Lam Research. "This joint development arrangement aligns well with Lam's mission to continuously seek new technologies that push the limits of product design and manufacturing. We are excited to lead the semiconductor industry in delivering value to our customers from AM."

Benny Buller, CEO and founder of Velo3D, stated, "Semiconductor manufacturing is one of the best examples of high-volume production and Lam requires the highest levels of repeatability and consistency to achieve precision control at atomic scale. Velo3D is well-positioned to provide confidence in metal 3D printing due to our calibration, metrology, and digital traceability capabilities."


The Velo3D Sapphire metal AM machine (Courtesy Velo3D)

"This relationship aims to accelerate Lam's journey of continuous innovation toward producing equipment that creates cutting-edge microprocessors, memory devices, and numerous related product types," Buller concluded.

www.velo3d.com
www.lamresearch.com
www.lamcapital.com

Shining 3D opens new European headquarters

Shining 3D Technology GmbH, the European subsidiary of Shining 3D Tech. Co., Ltd., Hangzhou, China, has expanded its presence in Europe with a new headquarters location in Stuttgart, Germany.

Established in 2017, the company provides a range of solutions for Additive Manufacturing, including industrial metal Additive Manufacturing machines and 3D scanning technology. Its new location comprises more than 1,000 m² of space, featuring two showrooms, spare parts supply, modern training rooms and various business departments such as sales, finance and marketing.

The show area houses numerous metal and plastic additively manufactured reference parts and products displaying the various fields of application for Shining 3D's AM technologies. In addition, a Porsche 911 body serves as a demonstrator for the capacities of the Shining scanning technology. The company employs a total of twenty staff in Stuttgart and its branch in Italy, and supports the EMEA region (Europe, Middle East and Africa) with an international team.

By storing spare parts and consumables at its new location, Shining 3D aims to guarantee availability on-site and within a short time for customers all over Europe. The training of employees on new AM machines at the customer's site is said to be coordinated from the new location.

"The new location enables us to present the entire process chain of Additive Manufacturing in an industry-oriented manner and to develop suitable solutions for our customers and partners promptly and competently," stated Xiaoping Huang, General Manager of Shining 3D Technology GmbH. "In addition, due to the central location in the heart of southern Germany with numerous important companies and industries as well as the proximity to the airport and important motorways, we are close to our customers and partners."

www.shining3d.com


One of the offices at Shining 3D's new headquarters, housing its EP-M250 Pro metal AM machine (Courtesy Shining 3D Technology GmbH)

BEAMIT and ZARE merge their Additive Manufacturing businesses

European Additive Manufacturing service providers BEAMIT SpA, Fornovo di Taro, Italy, and ZARE srl, Boretto, Italy, have announced the merging of their Additive Manufacturing businesses to create a new organisation, The BEAMIT Group.

The newly-formed joint organisation employs 100, with operations across five plants concentrated in a 40 km area between Parma and Reggio Emilia, Italy. The organisation also operates four commercial offices in France, Germany, the UK and Japan. Andrea Scanavini will serve as BEAMIT Group General Manager.

Both BEAMIT and ZARE will continue to operate under their own brands, but activities will converge into BEAMIT Group, which will specialise in providing a comprehensive range of materials, processes, technologies and certifications to the international aeronautical, aerospace and defence, energy, motorsport, oil & gas, transportation & industrial sectors.

With the merger, the group explains that it aims to make customer's lives and processes easier in all crucial strategic activities, through fully integrated operations with unique partner services.

Mauro Antolotti, BEAMIT president, stated, "I had the opportunity to meet special people and courageous entrepreneurs, Sauro Zanichelli and Andrea Pasquali. The idea to grow the group further was born during one of these meetings: BEAMIT, Pres-X and ZARE."

BEAMIT acquired a stake in Pres-X, a startup specialising in post-processing for Additive Manufacturing, early in 2020, as part of its strategic vision to broaden its knowledge and special process offering, strengthening its position as an AM service provider for demanding industries.

On the merger, Antolotti added, "The extended organisation is created to serve and support our common customers with a true 360-degree service span as well as greater investment capacity and financial strength, in order to become even stronger to meet further market challenges, while securing total reliability for present and new customers into this journey together. The group is now officially launched: our claim is [we were] 'born for you to stay by your side'."

Andrea Pasquali, ZARE's General Manager, commented, "We have known Mauro for quite a long time and when he shared with us the challenging project he had in mind, we were truly impressed by the potential that the creation of the group would generate."

"As he explained the amazing scenarios obtained by our merger, we immediately realised the huge step forward that this would bring in Additive Manufacturing as well as the maximisation of customer service: a must for ZARE," he continued.

"With the group, process optimisation and integration will be unprecedented: this will enable to unlock new opportunities and break process limits that are still difficult to overcome today. Integrated Additive Manufacturing is finally concrete: this group is ready for the market."

On his appointment as General Manager of the new joint company, Andrea Scanavini stated, "Having the opportunity to lead this new high-tech hub is a chance that very few people can experience in real life. Being here at the very moment where it all starts off, is an even rarer event."

www.beam-it.eu
www.zare.it
www.pres-x.com

The board of the newly-formed BEAMIT Group, from left to right: Cristina Bo; Mauro Antolotti; Sauro Zanichelli; Andrea Pasquali; Michele Antolotti and Andrea Scanavini (Courtesy BEAMIT Group)

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Velo3D's SupportFree tech enables AM of mission-critical turbomachinery for solar power array

Hanwha Power Systems, headquartered in Changwon, Gyeongsangnam-do, South Korea, recently used Velo3D's SupportFree™ metal Additive Manufacturing technology to produce a shrouded radial expander wheel for a solar power array, resulting in an 80% reduction in build time and a 90% reduction in the amount of support material required.

Power generation equipment may comprise hundreds of parts, but among them are select mission critical components that can determine the performance of the entire system. Many of these highly-optimised parts can be difficult to manufacture, and present some of the greatest engineering challenges. Tradeoffs must often be made between performance, availability, volume, quality and cost.

Chad Robertson, senior engineer at Hanwha Power Systems' US R&D centre, and his team are developing turbomachinery for a high-efficiency power-generation system utilising Supercritical CO_2 (s-CO_2) as the working fluid in a recompression Brayton cycle (RCBC). Heat input to the cycle will be delivered from a concentrated solar-power array. The solar power project, which is in-part supported by the US Department of Energy (DoE)'s office of Energy Efficiency and Renewable Energy, has the end-goal of using this equipment for a concentrating-solar-power plant.

The s-CO_2 being used for the solar-power project is a fluid state of carbon dioxide in which it is held above its critical pressure and temperature. At these conditions, the fluid is very dense, resulting in compact machinery and optimal thermodynamic cycle conditions allowing for increased thermal-to-electric energy conversion efficiency when compared to steam Rankine cycles. The overall system works by transferring heat from a large solar array into a working fluid (CO_2) that is channelled through a series of radial expanders to extract power. The final expander is connected to a gearbox that drives a generator and various additional compressors needed for completing the power cycle to deliver electricity to the grid.

"The temperatures and pressures in such a system need to be very high," explained Robertson. "Our goal of optimum efficiency drove us to design a shrouded turbine wheel, or impeller, where the flow path of the working fluid is covered on both top and bottom. This eliminates any gap between the impeller and the housing that would reduce wheel efficiency."

The Hanwha team evaluated several different potential manufacturing techniques for making the new component. "These shrouded impellers are a significant manufacturing challenge, even conventionally," he continued. "The geometry is quite complex, as the enclosed, sweeping blades are a three-dimensional shape that is not easy to define, and the high-temperature nickel alloy that we use is difficult to machine."

With these constraints in mind, the team reviewed and rejected a number of conventional techniques, such as five-axis milling or precision investment casting, due to roadblocks in cost and accuracy. With traditional manufacturing, the shrouded wheel would have taken multiple steps to manufacture; an open impeller and a shroud would have had to be produced separately and then brazed, with the bonding of the two having the potential for weakness or distortion in the finished piece.

Hanwha decided to explore Additive Manufacturing as a more direct route to simplification of the entire process. AM offered an opportunity to iterate more quickly, refine the design, increase performance and optimise function. The company worked with Stratasys Direct Manufacturing, Los Angeles, California, USA, to produce the part, having previously worked with the company on prototype test builds for shrouded impellers.

"We were looking for an additive vendor that could provide us with a turnkey part," noted Robertson. "We wanted to supply design specification, materials requirement – and then get back a finished part we could basically put right on our machine."

Andrew Carter, Senior Process and Manufacturing Engineer at Stratasys Direct, explained how the company came to select Velo3D's SupportFree AM to produce the part. "What enabled us to take on this shrouded turbine wheel project was what we're calling a next-generation Additive Manufacturing system," he stated. "We've found that the new Velo3D Sapphire system dramatically improves the process and really stands alone in this next-gen category."

The additively manufactured shrouded radial expander wheel for a solar power array (Courtesy Velo3D)

Prior to acquiring its in-house Velo3D Sapphire™ machine, Stratasys Direct wouldn't have bid on the Hanwha part, Carter said. "Previous projects with other AM-equipment vendors had shown us that the removal and clean-up of all the necessary support structures required for successful prints on their machines was labour-intensive, costly and, in some sections, basically impossible."

With the Sapphire metal AM machine, however, the need for supports is greatly reduced, if not entirely eliminated, due to the machine's ability to overcome the '45° rule,' which dictates that angles lower than 45° require additional vertical supports to hold up portions of a part during Laser Beam Powder Bed Fusion (PBF-LB).

By using the Velo3D system to additively manufacture the Hanwha shrouded impeller, Stratasys Direct was reportedly able to greatly reduce both the total volume of material used and the surface area for which the system needed to build supports. The engineers compared a Hanwha component design created with conventional AM support requirements against what would be required by the Sapphire. For the conventional AM machine, they modelled supports for all surfaces less than 45° from horizontal. On the Velo3D machine, they only needed to add supports on surfaces at less than 10° from horizontal.

The result was a 90% reduction in support material. Stratasys Direct has since continued improving its process with the Sapphire and can now build all the way down to zero degrees, in certain applications, without supports.

Using less material provides a number of significant savings, noted Carter. "In addition to lower material costs to our customers overall, requiring far fewer supports has eliminated a lot of post-processing work. This, in the long run, will contribute to reduced labour time and expense on the shop floor."

Using the Velo3D Sapphire also enabled Stratasys Direct to build the part using a high-temperature nickel alloy (718) for the impeller, with high accuracy. "Due to the consistency we get from the Velo3D system, we ended up with a near-net shape part on the build plate that required correspondingly less in the way of post-processing," explained Carter.

Build-time reduction was another benefit of using the next-gen AM system. The machine features two 1 kW lasers with full build-plate coverage aligned to less than a 50 µm overlay tolerance. This means that each laser has the capability to reach anywhere on the build plate and deliver a full kilowatt of power (for bulk-metal processing).

The lasers also create a virtually invisible overlap on larger parts like the Hanwha impeller. Combined with the time savings of producing much less support material, the dual high-power lasers are said to enable an 80% reduction in overall build time.

Ensuring the sound mechanical properties of the Hanwha turbine wheel is extremely important for the test programme as it moves forward, the company explained. The wheel will be rotating at greater than 14,000 RPM during testing and will be in a high-temperature environment, so it is critical that the material properties of the turbine are well understood. As part of the project, Stratasys Direct built test samples and heat-treated them alongside the turbine to measure tensile and stress rupture properties.

ASTM F3055-14 provides a general specification for the Additive Manufacturing of nickel alloy 718. At testing, the measured tensile results all exceeded the ASTM F3055 minimum requirements. The chemical composition of the test samples was also reviewed and met ASTM requirements.

The impeller was also subjected to review using digital X-ray, CT scanning and FPI. No measurable defects were detected by the scans. The turbine was then balanced and spin-tested at speeds exceeding the design conditions and rechecked for surface cracks using FPI.

www.velo3d.com
www.hanwhapowersystems.com
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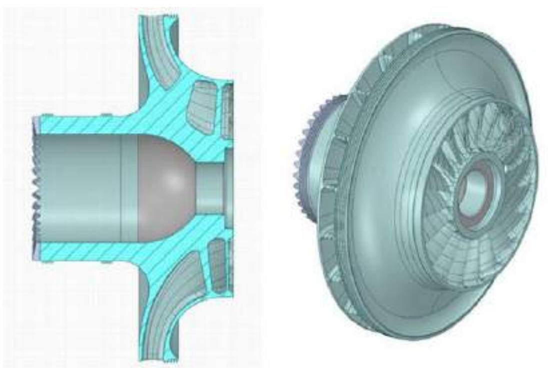
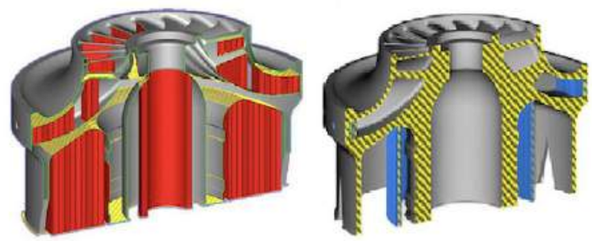


Cross-section of the Hanwha shrouded turbine wheel design for a concentrating-solar-power plant (left) and CAD image of the exterior structure of the wheel (right) (Courtesy Velo3D)



Most current PBF Additive Manufacturing machines would require a large quantity of support structures (shown in red, left) to produce the Hanwha impeller design. Velo3D's Sapphire machine can manufacture the same design with minimal supports (shown in blue, right) (Courtesy Velo3D)

Atherton Bikes: The journey from world title success to mastering Additive Manufacturing for performance bike production

The story of Atherton Bikes stands out as a shining example of how metal Additive Manufacturing (AM) can be successfully embraced and commercialised by a small, dedicated team of people. In the case of the Atherton family, the technology has not only enabled them to maximise their performance at the pinnacle of professional mountain biking, but has also opened a path to commercial bike production in an industry where frame manufacturing is dominated by Taiwan and China. In an article that will appeal to anyone considering the use of metal AM, the Atherton Bikes team shares its experiences with Robin Weston.

Until I started researching this article, I had no idea I had something in common with Dan Atherton. If you're into mountain biking, you'll be familiar with the Atherton family – for those whose interests lie elsewhere, the three siblings, Dan, Gee and Rachel, have been cleaning up the silverware in the Downhill and Enduro mountain bike world since 2004. The common ground? As kids, Dan and I both built bikes. I don't know about Dan, but in my case, the catalyst for this was the probably slightly unusual childhood that I experienced. My father, who was a woodwork teacher (figure this out if you can) taught me to weld using oxy-acetylene at the age of thirteen. Although not a remotely successful joining technique for wood, welding did prove to be a useful skill for keeping the family's beaten up car on the road and scraping through the UK's national roadworthiness test each year.

I used this relatively uncommon skill, in children at least, to construct ever more weird and wacky bikes. That's where the similarity ends though, with no competition titles to my name. I also imagine Dan's childhood bikes were much more purposeful, whereas my efforts were created more as a result of the fact that I could weld, so I just welded stuff. Look out for this pitfall if you're considering metal Additive Manufacturing: it doesn't suit every application.

I'm still a confirmed bike enthusiast and occasional oxy-acetylene welder, but I keep the two hobbies separate these days. Bikes and

Fig. 1 Detail of the metal and carbon fibre frame construction used by Atherton Bikes, initially for competition and now for commercial sale (Courtesy Sven Martin)

Fig. 2 Rachel Atherton winning in Round 2 of the UCI Mountain Bike World Cup (DH) in Fort William, Scotland. She has a record number of overall World Cup victories and multiple World Championship titles (Courtesy Sven Martin)

metal joining, as we will see, are inextricably linked and, whilst carbon fibre technology has made an enormous impact on the bike manufacturing industry, metal is still the go-to material for those parts that take the most abuse.

Solutions looking for a problem

It is dangerous to generalise, but for the most part, we take the products we use every day entirely for granted, from the tiniest widget to the most complex of products such as cars, aeroplanes, smartphones, computers and a myriad of other 'stuff'. The reality is that most of the population is unaware just how much effort must go into R&D, testing, manufacturing processes, training and documentation to be able to consistently manufacture products that comply with international standards for performance and safety.

As someone involved in technology product management for most of my career, I came into engineering via the apprenticeship route before returning to university to further my education. I am still amazed by the processes used in manufacturing and the levels of nuance, intellect and sheer dogged determination required. This is the case when developing a stable, dependable manufacturing process using established 'standard' technologies, let alone new technologies such as metal AM.

Since the industrial revolution, metal forming has continually evolved, with a myriad of discoveries and mini-revolutions taking place along the way. From the mid-1850s and the advent of steel, engineering materials and processes have been refined continuously in order to deliver higher and higher levels of performance. Sometimes, it is innovation that promotes change; solutions looking for a problem to solve. At other times, it is the ambition to achieve the impossible, or pure necessity, that drives advances.

In its early years, Additive Manufacturing, and metal Additive Manufacturing in particular, was a technology looking for problems to solve. Its adoption has been challenged by the dichotomy of promising freedom to over-constrained engineers, whilst being unable to demonstrate the track record necessary in order to be employed in the most demanding industries, where standards rule manufacturing output. Ironically, this is where many of the most appropriate opportunities for successful and worthy metal AM adoption can be found.

Since emerging at the turn of the millennium, metal Additive Manufacturing, particularly Laser Beam Powder Bed Fusion (PBF-LB), has developed significantly. This maturity is to be expected, given the promise of greater design freedom and operational agility it promises, plus a range of other benefits that emerge when the end-use capabilities permitted by AM show up in the final product.

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Atherton Bikes

Fig. 3 Gee Atherton putting the Atherton Bikes frame through its paces (Courtesy Moonhead Media)

Many well-established organisations have spent years investing significantly to prove, mainly to themselves and their existing customers, that harnessing metal AM in manufacturing is a vital step in remaining competitive, both from a technical and commercial viewpoint. This is, of course, an expensive business and companies guard their findings fiercely, especially now that their investments are starting to pay off. Because of this, companies willing to offer an insight into their metal AM journey are often circumspect, preferring to keep things mostly under wraps, at least until the obligatory NDAs are signed. Whilst their reticence is understandable, this can act to decelerate the pace of adoption, so when companies are willing to talk about their AM experiences, there is something to be gained for the whole industry. Thankfully, the team behind Atherton Bikes was happy to give some insight into their journey.

> *"While things were maturing in the Additive Manufacturing world, the Atherton siblings were making their mark in the world of Enduro and Downhill mountain biking, establishing themselves at the very top of the sport."*

Life in a parallel universe

While things were maturing in the Additive Manufacturing world, the Atherton siblings were making their mark in the world of Enduro and Downhill mountain biking, establishing themselves at the very top of the sport. As in many success stories, the beginning is humble and Dan, Gee and Rachel are no exception, with their passion for the sport fuelling their early campaigns rather than big bucks from sponsorships. However, as the results came, so did the deals.

Early on, accommodation for races came in the form of a white van and technical support from willing volunteers. Spares for inevitable breakages were 'blagged, begged or borrowed', and Dan's apprenticeship in downhill mountain-bike building and set up, which laid the foundation stone for the family's own bike manufacture, began with Dan learning quickly that not all downhill mountain bikes are equal.

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Atherton Bikes

Fig. 4 Dan Atherton at the family's other venture, the Dyfi Bike Park, located in Mid Wales (Courtesy Moonhead Media)

This early experience continues to inform the family's bike development. With win-or-lose margins in the realm of seconds, Dan's attention to detail is vital when identifying opportunities to improve. Knowing what to change is one thing. Executing that change in a controlled way, which doesn't diminish or eliminate the improvements already made, is a much more formidable challenge that requires a command of the engineering data combined with a manufacturing process that can respond quickly.

With this critical factor in mind, the Athertons knew that when the time came to pursue their long-held ambition to engineer, build and sell their own bike, following the conventional approach would not provide the edge they wanted. Well-trodden supply chains, often more focused on volume manufacture in Asia, would not offer the level of freedom or opportunity for original thinking demanded by the most elite bikes and riders. Dan stated, "We have always forged our own path in our riding – we always push to achieve things in our own way, on our own terms - we've never been interested in following the crowd."

Technology transfer from aerospace engineering

To achieve the impossible required a technology leap, and this came in the form of some early developments by a small team of fanatical aeronautics engineers. While pioneering the use of metal AM and carbon fibre in their day jobs in aircraft manufacturing, the team overcame the frustrations of long project timescales in civil aerospace by 'moonlighting' as bike designers with a couple of industry veterans. As an antidote to their day jobs, they used their combined expertise to pioneer the use of AM and carbon fibre technology to design and engineer a new mountain bike.

Never ones to follow convention, this project caught the attention of the Athertons. It turns out that this kind of technology transfer is not uncommon in the bike world: a quick internet search yields several bike-related AM projects, from the fanciful and fun end of the spectrum to the deadly serious end, which states: we are going to change the bike world forever.

"Strong, light, cheap – pick any two"

When manufacturing new products, it is vital to select processes that are capable, cost-effective and appropriate for the task. This requires a deep understanding of all the factors that will govern success and the inevitable trade-offs between cost, quality, and performance in use. It's a little oversimplified, but the old adage, "You can have any two of the following: fast, cheap or good, but not all three," or the version attributed to bike industry veteran Keith Bontrager, "Strong, light, cheap – pick any two," holds.

No prizes for guessing that in the case of Atherton Bikes, it is strength and lightness that are most important. Not known for compromising on their ambitions, the Athertons also recognise that achieving competitive pricing is vital. For most metal AM applications, and PBF-LB in particular, this is usually how the equation resolves, and it is probably one of the first decision points when choosing metal AM as a process.

Establishing opportunities to add value to the end product, or the manufacturing workflow that may be enhanced by metal AM's capabilities, is one of the first questions to answer; failure to truthfully assess the question 'why metal AM?' usually leads to disappointing outcomes.

Fig. 5 A set of lugs being built on a RenAM 500Q four-laser PBF-LB system. (Courtesy Renishaw PLC)

Fig. 6 The lug set on the build plate after removal from the RenAM 500Q build chamber. Note the structures that serve to both support the parts during the build and manage thermal stresses (Courtesy Renishaw PLC)

Competition-level mountain bikes: The engineering challenge

The function of a mountain bike is to carry the rider and to be tough enough to take the abuse from rough terrain. A quick look at the catalogues of most bike manufacturers reveals that lower-end models tend to be built using familiar materials such as steel and lower-grade aluminium. These are significantly over-engineered in order to pass the standard EN15194 and ISO4201 bike safety tests before they can go on sale.

To be competitive, higher-end bikes need to be lighter, so more exotic materials are used such as aircraft-grade aluminium and mass-produced carbon fibre. Beyond this, we head into the territory referred to by marketers as halo products: those that reside confidently at the very top of the pecking order. Bikes at this level draw on the best technology, materials and processes from high-performance industrial applications in aeronautics and F1 motorsport.

To be credible, they also need to be tested beyond the standard EN and ISO tests. For this, manufacturers turn to the EFBE TRI-TEST, in which tests are conducted under five usage conditions or levels as defined by ASTM F2043-13 / EN 17406. Depending on the riding application, bikes progress through the levels, with Level 5 providing the most extreme test conditions. Bikes that make it through to Level 5 are subjected to tests that mimic the conditions of speeds above 40 km/h and jumps and drops in excess of 1.2 metres. If you have ever watched any world-class downhill mountain bike footage, the phrase "in excess of 1.2 metres" actually equates to something more like "drops of over 12 metres".

As for speed, anything up to terminal velocity is considered fair game. Bikes designed to take this level of abuse without failing, whilst performing at the pinnacle of competition, need to be light and tough, so only the best design, engineering materials and processes cut it.

Fig. 7 Rachel Atherton and Ben Farmer, Chief Technology Officer at Atherton Bikes (Courtesy Moonhead Media)

Carbon fibre and titanium: A perfect combination

For demanding structural applications, two materials rise to the top when considering high performance: carbon fibre and titanium, in this case Ti6Al4V, or Ti64 for short. Neither is perfect at everything, and both can be difficult to work. Titanium is expensive and hard to process, and carbon fibre requires moulding expertise and precise lay-up to achieve the best results.

By blending the best of both – lightweight carbon fibre tubes for high strength and stiffness under specific load conditions, and supremely resilient titanium lugs that take the brunt of the stresses at the joints – the team at Atherton has created a bike that is both lightweight and tough. The result: a super stiff frame that performs without wasting the rider's energy input.

Coupled to this are the advantages of metal AM in allowing design and manufacturing freedom for the lugs, which are the interfacing geometry between the carbon fibre tubes. In this application, Atherton has achieved the perfect blend of lightness and resilience, with AM offering the freedom to create a double lap joint to increase surface area for the bond whilst adding minimal weight.

Whilst AM-produced Ti64 has an Ultimate Tensile Strength (UTS) of just over 1000 MPa after heat treatment, it is impractical to use this as a design limit for such a fatigue-critical application. To ensure a long product life under the most gruelling punishment,

"...the team at Atherton has created a bike that is both lightweight and tough. The result: a super stiff frame that performs without wasting the rider's energy input."

a minimum factor of safety is designed into the titanium components. This is generally based on no more than 50% of the peak stress for PBF-LB-produced Ti64, calculated on fatigue conditions of 10,000,000 load cycles.

The specific load cases are one of the few closely guarded secrets; however, Ben Farmer, Atherton Bikes CTO, suggested that they are significant multiples of the rider's weight when landing from the maximum expected jump height.

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Typically, peak stress at this level is 550 to 600 MPa for wrought Ti64 with PBF-LB-produced Ti64 bulk properties marginally lower at around 500 MPa. But these results are after machining, so don't include the influence of surface condition on fatigue life. To allow for unmachined surfaces to be used in the end product, an additional allowance is made that is below the fatigue run-out stress for 'as-built' stress-relieved Ti6Al4V.

After two seasons campaigning, the team has podiumed multiple times with its metal AM-lugged bike. There have been several offs and crashes, some injuries, bruises and occasional broken bones, but absolutely no frame failures in any of the bikes built. As Gee sagely comments, "We got through our first ever season without breaking a frame – unfortunately, we did manage to break Rachel, who suffered a snapped Achilles tendon in practice at Les Gets."

The track record of zero failures also includes the test bike that underwent the entire five-stage EFBE TRI-TEST and, as Ben was keen to point out, that test bike wasn't a shiny new out-of-the-box model: it was the prototype that had been vigorously and relentlessly thrashed by Dan through the Dyfi Bike Park, the Atherton family's other venture, located in Mid Wales, which Ben Farmer reckons has probably resulted in a marginally harder life than that led by the pampered race bikes.

Fig. 8 After heat treatment to relieve stresses from the build process, parts have to be removed from the build plate and machined to remove support structures. Critical surfaces are also machined to meet tolerances or provide a necessary functional surface (Courtesy Renishaw PLC)

Swift action: Design iterations in days, not months

Besides light weight and stiffness, one of the primary drivers for the Athertons' adoption of AM technology was the ability to iterate the design to achieve marginal but vital improvements in the performance of the bike and rider. Dan recognised that metal AM offers the opportunity to revise and adapt the bike design and geometry at a rate and frequency that cannot be achieved by conventional bike manufacturing processes, whilst maintaining top-level performance.

"In the past, when riding and developing conventionally manufactured bikes, a design iteration could take months to execute from start to finish," he explained. "With metal AM, and the way we approach design and build, this process is routinely reduced to less than four weeks from initial design to a complete bike ready for the next race."

In one case, by 'burning the midnight oil' and planning ahead, from finishing racing on Sunday, revised CAD was engineered by Monday lunchtime and a fresh AM build was running by Monday evening. With a complete frame lug-set taking 16 hours to build on the latest multi-laser AM system, this allowed just enough time to de-build, heat treat and finish machine the parts in time for the frame bonding process on Thursday.

As Ben Farmer attests, "It was a very tight timescale and, due to the accelerated bonding process requiring external heating, the frame was still hot to the touch when it left for the airport bound for Switzerland on Thursday night." Once received, it was built up and ready for practice on Friday. Whilst this is not a typical approach, it does show the potential to execute very rapid changes to what are complex components.

The importance of experience – your own or that of others

As you may have guessed, Ben Farmer was one of those moonlighting aero engineers and is a co-founder of the Atherton Bike brand. When I spoke to him whilst researching this article, he was keen to stress that the capability that they

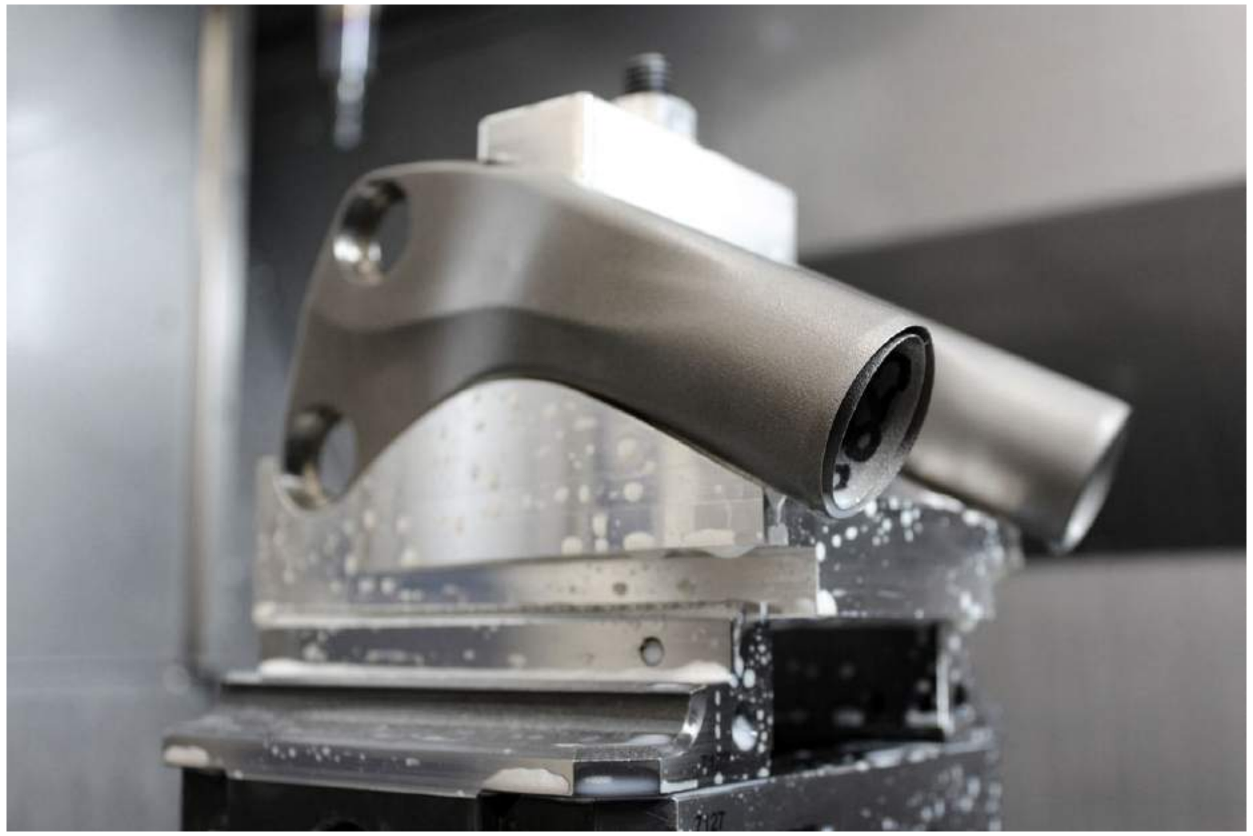

Fig. 9 Components after machining. The surface finish shown is as-built, with machining operation limited to support removal and the machining of critical inner diameters. Note that careful fixturing is required in order to secure such complex geometries for the machining process (Courtesy Renishaw PLC)

have has come from many years spent building the required skills and experience in industrial projects. "We have benefited hugely from developing our knowledge of AM and composite technologies in our day jobs as aeronautics and Formula 1 engineers, before embarking on the Atherton projects."

How regular companies acquire this level of knowledge around AM remains one of the barriers to adoption. Considering design for function, along with the principles of Design for Additive Manufacturing (DfAM), and navigating the demands of both, presents an engineering challenge that requires experience. Inevitably, this is a potential barrier to new adopters who may find success difficult to achieve without support from experts. Proficiency in metal AM is rarely achieved without a close relationship between designers and production engineers, combined with robust support from the technology and materials supply chain.

"Proficiency in metal AM is rarely achieved without a close relationship between designers and production engineers, combined with robust support from the technology and materials supply chain."

For those reading this who are new to metal Additive Manufacturing, it is crucial to understand that, even after you have navigated the complex AM design process, complexities just keep coming. Even small changes to part orientation between different builds can have an impact. Some factors peculiar to metal AM include the need for sacrificial features such as disks within tube-shaped areas that have to be built and then removed by machining, or permanent ribs inside the part. These are particularly prevalent in titanium parts, where distortion and the residual stresses generated in a part by the PBF-LB process itself need careful management.

I have my own memories of early PBF-LB developments in titanium, with parts pulling themselves apart before we could get them into the stress-relieving heat-treatment process. Much of this has been overcome by better AM systems that can control the build atmosphere more precisely and create better processing conditions, coupled with more advanced processing strategies, materials and parameters, but still needs to be carefully considered.

Fixturing the freeform shapes that AM can produce for post-processing can also be a challenge, and this requires some creativity and ingenuity. From the start, Ben and the team prioritised the non-machined features, such as the interfacing lap joints used to bond the carbon fibre tubes, at the expense of a little more material allowance on those that were machined.

When considering the commercial product, however, and with an eye to producing in higher volumes, some further economic factors come into play. With conventional carbon fibre bike manufacture, there are high upfront costs in terms of tooling; however, with volume production, these costs rapidly diminish as they are amortised over the entire production run until the tool life expires. With metal AM these costs do not decrease much over a production run, so greater attention must be paid to reducing material usage, and with it the build-time for the components, over the entire product life. Whilst this does not have a significant impact on the relatively low number of factory race machines produced by Atherton, the commercial product requires that the cost impact of each frame component over the entire production run is optimised.

Another area of sensitivity with PBF-LB parts is heat treatment and, whilst the best mechanical properties for titanium are achieved using a vacuum furnace, these are inherently expensive and tend only to accommodate a small number of framesets. Argon furnace heat treatment, by contrast, has lower capital equipment cost and higher ongoing running costs. As Ben attests, "Now we have a competitive bike, both in terms of performance on the mountain and commercially, the challenge is to scale up".

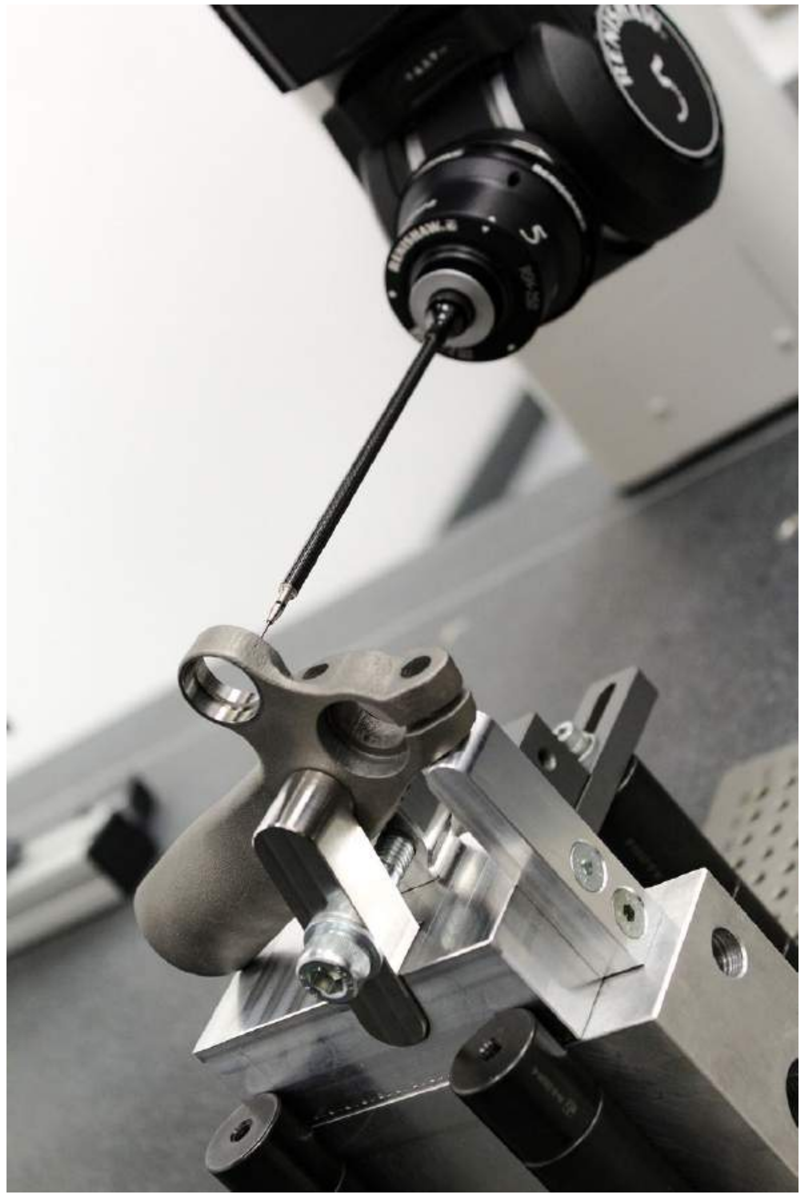

Fig. 10 The checking of tolerances after machining (Courtesy Renishaw PLC)

The 'win on Sunday, sell on Monday' factor

The Athertons' desire to create their bike brand goes way beyond their podium successes on their own hardware. The 'win on Sunday, sell on Monday' factor, coined by Bob Tasca in the 1960s to sell Ford cars, is a vital component in their future success with a commercial product. Dan is clear, "Without the race success, it's just another bike in a crowded market. Riders are fanatical and care intensely about the technology and the performance it brings."

Atherton is now progressing through the first fifty build slots for its commercial frames, with Ben keen to reinforce that there is absolutely no difference between the 'works' machines and the commercial product. If you want one though, you'll have to be patient: the first options on bagging your slice of Atherton success are to those dedicated fans who signed up to follow the Atherton brand and the newsletter at its inception.

The company is, however, making preparations to bring the Additive Manufacturing process in-house to

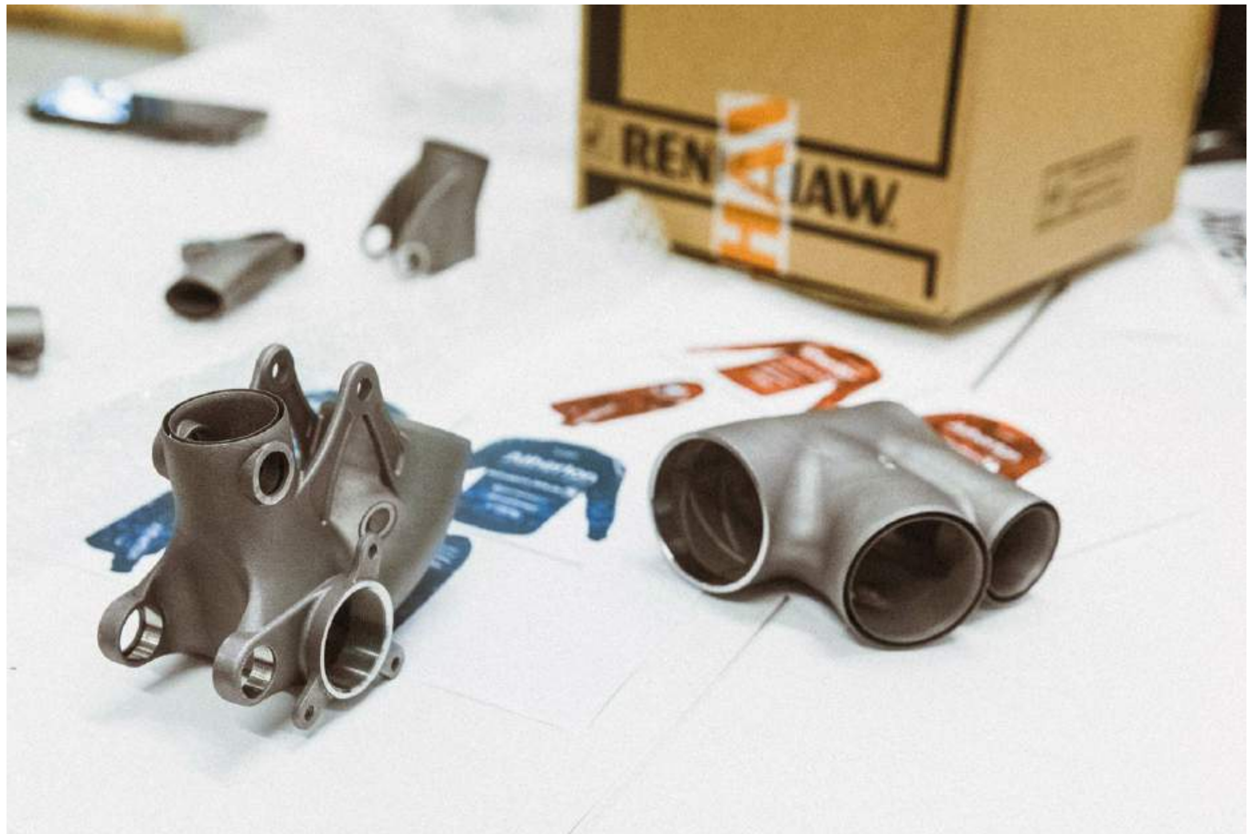

Fig. 11 Unpacking a new set of metal AM lugs at Atherton Bikes (Courtesy Renishaw PLC)

increase the production rate and cut waiting times. When I asked about the possibility of considering other AM technologies such as metal Binder Jetting (BJT) for subsequent commercial products, I got a pretty straight answer from Ben. "We are open-minded about other technologies, but it comes down to three things: tolerancing, mechanical performance and materials choice – beside the obvious questions about cost. Presently we see Powder Bed Fusion as the benchmark technology and the only one able to deliver all three, particularly our material choice, Ti6Al4V".

The clear expectation is that, independent of how things develop commercially, the Athertons' flagship products are likely to feature PBF-LB because of its maturity, and the significant improvements in productivity brought about by multi-laser AM systems. Maintaining a watch on how other technologies are developing will, of course, be an ever-present consideration.

> *"AM is just another manufacturing process; inappropriately applied, it will disappoint, but get it right and new products and businesses emerge."*

It's not too late, or too early, for your right place and right time

What strikes me about many of the AM projects I hear or read about is that the most impressive ones are journeys of discovery, going back years and sometimes over a decade. For those would-be AM adopters who have yet to start their AM journey, I can see that this could look quite daunting, and might foster the perception that those who are not making progress with AM already have somehow missed the boat.

There are a few things to consider when assessing this situation. Firstly, AM is just another manufacturing process: inappropriately applied, it will disappoint, but get it right and new products and businesses emerge. So, if your project doesn't work out, don't just write off AM, but think about what AM offers, assess if it supports the needs of another project or application, and try again, better prepared and armed with more knowledge.

Also, consider this (and I speak as an ex-product manager at a metal AM system manufacturer): all those who started their AM projects a decade or more ago had to contend with immature technology, limited process knowledge, and nothing like the digital tools and supply chain available today to support AM adoption. What took years for some can now be achieved in a fraction of the time using today's technologies and knowledge base. AM technology is not static: what didn't work yesterday may well work today.

The Athertons have applied PBF-LB metal Additive Manufacturing to the parts of a high-performance bike that make the most sense for that technology. It's not a question of missing out; anyone using AM needs to do it for the right reasons, which means understanding the capabilities offered by the various technology types and learning from your peers. You're in the right place for that if you're reading *Metal AM* magazine.

Fig. 12 Gee, Dan and Rachel Atherton taking time out at their bike park in Mid Wales (Courtesy Moonhead Media)

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Atherton Bikes

For more information on Atherton Bikes visit www.athertonbikes.com

Advancing rocket propulsion through Additive Manufacturing, novel surface finishing technologies and public-private partnerships

Whilst Additive Manufacturing is undoubtedly having a huge impact on the design and manufacture of rocket propulsion systems, most notably combustion chambers and nozzles, the Achilles' heel of most AM processes is as-built surface finish. Whilst in many AM applications surface finish may be largely irrelevant to a component's function or performance, when it comes to high-cycle fatigue properties, achieving the required level of smoothness is critical to performance. In this article, Justin Michaud, REM Surface Engineering, reports on advancements achieved in this area through a public-private partnership with NASA.

Metal Additive Manufacturing has for a number of years been seen as a way to reduce costs, increase capabilities and advance the state of the art for rocket propulsion applications. In 2013, Elon Musk famously revealed the SuperDraco engine, built by Laser Beam Powder Bed Fusion (PBF-LB) using an unspecified Inconel® alloy [1]. The potential to manufacture complex components such as this engine chamber as a single part, without the requirement for costly tooling, offers the potential to greatly accelerate the design to testing process [2]. NASA, in conjunction with Virgin Orbit, has successfully tested a combustion chamber incorporating a PBF-LB copper alloy (GrCOP-84) combustion chamber liner with a nickel superalloy structural jacket applied to its exterior [3], citing considerable manufacturing time-scale advantages.

"Traditionally, it takes many months to manufacture, test and deliver a conventional combustion chamber. We can reduce that time considerably," explained Paul Gradl, a senior engineer at NASA. Companies such as Relativity Space, Rocket Lab, Aerojet Rocketdyne, Orbex, Ariane, Vector Space Systems, Ursa Major, Blue Origin, Launcher, Masten Space Systems and many others are all looking to use AM and capitalise on its potential cost, lead-time and design advantages.

However, AM is not without its challenges and the need to advance the technology readiness level (TRL) of AM processes, as well as the required post-processing steps, is a generally accepted industry fact. Where the knowledge and capabilities do exist to fully realise additively manufactured rocket propulsion components, the associated data is often confidential and thus does not fully benefit the industry as a whole. To this end, NASA's Game Changing Development (GCD)

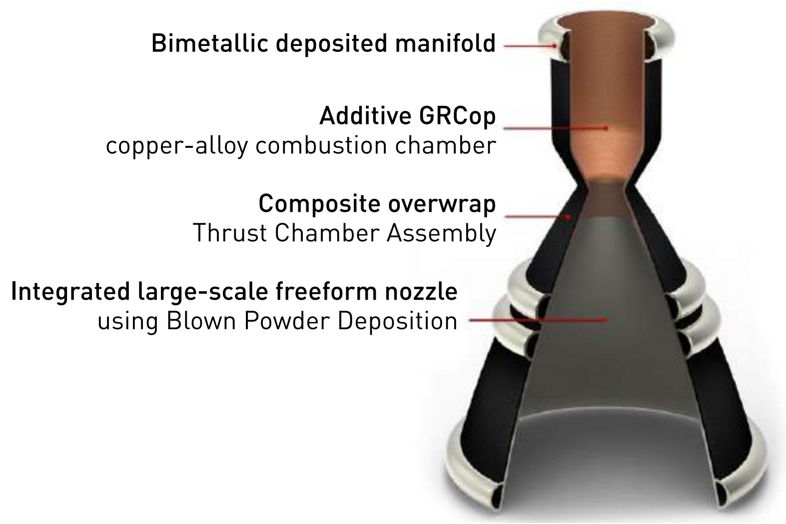

Fig. 1 RAMPT thrust chamber concept

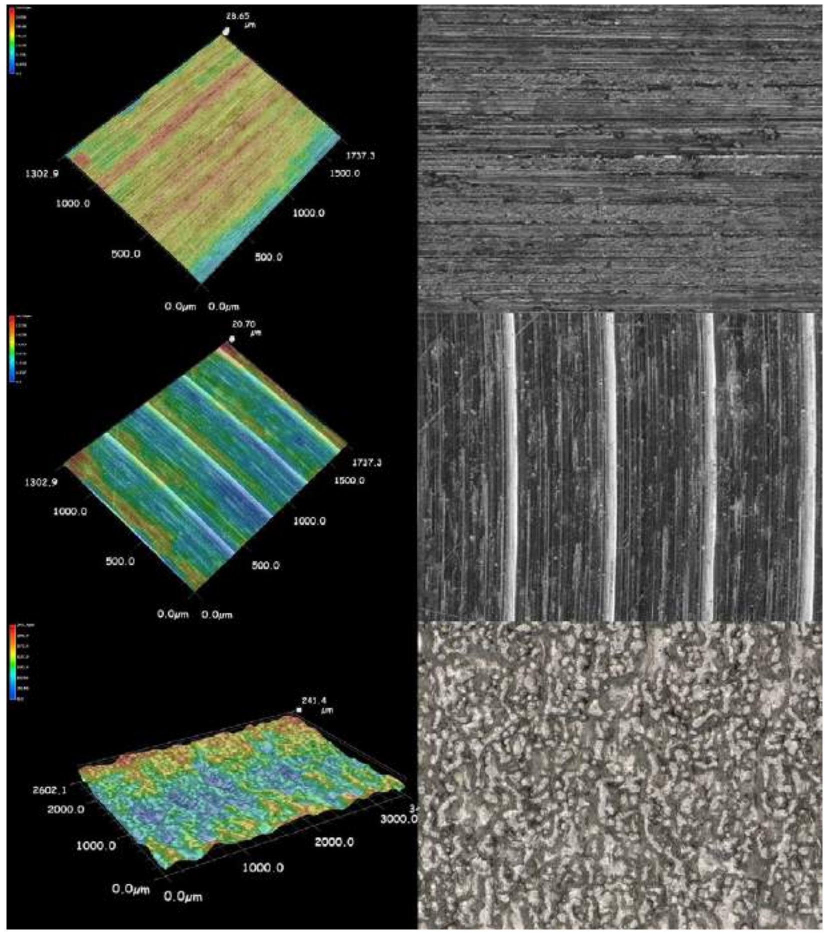
Fig. 2 Micrograph examples of the surfaces of ground (top), milled (middle) and PBF-EB additively manufactured (bottom) parts

Program, under the Space Technology Mission Directorate (STMD), serves as a perfect vehicle to help fund and accelerate the necessary technology developments and public data to advance and increase the use of AM for rocket propulsion and other high-risk/high-value applications. The GCD's stated goal is to take mid-TRL range technologies, "from initial lab concepts to a complete engineering development prototype," [4] in support of the STMD's goal to develop "transformative space technologies to enable future missions" [5].

Underneath the GCD is the Rapid Analysis and Manufacturing Propulsion Technology (RAMPT) programme. The RAMPT programme calls for the development of enabling technologies, improved production methods and advanced design and analysis tools related to the agency's objectives to expand human presence in the solar system, to mature novel design and manufacturing technologies to increase scale, significantly reduce cost and improve performance for regeneratively cooled thrust-chamber assemblies, specifically the combustion chamber and nozzle for government and industry programmes [6].

The programme cites the combustion chamber and nozzle, the two primary components of the thrust chamber, as "the longest lead [time], highest cost and heaviest component(s) in the engine system" and aims to address these issues by significantly increasing the scale of current AM technologies while integrating necessary special process development, hardware development, and testing to mature the overall concept. Some of the directed goals of the programme include the use of bimetallic manifolds, GrCOP AM combustion chambers mated to Directed Energy Deposition (DED) – in this case Blown Powder Deposition (BP-DED) – nozzles, and regenerative cooling via thin-walled structures and cooling channels (Fig. 1). The programme, which is underway, aims to partner with industry and academia to accomplish these goals while simultaneously advancing overall public and private capabilities for rocket propulsion and related industries. "NASA has been actively engaged in and leading technology development efforts to evolve and mature the entire supply chain of Additive Manufacturing, including not just the AM build process, but also post-processing areas such as surface enhancement, which we see as an important part of both our programmes and the needs of the AM industry at large," stated Gradl.

The challenge of surface finishing AM components

As referenced, there are challenges to realising the potential of AM. For critical applications such as rocket nozzles and combustion chambers, AM-produced components must undergo certain post-processing steps in order to meet the necessary design and performance requirements. Surface finish is a known challenge for all AM processes; the complexity that AM allows from a design perspective can increase the challenge of improving the as-built surface finish and/or removing material from an AM component uniformly. Many companies and technologies have sought to address these surface finishing challenges; one such company is REM Surface Engineering (REM).

REM is a third-generation, family-owned business with operations in the US and Europe specialising in surface finishing (polishing) technology. The company invented what is now commonly known as isotropic superfinishing – a technology created by combining the chemical activation of a surface with mass-finishing equipment to effect material removal, thereby creating optimal surface quality and process efficiency, while maintaining component shape more accurately than competitive technologies. REM's isotropic superfinishing processes are used on many conventionally manufactured components, ranging from high-volume, pre-plating applications, such as hand tools, to gas and steam turbine compressor blades, and most prevalently to flight-critical aerospace gearing, where over seventy known platforms make use of REM's ISF® process.

It was REM's link to the aerospace industry that first brought it into contact with AM, in around 2010, in the form of Ti6Al4V components produced by Electron Beam Powder Bed Fusion (PBF-EB). Compared to conventionally machined (ground/milled) components with a standard starting roughness of 0.5–1.50 µm, AM parts represented quite a different deliverable set in terms of starting surface conditions, at 10– 30 µm or higher, and required material removal to achieve comparable final surface conditions (Fig. 2). REM's traditional processes are very effective at controllably and uniformly removing very small quantities of material, with a standard helicopter gear process removing a total 5 µm from the surface of the component to achieve surface finishes of Ra 0.025–0.10 µm (Fig. 3). However, it became clear to REM very quickly that AM components would need surface material removal more in the 25–750 µm range to achieve 'as-machined' or 'superfinished' surface roughness properties.

Believing AM to be a step-change development in manufacturing, REM dedicated resources to developing technologies able to rapidly, yet controllably, remove the roughness from as-built AM components. Leveraging its existing isotropic superfinishing process technology and the principles of chemical surface activation, REM created two new process technologies under its AM surface finishing trade name


Fig. 3 Example of a gear processed using REM's ISF

Small Business Innovation Research (SBIR) awards

One method of funding public and private partnerships that NASA and other government agencies have utilised for many years are Small Business Innovation Research (SBIR) awards. The SBIR awards' goals are to stimulate technological innovation while meeting federal research and development needs and increasing the private sector commercialisation of innovations derived from, or supported by, federal funding. SBIR awards progress through two primary phases, where potential funding and timeline to completion increase (from Phase 1 to Phase 2).

A company must first submit a proposal deemed to uniquely meet a specific subtopic call, thereby winning a Phase 1 award, intended to establish the technical merit, feasibility and commercial potential of the proposed research or research and development efforts. Upon the successful completion of a Phase 1 award, a company has the option to submit a proposal for a Phase 2 award. The choice to fund Phase 2 proposals is linked to the results achieved in the Phase 1, and the scientific and technical merit and commercial potential of the Phase 2 proposal.

Far fewer Phase 2 awards are granted, but the technical and tangible advances possible in a Phase 2 award are considerably expanded. NASA's Phase 1 SBIR awards are capped at $125,000 and have a maximum six-month duration. In comparison, NASA Phase 2 SBIR awards can be worth up to $750,000 (with the potential for expansion via matching funding opportunities) and can last up to twenty-four months.

Finally, SBIR awardees can provide their developed technology to the US Government via Phase 3 awards/contracts – Phase 3 awards have no funding limits, but are paid via non-SBIR funds [7, 8]. Successful SBIR efforts have the potential to significantly advance technologies; thus, it should be no surprise that multiple SBIR awards are supporting the RAMPT programme.

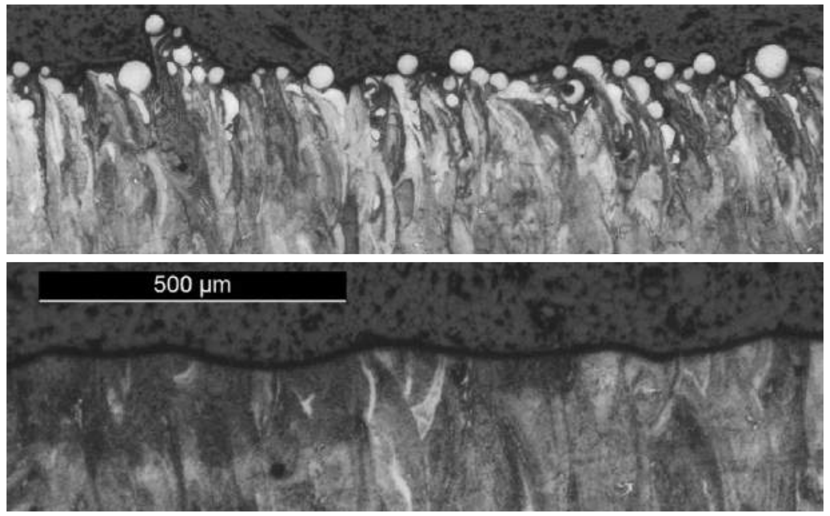

Fig. 4 Cross section micrographs of as-built PBF-EB (top) and chemically polished (bottom) examples

(Extreme ISF®): Chemical-Polishing (CP) and Chemical-Mechanical Polishing (CMP).

CP can best be described as a more controlled version of chemical milling, in that it is optimised to planarise or flatten a surface while removing or remediating any sharp micro-notch surface features. Traditional chemical milling is limited in its ability to reduce surface roughness and 'waviness', as the process tends to follow the existing surface texture. REM's CP processes are capable of more significantly reducing roughness/waviness as they are chemically engineered to reduce peak asperity height without chasing micro-valley features. Instead, these micro-valleys or notch features are gently radiused until their depth is reduced to the point where they merge with the surrounding surface (Fig. 4). Based on market demand, REM initially focused on developing a viable CP process for Ti6Al4V and achieved surprising dynamic fatigue life increases via this technology [9]. These increases surpassed all other surface finishing technologies (abrasive tumbling, laser polishing, etc), with the exception of machining.

In parallel, REM worked on a range of modifications to its traditional CMP isotropic superfinishing processes to increase their effectiveness on AM components. The CMP process works by exposing an AM component to an alloy-matched chemical solution designed to react with the component's surface in a self-limiting fashion, producing a self-assembling monolayer (SAM). This SAM is softer/more brittle than the base metal and

Fig. 5 Chemical-mechanical polished 17-4 PBF-LB component examples, additively manufactured by 3rd Dimension Industrial Printing

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is therefore valuable in that it can be easily wiped away in a mass-finishing/tumbling environment. Because of the associated reduction in the required force to refine a surface, CMP allows for the use of high-density non-abrasive or low-abrasive content media. These media have a much longer life than traditional abrasive tumbling media and, when used in conjunction with an appropriate active chemistry, facilitate a far more efficient and accurate material removal process from an AM component – edge radiusing is significantly reduced and recessed features can be more effectively refined.

Depending upon part requirements and alloy, REM can use the CP, CMP, or a combined CP + CMP process to achieve the required surface material removal and roughness reduction on AM components (Fig. 5). Increases in dynamic fatigue life and component cleanliness, reductions in foreign object debris (FOD) and increases in component cleanliness, and highly uniform material removal were initial success stories for REM's Extreme ISF Process. However, as the technology relies upon chemical surface activation, each alloy/material has the potential to require a new chemical formulation (although, in practice, similar alloys are often able to share a common processing formulation), and not all materials have developed processing compounds. For new or dissimilar alloys, formulation development can be required.

Fig. 6 Demonstrator component, BP-DED IN625 (Courtesy NASA MSFC)

Finishing the hotwall surface of AM rocket nozzles

In 2017, NASA Marshall Space Flight Center (NASA MSFC) contacted Dr Agustin Diaz, REM's Lead AM Scientist, regarding the potential of applying REM's process technologies to nickel-base superalloy components. Initial trials, coupled with REM's other alloy experience, showed potential, but, at the time, REM lacked an optimal CP or CMP chemistry for Inconel 625 – then the target alloy. NASA MSFC required a surface finishing technique that could controllably and uniformly remove 500 µm (0.020 in) of material

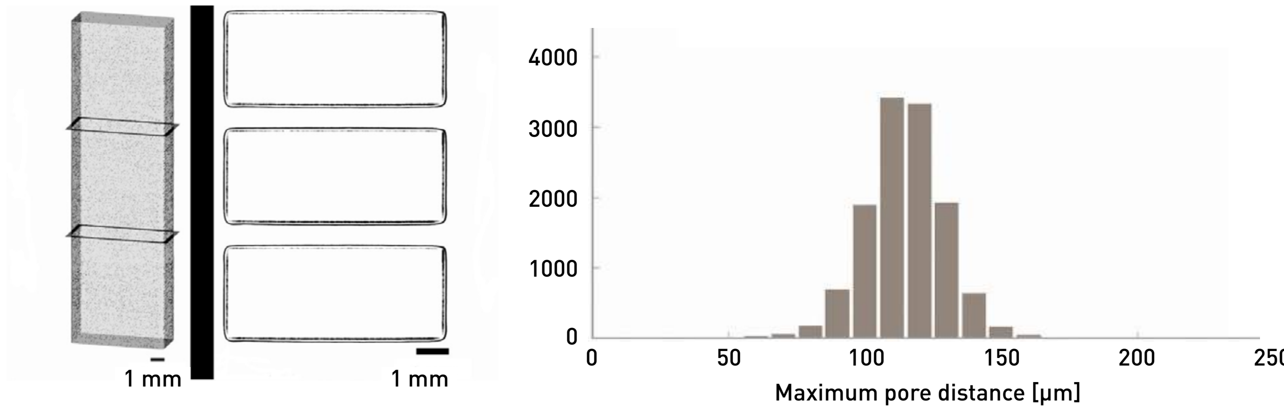
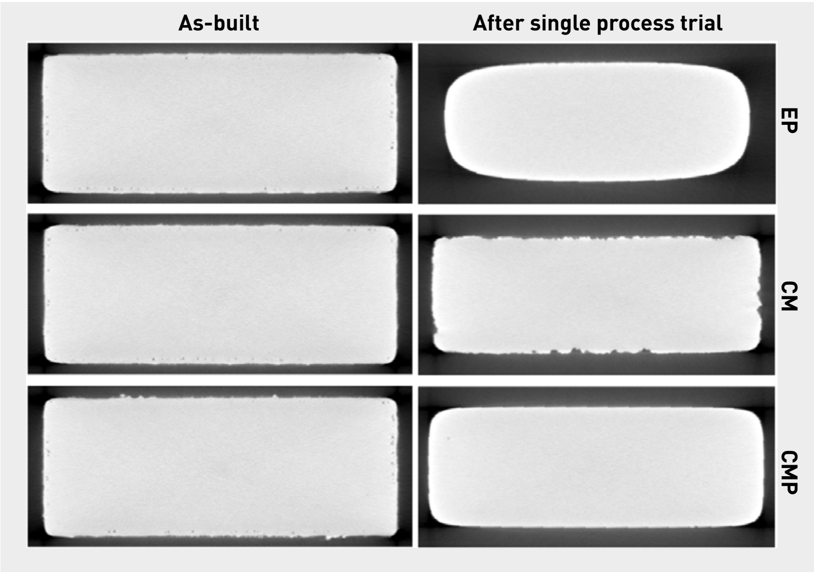


Fig. 7 X-Ray CT scan analysis of PBF-LB IN625 coupon gauge area



Process	ΔOD thickness	ΔOD width	W/T ratio
EP	585 µm ± 25 µm	1090 µm ± 50 µm	1.9
CM	600 µm ± 15 µm	560 µm ± 12.5 µm	0.9
CMP	585 µm ± 25 µm	530 µm ± 25 µm	0.9

Fig. 8 single process material removal uniformity comparison

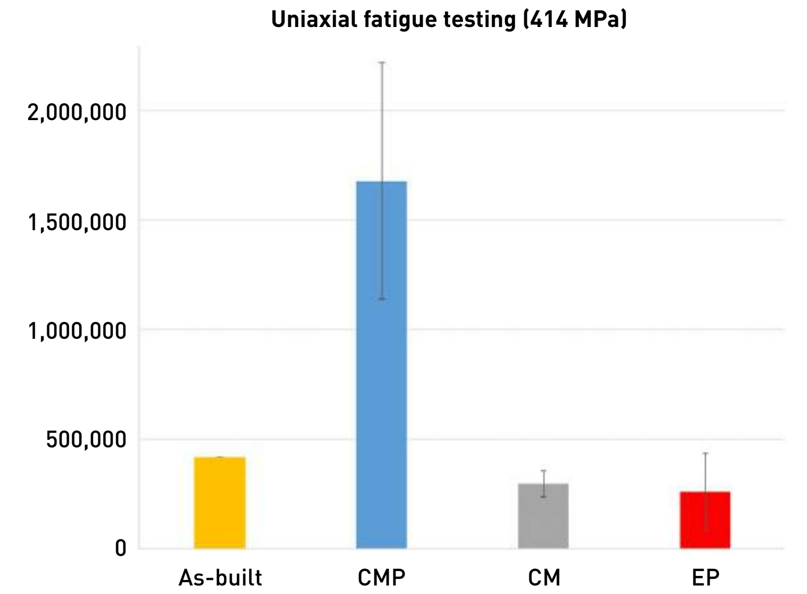


Fig. 9 Preliminary high-cycle fatigue data PBF-LB IN625 after CMP, CM and EP

from the hotwall surface of AM rocket nozzles while reducing roughness and offering scalability and cost advantages over manual techniques (Fig. 6). The nozzle designs had a specific hotwall thickness that was desired, but the targeted AM processes, coupled with the high levels of as-built roughness, dictated that a post-processing step would be required. Thus, an opportunity existed to advance REM's surface finishing technology, while meeting an otherwise unaddressed need for NASA, and REM submitted and won its first SBIR Phase 1 award (18-1-Z3.01-5453) as a part of the 2018-1 NASA solicitation.

This SBIR, 'Internal/External Surface Finishing of Additively Manufactured IN625 Components', had, as a primary goal, the identification of an Optimal Finishing Technique (OFT) capable of:

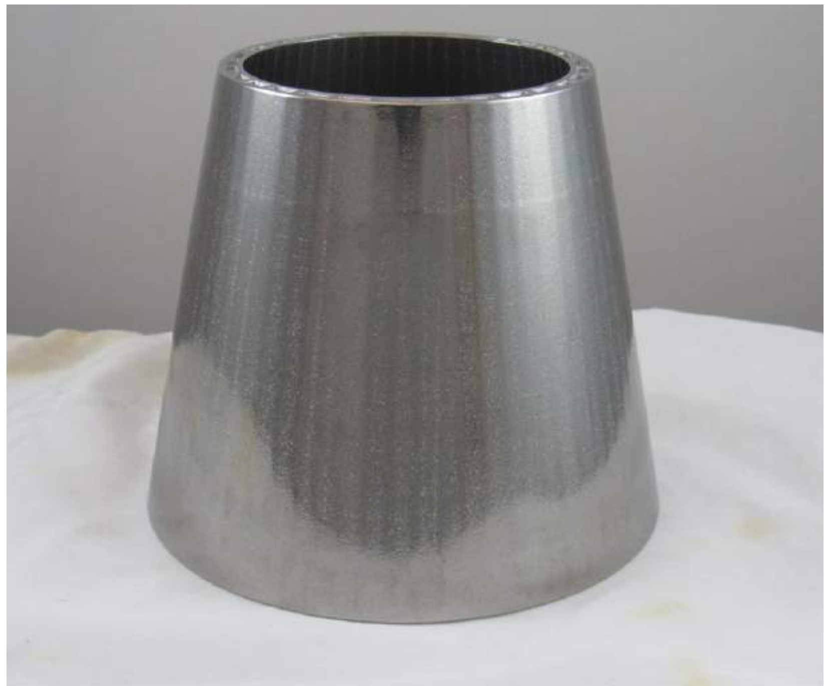
- Reducing surface roughness to < 0.8 µm Rms
- Uniformly removing 0.5 – 1.25 mm of surface material in the shortest practical time
- Eliminating surface defects
- Demonstrating scalability to hundreds or thousands of components without excessive footprint requirements
- Demonstrating a machine-controlled, automatable process requiring minimal operator interaction

In this SBIR, REM evaluated three primary finishing technologies individually and in combination: Chemical-Mechanical Polishing (CMP), electropolishing (EP) and chemical milling (CM – standard, non-optimised/not Chemical Polishing). Within the six-month period of performance, REM successfully developed a viable CMP process for IN625 and executed fifteen different processing approaches. X-Ray CT Scanning of components was used to determine the depth of primary near-surface void/porosity concentration (Fig. 7).

Results showed that near-surface porosity was strongly concentrated in the first 200 µm of material (well within NASA MSFC's material removal remit). Processes were evaluated for cycle time efficiency, their ability to maintain component shape (Fig. 8) and the quality of the final surface produced. Additionally, preliminary high-cycle fatigue (HCF) testing was conducted on coupon samples (Fig. 9). From this data, an OFT was selected – a combined processing approach of chemical milling (with a future goal of optimising formulations to convert to a CP process) followed by CMP. A demonstrator component (PBF-LB, IN625) was processed and showed the OFT's ability to meet all objectives (Fig. 10 and 11).

Based on the strong results of the Phase 1 SBIR and the needs of NASA MSFC/the RAMPT programme, REM was successful in obtaining its first Phase 2 SBIR (18-2-Z3.01-5453) – it is currently in the second year of this award. The objectives of Phase 2 are to optimise and scale the developed OFT while developing OFT variants (CP and/or CMP process chemistries) for additional alloys of interest: JBK-75, NASA HR-1 and IN718. Additionally, Phase 2 aims to generate statistically significant low-cycle fatigue (LCF) and HCF data on the alloys of interest, factoring in different Hot Isostatic Pressing (HIP) cycles and surface finishing as a result of the OFT; limited corrosion resistance data is also being pursued.

Through the first year of the Phase 2 SBIR, significant progress has been made on the development of both



Initial Ra	Final Ra	Surface Material Removal
7 µm	< 0.5 µm	500 µm

Fig. 10 OFT demonstrator part, PBF-LB IN625

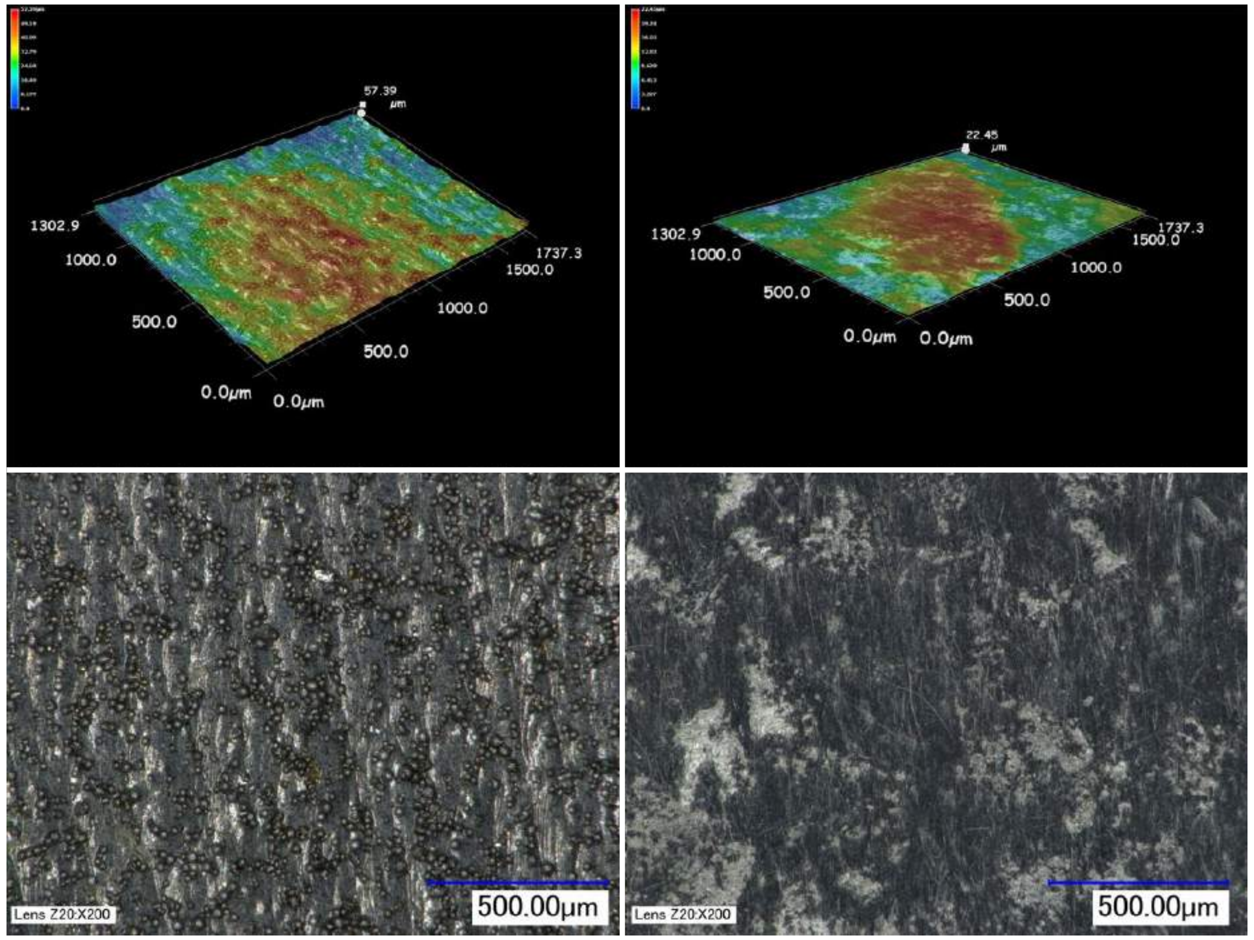


Fig. 11 PBF-LB IN625 as-built (left) and after OFT micrographs (right)

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Initial Ra	Final Ra	Surface material removal
7 µm	< 0.05 µm	500 µm

Fig. 12 PBF-LB IN718, as-built/HIPed (middle) and after OFT (top and bottom)

Fig. 13 Automated chemical polishing processing cell

an optimised CP process and CMP process (for a combined OFT) for IN718 (Fig. 12). REM has developed a CP solution capable of reducing PBF-LB IN718 surface roughness from its as-built state of ~8 µm Ra to a range of 1.8–3.5 µm Ra while transforming the surface from a highly granular state to a far more uniform texture. This development improves upon known, currently-available chemical milling capabilities that have demonstrated final surface roughness values for IN718 of 2.5–5 µm Ra. Further, REM's developed CMP process (used on its own or in combination with CP) for IN718 is able to reduce roughness to the levels associated with a full isotropic superfinish, effectively eliminating all surface-oriented fatigue initiation sites (< 0.10 µm Ra). Fatigue testing of OFT finished IN718 coupons is currently underway with results expected in the coming months. OFT optimisation of the JBK-75 and NASA HR-1 alloys is planned for the second half of the Phase 2 project.

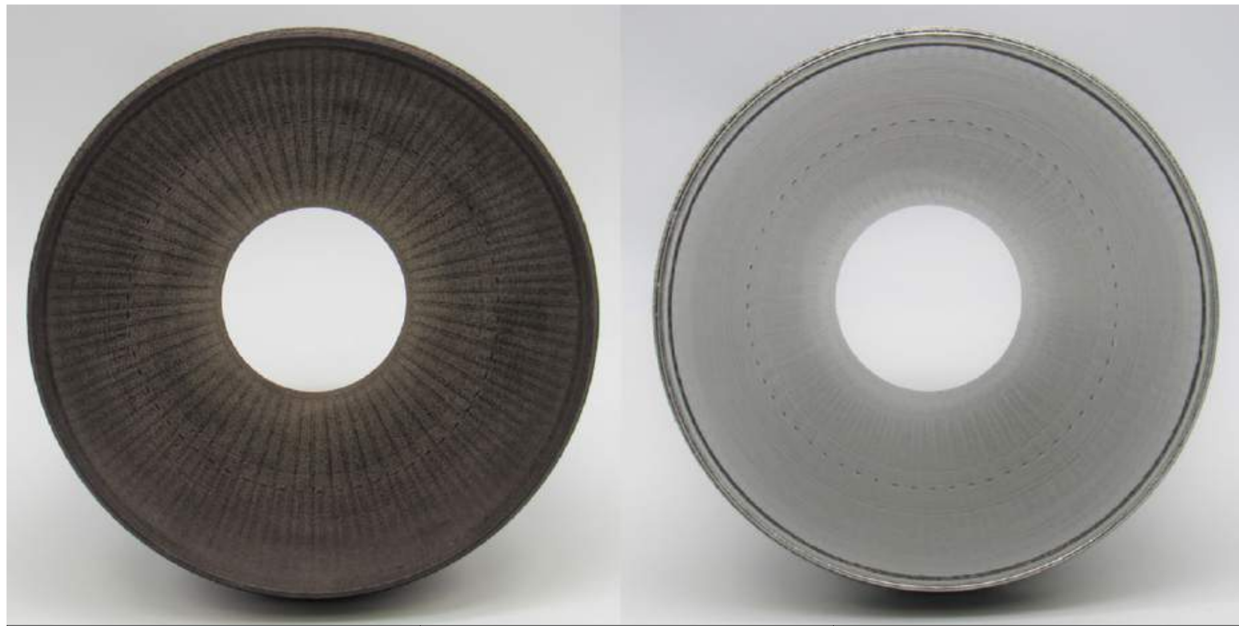
The next challenge: Larger parts and greater complexity

Scaling the OFT has been a significant focus of the Phase 2 SBIR, as NASA MSFC has aggressive component scaling goals. To this end, REM recently completed the installation of a Chemical Polishing cell at its location in Brenham, Texas, USA, currently capable of processing a component of up to 700x700x700 mm, depending on exact geometry (Fig. 13). This installation, coupled with CMP apparatus developments, allows REM to process up to 35K-sized nozzle and combustion chamber components. Further scaling of the technology to accommodate even larger components and, ultimately, full-sized RS-25-equivalent components is in consideration for the future.

In parallel to the Phase 2 award, in May of 2020, REM secured its first Phase 3 SBIR Contract with NASA MSFC, "Surface Enhancement using ISF of Additively Manufactured Hardware." This Phase 3 focuses on applying the in-development OFT to thrust chamber hardware including:

- 35K-size BP-DED nozzles (in both JBK-75 and NASA HR-1)
- Coupled 7K-sized BP-DED nozzle + PBF-LB combustion chamber components (NASA HR-1/GrCOP-42)
- Coupled 35K-sized BP-DED nozzle + PBF-LB combustion chamber components (NASA HR-1/GrCOP-42)

As a part of the application of the OFT to these components, novel masking approaches are required to isolate the less chemically resistant copper alloy (GrCOP-42) from the highly chemically resistant NASA HR-1 nozzles. Additionally, exterior coldwall surfaces and manifolds



Initial Ra	Final Ra	Surface Material Removal
> 15 µm	0.25-0.5 µm	500 µm

Fig. 14 1.2K BP-DED NASA HR-1 nozzles: (left) as-built/HIPed, (right) after in-development OFT (Manufactured by RPM Innovations, image courtesy NASA)

must be protected from the OFT, as material removal allowances are typically much lower than the hotwall material removal remit. REM is currently working towards these Phase 3 deliverables while continuing to optimise the respective OFTs and masking techniques for the alloys of interest. Hotfire testing of these components is expected to follow in 2020 and into 2021.

Parallel work with NASA MSFC and ASRC Federal Astronautics (ASRC) has equipped REM with baseline capabilities relative to both these masking demands and in the processing of the GrCOP alloys (both GrCOP-42 and GrCOP-84). Subsequent to REM's successful Phase 1, and prior to/in parallel with the aforementioned Phase 2, REM supported NASA MSFC in the processing of several 1.2K nozzles built using PBF-LB and BP-DED in JBK-75 and NASA HR-1, as well as 1.2K coupled nozzle and combustion chamber components (see Fig. 14). Additionally, REM supported ASRC in the preliminary process development of CP and CMP chemistries for the

Initial Ra	Final Ra	Surface Material Removal
>14 µm	< 0.75 µm	75 µm

Fig. 15 7K LLAMA combustion chambers: (left) after CMP, (right) as additively manufactured/HIPed (Courtesy NASA)

Fig. 16 7K LLAMA combustion chambers after CMP (Courtesy NASA)

GrCOP alloys. Both of these projects were driven by the needs of the RAMPT programme and REM's initial Phase 1 SBIR success.

REM subsequently applied these in-development processes to several GrCOP combustion chambers for NASA MSFC, with the most recent and notable application being to a 7K Long Life Additive Manufacturing Assembly (LLAMA) combustion chamber (Fig. 15). The primary deliverable on these initial combustion chambers has been exterior, coldwall clean-up/roughness reduction, but future programmes are being discussed to increase focus on the hotwall and cooling channel finishing to improve component performance and further optimise these AM designs.

Beyond NASA: From commercial space ventures to power generation

In addition to developing and scaling surface finishing technologies to meet NASA's needs, REM's work with NASA MSFC has yielded direct industry value in the form of multiple private projects in rocket propulsion, turbomachinery, aircraft engine, land-based gas turbine, RF and even fusion reactor applications. Since the completion of the Phase 1 project, REM has garnered more than fifteen significant customer engagements that are direct applications of the in-development or developed OFT. Several of these engagements represent private rocket propulsion applications. All of these engagements have a defined and otherwise unmet requirement for improved surface finishes and, for most of these applications, traditional surface finishing techniques would not be an option due to capability limitations. Thus, this rapid adoption of the OFT is a direct fulfillment of one of the primary goals of SBIR awards and is an example of the efficacy of the SBIR programme overall to accelerate technology development, which will in turn meet known and growing market needs. REM's AM business has grown over 500% from its pre-SBIR Phase 1 levels.

Outlook

Despite all of the progress that has been made as a part of REM and NASA's collaborations, there is still important future work that can be pursued to further advance TRL and broaden capabilities relative to rocket propulsion and other applications. Potential future work that is being considered includes process chemistry formula optimisation for GrCOP and similar copper alloys, as well as other superalloys/nickel alloys. As referenced, additional process scaling for potentially much larger components may be required. Cooling channel specific (and similar internal geometry) surface finishing applications of the OFT would be beneficial to many AM component types and would be a valuable area for further research and development. Lastly, the generation of more complete material property datasets across different alloys, build parameters and heat treatments relative to surface finishing would significantly aid industrial adoption of AM. The limited public data that does exist suggests that surface roughness/texture is a potentially significant influence on the fatigue life of AM components, but standard roughness evaluation parameters such as Ra have shown inconsistent correlation to fatigue when considered in isolation. Certain surface finishing processes have produced low Ra values, but have shown little to no improvement over as-built specimens. Thus, a complete understanding of AM component fatigue behaviour relative to surface finish is needed.

The significant potential for future work, however, should in no way detract from the impact that NASA is having on the rocket propulsion industry and the AM industry overall, via these types of public-private research engagements. By enabling the development of game-changing technologies and public material property datasets, NASA is accelerating the maturation of AM as a manufacturing tool for all and, in parallel, is driving the actualisation of the return of manned space flight to the Moon, Mars and beyond.

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Acknowledgments

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From aerospace engineering to AM: Melanie Lang on FormAlloy and the future of Directed Energy Deposition (DED)

When you mix a childhood obsession with rockets and space travel, a career at some of the biggest global names in aerospace, and a curiosity about hobbyist 3D printing developed through maker fairs, it was inevitable that FormAlloy's Melanie Lang would end up in the world of metal Additive Manufacturing. *Metal AM* magazine's Emily-Jo Hopson-VandenBos interviewed Lang, CEO and co-founder of Directed Energy Deposition (DED) specialist FormAlloy, about her route into AM, her company's technology and the outlook for the process.

Melanie Lang has a background rooted firmly in aerospace and defence. As a child, she found herself fascinated by all things space and space travel, and spent much of her free time launching model rockets. It was this early interest which put her on the path to study Aerospace and Aeronautical Engineering at the University of Illinois, USA, before entering the workforce as an Operations Analyst at Boeing in 2000.

In 2004, Lang joined Lockheed Martin's Engineering Leadership Development Program, serving three years in this position while studying part time for an MS in Systems Architecture and Engineering at the University of Southern California, USA, a period which afforded her a wider understanding of the architecture of systems, not just in aerospace but in a wider industrial context. For the next ten years, Lang occupied a range of roles and positions at Lockheed Martin, from engineering to programme management to systems development.

During her tenure at Lockheed Martin, Lang stated, "3D printing was starting to come online and become popular, but I didn't make the connection with aerospace until I started getting into 3D printing as a hobbyist." In around 2010, her interest piqued, Lang began attending 3D printing maker fairs and later built a small polymer 3D printer from a build kit at home. As her interest continued to grow, "I started talking and connecting the dots," she explained. "What were some of the big challenges I was seeing in aerospace and defence? Now, we

Fig. 1 FormAlloy founders Lang and Jeff Riemann outside FormAlloy's headquarters in Spring Valley, California, USA (Courtesy FormAlloy)

Fig. 2 Melanie Lang, FormAlloy CEO, an enthusiastic advocate for Additive Manufacturing, presents a live tech talk from inside FormAlloy's large DED Additive Manufacturing machine, the L5 (Courtesy FormAlloy)

had this capability to build things at home, or go to a makerspace and build things."

Of course, the Additive Manufacturing market in 2010 was very different to the market we see today, and the world of maker fairs has little in common with today's world of industrial metal Additive Manufacturing. However, Lang quickly spotted the potential advantages that AM could bring to her industry. "For the technology to be utilised in the aerospace and defence industry, I knew it would have to be metal, and it would have to be very high quality. I started to wonder: How do we take this technology and make real parts that can be useful for aerospace and defence?"

From here came the conception of FormAlloy, founded by Lang, CEO, and Jeff Riemann, CTO, in 2016, out of Spring Valley, California, USA. Like Lang, Riemann began his career at Boeing, but went on to develop ten years of expertise in machine design and integration at Hornet Cutting Systems, a manufacturer of CNC plasma, oxy-fuel and waterjet cutting machines.

Since debuting its first machine at RAPID 2016, FormAlloy's award-winning Directed Energy Deposition (DED) technology has been enabling customers to form, enhance and repair metallic parts in a range of often critical industries. Its metal AM technology uses DED to create metallic parts to near-net shape, while increasing design freedom and cost-efficiency compared to parts produced using conventional methods.

Why Directed Energy Deposition?

While co-founder Riemann had background experience in DED technology, Lang did not. What drew her to the technology was its capacity for producing high-strength, multi-material parts and, most of all, its versatility of use – this is a technology that can be applied to build parts from scratch, add features to existing parts, or repair damaged or worn ones.

"Especially if you look at defence applications, the parts are so high value," she commented. "I started thinking about what would happen if you could refurbish those parts by adding material to an area of wear or mismachining. These are very large, sometimes extremely large components, but if a hole was drilled in the wrong place then oftentimes they would have to scrap the whole part and start over. If you could add material back to the area, getting a full metallurgical bond [as is possible by DED], and then remachine the hole in the correct place, or finish machine a repaired part and put it back into service, you're not only saving significant cost but significant time."

Despite these capabilities, DED is less known and less widely adopted in industry than Laser Beam Powder Bed Fusion (PBF-LB), perhaps the most widely recognised of metal Additive Manufacturing technologies. PBF-LB also has wide uptake in the aerospace and defence industries, and is in use at a number of major players including Lockheed Martin, Honeywell Aerospace, Airbus, GE Aviation and Safran. For any less-used AM technology, the question that will inevitably be asked is: Does it compete with PBF?

Lang sees FormAlloy's DED technology as both competing with and complementing PBF. "There are applications that are currently using powder bed that might have better results with DED – for example if you're trying to do very large components, or multi-material parts, but in a lot of ways I do view it as another tool in your toolbox," she explained. "I don't view any technology in additive as being superior to another; you have to look at your specific application and decide which of your tools you're going to use, just like in traditional manufacturing. It's not that one is better than another, it's about what you want to do and what you want the results to be."

That said, "I do think DED is pretty amazing!" she added. "There are things that you can do with it that you simply can't do with other technologies." But those unique capabilities don't need to exist in isolation. Of special interest to FormAlloy, explained Lang, is hybrid Additive Manufacturing – and not in the sense in which it is generally understood in the industry today, where AM is combined with subtractive manufacturing to enable the building and machining of parts in a single machine. "I'm talking about components that are initially produced using powder bed AM, and then put into a DED process, maybe to add a second material to it or to add features that would be extremely difficult to achieve with powder bed."

Fig. 3 An X5 machine from FormAlloy's X Series (Courtesy FormAlloy)

FormAlloy's Directed Energy Deposition technology

FormAlloy's DED process deposits metal with a coaxially aligned laser/powder nozzle to produce parts with dimensions ranging from less than 1 mm to greater than 1 m, with bead widths from 500 µm and up. The company produces two lines of DED machines: its X and L Series (Fig. 3), which, among their other benefits, enable DED to be used with high-value materials.

Using the DED process, FormAlloy has access to a very broad portfolio of commercially and custom-made metal powders. Components fabricated by DED have properties similar to wrought material, and the company is committed to developing and optimising parameters for standard alloys such as Inconel 625 and Ti6Al4V, as well as the next generation of materials.

The same DED technology can be used to add features and different materials onto existing products to enhance their properties and provide repair solutions for reduced downtime and scrap rate. To rebuild damaged or worn areas of valuable machine components, dies or moulds, FormAlloy DED can be used to add 100% dense, metallurgically bonded features onto the damaged part, with layer thickness from microns and up, enabling a variety of repair applications that require minimal post-process machining.

This capability makes it possible to improve both legacy and new products with geometric and alternative material additions. The additional features can provide a wide range of benefits from improved mechanical properties to higher temperature capabilities for improved performance and extended life.

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Fig. 4 A FormAlloy DED build head in operation (Courtesy FormAlloy)

For additive enhancements, structures can be added onto work pieces in the same way as they may be deposited on a flat plate when building a part from scratch. Reinforcing structures such as ribs, grids, and plates can be strategically placed on components, and functionally graded material (FGM) applications can also be built in a single-step DED process to transition materials from one to another while reducing the residual stress during the build. FGM applications can then deliver the beneficial properties of specific alloys at localised parts of a component.

In addition to additive enhancements, FormAlloy's cladding capability can be used to create wear and corrosion-resistant coatings that are 100% dense and bonded metallurgically. DED provides very low dilution between the coating and substrate and allows for fine microstructures, precise control of the coating thickness and reduced distortion into the base part.

Lowering the AM equipment cost barrier

To enable manufacturers with existing production lines to take advantage of these capabilities, a series of FormAlloy OEM solutions is available that can be integrated with existing robotic or production lines to additively manufacture, clad and repair at a fraction of the cost of purchasing a turn-key DED system. These include:

- The FormAlloy AX metal deposition head (Fig. 4)
- The FormAlloy PF – a 1.5 litre powder feeder
- The FormAlloy Alloy Development Feeder (ADF), featuring 16 x 20 ml Powder Hoppers (Fig. 5)
- Lasers, including multi-mode IR or blue Lasers

Together, these OEM solutions are designed to stand up to very challenging environments and crashes, enabling use in the most demanding applications.

A coaxial design makes the FormAlloy AX metal deposition head very efficient, with liquid cooling for operation at power levels up to 8 kW. Various nozzle sizes are available to provide the optimum powder spot size for the given application, and the product has been rigorously designed and tested using advanced Computational Fluid Dynamic (CFD) models and real-world testing in FormAlloy's own DED machines.

Powder feed systems

FormAlloy's Powder Feeder enables precise metering of the powder delivered to the FormAlloy AX head. A novel planetary-drive design enables precise metering of the powder from 1 g per minute to more than 160 g per minute, and can deposit powder sizes between 10 to 250 µm. The modular design enables a very large range of configurations to be used, including multi-feeder setups for ease of powder changing and system redundancy, while an easy-align design makes powder changes possible within five minutes.

The Alloy Development Feeder is designed for materials development and research, and enables the rapid deposition of up to sixteen different alloys or alloy blends. Using a revolver-style motion, each powder vial can be accessed and deposited quickly and efficiently to reduce alloy development time by orders of magnitude. The FormAlloy ADF is compatible with the standard FormAlloy PF and can be used in parallel with multiple ADFs or PF feeders to enable interchangeability and integration with the X-Series or L-Series systems.

Process monitoring

FormAlloy also offers several options for in-process monitoring and closed-loop control. The FormAlloy Optical Monitoring tool provides a live dynamic range image to provide the operator with a view of the meltpool. With speeds up to 55 FPS, customers

Fig. 5 FormAlloy's Alloy Development Feeder, designed for materials development and research (Courtesy FormAlloy)

can have off-axis videos for live access during the process and recordings for post-build playback.

A further tool, Dynamic Layer Selection, enables a layer-by-layer inspection with closed-loop operation to achieve geometric accuracy during the build process.

A laser profilometer scans the build after each layer for a fast, accurate, and non-contact form of inspection. By enabling the closed-loop operation to auto-adjust a build during the process, and utilising the point cloud output for post-process analysis, users can achieve a high degree of accuracy and generate useful data for future builds.

Meltpool monitoring and control can be further achieved with tools designed by FormAlloy specifically to monitor meltpool size and temperature along the optical path of the laser. With a closed-loop option for either of these variables, laser power can be adjusted in-situ to control heat input into the part.

"Aerospace and defence was our first target area, and was a great place for us to start – one, because of my background, and two, because if a product is good enough for aerospace, it's probably good enough to go in your car..."

Applications in aerospace and defence, and beyond

As well as selling its machines, FormAlloy offers a variety of engineering services including part production, feasibility studies, material testing and research collaboration. Its team of Directed Energy Deposition experts, led by Lang and Riemann, is available to review and manufacture conceptual geometries and material systems for those wishing to make the most of this versatile technology, and has to date worked with an impressive list of clients including NASA and the Jet Propulsion Laboratory (JPL) and the United States Marine Corps.

Regarding application areas, Lang explained, "Aerospace and defence was our first target area, and was a great place for us to start – one, because of my background, and two, because if a product is good enough for aerospace, it's probably good enough to go in your car, in your home, etc."

Fig. 6 A typical rocket nozzle component produced by FormAlloy, featuring internal cooling channels and some external features (Courtesy FormAlloy)

An example of a typical aerospace application at FormAlloy is shown in Fig. 6. This rocket nozzle component has internal cooling channels and some external features, which, using FormAlloy DED, can be built with multiple or gradient materials. Fig. 7 shows a door handle built by FormAlloy for the commercial aerospace industry, which Lang describes as "a quick build".

While aerospace and defence may have been the driving market behind FormAlloy's development, the company is now starting to see demand in other areas, beyond aerospace and defence. "We are seeing some automotive applications specific to tooling. Our DED process can be used with materials that other additive processes probably haven't even touched or looked at," she added. "That makes it a good fit for some of the materials that might be used for tooling, for automotive and other industries."

New material development

Another area in which FormAlloy has consistently seen high demand for its technology is in research. "We still see a lot of use in research, particularly in new material development, ranging from research institutes to other education institutions, as well as powder makers and other companies that are trying to develop a particular material that has the exact properties they want."

In this way, Lang believes that DED can help companies address a common challenge seen across the AM market. "In additive, we are so often taking a material that was potentially developed decades or even centuries ago, and we're trying to make it work with a new process that it wasn't intended for. If you think about some of the material challenges that are associated with additive, you might start to wonder, what if we could reduce or eliminate those by optimising your materials or the AM process? That is a big growth area that we see across both academia and industry. One of the unique things that we've developed to help address that is the Alloy Development Feeder."

Fig. 7 A door handle produced by FormAlloy for a commercial aerospace application. Top: the as-built part, Bottom: the chemically finished part (Courtesy FormAlloy)

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FormAlloy and the future of DED

"The ADF works with FormAlloy's DED system to deliver very small amounts of powder and deposit them very quickly on a single build plate," Lang explains. "If you can imagine doing powder development in, say, a powder bed system, in order to even try it, you would have to make a lot of powder, which can be very expensive. You have to fill the powder bed with enough powder to be usable, so you could sink thousands and thousands of dollars into the creation of a single batch of powder to fill a powder bed system with." The Alloy Development Feeder, on the other hand, only requires about 10–15 ml of powder, in up to sixteen different variations, to enable extensive, rapid material testing of different combinations and alloy types until the formula is right.

Recently, FormAlloy completed a DED feasability study for NASA HR-1, a high-strength Fe-Ni-base superalloy, developed by NASA for liquid rocket engine component applications, that resists high-pressure hydrogen environment embrittlement (HEE) (Fig. 8).

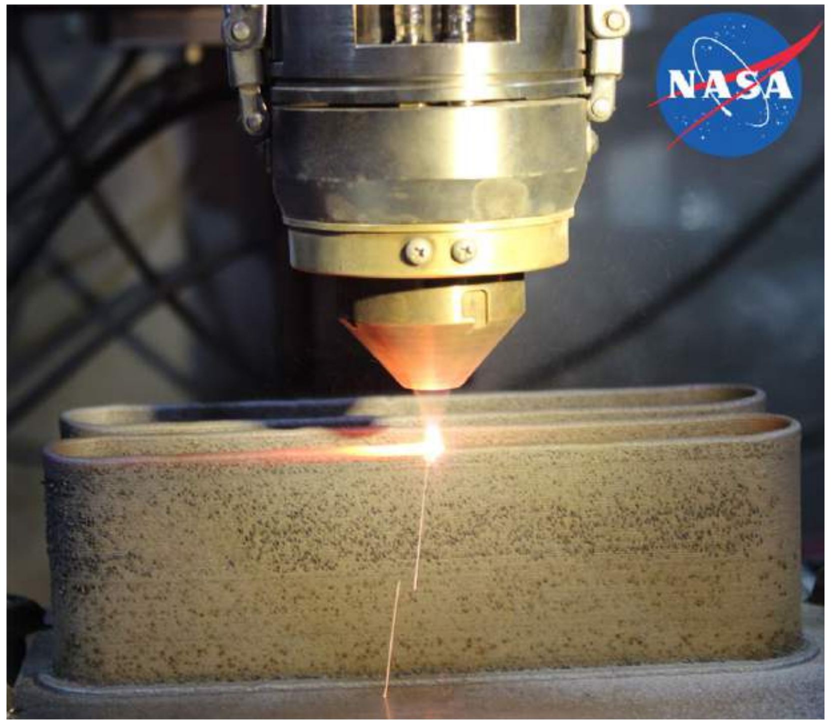

Fig. 8 A FormAlloy build head deposits NASA HR-1 powder for a feasability study conducted by the company (Courtesy FormAlloy / NASA)

Technology uptake: 'Pure AM' versus repair and cladding

Comparing applications for the repair and enhancement of existing, conventionally manufactured parts, and the building of parts from scratch, Lang reported that demand has been reasonably even, if slightly heavier for new additively manufactured parts than repair or enhancement. "This is simply because if someone is doing Additive Manufacturing, they're thinking of additive companies. If someone is doing cladding or repair, DED doesn't necessarily pop into their heads as the first solution, because there are other ways to do it.

What Lang has observed, though, is that once FormAlloy's technology has been introduced to a company, a repair or cladding application can often serve as an effective way to make the initial business case, and provide a suitable entry-level challenge to familiarise the customers' in-house team with its use. "Across the industry, it is understood that AM can do so many things, but it is often more advantageous to pick one thing, start with that and get really good at it before expanding from there," she stated. "We have companies that want to bring a printer in and they're so excited that they have a long list of applications they want to tackle with it. At that point, it's time to pick one thing and do that first so that they understand the process and we understand what they need from it. Oftentimes, repair and cladding is low-hanging fruit."

The need for customers to approach their AM adoption as a journey, and not a quick fix that can be adopted overnight to revolutionise workflows, is one which FormAlloy understands well. "It's important that our customers start with a single application or a couple of applications," said Lang. "This way, we can get everybody comfortable with the process and work with them on the journey to transition from low-volume production or R&D all the way to production. We will be that partner throughout the journey, and our product line supports that with the equipment we sell and the OEM solutions we offer."

"Across the industry, it is understood that AM can do so many things, but it is often more advantageous to pick one thing, start with that and get really good at it before expanding from there..."

Research and development within FormAlloy

Where a customer approaches FormAlloy with an application that is not immediately well-suited to its technology, the company's culture of constant innovation comes into its own. "When we find a customer application and we don't have a technology that can address it, you'd better believe we are working on developing a solution to help address that. This is why our systems continue to get better over time."

The Alloy Development Feeder is one example of FormAlloy's ability to take a project or a challenge that it sees in the market, in this case the ability to develop new materials and functionally graded materials with high accuracy.

The company's in-house process monitoring and control solutions are another example of this culture of innovation, particularly its development of a technology it calls dynamic layer selection, in which each deposited layer is scanned. Using this technology in a closed mode in R&D, adjustments will be made automatically based on layer height. In a production environment, it can function as a quality control tool, where layers are scanned to ensure they fall within tolerance and any variances measured, resulting in a real-time, recorded history of the part during the build process.

"Process monitoring is such a key area, because this is a new process in which trust has to be built through verification and validation," Lang explained. "Do you really want to have to do tensile testing on every single build plate that you do? Probably not, if you're going to take this to production – so how do you trust the process? How can you guarantee that there is some form of notification if the process goes wrong? That's one of the things we address with the dynamic layer selection technology."

"Additive Manufacturing is not just about perfecting the machine, it is about perfecting the entire supply chain, and to me this starts with materials."

The primary challenge which is next in FormAlloy's sights is the optimisation of materials for Additive Manufacturing. "Additive Manufacturing is not just about perfecting the machine, it is about perfecting the entire supply chain, and to me this starts with materials. So how do we get superior, optimised materials for AM and DED? Perhaps there is a copper alloy with a slight variation that makes it suitable for powder bed AM, and a copper alloy with a slight variation that makes it suitable for DED. How can we solve some of the challenges we are trying to solve now, on the equipment and process side, on the materials side? By doing so, we can improve the entire AM industry."

The future

According to Lang, FormAlloy's year has been only minimally impacted by the coronavirus (COVID-19) pandemic. "We saw a pause in activity from our customers for about six weeks. Part of this was probably because people were adapting to working from home, or in other cases customers were drastically reducing their R&D budgets, but I think that after a few weeks people started to gain confidence and work from home more efficiently, and some sort of normalcy resumed."

While FormAlloy was impacted in the short term, with some system and R&D orders delayed by around six weeks, the company was lucky in comparison to much of the global manufacturing industry. "That's part of the benefit of being in AM," Lang noted, "and especially of being in the essential sector of aerospace and defence: that kind of work never really slows down or stops for too long."

So, what does the future hold for FormAlloy? "We are very excited about what the future holds as new materials come online and we continue to go bigger in terms of build volume in our machines," Lang commented. "With a lot of new space companies coming on board, it's a great industry to be part of – and very exciting for me personally, with my love of space applications!"

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Additive Manufacturing of hardmetals: An evaluation of potential processes for tool production

Hardmetals, also known as cemented carbides, have played a huge and often overlooked role in modern industrial development. From the first application in wire drawing dies in the 1920s, hardmetals are today universal and their application areas range from metal cutting and the machining of wood, plastics and composites to the production of glass bottles, aluminium cans and the ubiquitous ball-point pen tip. Can Additive Manufacturing make inroads into a market worth tens of billions of Euros in annual sales? Dr.-Ing. Johannes Pötschke reviews the fundamentals of hardmetal production and considers the most viable AM processes for this complex family of materials.

Most tools used in the oil, gas, and mining sectors, as well as in the metal machining or forming industries, are made from hardmetals. This material class, also known as cemented carbides or sometimes just carbides, can be categorised as composite materials. Hardmetals possess the necessary properties for their intended use, namely high hardness, strength and toughness. As implied by the name cemented carbide, hardmetals primarily consist of very hard carbide grains which are 'cemented' together by a comparatively low amount of a ductile metallic binder. The most used hard phase material is tungsten carbide (WC) and the binder metal is mainly cobalt (Co), with typical binder compositions in the range of 10 to 30 vol.% (equivalent to 6 to 18 wt.% Co).

Traditionally, hardmetal parts are produced by a standard Powder Metallurgy shaping process to create green parts that have densities in the range of 55% theoretical density (TD). These green parts are then sintered in vacuum and protective gas atmospheres to 100% TD. While traditionally parts such as cutting inserts or dies are produced by uniaxial pressing, cylindrical parts are often produced by extrusion and more complex parts by Powder Injection Moulding (PIM). Even though this already allows the production of cooling channels for drills or milling cutters, more complex internal shapes and outer tool geometry are currently only possible with a high level of green machining and finishing - if possible at all.

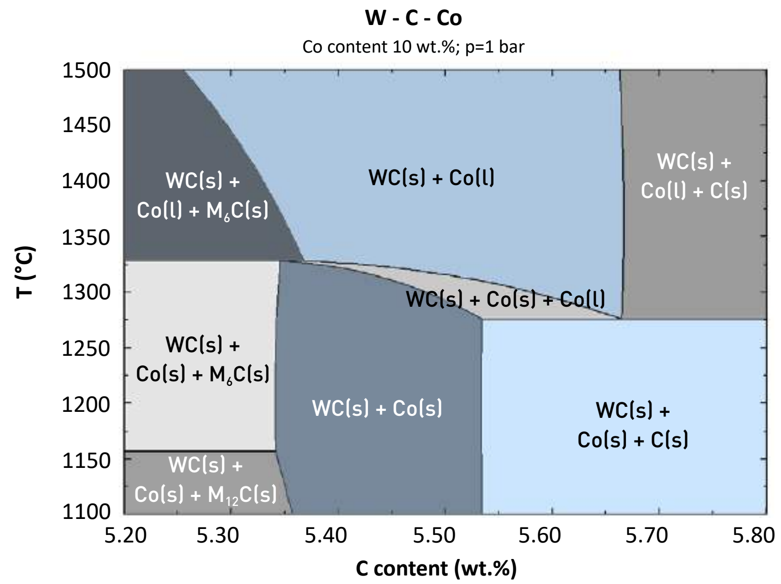

Fig. 1 W-C-Co phase diagram at 10 wt.% Co, desired hardmetal phase is WC (s=solid) + Co (s), unwanted phases are Carbon (C), M$_{12}$C and M$_6$C, calculated with Factsage 8.0

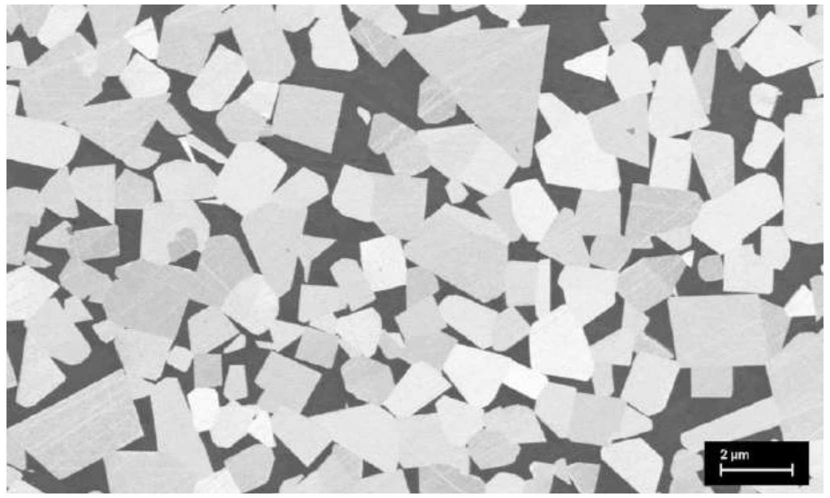
Fig. 2 Typical microstructure of a coarse grained WC-15 Co hardmetal with tungsten carbide grains in light grey and cobalt in dark grey (©Fraunhofer IKTS)

Whilst hardmetals are interesting as new materials for Additive Manufacturing, it should be noted that they were one of the first materials studied, as shown by early tests done in the US by Sachs at MIT in 1995 [1] using Binder Jetting (BJT) or by Zong at UT Austin in 1992 by means of Powder Bed Fusion (PBF) [2]. These early studies showed that the successful processing of hardmetals by AM is by no means an easy task.

The properties and peculiarities of hardmetals

As stated above, hardmetals are composites, consisting of the hard phase tungsten carbide and the metallic binder cobalt. Properties such as high hardness (up to 20 GPa), high bending strength (up to 5000 MPa) and high fracture toughness values (up to 20 MPa*m$^{1/2}$) are only achieved if the three elements (tungsten, carbon and cobalt) are present in the two phase state of tungsten carbide and cobalt alloy (WC+Co). To achieve this, the carbon content must be within a small compositional window, to avoid free carbon (C) or the formation of complex eta phases (M_6C or $M_{12}C$) when too low amounts of carbon are present, as shown in the phase diagram of W, C and Co (Fig. 1).

In both these cases, mechanical properties will drop off drastically and a product's use in tooling would be impractical. Furthermore, to achieve the required properties, the material has to be 100% dense, with only a very small amount of pores (< 0.2 vol.%) in the range of up to 25 µm being allowed. As for microstructural requirements, the tungsten carbide grains, as well as the metallic binder phase, must be distributed within the tool materials as homogenously as possible to guarantee the aforementioned properties, as can be seen in Fig. 2.

As for processing, it is important to keep in mind that tungsten is a quite heavy element and that tungsten carbide based hardmetals, therefore, have densities in the range of 13 to 15 g/cm³. Even small green parts therefore have a high weight, which can influence the green part stability or shrinkage during sintering.

Sintering of hardmetals takes place slightly above the eutectic temperature within the W-C-Co system of 1,310°C, as so-called liquid phase sintering. With a further increase of sintering temperature, more and more W and C can be dissolved within Co, increasing the amount of the liquid phase. However, if the temperature is too high, the metallic binder can evaporate.

With an even further increase of sintering temperature (ca. > 2,800°C), the hard phase tungsten carbide can disintegrate due to decomposition of WC into W_2C and C [3]. For handling and safety reasons it has to be further noted that cobalt is classified as a Cancerogenic Mutagen Reprotoxic (CMR) material, for which special care has be taken during processing [4].

It is also noteworthy that, in contrast to many ceramics, hardmetals are not transparent to light. Light-based lithography AM technologies could therefore only be used with indirect crosslinking approaches, limiting resolution and speed.

Potential AM processes

In principle, the whole range of AM technologies is available for hardmetals and quite a few have been tried already. However, due to the peculiarities of hardmetals, the following aspects limit the choice:

- Hardmetals consist of around 70 to 90 vol.% of the ceramic hard phase tungsten carbide (WC), thus the metallic binder content is accordingly low
- WC cannot be melted, but decomposes above ≈ 2,800°C [5]
- Cobalt has a low vapour pressure and is classified as a CMR material
- WC has a density of 15.67 g/cm³, so green parts are quite heavy
- WC is not transparent for any wavelength of light.

Considering the above, Electron Beam Powder Bed Fusion (PBF-EB) has to be excluded because of its intensive energy input, resulting in the decomposition of WC and the evaporation of Co. Also, VAT Photopolymerisation (VPP), also known as Stereolithography (SLA), is excluded because of the non-transparency of WC. Even though there are a few publications concerning both the PBF-EB [6] and VPP [7] of hardmetals, these processes are excluded from this report for the previously mentioned reasons and the results that can be anticipated.

The most promising results, however, have so far been achieved with Laser Beam Powder Bed Fusion (PBF-LB), Binder Jetting (BJT), Material Extrusion (MEX) and Material Jetting (MJT). In the following subsections, results for each of these AM technologies will be summarised and discussed accordingly.

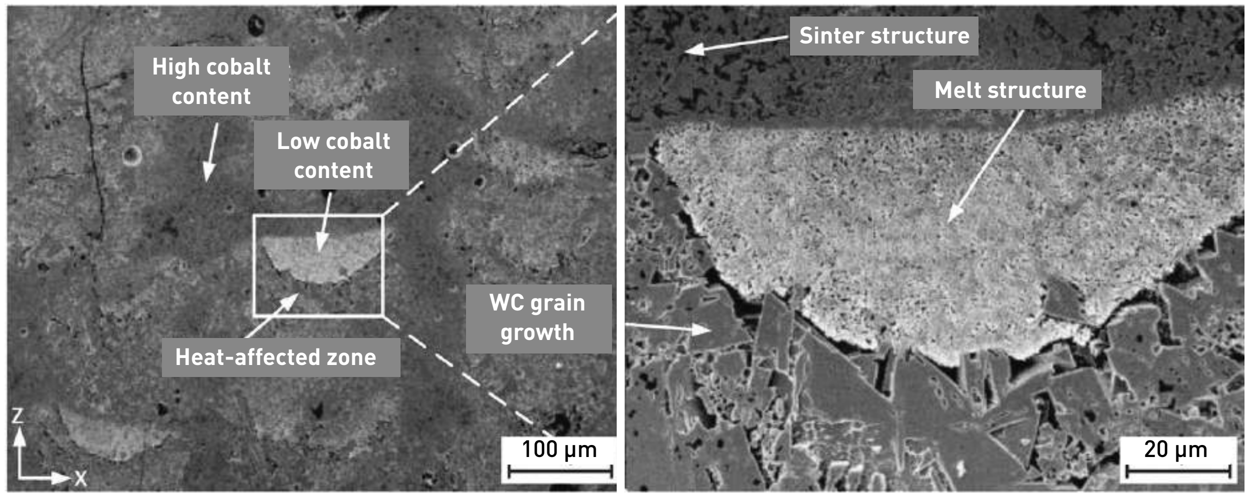

Fig. 3 Microstructures of PBF-produced parts made from WC-17 wt.% Co, from [11]

Laser Beam Powder Bed Fusion

PBF-LB processes, also known as Selective Laser Melting, Direct Metal Laser Sintering, Selective Laser Sintering, Laser Beam Melting etc., belong to the powder bed-based group of AM technologies and were among the first AM technologies evaluated for the production of hardmetal parts. In contrast to Binder Jetting or filament-based Material Extrusion processes, the PBF-LB process ideally creates a fully dense part in a single-step.

As mentioned in the introduction, PBF-LB, then referred to as SLS, was one of the first AM technologies tested for hardmetals. The tests conducted at UT Austin used agglomerated hardmetal powder (presumably thermal spray powders) with a composition of WC-12 wt.% Co and showed that the principle of fabrication of hardmetal parts is possible [2]. However, these parts were nowhere near dense, reaching approximately 60% TD. Further work by Kruth at the KU Leuven, Belgium, between 1996 to 2003, showed that, even with an increase of metallic Co to 30 wt.%, no dense parts could be made by PBF directly [8, 9]. Work in 1999 by Fraunhofer IKTS and IWS in Dresden, in cooperation with the University of Mittweida, all in Germany [10], showed that, with optimised granulated and pre-sintered granules, samples with densities above 60% of theoretical density can be achieved, which can be increased to nearly full density by a subsequent step combining sintering and Hot Isostatic Pressing (SinterHIP).

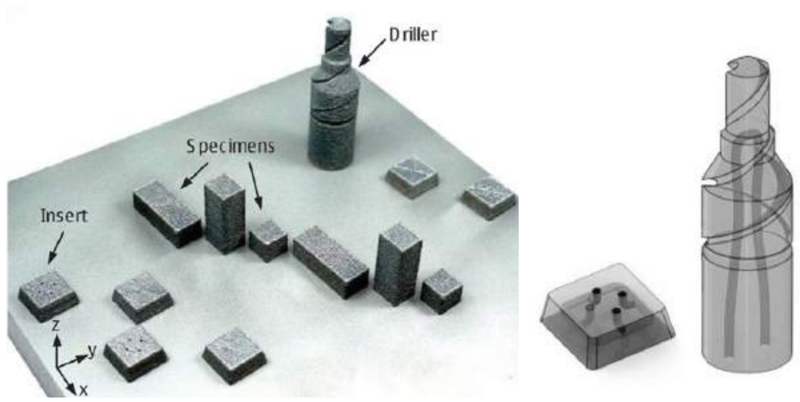

Fig. 4 Part geometries of PBF-produced parts made from WC-17 wt.% Co, from [11]

However, as also shown by other studies, the required energy input (laser power) to achieve sufficiently dense samples resulted in defects such as abnormal grain growth and local decomposition of WC into W_2C and carbon, as well as the unwanted formation of eta phases. Furthermore, the evaporation of Co, reducing the residual Co content of the hardmetal, led to the fact that often the composition of the produced part did not match that of the starting powders used [11].

In addition, the evaporated Co can deposit within the PBF-LB machine and is a risk regarding CMR issues. Nevertheless, nearly dense samples (98.5% TD) were achieved by researchers from Fraunhofer IPT, Aachen, between 2007 and 2009 [12, 13] with Co contents as low as 25 wt.%. However, in addition to unwanted phases, thermal stress induced cracks and pores within the more or less dense microstructure now appeared due to the high laser power used. Similar results in 2015 at Fraunhofer IPK, Berlin,

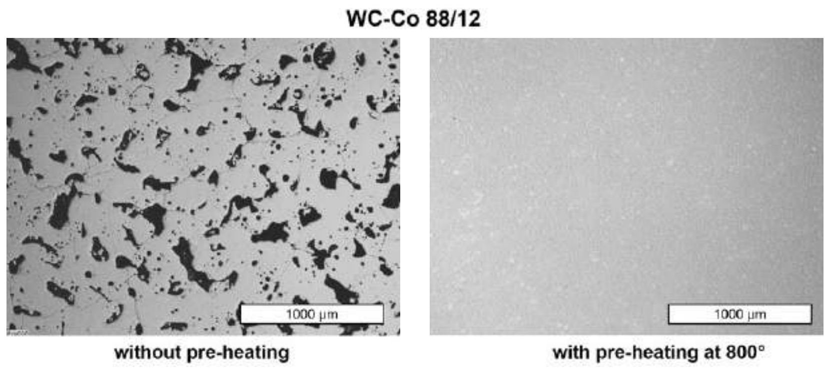

Fig. 5 Change in density and microstructure of WC-12 Co wt.% parts produced without and with preheating, reproduced from original data transferred by the initial authors of [14]

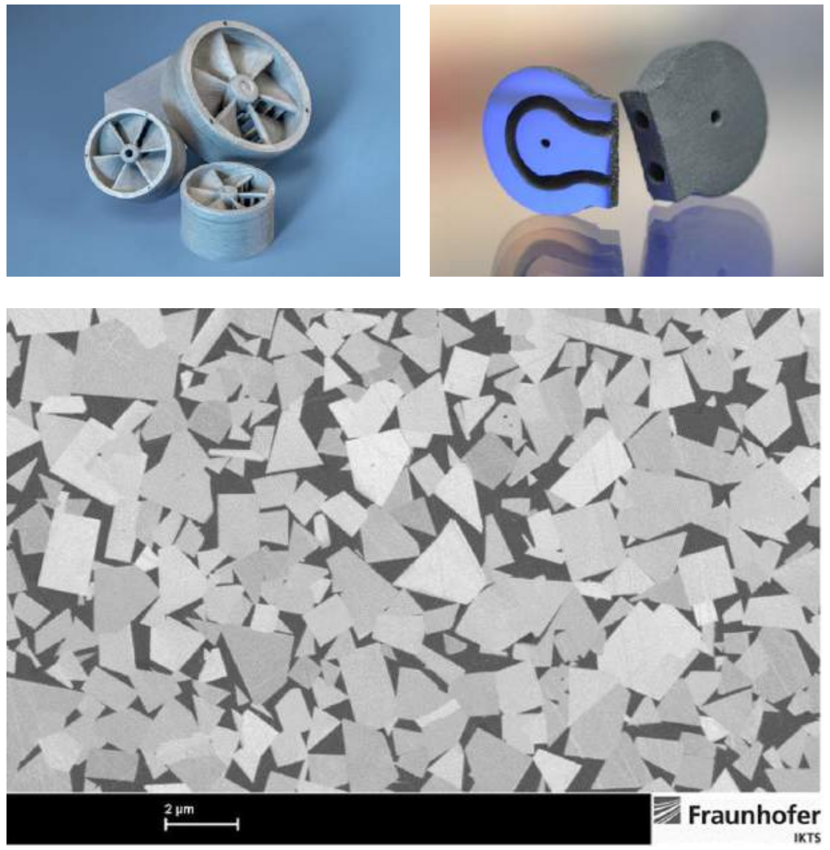

Fig. 6 Hardmetal parts produced by Binder Jetting (top) and SEM microstructure of a dense WC-10wt.%Co hardmetal (below)

Chemical composition	[wt.%]	WC-17 Co	WC-12 Co	WC-12Co (fine)
Density	[% TD]	99.9	99.5	99.7
Hardness	[HV10]	1020	1170	1330
Fracture toughness	[MPa m$^{1/2}$]	>17	>17	13.1
Average grain size	ISO 4499-2	medium	medium	fine

Table 1 Chemical composition and properties of various hardmetals produced by Binder Jetting (Courtesy Fraunhofer IKTS)

showed (Figs. 3–4) that interesting geometries are possible, but that the microstructure and the mechanical properties were significantly inferior to conventionally produced parts [11].

To address these issues, researchers at the University of Applied Sciences, Cologne, Germany, came up with the idea of preheating the powder bed to avoid thermal cracks and lowering the required energy input [14]. As shown in Fig. 5, preheating of the WC-12Co powder bed resulted in crack- and pore-free parts with five times higher bending strength values (~1000 MPa instead of ~200 MPa) as compared with parts produced with the standard PBF process.

Additional heat treatment by SinterHIPing of the PBF + preheating resulted in parts with further improved properties. However, abnormal grain growth as well as Co evaporation and the local decomposition of the WC phase still resulted in significantly inferior properties in comparison with conventionally shaped and sintered hardmetal parts [15].

Binder Jetting

Another powder bed-based AM technology is Binder Jetting (BJT). When it was first developed in 1990 by Prof. Sachs at MIT it was simply called 'three-dimensional printing,' or 3DP [16]. In contrast to PBF processes, BJT is a two-step sinter-based AM technology in which the built green part must undergo a subsequent densification process achieved through sintering.

In the first work in the area of hardmetals Sachs and colleagues between 1995 and 1998 used spray granulated WC-10 wt.% Co powders and produced simple bars with a green density of around 25% TD. However, due to this low green density (conventional pressed parts have ca. 55% TD), sintering at conventional temperatures (1,440°C) led only to sintered part densities of 60.9% TD [1, 17].

Further work was done in a national project at Fraunhofer IPT with partners from the tooling industry from 2007 to 2009 [18]. They used a granulated and pre-sintered WC-25 wt.% Co powder and a R2 BJT machine from Prometal RTC, Augsburg, Germany, now part of ExOne. After sintering (presumably gas pressure assisted SinterHIP sintering), crack free microstructures with densities above 99% TD and hardness values of around 1020 HV0.5 could be achieved.

Further work done at Fraunhofer IKTS in Dresden, Germany, with pre-sintered WC-Co granules in 2015 to 2016 [19, 20] showed, for the first time, that hardmetal compositions with typical Co contents in the range of 12 to 20 wt.% could also be successfully processed by BJT (Fig. 6). As seen in Table 1, different compositions can be processed and different properties achieved.

In recent years, a slightly modified process called 'Solvent on Granule 3D-Printing' was also successfully used to produce similar complex parts with Co-contents of 17.7 wt.% Co [21].

So far, however, dense hardmetal parts with mechanical properties comparable to conventionally produced parts have only been achieved by Binder Jetting for hardmetal compositions with ≥ 12 wt.% Co. Results for the widely used hardmetals compositions with 6 to 10 wt.% Co have, to date, not been published.

Furthermore, it should be kept in mind that, due to the comparatively low green density of BJT green parts, shrinkage is greater than with conventional pressed parts, resulting in more problems with distortion after sintering. The reason why the use of lower Co levels is difficult is because of an insufficient amount of liquid phase during sintering, which in turn is needed for the greater shrinkage of BJT parts.

Material Extrusion

Material Extrusion (MEX), widely known as Fused Filament Fabrication (FFF) when using a filament-based feedstock, is, like Binder Jetting, a two-step sinter-based AM technology. However, in contrast to BJT or PBF, it

Fig. 7 MEX produced hardmetals (top left), SEM image of a dense WC-8 wt.% Ni hardmetal (bottom left) and optical image of a surface cross section (right)

is not powder bed based but is a 'free form' AM process. Here, particle-filled thermoplastic filaments are produced by mixing, kneading and extrusion. These can then be used in standard MEX machines. Within these filaments, the volume percentage of particles (solid content) can easily be in the range of 50 to 60%, resulting, for hardmetals, in shrinkage ratios comparable to conventional powder injection moulded or even pressed parts.

Since, in MEX, layers and volumes are produced by a layer-wise deposition of filaments, the production of 100% dense parts (after sintering) is complicated due to the anticipated presence of cavities resulting from the potential gap between deposited filament layers. Examples of such problems, in the case of hardmetals, were shown by Lengauer *et al.* in 2019 [22].

Work done on FFF of hardmetals at Fraunhofer IKTS shows that cavity- and pore-free parts can be produced (Fig. 7) and that, due to the low shrinkage, hardmetal compositions with Co contents as low as 8 wt.% and with nickel as a binder element can also be produced (Table 2), resulting in hardness values of up to 1700 HV [23].

Thus, and in contrast with PBF and BJT, MEX can achieve dense parts with low cobalt contents and high hardness values. However, due to the high amount of organic thermoplastic backbone binder, debinding has to be calibrated to the thickest dimension of the as-built part, thus limiting the manufacture of larger parts without inner channels because of the very long debinding time needed to remove the binder components. Furthermore, MEX using filaments is, in standard machines, a single process, meaning one part is created at a time, making it significantly slower than PBF – even more so when compared with BJT.

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AM of hardmetals

Chemical composition	[wt.%]	WC-8 Co	WC-12 Co	WC-9 Ni
Density	[% TD]	100	100	100
Hardness	[HV10]	1700	1200	1540
Fracture toughness	[$\text{MPa m}^{1/2}$]	9.5	>17	9.5
Average grain size	ISO 4499-2	fine	coarse	fine

Table 2 Chemical composition and properties of various hardmetals produced by MEX (Courtesy Fraunhofer IKTS)

Material Jetting

Another technology investigated for the Additive Manufacturing of hardmetals is the thermoplastic 3D printing (T3DP) process developed by Fraunhofer IKTS [24]. Because of its jetting-like process, it belongs to the MJT category of AM processes. Like MEX, thermoplastic 3D-Printing is based on the selective deposition of molten, particle-filled thermoplastics. However, in T3DP, droplets rather than filaments are deposited. The thermoplastic binder system used consists of different waxes and additives. This results in low viscosities at relatively low temperatures and solidification by cooling. Work done at IKTS, starting in 2016, showed that T3DP can be used for hardmetals with low Co contents and small tungsten carbide grain sizes [25, 26]. Work done for the manufacture of cutting inserts and test structures showed that, with nanoscaled WC powders and Co contents of just 10 wt.%, fully dense parts with a perfect microstructure (Fig. 8) and hardness values of above 1900 HV can be achieved (Table 3).

Currently, the vertical resolution of T3DP is around 80 to 100 µm and the horizontal resolution is 250 to 350 µm, bringing it in the range of standard BJT produced parts. In T3DP, a quite high solid loading in the range of 50 to 60% ensures low shrinkage and subsequent distortions. However, as with MEX, debinding has to be addressed, limiting the parts sizes in the case of larger bulk parts.

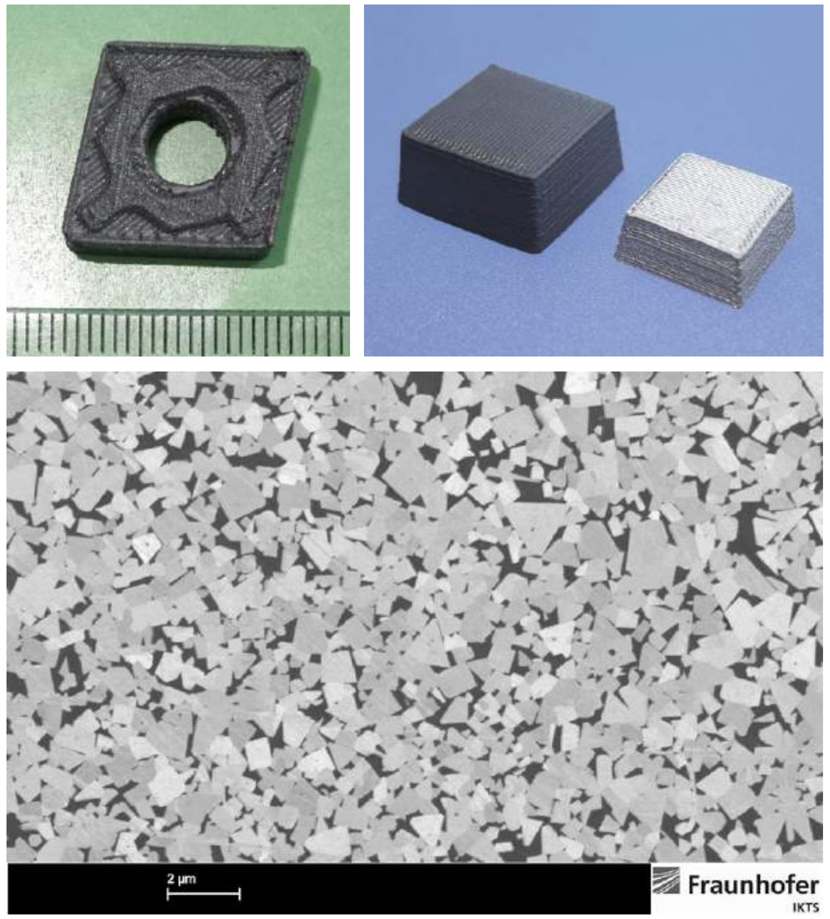

Fig. 8 T3DP hardmetals parts (top) and SEM image of a dense WC-12 Co microstructure (bottom)

Summary and conclusion

Even though hardmetals have not yet been successfully commercialised by the AM industry, they are a promising material for a number of AM processes. Sinter-based AM technologies, such as Binder Jetting, Material Extrusion and Material Jetting, seem to be the AM technologies with the highest potential for industrial use, as they appear to be the only ones capable of delivering the specific requirements for hardmetal tooling, namely full density, microstructures with a homogeneous distribution of WC and Co and the maximum possible ratio of hardness and fracture toughness combined with high bending strength values above 3000 MPa.

These properties are similar to conventionally manufactured parts with the same grain size and metallic binder content. PBF-produced hardmetal parts currently show significantly inferior properties due to the formation of cracks, unwanted phases and inhomogeneous microstructures.

So far, each of the potential technologies that have been highlighted appear to have strengths and weaknesses, depending on the material composition, production speed, accuracy and part size achievable.

For hardmetals parts with sizes of up to several centimetres and hardness values of up to 1400 HV, BJT is a fast and suitable process. However, for smaller parts with higher hardness values up to 1800 HV, MEX and, for delicate parts with hardness values of up to 1900 HV, MJT, appear most suitable.

In the future, adjusted materials for BJT and optimised process parameters for MEX and MJT will most likely overcome the current limitations of the Additive Manufacturing of hardmetals and will open the field to even more challenging possibilities, such as the multi-material printing of tools with different hardmetal compositions, resulting in specific tailored properties in different parts of a tool.

Chemical composition	[wt.%]	WC-10 Co	WC-12 Co	WC-12Co (coarse)
Density	[% TD]	100	99.8	99.7
Hardness	[HV10]	1930	1470	1300
Fracture toughness	[$\text{MPa m}^{1/2}$]	8.2	13.4	14.2
Average grain size	ISO 4499-2	nano	sub-µ	coarse

Table 3 Chemical composition and properties of various hardmetals by thermoplastic 3D printing (Courtesy Fraunhofer IKTS)

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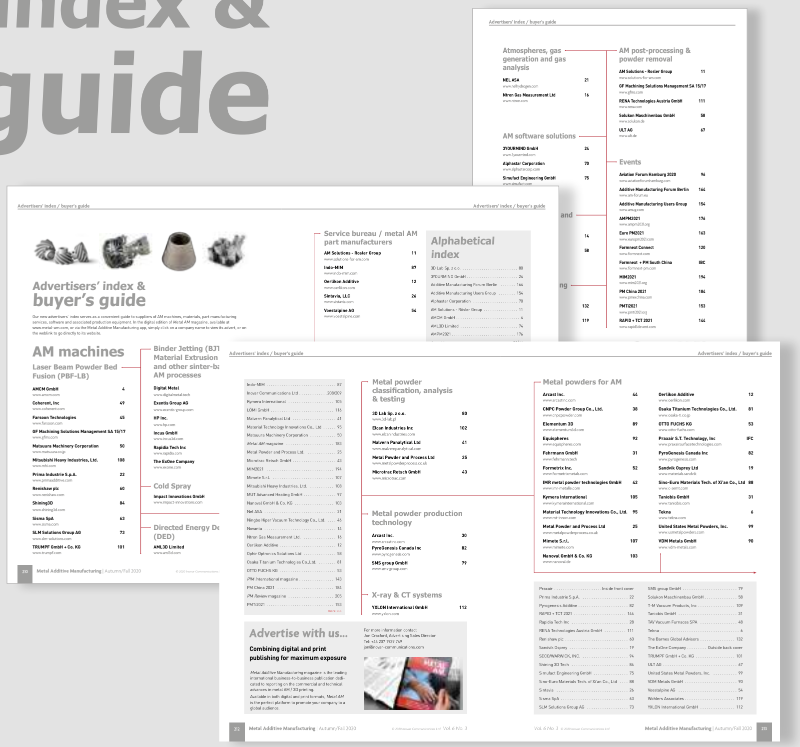

High-performance nickel-base alloys for Additive Manufacturing: A review of their limitations and potential

Nickel-base superalloys are an important material group for components used in the gas turbine, aerospace and chemical processing industries. Many of the well-established superalloys available today do not, however, adapt well to processing by Additive Manufacturing. In this article, Dr Tatiana Hentrich and Dr Christina Schmidt, VDM Metals International GmbH, present an overview of nickel-base alloys with a focus on strengthening effects, mechanical properties and weldability, comparing production challenges by conventional production routes and Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing.

Conventionally produced wet corrosion, high-temperature (heat resistant) and special purpose nickel-base superalloys such as Alloy 59, Alloy 625, Alloy 718, Waspaloy, Alloy 939, Alloy 738 and Alloy 247 have been in existence for decades. They are widely used in demanding industries such as gas turbine production, aerospace and the chemical processing industries, and belong to the most studied of alloy systems. While the focus for the development of most wrought Ni-base alloys has generally been on post-processing properties such as weldability, the development of superalloys has primarily concentrated on end-part performance. Furthermore, the weldability of superalloys was sacrificed for the increase in strength as related to the volume of strengthening phases. Consequently, many superalloys are available as castings.

To date, research into Additive Manufacturing using Ni-base powders has led to some interesting results. However, for a successful transfer to the commercial series production of components by processes such as Powder Bed Fusion (PBF) and Directed Energy Deposition (DED), material performance remains a critical factor.

Unfortunately, the use of established nickel-base alloys designed for casting is not viable because of their specific thermodynamic properties, such as phase precipitation kinetics and crack susceptibility, unless the processing side of AM, including post-processing, progresses significantly.

This article presents an overview of nickel-base alloys with a focus on strengthening effects and mechanical properties in relation to conventional production routes and weldability, including the related opportunities and limitations for Additive Manufacturing. Moreover, we will discuss the newly-developed alloys VDM Alloy 699

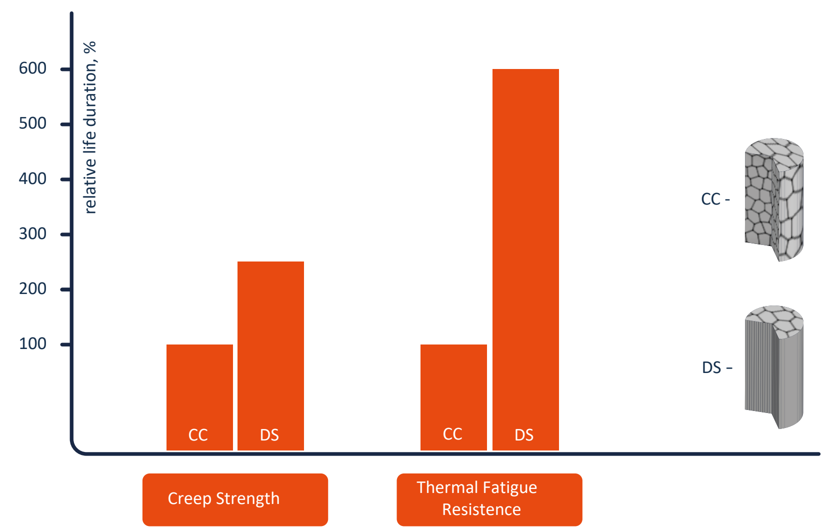

Fig. 1 Comparative relative lives of CC and DS alloys [after 1]

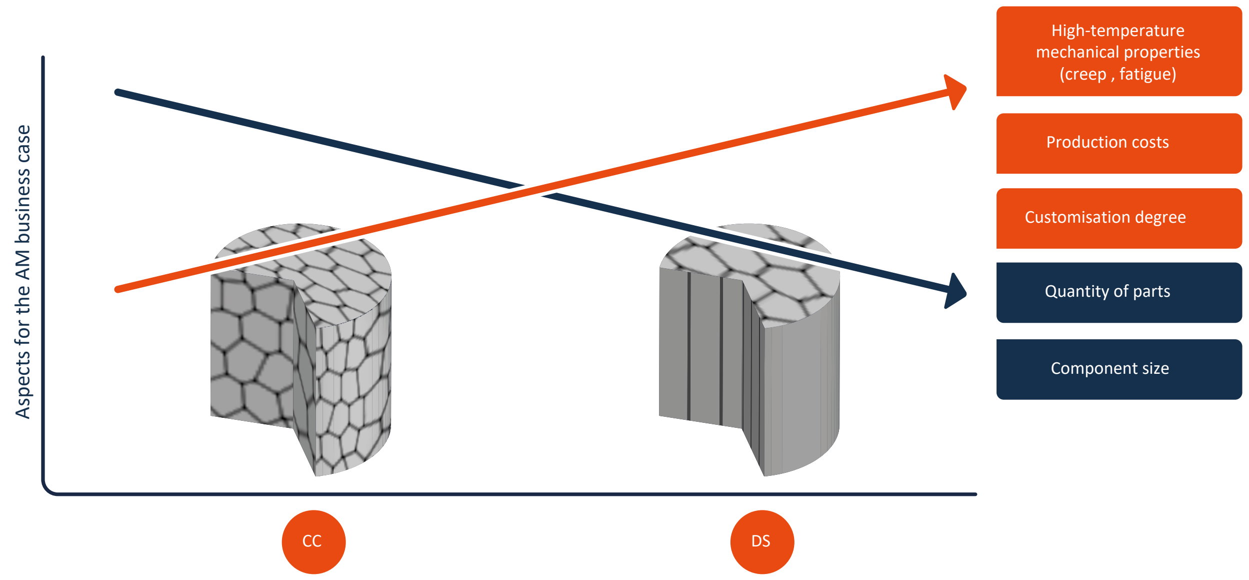

Fig. 2 Important aspects of AM related to polycrystalline cast (CC) and directional solidified (DS) alloys

XA and VDM Alloy 780, designed for high-temperature usage in chemical processing and aircraft applications by VDM Metals Group, a specialist in high-temperature nickel alloys, cobalt and zirconium alloys and high-alloyed special steels, headquartered in Werdohl, Germany.

The motivation for this paper arose from discussions with customers and partners from different projects on aspects of material selection, for example, for part design and prediction of total life to failure. This article is not intended to replace scientific work and/or publications in AM. However, it should help to build an overview and guide a successful implementation of Ni-base materials processed by AM.

The motivation for an Additive Manufacturing business case

Additive Manufacturing, as a comparatively new group of manufacturing processes, has made rapid progress in recent years. AM best fulfils industrial niches which require a low production volume of parts, and complex designs that formative or subtractive manufacturing methods are unable to produce due to high costs, logistics or long delivery times. In the process of selecting components suitable for developing a business case for AM, some further aspects should be considered:

- Material production costs, including virgin metals and alloy production costs
- Customisation degree, usually combined with the opportunity for improvement of performance efficiency
- Part size

In many industries, AM is seen as a performance enabler, rather than a cost-reduction enabler. What needs to be accounted for is the benefit derived versus euros spent. In this case, material performance becomes a key factor. The casting process for turbine blades using conventional production technologies can be used as an example here: switching from the conventional cast (CC) process to the conventional directional solidification (DS) process results not only in a change of microstructure from polycrystalline to columnar-crystalline, but also in an increase in the creep strength of the material by 150%, and thermal fatigue resistance by 600% (Fig. 1) [1].

The major difference in the material in this case is in its microstructure, in particular the much lower number of grain boundaries and their orientations. This means that not only the previously highlighted motivations for using AM should be considered when making a business case, but the material performance of the conventional part must be compared with the AM part.

In this paper, we will discuss current industry standards and the requirements, opportunities and limitations of the existing alloys and available industrial machines for Laser Beam Powder Bed Fusion (PBF-LB). Also discussed are material characteristics, which are important to consider in successfully implementing high-performance alloys in AM.

Fig. 2 summarises aspects of the selection process for AM parts, as discussed above. The first potential problem that can be seen in this figure arises if DS alloys are considered. Small quantities of parts, relatively small part sizes, high levels of mechanical properties (creep, fatigue, oxidation and corrosion behaviour) and high production costs can all be readily identified in the selection process for potential

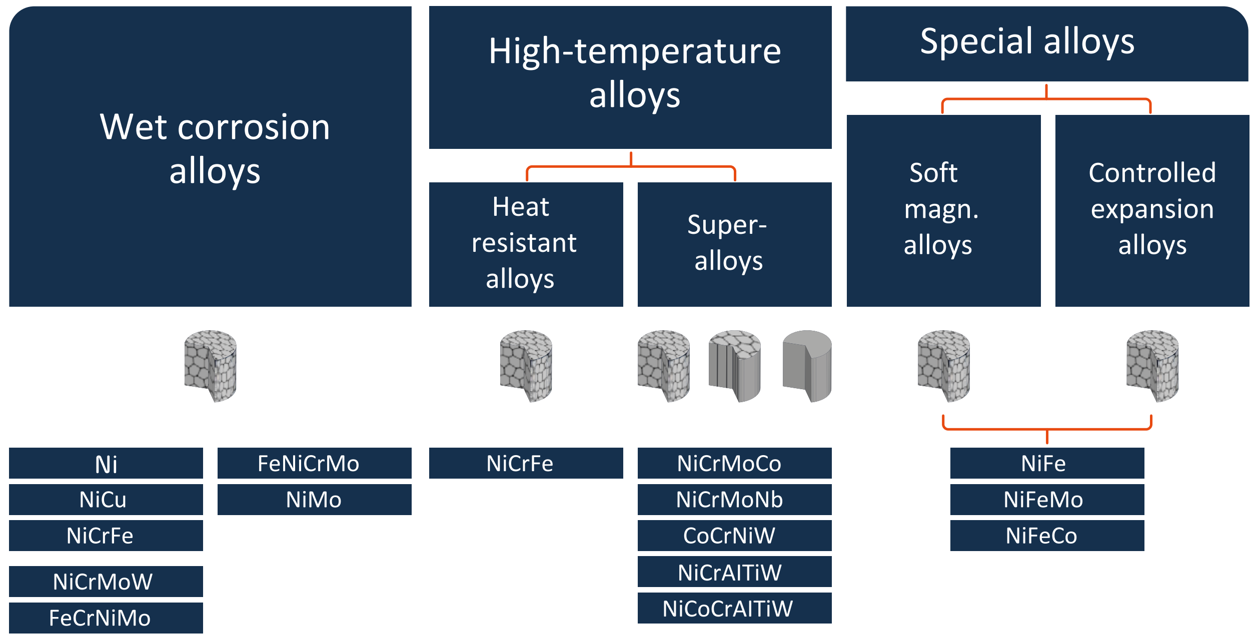

Fig. 3 General classification of Ni-base alloys

AM part substitution. In addition, the high potential for customisation and increase in a component's efficiency achievable with specific AM opportunities make parts produced with the DS technique very promising for the AM community. However, the currently-available AM processes produce polycrystalline structures (and so the expected properties decrease automatically on the left side of Fig. 2); secondly, conventional DS alloys are very difficult to weld, and achieving some complex geometries with the AM process may be problematic.

Generally, the main challenge to the successful application of high-performance Ni-base superalloys to be addressed is weldability. Another challenge relates to microstructural considerations: during AM processing, inherently small grain sizes are produced, elongated in the build direction, resulting in anisotropic material behaviour. This may cause a significant variation between a component's expected and actual performance. Properties such as creep strength, fatigue resistance and stress-rupture properties for AM parts can be degraded, compared with conventionally produced parts, if dimensional adjustments are not made. If the grain sizes of CC materials are around 1 mm and the grain size of DS materials is about 10 mm in the load direction, the grain size of AM materials is significantly smaller than 1 mm. This reduces the expected creep properties of AM parts, even in comparison with CC components.

The classification of Ni-base alloys according to application, conventional production methods and volume of strengthening phase

Ni-base alloys are widely used because of their unique characteristics – nickel does not change its crystal structure, in contrast to iron (Fe) or cobalt (Co), with a similar high melting temperature, and reveals good corrosion and oxidation resistance. Due to the Face Centred Cubic (FCC) structure, these alloys have a low diffusion rate at high temperatures. Ni can dissolve many alloying elements – up to around 50 wt.% – and many modern Ni-base alloys contain more than ten alloying elements. Alloying with Cr, Mo and Al is responsible for significantly improving corrosion and oxidation resistance. Al triggers another important effect in Ni-base alloys, as it is responsible for the precipitation of the strengthening γ'-phase.

Generally, Ni-base alloys can be divided into three classes: wet corrosion alloys, high-temperature alloys and special alloys, as shown in Fig. 3.

High-temperature alloys can be further split into two groups: heat-resistant alloys and superalloys. The major difference between these groups is the main strengthening mechanism: superalloys are strengthened by γ'-phase, which will be considered later.

On the basis of market size, most Ni-base wet corrosion, heat-resistant and special alloys are wrought alloys. They have found a wide range of application in the chemical processing, oil & gas, automotive and power generation sectors. Because of their chemical composition and specific production route, the following strengthening techniques can be used:

- Solid solution hardening
- Precipitation (carbides) hardening
- Fine grain or cold-forming hardening, depending on application temperature

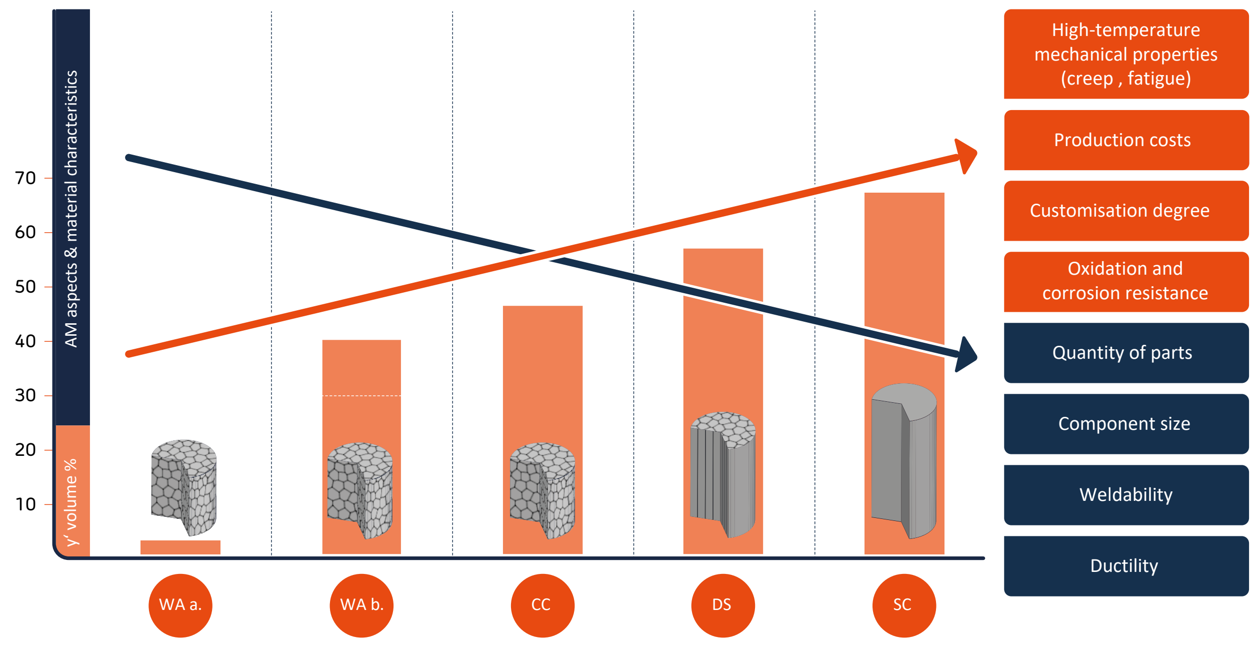

Fig. 4 Classification and properties of Ni-base alloys including SC, wrought alloys with no γ'-phase (WAa), wrought alloys with γ'-phase strengthening (WAb), conventional cast (CC), directionally solidified (DS) and single crystal (SC) alloys

γ'-phase can precipitate in these alloys, particularly in the case of Al additions; however, this generally only occurs in small amounts. Thus, alloys such as Alloy 59, Alloy 625 Grade I or Alloy 699 XA show an excellent combination of corrosion resistance and mechanical properties at moderate temperature levels. Moreover, due to design and application requirements, many efforts have been made during alloy development with regard to the weldability of these materials [2]. These alloys have not typically been represented in the AM community, but should be considered 'ready-to-use' for AM. Luckily, they are slowly attracting more attention.

The aerospace and energy sectors can be considered the main drivers of AM, so superalloys have inevitably been a major area of focus for the AM community. In addition, typical target parts for AM are relatively small, use expensive materials, and have a high potential for customisation to leverage AM-specific design opportunities, such as cooling channels. Because of the required strengthening γ'-phase, many of the alloys used are generally cast.

One typical differentiation between wrought and cast alloys is based on the γ'-phase volume: wrought alloys contain less than 40% of γ'-phase, cast alloys above 40% [3]. The development of the casting process allows the production not only of polycrystalline CC and DS alloys, but also single crystal (SC) materials. In this case, the whole part contains only one grain with no grain boundaries (Fig. 4). The casting process for SC turbine blades requires enormous effort and highly specific processes. These components are the leaders in the category 'processing costs of a material' and, because of their niche applications, only a small quantity of parts are produced with a high degree of customisation. These alloys contain more than 60% of γ'-phase. Based on their chemical composition, thermodynamic properties, cracking susceptibility and the current state of AM, it is not reasonable to consider the industrial application of SC alloys for AM in the near future.

The chemical compositions of Ni-base alloys can be seen, along with a typical production route, in Table 1.

Weldability, a tendency to cracking during production, and the ductility of alloys are necessary considerations which define limitations in the successful application of alloys for AM.

γ'-phase

The γ'-phase is the most important phase in Ni-base superalloys. It is a coherent phase, meaning that it has a good lattice fit with the matrix, with stoichiometric composition Ni_3Al and a crystallographic FCC structure Cu_3Au. Due to its coherence, γ'-phase precipitates homogeneously in the whole material, in particular within grains, and creates a strengthening effect. Moreover, the γ'-phase is stable up to high temperatures and is thus responsible for the superior creep resistance of Ni-base superalloys. Generally, the precipitation of γ'-phase is based on Al. Additionally, Ti, Ta and Nb can be substituted in γ' in Al lattice positions. Elements such as Co, Fe and Cr can be included in the γ'-phase instead of Ni atoms [3, 4] (Fig. 5).

	Alloy 59	Alloy 625	Alloy 699XA	Alloy 718	Waspaloy	Alloy 780	Alloy 939	Alloy 738
	WA(a)	WA(a)/(b)	WA(a)	WA(b)	WA(b)	WA(b)	CC	CC
C	max. 0.01	max. 0.03	0.005-0.10	max. 0.08	0.02-0.1	max. 0.1	max. 0.15	0.009-0.13
Cr	22-24	21-23	26-30	17-21	18-21	16-20	22-23	15.7-16.3
Ni	bal.	58-71	bal.	50-55	bal.	bal.	bal.	bal.
Mn	max. 0.5	max. 0.5	max. 0.5	max. 0.35	max. 1	max. 0.5	max. 0.5	max. 0.02
Si	max. 0.1	max. 0.4	max. 0.5	max. 0.35	max. 0.75	max. 0.3	max. 0.5	max. 0.3
Mo	15-16.5	8-10		2.8-3.3	3.5-5.0	2-4		1.5-2.0
Ti		max. 0.4	max. 0.6	0.65-1.15	2.75-3.25	0.1-1	3-4,5	3.2-3.7
Nb			max. 0.5	4.75-5.5			0.5-1.5	0.6-1.1
Fe	max. 1.5	max. 5	max. 2.5	bal.	max. 2	max. 4		max. 0.05
Al	0.1-0.4	max. 0.4	1.9-3	0.2-0.8	1.2-1.6	1-3	1-3	3.2-3.7
Zr			max. 0.1		0.02-0.12	max. 0.05	max. 0.1	0.03-0.08
W							1-3	2.4-2.8
Co	max. 0.3	max. 1		max. 1	12-15	22-28	18-20	3-9
B			max. 0.008	max. 0.006	0.003-0.01	max. 0.02	0.01	0.007-0.012
Nb + Ta		3.2-3.8				4-6	1.5-3.3	2.1-3.1

Table 1 Chemical composition of Ni-base alloys and their production route

During wrought processing, γ'-phase should be dissolved. This is beneficial because of its strengthening effect, which causes an increased material flow resistance and reduction in material ductility. With increasing γ' volume, the stability area of this phase and the solvus temperature shift to higher temperature, with the consequence that wrought processes cannot be conducted.

Another important aspect related to γ'-phase is a 'misfit'. The misfit is the difference between the lattice parameters of the matrix and of the γ'-phase and can be influenced by the chemical composition of the alloy. Misfit is responsible for morphology (spherical, cubic or plate like), precipitation kinetics, the temperature stability of γ'-phase and the main mechanical properties of an alloy [3, 4]. For example, Ti substitutes for Al in the γ'-phase and causes a strong increase in its precipitation kinetics.

The precipitation kinetics of γ'-phase is an extremely important parameter for technological properties such as forgeability, weldability and, finally, for processability in AM. Alloy 699 XA can be used here as an example for excellent material design and understanding of production and application needs. This alloy was developed for the chemical processing industry for use in extremely aggressive atmospheres at high temperatures. In this case, in addition to Cr, Al is an important alloying element in achieving corrosion resistance. For this reason, Ti and Nb contents were severely limited, in order to slow down precipitation of γ'-phase. Al can be used in VDM Alloy 699 XA as a solid solution strengthening element in the matrix.

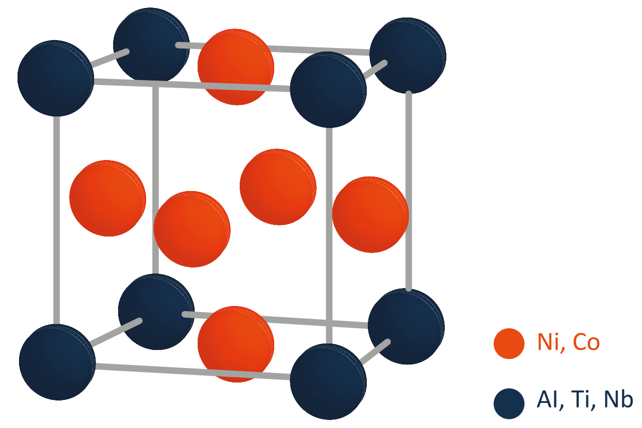

Fig. 5 Structure of γ'-phase [after 3, 5]

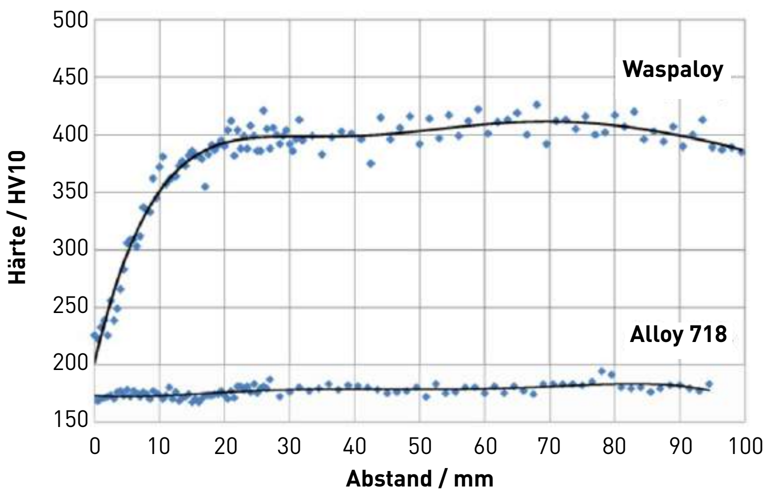

Fig. 6 Results of Jominy end quench tests for Alloy 718 and Waspaloy [5, 6]

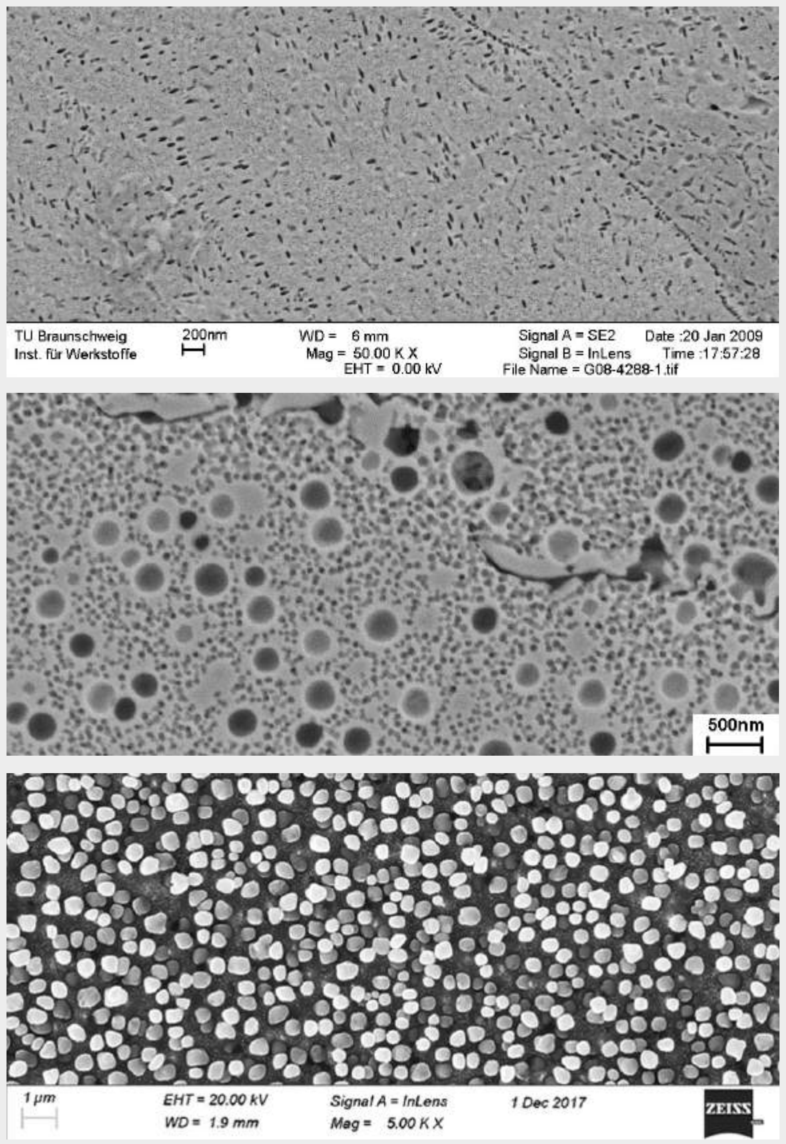

Fig. 7 Microstructure – γ'-precipitation in Alloy 718 (top), Waspaloy (middle) and Alloy 939 (bottom) (Courtesy IfW TU Braunschweig and Siemens AG)

Alloys 718 and Waspaloy can be considered as another example. Fig. 6 shows the difference between γ'-phase precipitation kinetics and the consequent influence on hardness in the two alloys. Alloy 718 shows about 10%, Waspaloy about 29% γ'-phase (Table 2).

Because of very slow γ' precipitation kinetics in Alloy 718, this alloy is much easier to process than Waspaloy. To demonstrate these differences, Jominy end quench tests can be used, according to DIN EN ISO 642. In a study, samples were heat treated before quenching at 980°C/1 h and 1080°C/1 h for Alloy 718 and Waspaloy, respectively, ensuring complete dissolution of the strengthening phases. After water quenching of one circular end, the hardness was measured as a function of the distance from this end. The results are plotted in Fig. 6. Clearly, the differences are drastic. In the case of Waspaloy, the hardness increases immediately with the distance from the quenched end, demonstrating that γ'-precipitation takes place even close to the quenched end. For AM processes, this means that Waspaloy has a higher cracking susceptibility during building and post-processing, because fast strengthening in the material causes not only a reduction of ductility but also additional stress in additively manufactured components.

Furthermore, the difference in γ' in the two alloys can be seen in their microstructures. Fig. 7 shows the microstructures of Alloy 718, Waspaloy and Alloy 939. γ'-phase size and morphology can be influenced by the chemical composition and heat treatment. Because of the γ'-phase's coherency, its size, morphology and distribution behaviour can be obtained equally in conventional and AM-produced alloys after adjustment of heat treatments.

In Table 2, the approximate amount (this can be influenced by heat treatments) of γ'-phase volume can be seen. Alloy 939 and Alloy 738 LC, which belong to the CC group and are promising for the AM community due to their high-temperature mechanical properties, are also shown. These alloys contain higher γ'-phase volumes and reveal advanced thermomechanical properties in comparison with Alloy 718 and Waspaloy, but also a higher crack susceptibility.

Depending on component geometry and complexity, it can be difficult to achieve a crack-free microstructure in these alloys using AM. In some cases, the additional process step of Hot Isostatic Pressing (HIP) is necessary. HIP processing can be used for both crack healing and homogenisation heat treatment in a single treatment.

Table 2 also shows VDM Alloy 780. This alloy is a wrought alloy and was developed with the aim of providing a material superior to Alloy 718. Its long-term operating temperature is at least 50°C higher than Alloy 718. During development work, much effort was applied to ensuring a good workability of this material. The good workability of superalloys is related, amongst other issues, to slow precipitation kinetics of the γ'-phase. VDM Alloy 780 has about 35% γ'-phase, but, because of its relatively large misfit, it shows slow precipitation kinetics. As a result, it can be processed in the AM process window of Alloy 718 without any crack formation.

Based on improved thermomechanical properties (Fig. 8), good microstructure stability at 800°C, combined with user-friendly weldability, makes this alloy a strong potential candidate as a new alloy for AM industrialisation.

Alloy 718: microstructural considerations

Alloy 718 should be considered as an important alloy for all industrial applications besides this discussion due to its complex structure. It has two strengthening phases: γ' and γ''. γ''-phase is a semi-coherent metastable phase with a stoichiometric composition Ni_3Nb and an ordered crystallographic structure DO_{22}. The γ''-phase is responsible for high strength with a good level of ductility at moderate temperature in Alloy 718. The semi-coherence causes not only high strengthening effect and slow precipitation kinetics but also rapid coarsening behaviour. Due to these phase properties, Alloy 718 can be used for critical applications only up to 650°C.

	Alloy 718	Waspaloy	Alloy 780	Alloy 939	Alloy 738 LC
γ' volume, %	10–15	25–29	30–35	ca. 35	ca. 45

Table 2 The approximate amount of γ'-phase volume

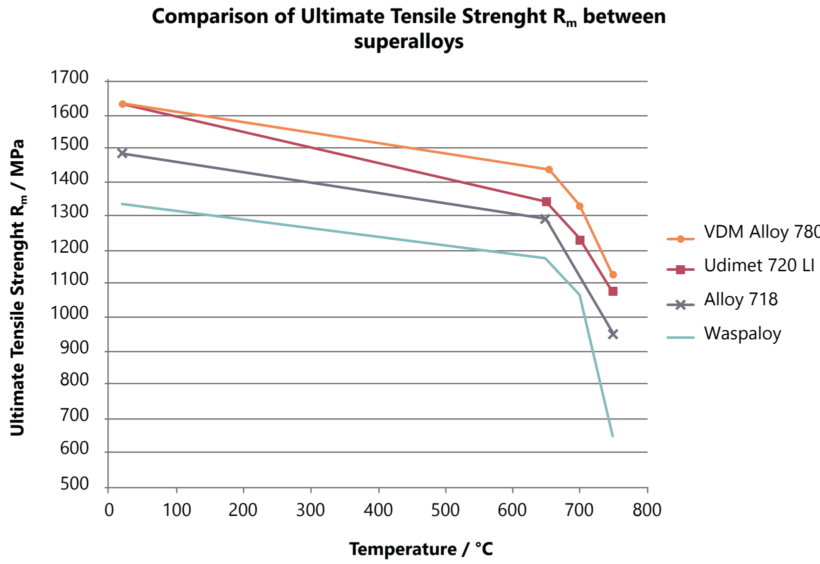

Fig. 8 Comparison of ultimate tensile strength Rm between Ni-base wrought superalloys (WAb)

Production route and technological properties vs chemical composition

Achieving advanced material properties is only possible with the careful development of production routes. In recent decades, improvements in production capabilities have led to enormous advances. From the use of extremely clean virgin material to vacuum melting and remelting technologies, the processing of Ni materials requires knowledge and allows for certification to stringent requirements. For example, Alloy 718 requires either a double-melt (melting and one remelting process) or triple-melt process (melting and two remelting processes) in order to achieve extremely homogeneous elemental distribution and the lowest level of trace elements such as S. A homogeneous elemental distribution helps in the avoidance of phase segregation behaviour. Narrow control of minor elements, such as B, C and trace elements, can greatly improve high-temperature properties.

Based on more than ninety years of experience in material production and an understanding of customer-specific needs, VDM Metals offers products and services to support AM. VDM Metals has the opportunity to use the same pre-material from conventional production as the feedstock for powder production in order to achieve the highest requirements with regard to the chemical composition of powder.

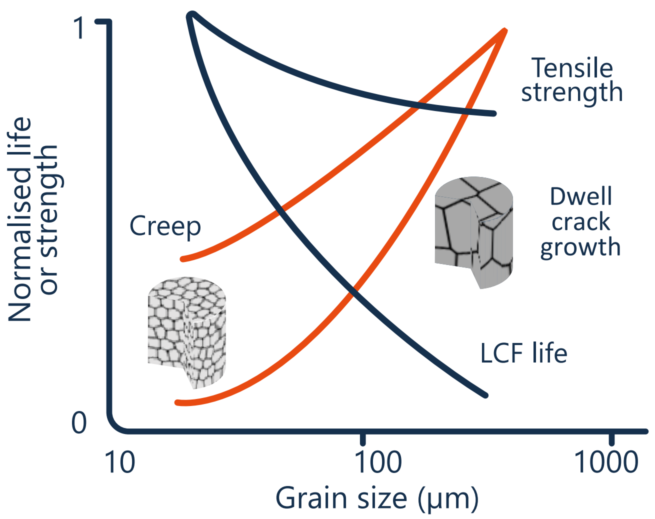

Fig. 9 Correlation trends between grain size and expected properties [after 9]

Another important aspect to understand is the correlation between chemical composition and technological features such as the mechanical properties of alloys. Taking Alloy 718 as an example, it was found that the positive effect of B on grain boundary cohesion and high-temperature properties could be improved by alloying with P. 40 ppm B and 80 ppm P increased the stress-rupture life at 200 h in comparison with the standard Alloy 718. By further increasing the B and P contents to 110 ppm and 220 ppm, respectively, the stress-rupture life can be improved by 300%. Complete research work was done with a C content of 50 ppm [7], but these results were performed on wrought components. In AM, weldability also needs to be considered: the influence of B, C and P should be considered not only with reference to the resultant material performance, but also to weldability and crack susceptibility. So, it was reported that the similar B (100 ppm), P (220 ppm) and C (60 ppm) content caused a catastrophic effect on alloy weldability, with crack susceptibility being increased [8].

For this reason, VDM Metals produces modifications of this alloy, in particular for welding products. These chemical modifications also offer an advantage for AM applications.

Similar effects of minor elements can also be seen in cast alloys. Elements such as B, C and Zr are widely used for grain boundary strengthening [1]. All these examples show that, during the component dimensioning process for AM-produced components, it is extremely important to consider not only the expected part performance level in order to replace conventionally produced components, but also the need to obtain production route and chemical composition restrictions.

Considerations of microstructure

A material's microstructure has a strong influence on both a component's properties and service life expectations. The existence and distribution of precipitates, phase stability, the amount and morphology of grain boundaries, grain size and homogeneity define a material's performance, amongst other factors.

Generally, the goal of a material producer is to process a homogeneous material independent of an application's form and size. Homogeneous distribution of precipitates such as carbides, the avoidance of local precipitation of detrimental phases and homogeneous grain size are important characteristics in defining a material's quality.

Different grain sizes are beneficial, depending on an application's requirements. The correlation between grain size and expected properties is plotted in Fig. 9. For example, because of its complex structure and high Nb content, Alloy 718 can be wrought to a small grain size microstructure of about 10–15 µm and achieves the necessary Low Cycle Fatigue (LCF) and dwell crack growth properties. This is possible due to Delta-phase (Ni_3Nb). Delta-phase precipitates at the grain boundaries pin the grains and thus avoid grain growth.

In order to achieve this fine grain size, the Nb content should be increased to the technically maximum level (about 5.4 wt.%) within the alloy specification (max. 5.5 wt.%). However, distributing Nb homogeneously is very challenging due to its segregation behaviour. This is one of the reasons why Alloy 718 should be produced by a double- or triple-melt production route.

AM processing produces a fine-grained microstructure. In fact, little Delta-phase is needed for the pinning of grain boundaries because wrought processing is no longer part of the production chain. For this reason, VDM Metals tries to discuss with its aerospace customers whether the use of a modification of Alloy 718– Alloy 718 CTP is appropriate. Originally, Alloy 718 CTP was a modification of Alloy 718 for the oil & gas industry; its chemical composition is still within the specification of Alloy 718, but it has a slightly lower Nb and C content. As a result, processability improvements (especially for very complex and large components) can be achieved by reducing crack susceptibility while retaining similar mechanical properties.

Microstructural considerations for Waspaloy can demonstrate a correlation between grain size and stress-rupture test results. Material with a grain size of about 30 µm shows an average time to rupture of about 25 h. The increase of grain sizes to 210–230 µm can improve the time to rupture to about 80 h and higher.

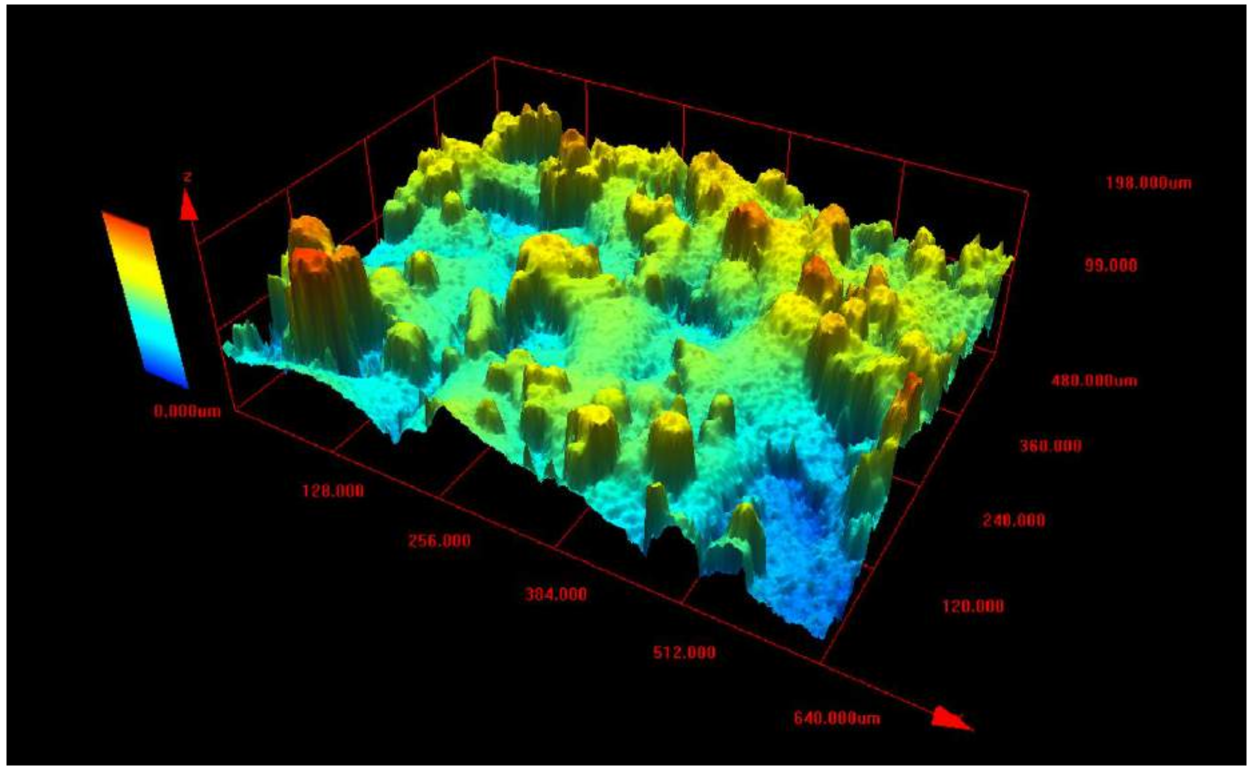

Fig. 10 Surface structure of a component with non-optimised process parameters. Laser scan microscope, mag. 20x, measured surface area 0.64 x 0.48 mm² (Courtesy Fh IST)

Additionally, an important aspect not considered yet should be highlighted – surface characteristics and their impact on the part's lifespan, especially if a component is to operate under fatigue load. Surface defects can have a strong detrimental notch effect and, consequently, dramatically reduce time to failure. This aspect has begun receiving attention recently and is now being addressed in the AM community. Fraunhofer Institute for Surface Engineering and Thin Films (IST) has been working on a standardisation routine for the surface qualification of AM components. In Fig. 10, the surface of an AM-produced part with non-optimised process parameters can be seen. Usually, overhanging surfaces provide the worst surface quality. Hence, internal channels with an overhanging surface that cannot be smoothened provide an issue for component fatigue life. The probable surface defects and their influence on fatigue properties should be investigated before new component implementation in the field. Knowledge of microstructural considerations helps VDM Metals to customise both the chemical composition of materials and the production route to achieve the best possible performance required by the customer.

> *"Surface defects can have a strong detrimental notch effect and, consequently, dramatically reduce time to failure. This aspect has begun receiving attention recently and is now being addressed in the AM community."*

Weldability of Ni-base alloys

A lot of research and industrial work has been conducted in the area of weldability of Ni-base alloys. Wrought alloys (especially WAa and some WAb) were developed with the attention on weldability. Cast alloys are more challenging, in respect to their weld characteristics. Fig. 11 summarises the relationship between alloy chemistry and crack susceptibility, based on the γ'-phase amount that can be correlated to Al and Ti. Elements such as Nb and Ta are also substituted in γ'-phase. However, they do not influence precipitation kinetics as strongly as Ti. The susceptibility of the alloys to strain-ageing and ductility deep cracking grows with increases in the volume fraction of γ'-phase.

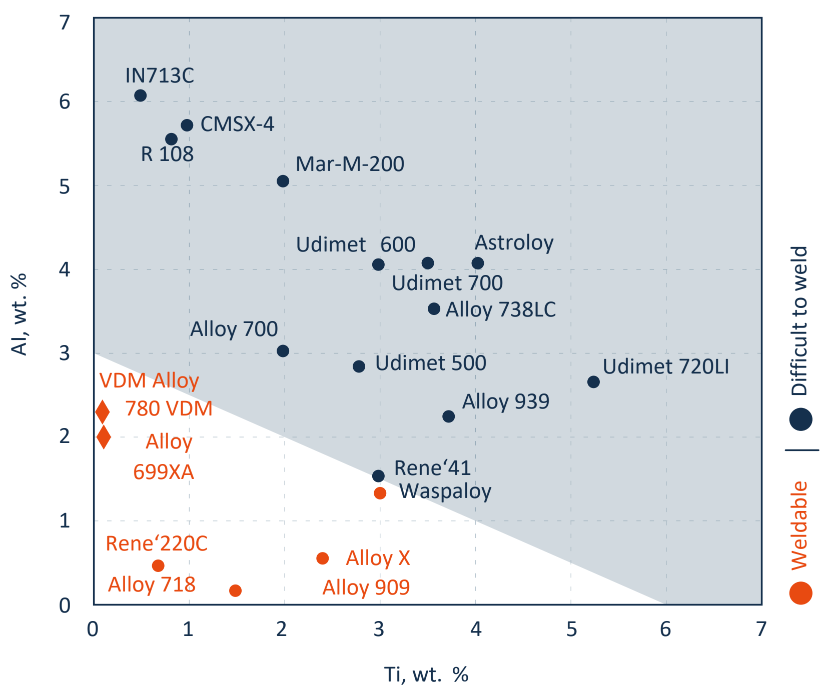

Fig. 11 γ'- phase related to hot cracking [11]

Fig. 11 cannot indicate the influences of detrimental elements such as S and grain boundary strengthening elements such as B, C, Zr and P and also does not show other cracking mechanisms (liquation or solidification cracking). Both of these cracking mechanisms can be related to the chemical composition and to process conditions.

> *"...weldability can be a general term and can have different meanings from different sources... Weldability here does not guarantee that the alloy would be suitable for an AM part with complex geometry and large variations in wall thicknesses."*

Alloy 699 XA deserves special attention in relation to weld characteristics. The alloy contains a relatively high amount of Al (2 wt.% – similar to Waspaloy) and limited amounts of Ti and Nb. It was possible to reduce the stability area of γ'-phase and its precipitation kinetics. This alloy shows excellent creep properties, in combination with user-friendly technological properties, including weldability.

The AM process has many similarities with a conventional welding process. Simply put, the AM process can be described as a multi-layer micro-welding process. Because the AM process is usually carried out under well-controlled conditions, such as the use of protective/shielding gas, a minimised size of the molten pool and a maximised cooling rate, AM can have an advantage over conventional welding. However, there can be many hidden risks when choosing AM-relevant components. Fig. 11 (and similar graphs from the literature) shows the general weldability of Ni-base superalloys – especially high γ' containing materials. However, weldability can be a general term and can have different meanings from different sources. In the case of cast alloys, 'weldability' means joint welding and/or repair welding [12]. Weldability here does not guarantee that the alloy would be suitable for an AM part with complex geometry and large variations in wall thicknesses.

Limitations and opportunities of Ni-base alloy application in AM

This article has discussed different material characteristics related to chemical compositions and production techniques. Primarily, we have addressed the need to consider the material and its characteristics carefully for successful implementation in the AM process.

The material characteristics summarised in Fig. 4, including weldability, crack susceptibility, microstructure and expected level of component performance are necessary considerations, which define, in some cases, the limitations of successful alloy applications for AM.

The following questions should be considered during this process:

1. Is the selected material weldable? Is it possible to produce a crack-free structure with current AM machines?
2. Is it possible to expect the same component performance level based on a change to the AM process? If not, can another alloy be applied with an expected lower performance level, but with better processability (weldability)?
3. How important is the surface condition for the component's performance? Does a component design allow a surface treatment?

This article has focused on materials which are already implemented in AM or are expected to be implemented in AM production. In other words, no further alloy development is needed.

AM has changed not only the industrial landscape of manufacturing techniques, but also the daily life of the material producer. In conventional production routes, material producers are usually the breakpoint in the component production chain. All questions regarding homogeneity, product sizes, workability and achievement of microstructural requirements are answered by the material producer for certain alloys.

Now, we are able to produce any powder material, but the question of successful component production is relocated to AM part producers. For this reason, VDM Metals always tries to discuss its partners' and customers' goals with them ahead of material production, in order to prevent unnecessary efforts, balance expectations, and meet their requirements.

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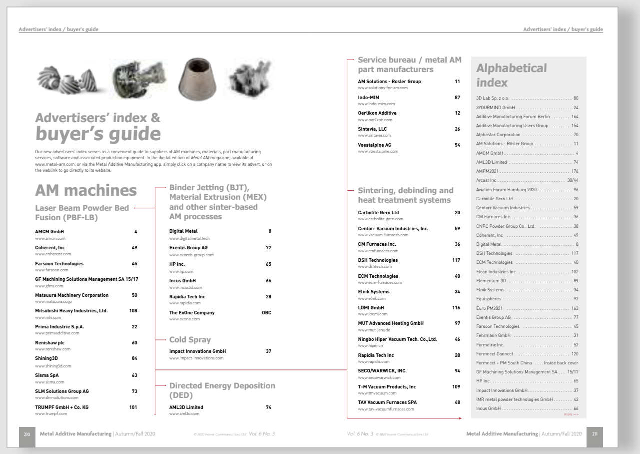

Metal Additive Manufacturing in New Zealand: An overview of research, commercial activities and strategic initiatives

For a country with a total population significantly smaller than that of cities such as London or New York, New Zealand is 'punching above its weight' when it comes to developing expertise in Additive Manufacturing and educating design engineers in how to use it. Olaf Diegel, a professor at New Zealand's University of Auckland and associate consultant at Wohlers Associates, and Terry Wohlers, president of Wohlers Associates, report on AM activities and highlight a novel range of successful commercial applications.

New Zealand, a small country in the Pacific with a population of just under five million, has always had a reputation of 'number 8 wire' problem solving. This refers to the ability of finding ingenious solutions to problems with limited resources, using whatever is available - with number 8 wire being commonly used by farmers for fences. Consider what might happen when exposing them to advanced manufacturing technologies such as Additive Manufacturing.

New Zealand has embraced AM in a way that punches above its weight on the international scene. Since the earliest machines began to appear in the country in the mid-nineties, the technology has been spreading at a rapid rate. More importantly, the adoption of AM by industry is now beginning to have a serious impact; because of its geographic isolation, AM has also proven to be a key technology for New Zealand in replacing the need to import parts from around the world.

Commercial metal AM service providers

New Zealand has two commercial service providers (aka, bureaus) that offer metal AM as a service to companies in New Zealand and around the world.

RAM3D, a world-class service provider based in Tauranga, is the largest metal AM service provider in Australasia. It has played a vital role in evangelising the technology in New Zealand by producing metal parts for a wide range of customers and having a strong focus on raising awareness.

Fig. 1 Oceania Defence firearm suppressors (Courtesy RAM3D)

Fig. 2 Satellite bracket produced by EBM (Courtesy Zenith Technica)

The company has also helped educate many on the importance of Design for Additive Manufacturing (DfAM) and moving industry from prototyping to production. RAM3D currently operates eight metal AM machines, including seven from Renishaw. The company offers parts in 15-5 PH and 316 stainless steels, Inconel 718, titanium (Ti6Al4V) and maraging tool steel.

In collaboration with Oceania Defence, it has recently produced more than 1,000 firearm suppressors for the Australian Defence Force. A suppressor, sometimes referred to as a silencer, reduces noise when firing rounds of ammunition (Fig. 1).

Zenith Technica is one of the largest service providers to offer Electron Beam Powder Bed Fusion in Australasia. It operates three Arcam Q10 Plus and two Arcam Q20 machines from GE Additive. It produces parts in titanium and has manufactured more than 400 components that are now in orbit (Fig. 2). Zenith Technica is working with Massey University to create an AM materials testing lab to serve the industry.

Strategic Initiatives: Government and academic investment and facilities

The majority of New Zealand's academic institutions and Crown Research Institutes have invested considerably in Additive Manufacturing over the past decade. Crown Research Institutes date back to 1992 and most were created from elements of the former Department of Scientific and Industrial Research, as well as parts of other government departments. At least five of the country's eight universities currently have metal AM machines, either directly or in collaboration with research institutes, and all have some form of polymer AM.

Fig. 3 Air New Zealand monitor bracket, with weight reduction of 40% (Courtesy AddLab)

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Research is being conducted in new materials for metal AM and DfAM, including methods, topology optimisation, lattices and other light-weighting strategies. Research is also underway in software for Industry 4.0 and AM, new AM technologies, AM post-processing, surface finishing techniques, and automation.

Callaghan Innovation, the country's largest Crown Research Institute, has invested heavily in its AddLab, an AM facility that allows companies to explore new business opportunities and find new solutions to their R&D problems. The lab is equipped with a range of metal and polymer manufacturing processes and provides access to Callaghan Innovation's wide range of research expertise. In 2019, it produced a monitor bracket for Air New Zealand that reduced weight by 40% compared to the conventionally manufactured part (Fig. 3).

In 2019, the Creative Design and Additive Manufacturing (CDAM) Lab was launched at the University of Auckland. New Zealand government's Entrepreneurial Universities funding scheme, along with the University of Auckland, are investing NZ$10 million in the lab over a period of four years. The CDAM Lab is equipped with comprehensive metal and polymer AM capabilities and aims to alter the way AM is implemented in industry. The goal is to transition the use of AM from mostly prototyping to high-value methods of manufacturing. The CDAM Lab specialises in DfAM, light-weighting, topology optimisation, and educating students and industry on how to use AM in ways that add value to their product offerings (Fig. 4).

The New Zealand government has strategically invested in a range of research projects related to AM. An example is the National Science Challenges, funded by the Ministry of Business, Innovation and Employment, which is investing NZ$1 million annually for three years in a project titled "Additive Manufacturing and 3D printing of Bio-composites." The expected outcome is a range of new bio-composites for AM.

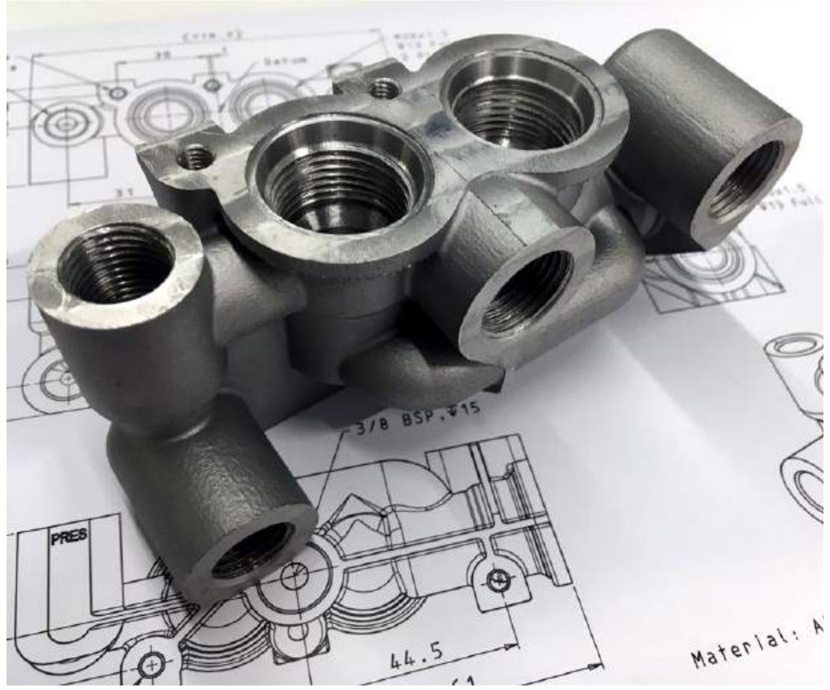

Fig. 4 High-pressure 600-bar manifold in AlSi10Mg and representing 85% weight reduction, compared to conventional steel block manifold (Courtesy CDAM Lab)

Industrial adoption

Rodin Cars

Rodin Cars designs and builds high-performance cars for the track and road. They have been an avid proponent of advanced manufacturing and have a

Fig. 5 FZed exhaust collector additively manufactured in titanium and PVD-coated in titanium nitride (Courtesy Rodin Cars)

Fig. 6 Rocket Lab's Rutherford metal AM engine (Courtesy Rocket Lab)

Fig. 7 Kiwi Klimbers toothed cams for climbing equipment (Courtesy of RAM3D)

comprehensive in-house metal and polymer AM workshop. It is used to manufacture many of their production parts, including exhaust collectors, mufflers, uprights, hubs, and brackets, by polymer and metal Laser Beam Powder Bed Fusion (Fig. 5).

Rocket Lab
Rocket Lab manufactures and operates a lightweight orbital rocket known as Electron, which provides dedicated launches for SmallSats and CubeSats from New Zealand. The company is now headquartered in the U.S., but Rocket Lab was founded in New Zealand in 2006 by engineer Peter Beck, and with much of its operations and manufacturing remaining in New Zealand. Rocket Lab relies heavily on metal AM for producing several of its rocket components, including its Rutherford engine.

Kiwi Klimbers
Kiwi Klimbers is a New Zealand company that produces climbing accessories for arborists. Qualified arborists require a range of climbing and rigging equipment for the dismantling of trees. Kiwi Klimbers, using the services of RAM3D, have been producing their spikes, also known as gaffs, and toothed cams (part of their pulley system) in titanium using AM.

Fig. 8 Radic Performance brake caliper (Courtesy Radic Performance - Photo: Cameron Baker)

Radic Performance
Radic Performance is a startup company specialising in the manufacture of advanced mountain bike parts. It is the creation of Taylor Grey and Jake Powell, two mechanical engineers from the University of Auckland with a passion for design, engineering, and mountain biking. The company's flagship product is the Gamma light-weight aluminium additively manufactured brake calliper.

Ossis
Since 2007, Ossis has been using AM to produce patient-specific orthopaedic implants, specialising in solutions for acetabular revisions and pelvic tumours. Acetabular implants for severe bone loss and pelvic dissociations are time-consuming and challenging surgeries without a custom solution. Metal AM provides the perfect manufacturing platform for producing patient-specific implants.

Victory Knives
Victory Knives manufactures products used by nearly all major meat and fish processing companies in New Zealand and Australia. Commercial divers around the world use the company's diving knife product. For Team New Zealand and the Americas Cup yacht race, Victory Knives and RAM3D designed a state-of-the-art knife that is light weight but strong enough to cut through marine ropes. The knife and sheath were additively manufactured in Ti6Al4V titanium alloy and super-coated to produce a knife that can cut strong marine ropes in one blade stroke, compared to existing knives that required up to ten strokes. These knives are now commercially available from knife shops in New Zealand.

The New Zealand art community
Several New Zealand artists have been actively exploring how AM can influence their practice. Gregor Kregar, a prolific user of AM, has been actively working with the CDAM Lab to push the boundaries of metal AM in new and exciting ways.

Fig. 9 Acetabular implant (Courtesy Ossis)

Fig. 10 Victory Knives Team New Zealand Americas Cup knife (Courtesy RAM3D)

Fig. 11 Gregor Kregar dinosaur family built in aluminium (Courtesy CDAM Lab)

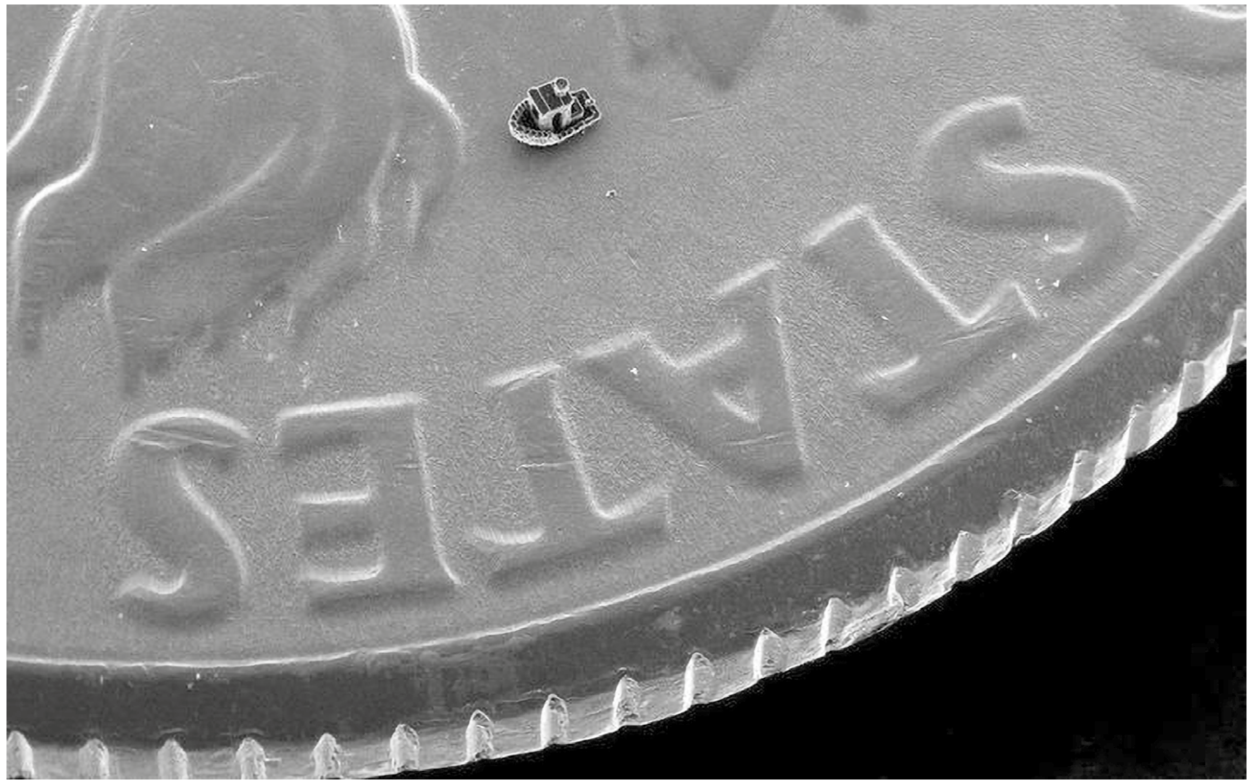

Fig. 12 A Benchy calibration part manufactured using the LRM process on top of an American quarter coin (Courtesy Micromaker)

Micromaker

Miniaturised structures are vital components in an increasing number of devices and manufacturing applications. Callaghan Innovation's scientists have rethought how to produce these structures using a method of Additive Manufacturing in a cost-effective way. The result is its patent-pending Laminated Resin Printing (LRP) process, a new method of AM for prototyping electronics, microsensors, IoT components, and optical devices. The Micromaker team is using LRP to produce a range of structures for a variety of applications (Fig. 12).

DfAM courses

An area of growing expertise in New Zealand is DfAM. The University of Auckland CDAM Lab, RAM3D, Callaghan Innovation, and others are working with companies to educate them on how to design for AM that adds value. Staff at the CDAM Lab, for example, in collaboration with Wohlers Associates and others, have delivered a range of DfAM courses to organisations around the world. These multi-day courses feature hands-on exercises and practice using best-in-class methods and software tools.

DfAM courses have been conducted for Alfa Laval, Callaghan Innovation, Central University of Technology, GKN Aerospace, Lund University, Materialise, NASA, New Zealand Defence Force, Protolabs, RMIT University, Siemens, University of Auckland, Volvo, ZAL Centre for Applied Aviation Research, and others. The courses have engendered a seminal DfAM textbook entitled *A Practical Guide to Design for Additive Manufacturing*, published by Springer.

Summary

New Zealand continues to advance its adoption of AM. Several companies and other organisations are performing world-class work in the design of products for AM. Support by government entities and universities is helping to bridge the gap from using AM principally for prototyping to series production and custom product manufacturing. Organisations in a range of industrial sectors see AM as a key to offering products that set them apart from the competition. Increasingly, they recognise the importance of AM and its growing significance around the world.

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Hybrid inserts for mould and die production: How workflow optimisation can help make the business case for AM

The use of metal Additive Manufacturing for the production of injection moulding tools that have been optimised by conformal cooling is growing internationally. For many companies, however, the main obstacles to adoption are not concerns about material properties or apprehension about unfamiliar processes, but simply initial cost - the tooling industry is extremely competitive and AM inserts can be expensive. Here, 3D Systems' Mark Cook and GF Machining Solutions' Dogan Basic present a case study from leading toolmaker and injection moulding specialist TK Mold that highlights how such inserts, when efficiently manufactured, can reduce overall manufacturing costs and improve part quality.

Injection moulding is, without a doubt, one of the most widely-used and successful manufacturing processes. It is most commonly applied to the production of thermoplastic and thermosetting polymer parts, using moulds manufactured from steel alloys, which allows for, in many cases, millions of injection cycles in serial production. The process entails injecting molten material into a cavity shaped like the final part, followed by rapid cooling to ensure hardening. The cooling time must, however, be sufficient for the part to properly solidify so it can be ejected with limited deformation. The cooling aspect of the injection cycle is, therefore, a key factor in achieving high-quality parts while keeping the cycle time efficient. Cooling of the mould insert is achieved by circulating a cold fluid (typically water or oil) through the mould to cool the mould surface.

Additive Manufacturing has proven to be a valuable solution for the optimisation of the cooling process, because it allows for the creation of cooling channels that closely follow the moulding surface – this is known as conformal cooling. These moulding surfaces can be highly complex and are therefore difficult to cool. AM enables the design and manufacture of parts that incorporate cooling channels that would be impossible to produce using conventional manufacturing technologies.

With AM, cooling channels can be set at a constant distance from the surface of the part to achieve uniform cooling, and deliver two main advantages:

- Cooling time can be reduced due to more efficient heat dissipation, which reduces the time required to harden the part
- The part will cool uniformly, preventing the warping and deformation that can arise from an uneven temperature gradient

Fig. 1 The TK Mold factory in Shenzhen, China. In this location, moulds are manufactured with more than fifty machine tools from GF Machining Solutions, including the DMP Flex 350. Plastic parts are also injected in this location

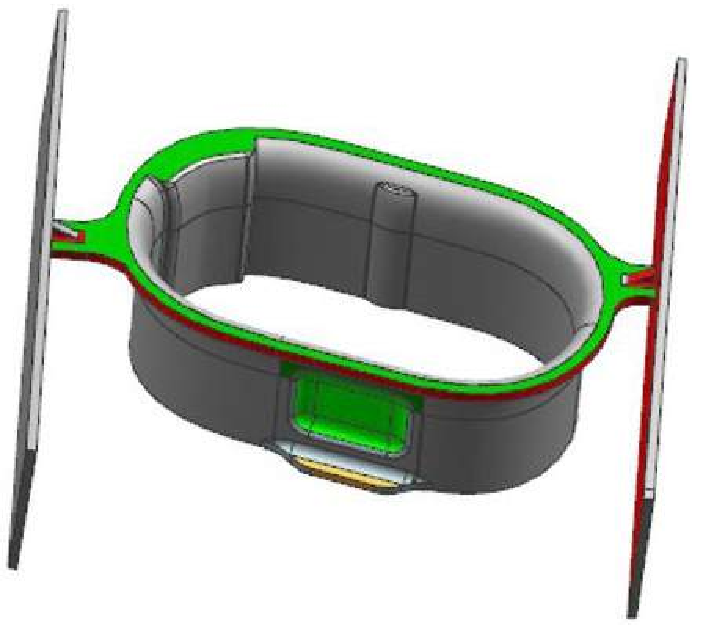

Fig. 2 A visualisation of the final plastic part in this case study: a support structure for fixing a smartwatch to the inside of its packaging

Although the benefits of AM for efficient cooling are well-documented and have often been presented, adoption has been slow due to initial concerns about material properties, costs, and a lack of knowledge on how to apply the technology in a market segment that is often regarded as quite traditional. In addition to the fact that mould makers are often risk-averse, they are generally under tremendous pressure to manufacture injection moulds at the lowest price possible. The use of additively manufactured inserts in moulds offers significant benefits, but also comes with additional costs. Mould manufacturers must, therefore, demonstrate the value of the additional investment to the final customer. This is clearly illustrated by the fact that adoption of conformal cooling has been higher in companies which manage both mould production and injection moulding. These companies fully understand the value, and actively incorporate AM into their manufacturing workflow, demonstrating return on investment (ROI) and increasing their use of the technology as they further master the process.

The importance of technology integration

While the adoption of AM is increasing, many manufacturers are still reluctant to take this step. One of the biggest challenges in using AM is the need to integrate the new process into manufacturing workflows built on well-established, mature manufacturing technologies. In particular, in the mould-making segment, additively manufactured components and inserts require – in nearly all cases – additional subtractive machining operations to achieve the very high surface quality required on the mould surface.

As a result, manufacturers expect metal AM providers' solutions to cover the complete workflow, from design to final part, to deliver moulds that meet precise specifications. Software, AM machines, materials, subtractive technologies, automation and clamping solutions must be combined to provide an efficient ecosystem to drive down costs and complexity.

Rethinking mould design with AM at TK Mold

To demonstrate the benefits AM can bring to the injection moulding process, this article reports on how TK Mold, a customer of GF Machining Solutions' subtractive and additive systems headquartered in Shenzhen, China (Fig. 1), is using Laser Beam Powder Bed Fusion (PBF-LB) technology and, specifically, how workflow optimisation was able to support the business case for AM mould inserts with conformal cooling.

Established in 1983, TK Mold is a subsidiary of TK Group (Holdings) Limited, a well-regarded manufacturer of plastic moulds and parts for a variety of industries including healthcare and consumer goods. TK Mold manufactures plastic moulds and parts for mobile phones, healthcare applications, smart homes, packaging and precision electronics. In addition to its Shenzhen base, TK Mold has three other factories in Suzhou and Huizhou, China, and Braunschweig, Germany.

With thirty-seven years of mould design and fabrication experience, the company is dedicated to providing the best performance injection mould solutions and final plastic parts. As both a mould maker and a parts producer, the company quickly grasped the advantages of metal AM and invested in it to develop mould inserts with conformal cooling channels. TK Mold's mould-making and injection capabilities uniquely position the company to benefit from using these inserts to produce final parts – the benefits include productivity and quality gains, as well as the ability to deliver more efficient solutions to its customers.

TK Mold applies AM to produce mould inserts where conventional subtractive machining is unable to achieve the necessary quality and productivity at a reasonable cost. The example presented here is common in the packaging sector – particularly for products linked to the information and communications technology (ICT) industry. Used as an element of the packaging box of a smartwatch, the plastic part is the support for fixing the watch inside the box (Fig. 2).

As the part is produced in large series, the packaging and the support must also be produced in large series. The challenges therefore relate to cost and productivity. As the final product is considered a high-value item, there are also requirements in terms of the support's aesthetics.

The challenges of this type of packaging component are quite common, and the number of similar applications is infinite. Concerning this application, TK Mold faced three critical manufacturing challenges:

- Productivity targets and minimum cost per part could not be reached with conventional mould insert manufacturing processes
- Non-conformal cooling channels resulted in suboptimal thermal regulation
- Costly assembly of mould insert components was required to improve the cooling via traditional manufacturing methods

To improve the process, TK Mold's engineers focused only on the improvement of the most critical mould inserts: those with the most influence in terms of cycle time or part quality. This is where the ROI in metal AM is the highest.

Efficiently integrating AM in the manufacturing process of a mould insert

GF Machining Solutions and 3D Systems have partnered to develop an end-to-end solution that enables manufacturers to more efficiently produce complex metal parts. This is accomplished by seamlessly integrating metal AM into existing manufacturing processes through the development of an optimised workflow. Here, each step of the workflow is illustrated as it applies to the custom solution created for TK Mold.

Fig. 3 The conventional cooling channels in the section of the mould that is being manufactured subtractively

Design

Through the adoption of AM, new design possibilities are available to mould manufacturers. Such design freedoms must be mastered, bearing in mind both the layer-by-layer manufacturing approach as well as the raw material involved in the process – the fine metal powder. These two elements result in a very limited set of constraints to the part design, mainly related to overhang regions, feature size and ease of powder removal. For additively manufactured parts with conformal cooling channels, such constraints may be easily overcome by adhering to a few design guidelines, which have become well-established over the years.

First, the size and shape of the internal channels have design constraints. Large overhanging regions require support structures that are impossible to remove from the inside of the part after Additive Manufacturing. Channel diameters are thus constrained in size and self-supporting channel shapes (such as diamond, elliptical, or teardrop, among others) are preferable to the traditional round cross-sections typical when straight-drilled holes are used by traditional methods (Fig. 3).

Additionally, some traditional design considerations for the mould-making sector are still valid in the case of additively manufactured moulds and dies. These mainly concern the minimum distance of channels from part walls for structural resistance, as well as the pressure drop throughout the whole channel path, and ease of cleaning (both mostly influenced by the channel section size, path and number of branches). Leakage is not an option. In these cases, the minimum distance should be large enough to safely process and post-process the mould. Thus, from the design phase, risks can be greatly reduced.

The generation of conformal cooling paths in adherence to the above design guidelines may quickly become very time-consuming with traditional computer-aided design (CAD) software tools. For this reason, a dedicated software solution such as 3DXpert®– and particularly its Additive Moulding Add-on – is very

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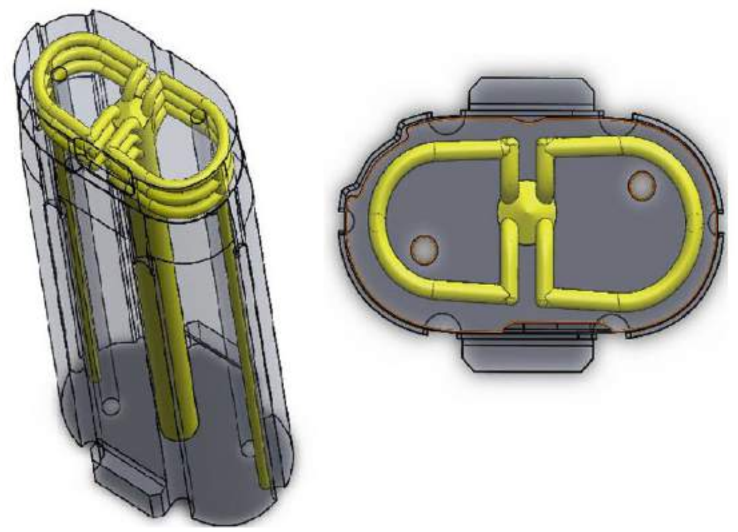

Fig. 4 The mould insert showing the placement of the conformal channels

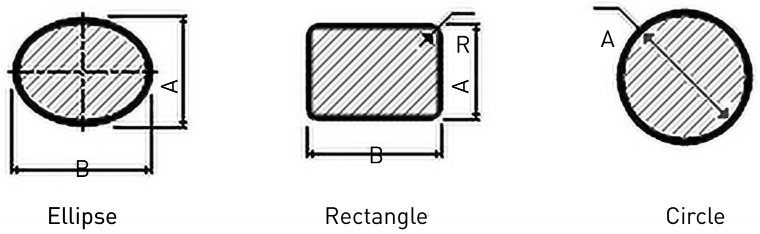

Fig. 5 Shape options for cooling channels in 3DXpert's Additive Molding module. This module allows mould makers to create conformal cooling inserts, combining traditional and conformal cooling where appropriate

helpful for mould designers and tooling manufacturers in optimising part quality and reducing design and manufacturing costs.

This add-on makes it possible to create conformal cooling inserts and to combine traditional and conformal cooling where appropriate (Fig. 4). This is made possible by a unique set of functionalities that save the user hours of design work before moving to the simulation-based verification and validation stages of the mould design:

- Automated as well as manual generation of the conformal cooling path – essentially generating the channel path based on a set of input data from the user
- Easy and fast creation of channel geometry (Fig. 5)
- Analysis of channel overhang areas
- Analysis and optimisation of channel distance from part walls
- Colour map of channel distance from active surfaces

3DXpert includes tools such as the 'heat map', which allows designers to quickly evaluate the homogeneity and efficiency of the cooling. This does

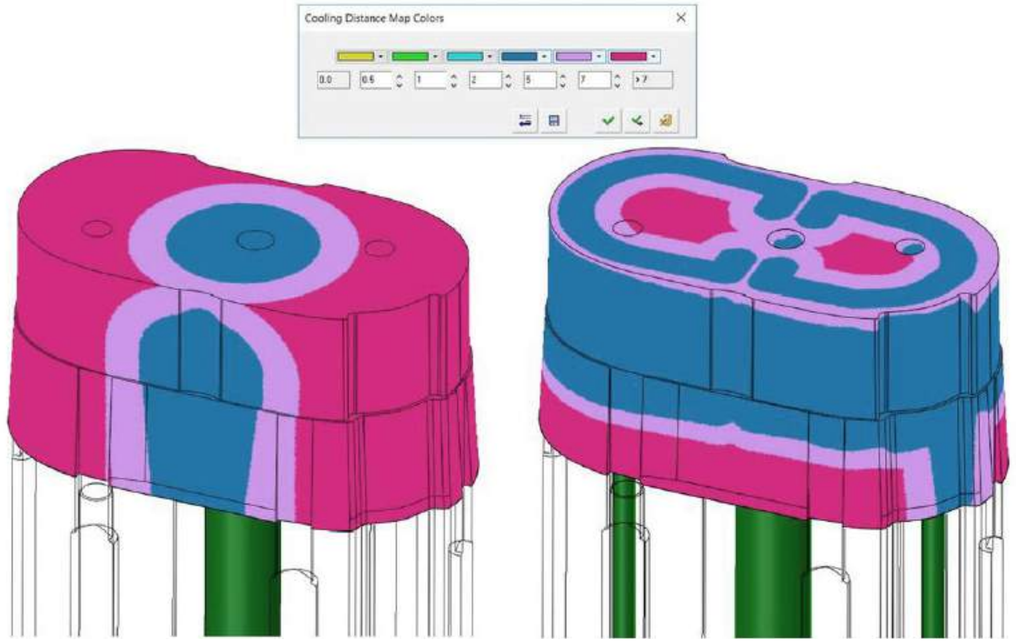

Fig. 6 Heat map comparison for conventional vs. conformally cooled inserts. The heat map tool in 3DXpert allows designers to quickly evaluate the homogeneity and efficiency of the cooling early in the design process

not replace more complete rheology simulations, but allows the user to quickly assess the design quality early in the process.

Simulation

Before starting to build a mould insert in an AM machine, performing rheology thermal assessments is often done to detect where potential issues may arise. This makes it possible to interpret whether the optimised channels will be effective, particularly whether there is a need to improve the temperature homogeneity to reduce hot spots (Fig. 6).

In Fig. 7, we can observe the temperature inside the 'outer channels', which transport the coolant in the insert. In this image, the latter is located in the middle in a grey colour. We can already see a colder temperature inside the channels, but also more homogeneity between the conventional approach and the conformal approach.

In Fig. 8, we can analyse and compare the potential hot spots during injection with or without conformal channels. Here again, we observe a decrease in the temperature of the hot spots, going for example from 96°C to 86°C. Most important is the much more even temperature gradient, which is the critical factor influencing the quality

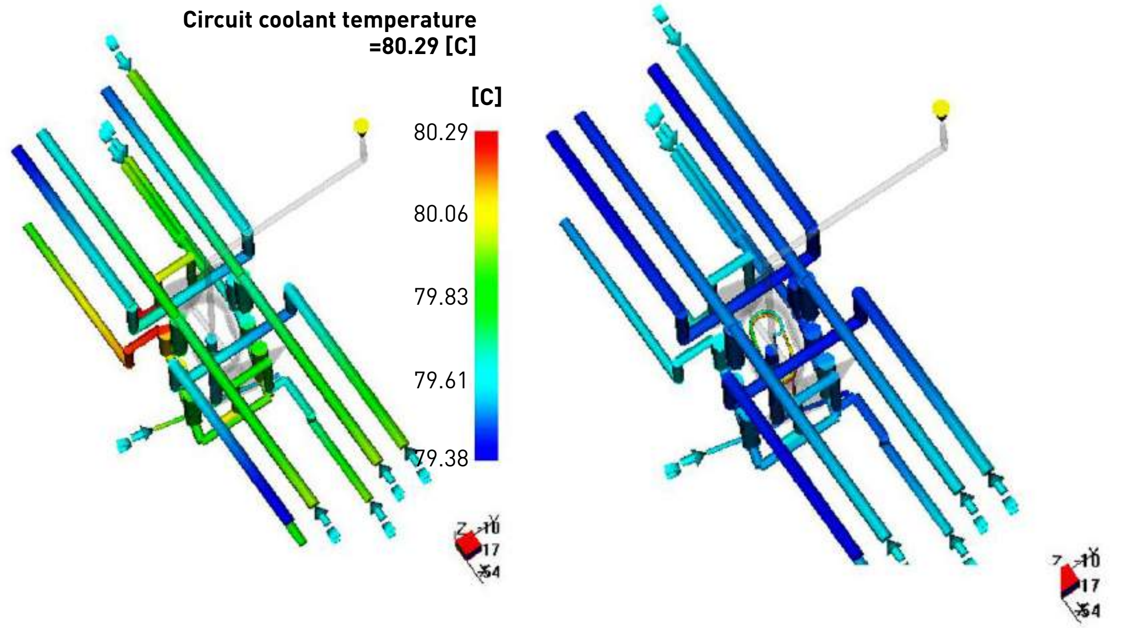

Fig. 7 Simulation of rheology thermal performance, here of the outer channels, helps to improve temperature homogeneity to reduce hot spots

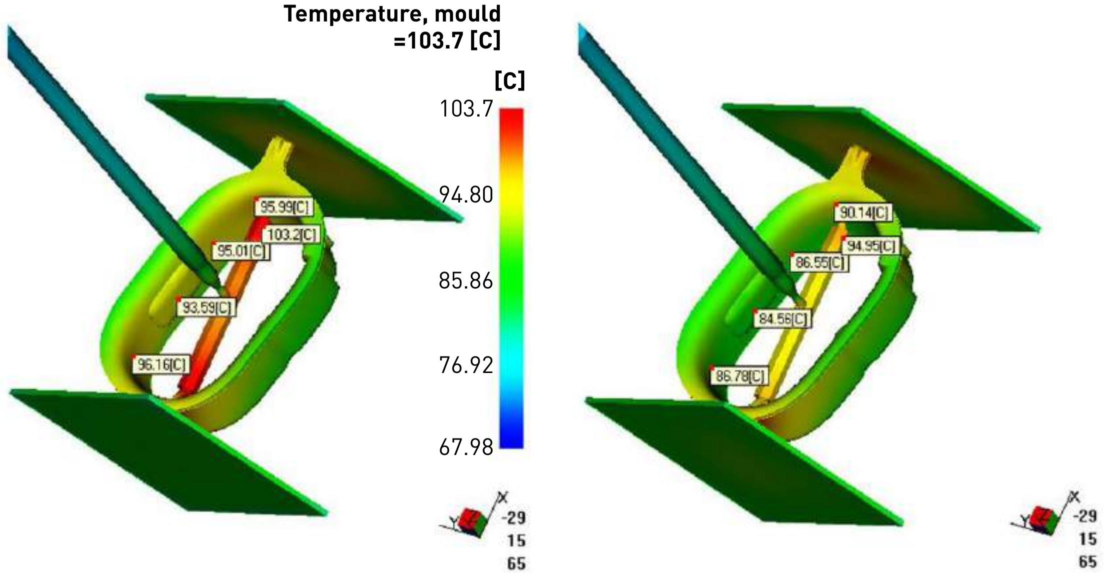

Fig. 8 Comparison of potential hot spots during injection with (right side) or without (left side) conformal cooling

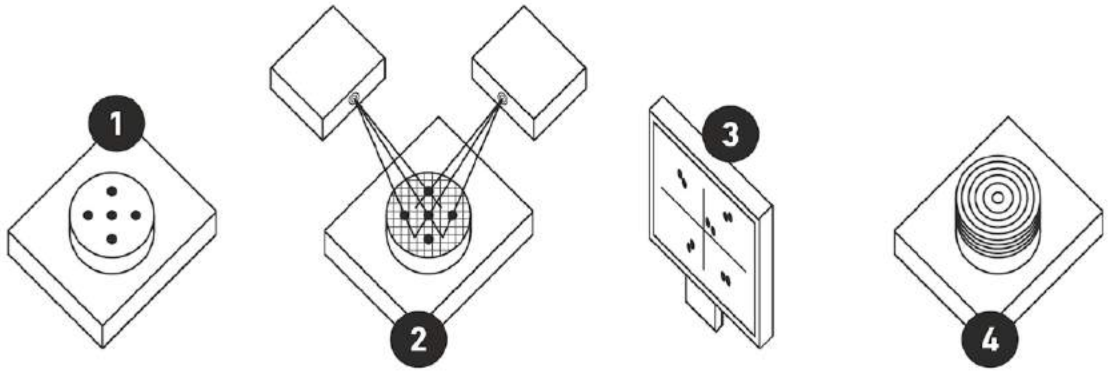

Fig. 9 Key to successful hybrid manufacturing is an effective referencing process: data from light-sensing hardware

of the part in terms of warpage and distortion. In this specific case, a productivity increase is the main goal, but customers are always looking for quality improvements.

Today, these simulations are more reliable as rheology models have improved, taking cooling geometries into consideration; this type of data was previously not easy to simulate.

The simulation tools allow the designer to better predict the real-life efficiency, and thus more confidently design, the conformal channels placed inside the mould insert. It theoretically validates that the channels will have a positive impact on the injection process and, ultimately, on the plastic part. TK Mold uses these types of tools to demonstrate the added value of conformal cooling to its customers (internal or external) before the manufacturing of a mould.

Hybrid manufacturing

While AM technology is helping many companies in the mould and die sector achieve new cost savings and efficiencies through conformal cooling, the economic viability of many applications requires other approaches. Indeed, for structural reasons, these applications typically include parts that require large amounts of mould material – in the case of AM, metal powder. This can make large parts costly to manufacture, as an AM insert's price will be directly linked to the volume of material required for the AM process.

To overcome these challenges and find ways to profitably integrate this new technology into their operations, manufacturers can pre-machine a so-called preform and then, using AM, produce a portion of the part with value-added features in the location where the technology can prove most beneficial.

In addition, when using AM directly on a section of the final machined geometry, the costly cutting operation needed to remove the insert from the build platform is eliminated. This combination of subtractive and additive technologies – which is proving cost-effective – results in what is now commonly referred to as a hybrid part.

Unlike many AM applications, here the manufacturing process begins with the machining of the preforms. In this case, the outer geometry of preform is typically produced by cutting a blank plate with wire electrical discharge machining (EDM). Ejection holes and cooling channels are, on the other hand, previously machined in the blank by deep-hole drilling. It is crucial that all preforms are identical in terms of height, since the Additive Manufacturing process must be conducted on a level plane.

Beginning the process with subtractive machining, however, introduces new positioning and referencing challenges. This type of hybrid process must therefore start with the preform fixed on the build platform before the intended AM section is aligned by using a referencing system. The use of this type of referencing is especially challenging because, unlike in CNC machining, in an AM machine there is no physical link between the optics and the target substrate.

Instead, manufacturers generally have to rely on visual alignment or external coordinate measuring machines (CMMs) to confirm positioning accuracy. Both techniques are time-consuming and, in the case of simple visual alignment, prone to operator error. With variances in excess of 100 µm, these techniques are also unable to provide the accuracy required for most final applications.

To overcome this issue, GF Machining Solutions and 3D Systems have developed a software solution that leverages the power of the meltpool monitoring hardware available on the partners' DMP series of metal AM machines. In machines such as the DMP Flex 350, DMP Monitoring in-process monitoring software acquires meltpool data during the build process to detect potential defects such as lack-of-fusion pores.

The DMP Calibration tool function exploits this light-sensing monitoring hardware for another purpose: scanning preforms to identify pre-machined locating holes in the part surface. The contrast in light reflection between the part surface and such holes allows for an extremely reliable method of establishing the precise location of the preform on the build platform (Fig. 9).

With user-defined threshold values, this referencing process offers exceptional repeatability and accuracy without any risk of human error. Furthermore, the use of the laser enables the referencing of multiple parts on the same build platform in a single operation, further accelerating high-volume production. Thanks to this optical system's exceptional level of accuracy, the final quality of the referencing operation, and thus of the resulting hybrid parts, is higher as well.

Lastly, the use of dedicated tooling and fixtures, such as those from GF Machining Solutions' System 3R unit, allows the hybrid parts built in the DMP machine to undergo all the necessary post-processing operations with reduced setup and changeover times, thanks to the standardised part interfaces being compatible with multiple machines.

TK Mold uses the above-described process and equipment to produce high-quality hybrid parts, and manufactures around 90% of the moulds requiring AM-enabled conformal cooling by this method. As an example, the hybrid mould insert object of the smartwatch packaging support was achieved from a preform obtained by wire EDM in two different positioning steps. Each preform was then clamped onto the System 3R interface plate 'AM Carrier', mated with the DMP machine (Fig. 10). Here the DMP Calibration tool was exploited to correctly reference each preform independently through its set of two locating holes, automatically calculating and applying both translation and rotation corrections to the job file (Fig. 11).

As a last step, the AM build was performed in 3D Systems' LaserForm® Maraging Steel – a proven material for the mould and die sector thanks to its wear resistance – on a DMP Flex 350 machine.

Surface and sub-surface porosities are particularly critical for mould and die applications, as they may emerge on the part cavity walls after their subsequent machining, leading to defects on the moulded product; moreover, they may be greatly

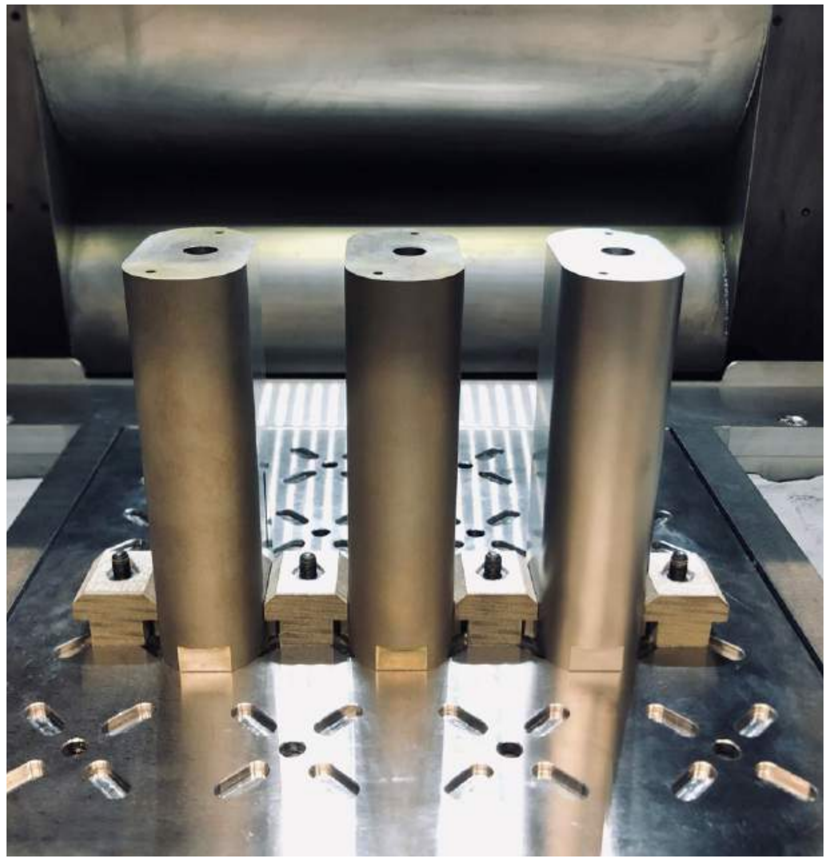

Fig. 10 Machined and cut preforms are placed inside DMP Flex 350 metal AM machine for the building of the conformally cooled section of the insert on top

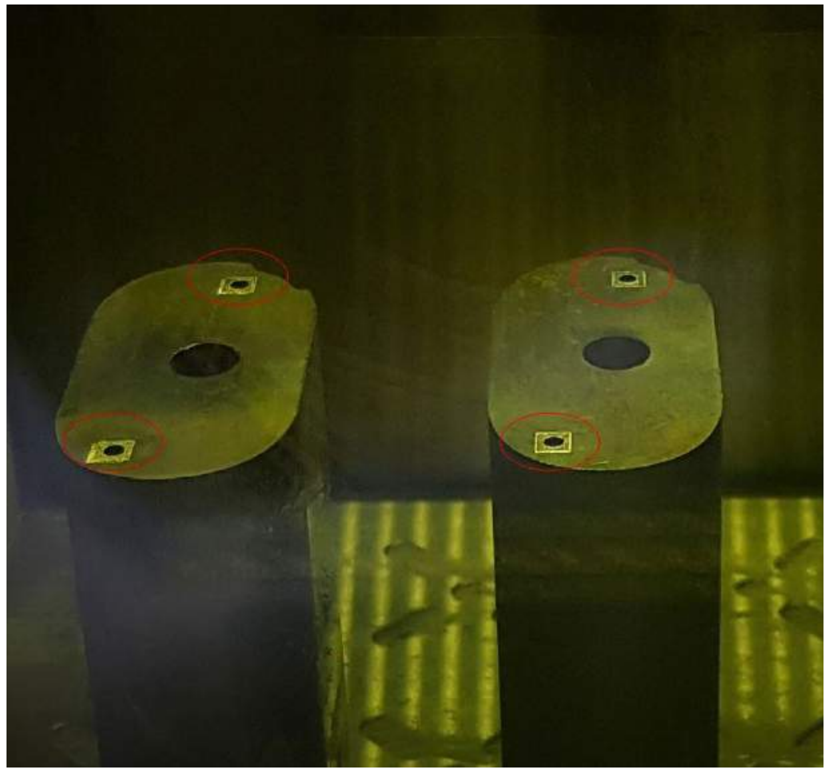

Fig. 11 Here, holes are being scanned for preform referencing. With user-defined threshold values, this referencing process offers exceptional repeatability and accuracy without any risk of human error

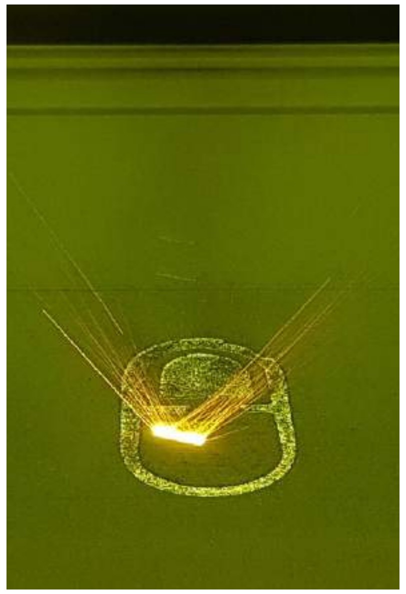

Fig. 12 The section of the mould with conformal cooling channels is built on top of the preforms in DMP Flex 350 machine

Fig. 13 Hybrid AM mould insert as it comes off the DMP Flex 350 machine. Finely tuned laminar argon flow guarantees a high removal rate of fumes which are the main driver of inconsistent density. Thanks to the unique calibration process, the alignment between the AM section and the preform is very accurate

detrimental for the lifetime of the mould/die, constantly undergoing thermal fatigue while being in operation. Thanks to a finely tuned laminar argon flow, the DMP Flex 350 ensures a high removal rate of fumes which are the main driver of inconsistent density (Fig. 12).

Post-processing

Once the part is built (Fig. 13), final machining operations are required to achieve the expected surface roughness on the final geometry. A first programming stage is performed to generate the tool path for the surface finishing of the required area. A real benefit here is 3D Systems' Cimatron® software, which provides the technology user with a seamless transition between AM and post-machining.

Once the program is ready, the insert is clamped inside a Mikron MILL S 400 U Milling machine from GF Machining Solutions. This product is well-established in the mould-making industry and enables a perfectly homogeneous surface finish. The excellent mould surface quality is particularly valuable for plastic parts with a final transparent finish, where flaws can be easily visible. Mirror surface finishing also reduces the need for hand polishing of mould components, reducing lead time. The square sections of the ejector pins required a milling operation (3+2 pre-machining) and a final grinding operation.

Improved efficiency and productivity with lower total cost of operation

Once the optimised insert is finished, it replaces the conventional insert inside the mould, and the injection process can begin. This article's observations focus on two elements: cycle time and part quality. The first element influences productivity and the second element influences waste costs.

The injection data collected in Fig. 14 show that the total injection cycle time varies between 21.70 and 21.79 seconds with a traditional insert. With the optimised insert, the cooling time of the plastic is reduced and cycle times stabilise between 16.98 and 17.01 seconds. This represents a significant cycle time reduction of 22%.

The consequences of this productivity gain are multiple. TK Mold was able to increase its production from 189,788 pieces to 242,250 pieces produced per month, equating to an increase in monthly revenue from this application of RMB 92,871, or approximately €12,000.

Additional considerations are the cost savings that are available due to improved productivity by reducing the hourly cost of machine use and increased flexibility in terms of machine capacity. Due to the improvements in thermal homogeneity and the reduction or elimination of hot spots, TK Mold also improved repeatability and final part quality, thereby reducing these waste costs while better satisfying its end customer.

Such a solution can also help companies to meet demand without needing to invest in additional new moulds. According to TK Mold, the ROI on the production of this insert by AM is very attractive and, in this specific case, was achieved in fewer than twenty-six days of production.

Considering that this case represents just one application, and that TK Mold can use this technology for many moulds and produce them at multiple locations at the same time, AM is very quickly paying for itself. As a result, TK Mold is now operating its AM machine at a very high capacity, in order to meet the demand for various optimised inserts.

Conclusion

By enabling the generation of conformal cooling paths within inserts, the adoption of AM in the mould and die sector has repeatedly been proven as an effective way to enhance the yield of moulding processes in terms of both productivity and part quality. This is confirmed by the application case study from TK Mold, and its now firmly established use of AM mould inserts in everyday production.

Moreover, as this case study demonstrates, for companies to fully grasp the end-to-end value offered by this disruptive manufacturing technology, and thus quickly achieve ROI, AM should not be evaluated as a 'stand-alone' process. For the technology to shift to the full industrial scale, its integration with conventional, well-established manufacturing processes is crucial; a complete workflow approach, from design to final part, is required.

Thanks to their expertise in multiple fields and processes, GF Machining Solutions and 3D Systems are able to offer industrial solutions that make this possible. Their joint offering is further enhanced by the availability of dedicated products and tools, such as the Additive Molding module of 3D Systems' 3DXpert software for the design and analysis of conformal cooling channels, and the DMP Calibration tool offered with the DMP machine series for the manufacturing of hybrid parts through the automated, user-error-free alignment of preforms and substrates to the highest accuracy inside the AM machine.

In conclusion, for the mould and die as well as other sectors, a whole ecosystem has to be considered, encompassing software, AM and subtractive machines, materials, automation and tooling solutions. These must be efficiently combined and integrated to drive design and manufacturing costs down, thus allowing AM technology to express its full potential as an industrial process.

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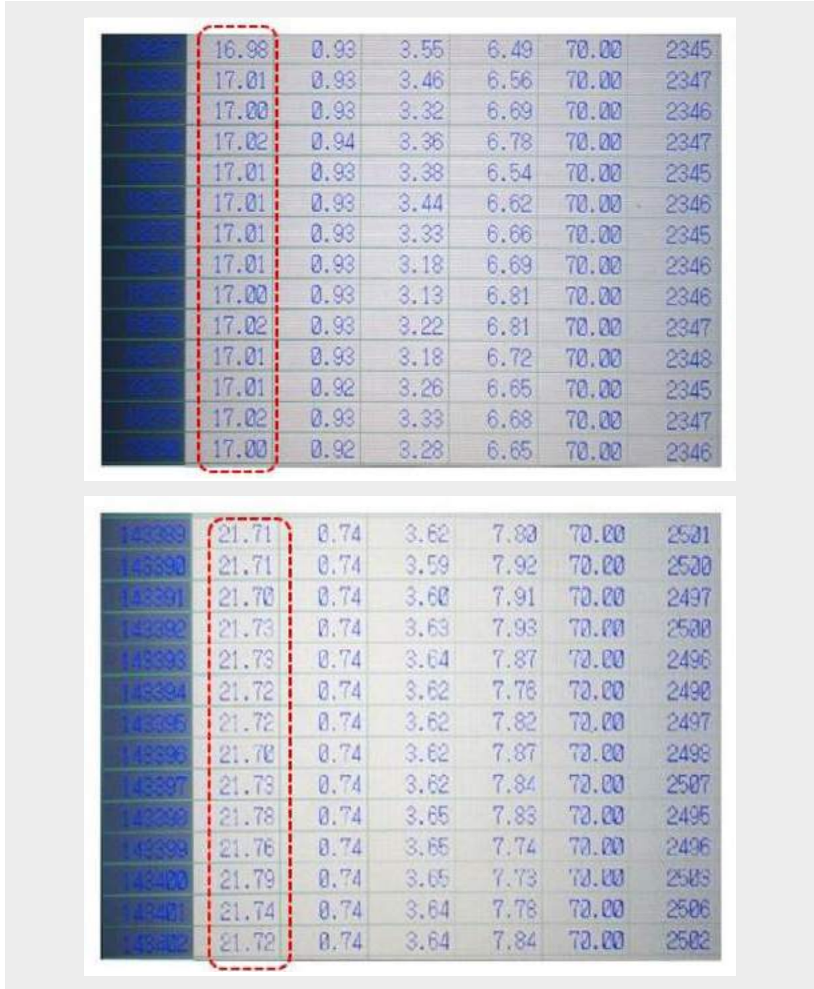

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143392	21.73	0.74	3.63	7.93	70.00	2500
143393	21.73	0.74	3.64	7.87	70.00	2496
143394	21.72	0.74	3.62	7.78	70.00	2490
143395	21.72	0.74	3.62	7.82	70.00	2497
143396	21.70	0.74	3.62	7.87	70.00	2498
143397	21.73	0.74	3.62	7.84	70.00	2507
143398	21.78	0.74	3.65	7.83	70.00	2495
143399	21.76	0.74	3.65	7.74	70.00	2496
143400	21.79	0.74	3.65	7.73	70.00	2503
143401	21.74	0.74	3.64	7.78	70.00	2506
143402	21.72	0.74	3.64	7.84	70.00	2502

Fig. 14 The injection data collected shows a reduction in cycle time of 22% down to 16,98 to 17.01 seconds

Fig. 15 The DMP Flex 350 robust metal AM machine for 24/7 part production and flexible application use

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Hybrid inserts for mould and die production

Neighborhood 91: The bridge to Additive Manufacturing production

Whilst Additive Manufacturing as a technology is proving its worth through an ever growing list of innovative, real-word applications, the obstacles faced by players in the current AM supply chain are numerous, ranging from skills shortages to a highly-complex supply chain, high costs and fluctuating product demand. To address this, Neighborhood 91, an end-to-end AM production campus, is being created in the US city of Pittsburgh that, as Laura Ely and John Barnes report, seeks to condense and connect all components of the Additive Manufacturing supply chain into one powerful production ecosystem.

Bridges represent connections to people, places and ideas. In the technology field, we talk about building a bridge over the 'valley of death'. This is the stage in a technology's development when both technical and business requirements are very high as it transitions from research to production; the valley is riddled with the hopes and dreams of technologies that didn't quite make it.

In Clayton Christensen's bestselling book, *The Innovator's Dilemma*, he describes principles that stifle innovation or the progress of innovation [1]. Principle five states that, "Technology supply may not equal market demand". Disruptive technologies like AM, he says, can initially only be used in small markets, not in the mainstream. They are disruptive because "they subsequently can become fully performance competitive within the mainstream market against established products." AM requires help with the cost barriers to help companies make use of it outside of the niche markets.

For decades, Additive Manufacturing has captured the hearts and minds of engineers, designers and everyday makers because it represents a transition from the centuries-old legacy methods of carving objects from rock and metal, to adding material layer by layer. Slowly but steadily, the advanced manufacturing processes that fall under the umbrella of AM have found their way over the valley of death to a home in production operations, buying their way in via cost reductions, schedule savings, safety enhancements and performance or functionality improvements. The biggest leaps are seen when AM enables systems that are impossible with conventional manufacturing. AM parts and systems are now flying, driving, orbiting, drilling, hurtling through space towards Mars and 'living' in people.

Fig. 1 The skyline of Pittsburgh, home city to Neighborhood 91 (Photo Ronald C. Yochum Jr.)

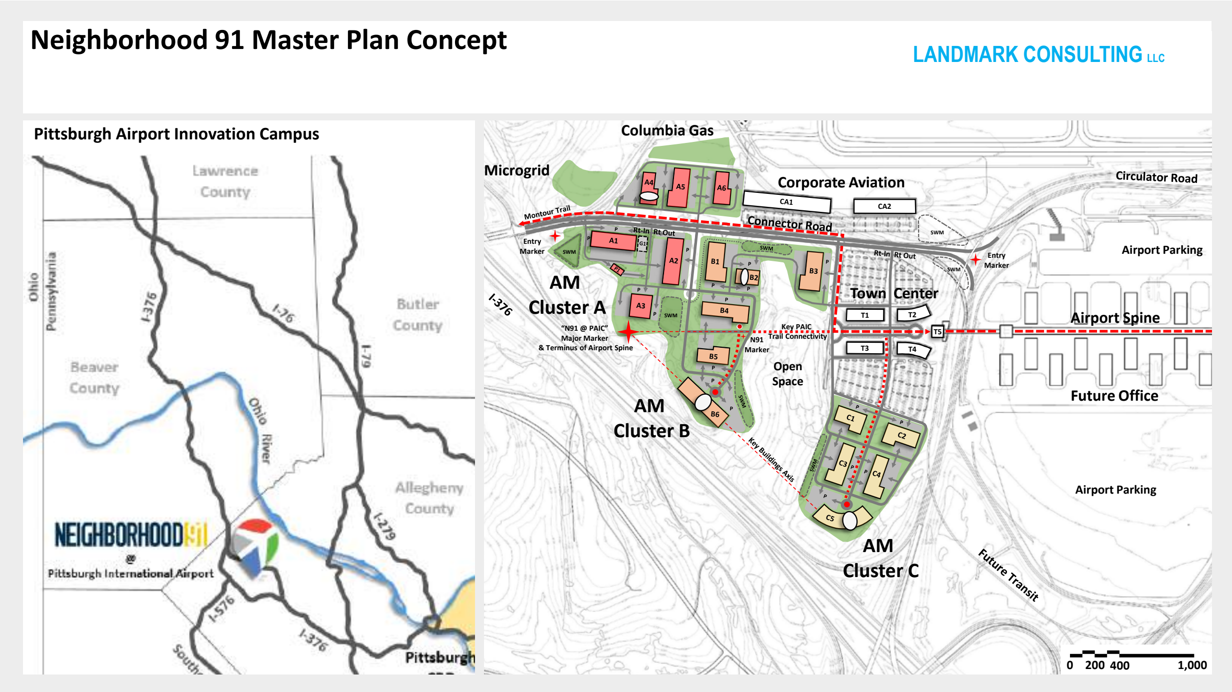

Fig. 2 Left; The Neighborhood 91 campus in relation to the region, Right; 195 acres adjacent to the Pittsburgh International Airport with the phased AM Cluster build-out

These successes are the culmination of hard-fought battles, with AM's current adopters having conquered numerous hurdles, including an immature, fragmented and expensive supply chain. To simplify and accelerate adoption, industry needs to approach AM production in a new way. This means creating connections, collaborating, placing the right players in the right roles and building bridges to further the large-scale adoption of AM.

In Pittsburgh, Pennsylvania, USA, there is no shortage of bridges. In fact, 'The City of Bridges' boasts 446 of the structures, which act as connectors across the city. Along with its physical bridges, the Pittsburgh region is a connector for advanced manufacturing globally, making it a natural home for Neighborhood 91.

Solving an AM problem

Advanced technologies, like AM, are disruptive and create an opportunity to do business in a new way. Using AM, new business concepts have emerged as to what product is being sold, how it is sold and the processes used to create it. It follows logically that the supply chain that produces that product could also benefit from some serious innovation. The obstacles faced by players in the current AM supply chain are numerous, ranging from people to business issues:

A shortage of skilled workers

A new set of skills is needed to compete in advanced manufacturing. Only a few AM training programmes exist and the demand for skilled workers exceeds the supply. As a point of reference, Alexander Daniels Global, a leading AM recruiting firm, stated in its *3D Printing Talent Market Whitepaper*, "The AM industry has an unemployment rate very close to zero" [2]. This creates a challenge for a company, which needs people to run the business.

Dispersed supply chain

Nearly all parts utilising AM also require other manufacturing capabilities for post-processing, such as machining and heat treatment, and for testing and inspection. The current AM production supply chain is fragmented, adding transport distance and time to the workflow, which results in increased costs.

High operating costs

AM operations are capital intensive, requiring back-up power and specialised powder storage facilities, to name a couple. Recurring costs are also significant in consumables like powder, argon gas and electricity. Additionally, many companies spread their skillsets thinly across a broad range of manufacturing processes in an attempt to control schedule and cost. This approach can also increase overheads if machine utilisation is not high for all equipment.

Inconsistent product demand

Fluctuating order volumes and a lack of long-term contracts create an inconsistent product demand, which can lead to equipment underutilisation. This also means

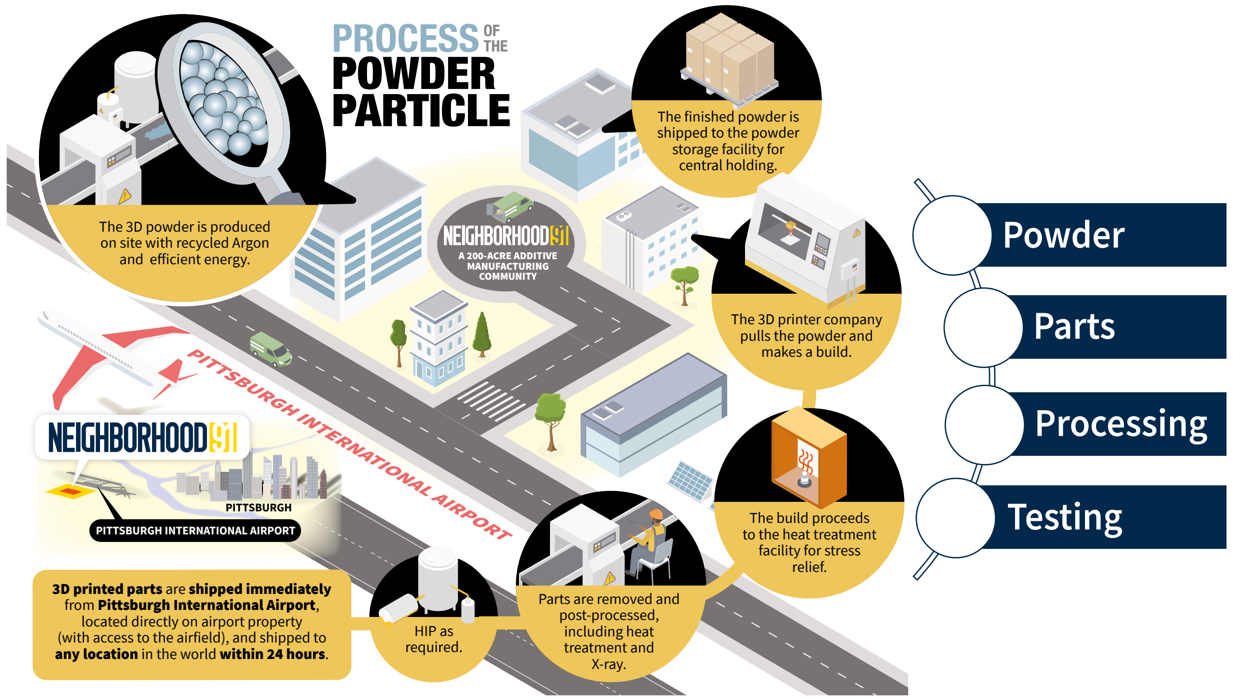

Fig. 3 A schematic of the potential flow of material through the Neighborhood 91 supply chain

that, when demand does come, the supply chain may not have the surge capacity to keep up. Another possible consequence of inconsistent demand is an increase in work in progress (WIP) and inventory, which represent money invested without any return.

Extra burdens

Amid the current global pandemic, supply chain struggles are amplified. A survey run by The Barnes Global Advisors in mid-summer 2020 asked the question, "Do you see the pandemic truly causing a rethinking of the supply chain?" to which 50% of respondents replied "Yes". The top three reasons given for this answer were:

1. Re-shoring or onshoring increases in importance
2. Distributed / localised manufacturing increases in importance
3. Agility increases in importance

This gives us indications as to the additional pain points companies are enduring due to global supply chain disruptions related to the pandemic.

Neighborhood 91: A production campus offers the solution

Neighborhood 91 is believed to be the world's first end-to-end AM production campus and occupies 195 of the 8,800 acres owned by Pittsburgh International Airport (Fig. 2). Its inception was a collaboration between by the Allegheny County Airport Authority and the University of Pittsburgh, with local government having been supportive from the County Executive to the Commonwealth of Pennsylvania, providing funding to enable construction of the site.

The Neighborhood 91 Mission Statement is to condense and connect all components of the Additive Manufacturing supply chain into one powerful production ecosystem. A centralised campus with capabilities starting with material production and spanning across Additive Manufacturing, machining, heating treating, post-processing and inspection intends to reduce manufacturing barriers and accelerate adoption. The campus will offer:

- Recycling of argon, helium and other noble gases, which are essential elements of Additive Manufacturing and can account for up to 60% of the total cost
- Campus microgrid providing clean, resilient energy, eliminating the need for uninterruptable power supply (UPS) or generators
- Powder, parts, post-production, testing and analysis
- Common powder storage facilities
- Efficiencies in production/post-production and delivery
- Tenants' cost savings from AM enabling a lean production cycle
- Reduced transportation costs
- Transportation logistics including airport, interstate and rail access

Neighborhood 91 enables a simplified supply chain and provides relief to manufacturers' key pain points across the industrial value chain (Fig. 3). The impacts waterfall based on the efficiencies created on campus:

Increase speed
Production timelines, work in progress and inventory will be reduced with the elimination of geographical distance. When problems do arise, they can be resolved faster by simply walking next door.

Reduce cost
Persistent production costs will be minimised with attractive rent, low energy rates due to the microgrid and low gas costs due to argon recycling. Capital expenditures will be minimised for tenants, as well as transportation costs.

Encourage specialisation
The availability of diverse services on campus encourages each company to specialise while relying on neighbours to deliver the rest.

Develop a workforce
Workforce development needs will be met with academic and industry partners in the region.

Foster collaboration
Neighborhood 91 will enable multi-company innovation and enable the collective to pursue state and federal funding.

The efficiency of agglomeration

Through an economist's lens, Neighborhood 91 is an agglomeration: a collection of firms from a given industry. At its core, agglomeration's underlying theory is that businesses and resources can take advantage of efficiencies by being located close to one another, enabling specialisation, workforce development and knowledge generation. The advanced manufacturing sector is differentiated from traditional manufacturing in that it requires innovative thinking to exist.

History also shows that innovative thinking attracts more innovative thinking with 'innovation sectors' clustering and growing due to knowledge-based economies. Geographic proximity has profitability and productivity benefits built on the key advantages of agglomeration: input sharing, knowledge spillovers and labour pooling. In his book *The New Geography of Jobs*, Enrico Moretti explained, "... in the innovation economy, a company's success depends on more than just the quality of its workers – it also depends on the entire ecosystem that surrounds it. Cities are not just a collection of individuals but complex, interrelated environments that foster the generation of new ideas and new ways of doing business. For example, being around smart people makes us smarter and more innovative" [3].

> *"To be successful in AM you must understand or appreciate the entire supply chain. Akin to how we approach Design for AM, we are only as strong as our weakest link."*

The push for specialisation
Looking at the supply chain for AM, a series of specialised processes are involved, especially in the supply of metals. While it is logical to want control over the series of processes, the question remains as to whether the increase in overhead can be sustained. Effectively, parts manufacturers need to differentiate and be extremely competitive and, often, being competitive comes down to machine utilisation. We have all watched the seesaw supply chain strategies of the giant Original Equipment Manufacturers (OEMs) in different industries as they go through a vertical integration phase followed by a major outsourcing campaign five years later. The argument for vertical integration is control over schedule and intellectual property, while the counter argument for outsourcing is competitive pricing and specialisation.

The strategy adopted by small- to medium-size businesses often lands somewhere in between and we have seen a few Additive Manufacturing groups stumble when trying to strike the right balance. When crafting the strategy for Neighborhood 91, we first asked: What problems need to be solved to encourage further utilisation of AM and the AM supply chain? Of those problems, which can Neighborhood 91 affect? To be successful in AM you must understand or appreciate the entire supply chain. Akin to how we approach Design for AM, we are only as strong as our weakest link. We first sought answers to questions such as:

- As manufacturing processes become more diverse, does it make sense for businesses to own all the processes themselves?
- Is it possible for a company to sufficiently master all the processes and maintain both the capital investment and skillsets to maximise the assets?
- Can I utilise all my equipment effectively and efficiently, or am I best partnering for specialised services?
- How can I lower my cost of operations without reducing customer service and quality?

An article published in Forbes [4] stated five reasons for specialisation:

1. Better value proposition
2. Smaller learning curve
3. Higher perception of authority
4. Higher conversions
5. Better networking

Neighborhood 91's clustering of advanced manufacturing providers creates an environment that encourages and enables specialisation and it addresses many of the issues that companies are facing today. A specialised business at Neighborhood 91 can keep operating costs down and maximise agility by purchasing only required assets, hiring the right skillsets, using the localised supply chain and, hopefully, filling its assets.

Building a workforce – labour pooling
A company can buy a newer, faster machine and the latest software, but it is not as easy to acquire the skills to use them. Without skilled people, those tools are useless. Through academic and training partners, the Neighborhood 91 innovation ecosystem will develop a pool of trained workers for the greater Pittsburgh region.

Investment that keeps paying off – knowledge spillover
Around the world, we see areas of knowledge pooling in regional clusters like Silicon Valley where success begets success. Studies also show that research and development and workforce development investments have a spillover benefit to other actors across the industrial spectrum [5]. Therefore, people and companies in the greater Pittsburgh region, other than those carrying out the work, can also enjoy higher productivity and revenues because of the Neighborhood 91 investments. These spillovers relate to various types of knowledge transfer.

Advanced manufacturing in the Pittsburgh region

A large portion of the AM supply chain exists within a four-hour radius of Pittsburgh. Consolidating and connecting this supply into a 195-acre campus is the goal behind

Why specialise?

Better value proposition
Specialisation can come in a variety of forms: a focus on specific markets, products, or processes. Striking the right balance is key to delivering value for each customer. For example, having a diverse set of processes under one roof might help schedule, but will create extra cost burdens. When each company on the campus can specialise and become more efficient at their operation, the whole supply chain benefits. There is an interdependence, which is healthy, and is the actualisation of the phrase "a rising tide floats all boats." The collective succeeds when a better product can be offered at a competitive price in a shorter period of time.

Shallow learning curve and workforce
Additive Manufacturing represents a way of manufacturing that is fundamentally different than subtractive; therefore, the skills required to be successful are also different. Additionally, manufacturing best practices are not yet well established across the industry, creating a steeper learning curve. To perform a diversity of processes well, you either need extremely multi-skilled workers, or experts in each of your processes. Specialisation shortens the learning curve and allows for the development of deeper expertise. Additionally, Pittsburgh's talented workforce puts manufacturers starting point further up the curve enabling earlier profits.

Higher perception of authority
Perception is often times reality. In manufacturing, new processes are initially met with a level of distrust until enough data and applications are available to validate robustness. A "guilty until proven innocent" policy prevails. Therefore, as a production provider, building trust is paramount. AM is also lacking an authority in production. A campus cluster for production will provide an actual authoritative voice built on the voices of many versus a self-declared "expert".

Higher conversions
Knowing where to find AM production makes it easier to connect customers to suppliers and translate leads to sales. Being narrow makes a business easier to find. Not only can the campus deliver parts in a short period of time, it should shorten the customer acquisition time as well. In addition, once people associate precision machining or unique heat treatment with AM, they will know where to get those services.

Better networking
AM is a global effort, and knowing where to go to get any specialty is important. The AM community is quite small and tight knit meaning both good and bad news travel quickly. If you are a specialised company delivering a superior product, you will naturally benefit from better networking. Growing an entire AM campus has its challenges, if not only because AM is sufficiently diverse in terms of equipment, processes, materials, and services. The Pittsburgh region is well networked in the physical manufacturing arena and competes well in innovation, digital and connectedness globally.

Fig. 4 A map of the Manufacturing USA institutes and academic institutions within a four-hour drive of Pittsburgh.

Neighborhood 91. Around the world, people understand this choice: the Pittsburgh region is known for manufacturing, materials, robotics, big data, machine learning and artificial intelligence, all of which are the necessary ingredients for a robust advanced manufacturing future. Pittsburgh is also known for its vibrant growth, excellent workforce and above average advanced degrees per capita.

America Makes

Within this comfortable driving distance of Pittsburgh, three Manufacturing USA Institutes can be found, including America Makes, Youngstown, Ohio, responsible for Additive Manufacturing. The first Manufacturing USA institute, America Makes serves as the national accelerator for AM. Established in 2012 and structured as a public-private partnership with member organisations from industry, academia, government, non-government agencies and workforce and economic development resources, the institute works to innovate and accelerate Additive Manufacturing to increase the USA's global manufacturing competitiveness.

A wide range of further notable activities exist within the city of Pittsburgh alone:

Hazelwood Green

Hazelwood Green is establishing a new model for economic development in Pittsburgh, which is aligned with community and grounded in the principles of sustainability, equity and inclusive economic opportunity.

Carnegie Mellon University

Carnegie Mellon University's Manufacturing Futures Initiative (MFI) is building Pittsburgh into the country's leading manufacturing hub. MFI, anchored by CMU's NextManufacturing Center for Additive Manufacturing research and education, Robotics Institute and CyLab Security and Data Privacy Institute, will attract and collaborate with industry as well as public/private and academic partners, with a mission to accelerate the adoption of new technology through interdisciplinary research on materials discovery, Additive Manufacturing, robotics and automation, machine learning/AI, policy, cybersecurity, workforce training and education. MFI manages the approximately 5390 m^2 (58,000 ft^2) advanced manufacturing facility at Mill 19 at Hazelwood Green, which is also home to the Advanced Robotics for Manufacturing Institute (ARM).

University of Pittsburgh Center for Advanced Manufacturing

The University of Pittsburgh's Center for Advanced Manufacturing (UPCAM) acts as a liaison between The University of Pittsburgh (Pitt) and Pittsburgh's manufacturing community. Working in advanced manufacturing, Pitt offers innovations from conventional manufacturing to new and novel manufacturing technologies, leveraging its materials data science, machine learning/AI, cybersecurity and cyber policy for manufacturing as well as workforce development.

Advanced Robotics for Manufacturing Institute (ARM)

As one of the Manufacturing USA Institutes, The Advanced Robotics for Manufacturing Institute will be the leading catalyst of robotics innovation and expertise. Headquartered in Pittsburgh's thriving robotics community, ARM is an integral part of Pittsburgh's strategy to define the future of the global manufacturing economy. ARM has a state-of-the-art headquarters at Mill 19 in Pittsburgh's Hazelwood neighbourhood; this brand-new development provides space for ARM member collaboration, dedicated classrooms for workforce training and more.

Lightweight Innovations for Tomorrow

Lightweight Innovations for Tomorrow (LIFT), a Manufacturing USA institute, designs and deploys advanced lightweight metal manufacturing technologies and implements educational programmes to close the gap between research breakthroughs and commercialisation. LIFT is operated by the American Lightweight Materials Manufacturing Innovation Institute (ALMMII), a public-private partnership between the U.S. Department of Defense, industry and academia. LIFT's mission is to advance technology and talent development, driving rapid implementation of smarter manufacturing.

AM requires a supply chain that is integrated, but which is also diverse, automated, generates big data, employs machine learning/AI and is increasingly robotic: it must drive design thinking and materials innovation. What companies need now more than ever is innovation. The Pittsburgh region is punching above its weight in this innovation thrust, in part because it has the right balance of a currently available workforce and the academic network to develop the skills and fill the future talent pipeline to feed the innovation system.

The Class of 2020 at Carnegie Mellon University's Engineering and Public Policy Spring Semester class studied various aspects of Neighborhood 91, including an evaluation of the question: How competitive is the metal Additive Manufacturing ecosystem of greater Pittsburgh as compared to other regions? Using America Makes membership data, an assessment of three United States regions showed a significantly higher concentration of metal AM companies in the greater Pittsburgh and Ohio region than that of the Carolinas or Alabama, two other regions advertising AM growth. Fig. 5 shows an output from the CMU study, which indicates that "the Regional Pittsburgh network is the largest network by far, and includes almost half of the nodes in the US. The remainder of the nodes are spread out across other regions in the US."

In addition, the CMU study found that the Pittsburgh regional internal network is very complex and well connected, whereas the competing regions do not enjoy the same level of complexity and in some cases have a single point of failure, where, if one hub were to fail, the network would dissipate. It is worth noting that the data, which fed the study, was limited to America Makes' data and excludes the international connectivity that the Pittsburgh region also enjoys and that it is exclusive to metal Additive Manufacturing and does not represent the wider areas of advanced manufacturing, materials production, machine learning, artificial intelligence and robotics, which are also quite prominent in the region.

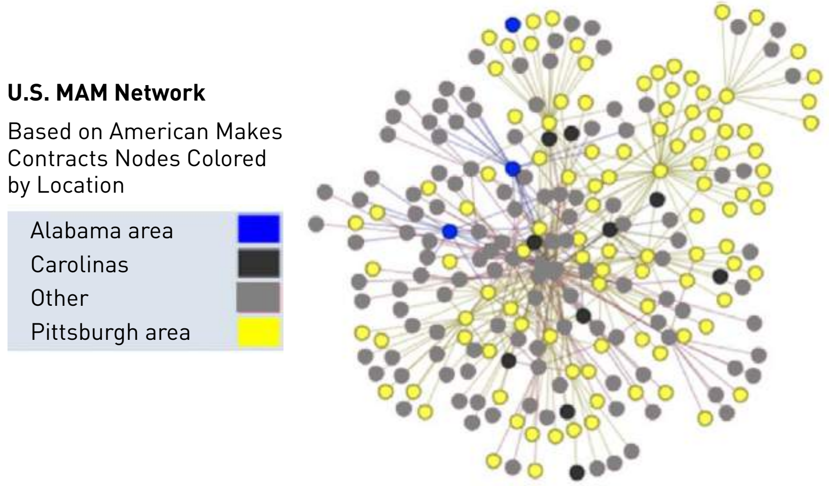

Fig. 5 The metal AM network comparing the Pittsburgh region (yellow) with the wider US (grey) and the Carolinas and Alabama (black, blue) from CMU's spring semester Engineering and Public Policy course

Creating value for the manufacturer

The Neighborhood 91 vision complements the region's assets and inherent workforce. Allegheny County Airport Authority is in the role of strategic landlord and is making investments in the infrastructure to nurture advanced manufacturing in the Pittsburgh region. Companies can choose to rent from a master developer or build their own building on the airport's property. Arencibia, a supplier of industrial gas solutions focused on cost reductions and supply chain stability, is an anchor service provider for Neighborhood 91, providing gas recycling on-site to reduce the cost of gases for the tenants. The investment in infrastructure enables low-cost gas recycling solutions even for smaller companies, who would not otherwise have access to these capabilities.

The Barnes Global Advisors is leading the strategy development and tenant attraction through its connector role for the campus, linking companies, people, equipment, materials, data, insights and digital solutions, to help steer Neighborhood 91's vision and bring maximum value to its tenants. The University of Pittsburgh brings world class advanced manufacturing research to complement the ecosystem.

Current status of Neighborhood 91

At the time of writing this article, the first buildings of Neighborhood 91 are under construction. Letters of Intent to occupy have been received for 100% of the first 4,180 m^2 (45,000 ft^2) building and about half of the second. The strategy to pursue AM parts producers and powder producers has been effective, as those companies then feed the subsequent sub-tier manufacturers. The other would-be 'neighbours' activities include heat treatment, testing and inspection, with many ongoing discussions underway.

The move-in date for the first neighbours will be in the second quarter of 2021. The characteristics of the first several companies validate the strategy of leading with parts and powder and represent the skeleton of the supply chain. The current activities of the companies committing range from AM part production to powders, machining, heat treatment and testing and inspection.

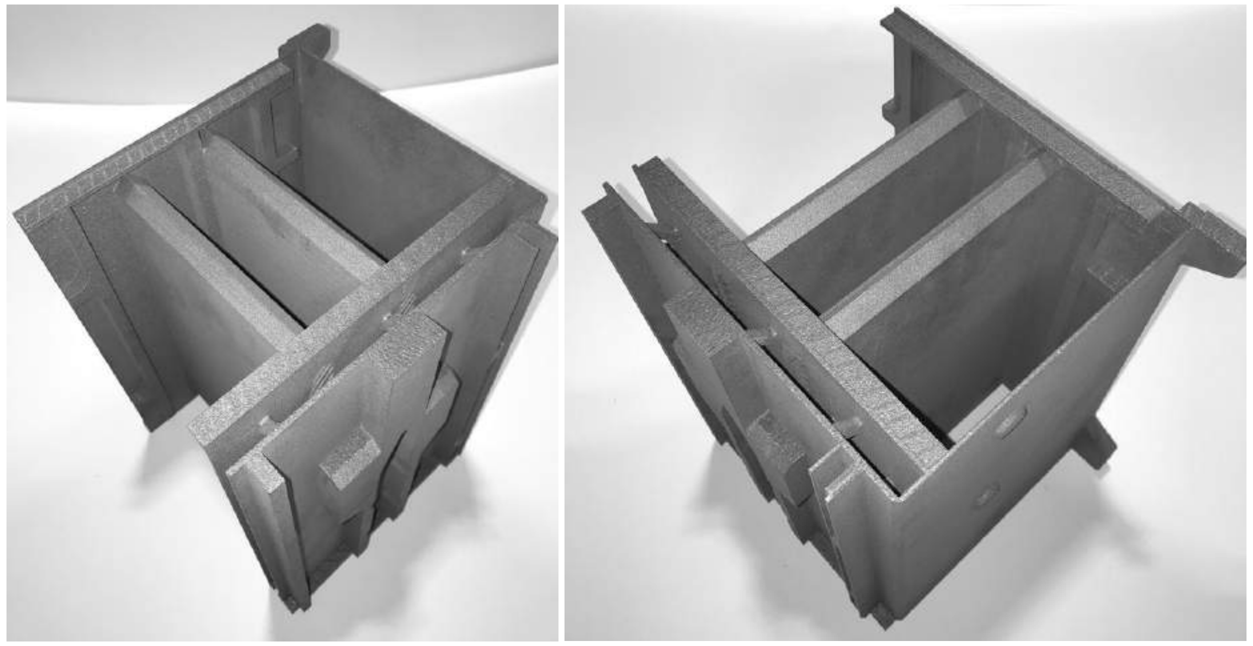

Fig. 6 Wabtec's Integrated Cooling Chassis (Courtesy Wabtec Corporation)

As Neighborhood 91 grows, a key part of its strategy is to manage the impact on the current capabilities in the region and how to make good on the adage, "a rising tide lifts all boats." Simultaneous to this connection, effort is maturing the workforce development strategy and activities. Neighborhood 91 is working with the existing universities, trades and public/private entities to ensure that the pipeline of people to power the growth will be there.

"Wabtec will employ the latest in AM technology to produce state-of-the-art, large-scale, lightweight parts for transit and rail customers to reduce lead times by up to 80%."

Wabtec announced as anchor parts producer

Wabtec Corporation has been announced as the first company to move into Neighborhood 91 and will be using the campus as a production site for its own AM parts. The Neighborhood's first production AM part is an integrated cooling chassis (Fig. 6), which is used as a dual fuel locomotive engine electronic card cage with integrated forced-air multi-pass cooling; a high-powered cooling system for locomotive electronics.

Wabtec will employ the latest in AM technology to produce state-of-the-art, large-scale, lightweight parts for transit and rail customers to reduce lead times by up to 80%. Wabtec will operate a new SLM®800 Laser Beam Powder Bed Fusion (PBF-LB) AM system. The installation will include the SLM 800 and the automated material handling solution, HUB, making it the first production installation of the SLM 800 with HUB in North America. This large build envelope will enable Wabtec to create large, complex and precise aluminium transit and freight components like brake parts and heat exchangers. The highly automated machine enables Wabtec a path for autonomous, continuous and scalable production of large metal parts.

Speaking on the decision to join Neighborhood 91, Philip Moslener, Executive Director of Engineering at Wabtec Corp, stated, "Additive technology is a key focus area for us that provides new capabilities to drive innovation in areas where traditional manufacturing could not. This agreement continues our investment in resources that enable our engineers to design new and complex products for the industries we serve. As the first development in the world to connect all elements of the Additive Manufacturing supply chain into a single location, Neighborhood 91 is the ideal location to fully realise the potential of this technology."

Neighborhood 91 adds to Wabtec's additive facilities in the Pittsburgh region, which include AM labs in Erie and Grove City. Wabtec is now exploring how AM can be integrated into its business to positively impact its products and transform the supply chain. In 2019, Wabtec began its journey by launching twelve parts in production and it is working towards introducing up to 250 unique production components by 2025.

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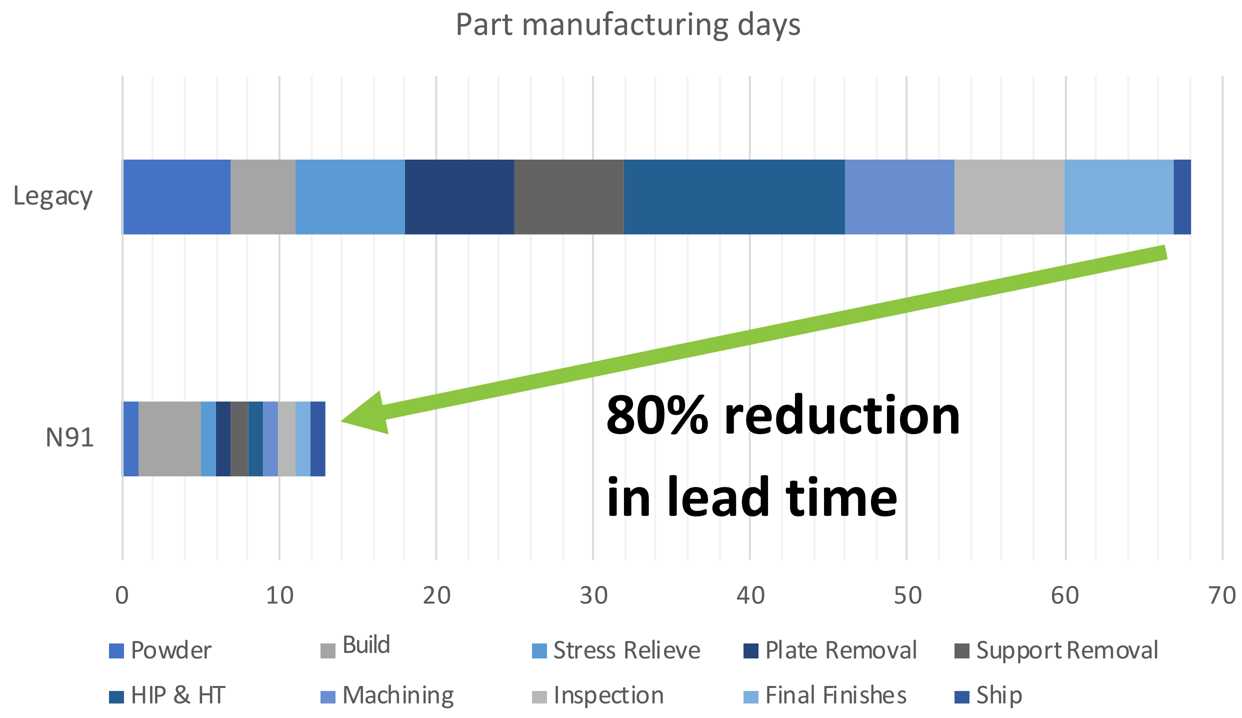

Fig. 7 A comparison of a typical AM supply chain compared to an optimised Neighborhood 91 equivalent

Rusal anchors the powder storage facility

Rusal, the largest producer of low-carbon footprint aluminium in the world, has chosen Neighborhood 91 as a powder storage and distribution site. Of equal importance to Rusal's mission to develop high-strength, temperature-stable and highly AM-compatible aluminium alloys is a focus on minimising material costs to expand the number and types of AM solution implementations in aerospace, automotive and general industry.

The company does so through intentional alloy design and operational excellence. As it continues a United States expansion, Neighborhood 91 provides a cost-effective solution for powder storage and distribution. Additionally, the campus's focus on energy efficiency via a micro-grid and gas recycling align with Rusal's core sustainability objectives. Adam Travis, North American AM Bureau Manager for Rusal Americas, explained, "Neighborhood 91 is an ideal location from which to introduce Rusal's innovative alloys to the US market. Its co-location with Pittsburgh International Airport provides convenient logistics for meeting our customers' demands, while its AM and powder focused construction allows us to maintain our competitive cost advantage by utilising their efficient systems for powder storage and distribution."

Neighborhood 91 is a viable powder production site

At the start of the metal powder bed AM supply chain is powder. In powder production, specifically atomising, argon is one of the top operating expenses. A typical atomised powder will use 3–5 kg of gas for every 1 kg of alloy product. For some AM parts, argon can be used at many steps along the way: powder production, part building, heat treatment and Hot Isostatic Pressing (HIP), so its use is pervasive in the value chain. In addition, availability is frequently an issue since argon supplies are tied to demand for other air gases. Both cost and supply issues can be significantly reduced using argon recovery for a range of different system flows and pressures.

Argon recovery technology has been successfully deployed at many large alloy production facilities. These can cover operating conditions with delivery pressures up to 400 bar and flows up to 140 Nm^3/min. Typically, these higher capacity conditions are necessary to justify the economics of recycling. However, with Neighborhood 91, a larger portion of the AM supply chain is co-located in a way that allows a central recovery operation to serve all scales of gas users, with inexpensive gas available for all tenants. This creates a true 'plug-and-play' market for low-cost inert gases and results in a low carbon footprint. The Neighborhood 91 campus will employ sitewide noble gas recycling, operated by Arencibia, as a utility service to tenants. Joe Arencibia, Arencibia's President and CEO, commented, "Using economies of scale in a single campus, the script is flipped on gas supply, creating net cost savings of over 50% and a reduction in supply risk by 90%. All tenants gain an intrinsic and integral advantage against global competition."

Neighborhood 91: Building the bridge

2020 has been an influential year, which has seen many unprepared for the rapid changes it brought. However, in a TBGA survey, most firms interviewed did not change their priorities, but rather doubled down on them. The truly strong companies, with a compelling value proposition and vision, are surviving. Reducing operational costs and a laser-like focus on where a company adds value is a compelling reason for a firm to locate at Neighborhood 91. Whilst partnering with the supply chain to deliver parts faster is not for the meek; when coupled with each firm optimising their utilisation of equipment, the payoff will benefit all. The Neighborhood 91 campus creates an opportunity for manufacturers to maximise their investment and keep a keen focus on the area of advanced manufacturing specialisation required to meet their end goal.

Neighborhood 91 enables powder manufacturers to focus on making powder, the part makers on building parts, machinists on machining and heat treaters on producing optimised microstructures. The tenants of Neighborhood 91 will thrive on the connections (shall we say bridges?) created and the efficiencies realised by the formation of a simplified and optimised production campus.

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Events guide

Industry events

***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. View our complete events listing on www.metal-am.com**

2020

Formnext Connect
November 10-12 - Digital Event
www.formnext.com

ICAM2020
International Conference on Additive Manufacturing
November 16-20 - Digital Event
www.amcoe.org/icam-2020

Aviation Forum Hamburg 2020
November 17-18, Hamburg, Germany
www.aviationforumhamburg.com

EuroAM 2020 Additive Manufacturing Seminar
December 2-3 - Digital Event
www.seminars.epma.com/am-2020/home

AMTech Expo
December 9-10, Mumbai, India
www.amtechexpo.in

2021

MAPP 2nd International Conference
January 13-14, Abingdon, United Kingdom
www.mapp.ac.uk/events/mapp-2nd-international-conference

Additive Manufacturing Strategies 2021
February 9-12 - Digital Event
www.additivemanufacturingstrategies.com

MIM2021
February 22-25 - Digital Event
www.mim2021.org

5th Additive Manufacturing Forum 2021
March 11-12, Berlin, Germany
www.am-forum.eu

AMUG 2021
March 14-18, Chicago, IL, United States
www.amug.com

METAV
March 23-26, Düsseldorf, Germany
www.metav.com

Hannover Messe – Home of Industrial Pioneers
April 12-16, Hannover, Germany
www.hannovermesse.de

Rapid + TCT
April 26-29, Chicago, IL, United States
www.rapid3devent.com

Space Tech Expo USA 2021
May 10-12, Long Beach, CA, United States
www.spacetechexpo.com

AM Summit 2021
May 20, Kastrup, Denmark
www.amsummit.dk

PM China 2021
May 23-25, Shanghai, China
www.pmexchina.com

HI-AM Conference 2021
June 1-2, Halifax, Canada
www.nserc-hi-am.ca/2021

3D PRINT Congress & Exhibition
June 15-17, Lyon, France
www.3dprint-exhibition.com

PowderMet2021
June 20-23, Orlando, FL, United States
www.powdermet2021.org

AMPM2021
June 20-23, Orlando, FL, United States
www.ampm2021.org

Tungsten2021
June 20-23, Orlando, FL, United States
www.tungsten2021.org

TCT 3SIXTY
June 29 - July 1, Birmingham, UK
www.tct3sixty.com

EPMA Powder Metallurgy Summer School
July (TBC), Ciudad Real, Spain
www.summerschool.epma.com

Formnext + PM South China 2021
September 9-11, Shenzhen, China
www.formnext-pm.com

PMTi2021
September 15-17, Montréal, Canada
www.pmti2021.org

AMTC4
October 12-14, Aachen, Germany
www.munichtechconference.com

Euro PM2021
October 17-20, Lisbon, Portugal
www.europm2021.com

4th International Symposium Additive Manufacturing
December 6-8, Dresden, Germany
www.isam.network




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