Vol. 4 No. 4 WINTER 2018

THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

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FORMNEXT 2018 REPORTS

Published by Inovar Communications Ltd

www.metal-am.com

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Subscriptions
Metal Additive Manufacturing is published on a quarterly basis as either a free digital publication or via a paid print subscription. The annual print subscription charge for four issues is £95.00 including shipping. Rates in € and US$ are available on application.

Printed by
Cambrian Printers, Aberystwyth, UK

ISSN 2057-3014 (print edition)
ISSN 2055-7183 (digital edition)
Vol. 4 No. 4 Winter 2018

This magazine is also available for free download from www.metal-am.com

METAL ADDITIVE MANUFACTURING

Productivity and efficiency the keywords as AM evolves

There was a clear sense across the board at this year's Formnext exhibition that the metal AM industry is evolving at a rapid pace. Past excitement about potential new applications, equipment launches and mergers & acquisitions has been replaced by the reality that series orders are starting to come in and the industry needs to deliver.

This means that there is now real pressure to not only maximise the productivity of currently installed AM equipment, but to optimise the complete process chain and ensure that the next generation of systems brings even greater productivity gains.

Support for this move towards maximising productivity is provided not only by the machine manufacturers optimising their systems, but crucially by enhancements in the software ecosystem that fundamentally enables the AM process, and by considerable improvements in the capabilities of the innovative post-processing solutions that were on display in Frankfurt.

The biggest challenge for this evolution is maintaining quality as production speeds increase. This will inevitably be high on the agenda as we move towards 2019's packed schedule of international conferences and exhibitions.

Nick Williams
Managing Director
Metal Additive Manufacturing

Cover image
A conventional Mini Cooper suspension trailing arm (left) and optimised one weighing 48% less, designed in ParaMatters (Courtesy ParaMatters, Techniplas and XponentialWorks)

METAL
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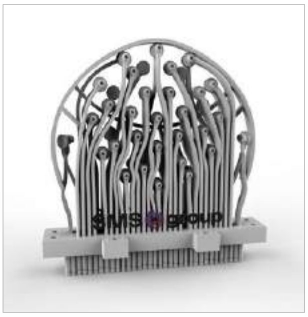
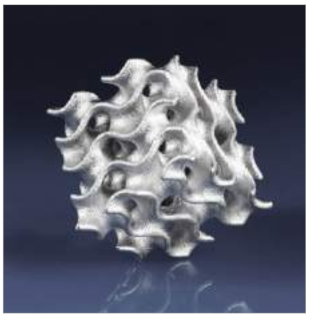
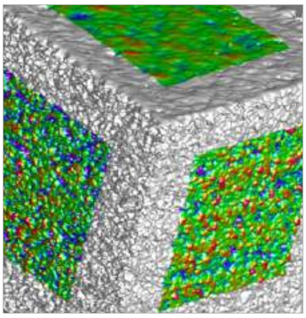
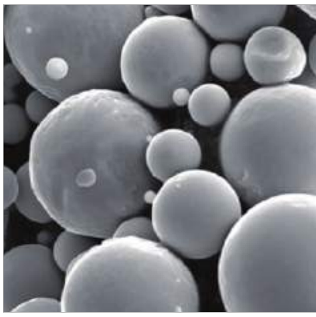

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Materials Solutions new state-of-the-art facility

Materials Solutions' new facility in Worcester, UK

Materials Solutions Ltd - A Siemens Business, based in Worcester, UK, has opened a new state-of-the-art metal Additive Manufacturing facility aimed at driving the industrialisation of Additive Manufacturing. The new facility is the result of a €30 million investment and will enable the growth of the business by doubling the capacity of AM machines to fifty, while also increasing the company's post-processing capabilities.

The company stated that it is now taking AM "out of the traditional research laboratory into an industrialised production factory." At a press day attended by *Metal AM* on December 13, 2018, it was stated that since Siemens' initial decision to invest in AM in 2009, and subsequent acquisition of Materials Solutions in 2016, it has moved beyond the production of AM parts which could feasibly be produced by casting, into the production of parts for which AM is the only production technology - this, stated Markus Siebold, VP AM at Siemens Power & Gas, was the "point of no return" on the company's AM journey.

"If in the beginning one of the challenges was how to get our designers to change their mindset to design for AM," added Vladimir Navrotsky, CTO Siemens Power Generation Services, "there is now no way we could convince them to return their mindset to conventional design."Materials Solutions already has extensive experience serving customers in the aerospace, power generation, automotive and motorsport sectors, as well as tooling and processing. During the event, Phil Hatherley, General Manager, Materials Solutions, stated that the company has manufactured thousands of functional parts to date, as well as providing legacy parts through reverse engineering and tooling, to more than eighty customers worldwide.

The new factory has a footprint of 4,500 m^2, housing multiple metal AM machines on the shop floor, including an EOS M 300-4 system on a pilot customer basis, and a Renishaw RenAM 500Q. Parts move through a variety of processes at the facility, with engineers ensuring compliancy throughout. The factory also employs many of Siemens' latest digital factory and AM technologies, including an end-to-end product lifecycle management (PLM) chain, Siemens NX software, and MindSphere, a cloud-based Internet of Things (IoT) operating system that connects products, factories, systems and machines through data analytics.

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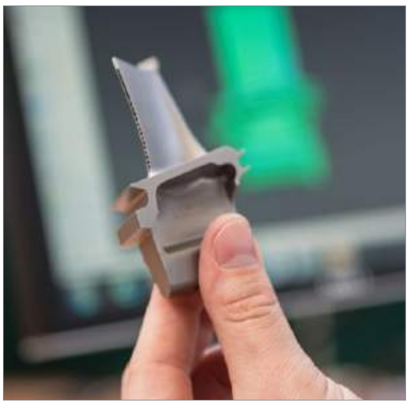

Additively manufactured gas turbine burner head (left) and gas turbine blade (right) for use in power plant operation

By drawing on Siemens' design experience, Materials Solutions is now offering various design services for AM, including engineering and consulting for the creation of a digital twin for an additively manufactured component. Willi Meixner, CEO of Siemens Power & Gas Division, stated, "Siemens is the only company with such a comprehensive portfolio for driving the industrialisation of AM. Built on the foundation of our global Siemens R&D and manufacturing footprint, the new facility is a huge step in pioneering the industrialisation of high-end AM."

"Combining the full power of Siemens with the strengths of Materials Solutions offers unique and proven technologies for our in-house gas turbine business and for external markets and industries. We already have a significant number of core AM components in our portfolio," he concluded.

Siemens' metal AM technology has been validated through in-house application in the company's Power and Gas Business. It has been additively manufacturing hot rotating parts for use in its gas turbines for some time, and stated that it has now gathered more than 110,000 hours of engine experience with AM gas turbine parts in fully-operational power plants.

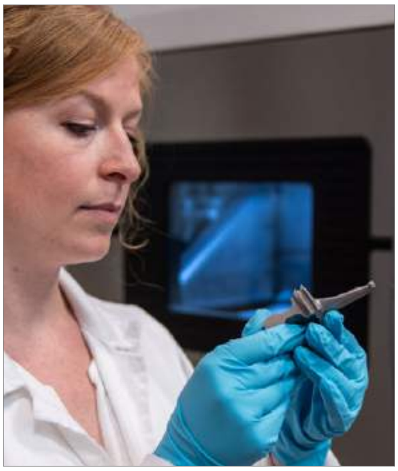
Materials Solutions is also supporting Siemens' latest HL-class gas turbines with the serial production of metal AM components to drive emission reduction and increase the performance of gas turbines. Siemens will use its AM technology to manufacture combustion components for the SGT5-9000HL gas turbine, and these will reportedly be employed for the first time by Scottish-based energy company SSE plc at its plant Keadby 2 in Lincolnshire, UK.

"Whether it's materials, machines, processes, or the digital value chain, we're always pushing the boundaries of technology," stated Markus Siebold, Vice President AM at Siemens Power & Gas. "Printing components for gas turbines means the highest material and technology requirements. If you can print a gas turbine blade, you can print pretty much anything."

"The end-to-end software and automation solutions - combined with our comprehensive expertise and our large printer fleet - makes Siemens a world leader in industrialising Additive Manufacturing, driving productivity, and getting complex 3D printed parts right the first time," he continued. "We're in the unique position of being able to leverage our advanced user expertise to bring these solutions to external customers via Materials Solutions Ltd."

Siemens recently applied its AM technology and engineering solutions to restore a one-hundred-year-old Ruston-Hornsby car to working order. By reverse engineering the broken steering box in the original vehicle using 3D scanning, Siemens digitally reassembled the part and created a working model for metal AM. The company also scanned and reverse engineered the corroded 'imp' mascot on the car bonnet to produce a copy in-line with the original appearance.

www.siemens.com



Siemens uses AM in-house as well as providing its full expertise as a partner to customers in the power, aerospace and automotive industries

The 1920 Ruston-Hornsby car restored by Siemens features a metal AM steering box and imp mascot

GE to install first metal additively manufactured part on GEnx commercial airline engines

The Federal Aviation Administration (FAA) has given 'change in design' approval to GE Additive and GE Aviation to replace a conventionally manufactured power door opening system (PDOS) bracket, used on GE Aviation's GEnx-2B commercial airline engines, with an AM bracket. The new additively manufactured brackets will enter mass production at GE Aviation's facility in Auburn, Alabama, USA, using GE Additive Concept Laser M2 cusing Multilaser machines, this month. GE Aviation anticipates the first GEnx engines installed with the new brackets will be shipped in January 2019.

GEnx-2B commercial airline engines power the Boeing 747-8. The PDOS is used on the ground to open and close the fan cowl doors to enable access to the fan compartment for maintenance reasons. The original PDOS brackets on GEnx-2B engines were produced from a solid block of metal, using conventional methods such as milling; this technique resulted in around 50% of the material being wasted.

Using Additive Manufacturing to produce the new brackets, waste generated during the part's manufacture has been reduced by as much as 90%. GE Aviation stated that it has also improved the design to reduce the bracket's weight by 10%. In addition, the decision to mass produce using a cobalt-chrome alloy, over a traditional nickel-based superalloy, has enabled a faster build.

Using a bespoke, interlocking design to house all four brackets on a single build plate, the Concept Laser M2 cusing machine's pair of lasers can additively manufacture an aircraft's worth of brackets in one build, before post-processing and inspection. By taking production of the brackets entirely in-house, GE Aviation also expects to reduce its production costs.

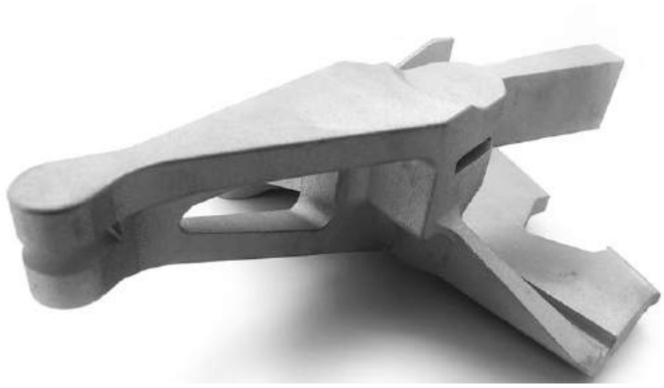
"We chose this project because it represented several firsts for us," stated Eric Gatlin, General Manager, Additive Integrated Product Team, GE Aviation. "It's the first programme we certified on a Concept Laser machine. It's also the first project we took from design to production in less than ten months."

"To ensure the M2 cusing machines were certified to meet the strict requirements for the aerospace industry, collaboration on this programme has been closer than usual with our colleagues at GE Additive," he added. "As we continue thinking about the many parts we can design, redesign and manufacture on GE Additive machines, I'm looking forward to putting both our teams and the technology through their paces."

Jason Oliver, President & CEO, GE Additive, commented, "It's been outstanding to watch teams from GE Aviation and GE Additive across the US, Mexico and Germany collaborate. In such a short space of time, they have really excelled with the PDOS bracket and achieved a truly groundbreaking success. Seeing the M2 machines produce flight quality hardware, and demonstrating what it is truly capable of, is another great milestone in our own additive journey."

www.ge.com/additive

www.geaviation.com



The PDOS additive bracket for GE Aviation's GEnx-2B commercial airline engine

Farsoon strengthens its European sales and service subsidiary

Farsoon Europe GmbH, Stuttgart, Germany, the European subsidiary of Farsoon Technology Inc., headquartered in Changsha, China, has begun building its regional sales, service and maintenance capabilities with the employment of a number of qualified service engineers. The company is also in the process of establishing a warehouse for parts and powders.

Farsoon stated that it will be represented by dedicated agents in various countries and regions in Europe, and has now launched a tender process for identifying qualified agents in Poland and the Baltics, Spain and Portugal, UK and Ireland, Czechia and South East Europe. The company is currently represented by In-Tech srl, Turin, Italy, which will serve as its exclusive agent in that country.

Farsoon Technologies was founded in 2009 in China and supplies industrial grade metal laser melting and plastic Additive Manufacturing systems. Its team includes competence in electrical and mechanical engineering, laser, scanning and optics, thermal controls, and material development and applications engineering.

www.farsoon.com


TRUMPF
TruPrint 3000

AM powder demand drives capacity expansion at Osaka Titanium Technologies

Osaka Titanium Technologies Co., Ltd., Amagasaki, Hyogo Prefecture, Japan, is expanding its powder production capacity to meet increasing demand for titanium alloy powders from the metal Additive Manufacturing industry. The company will invest approximately JPY 1 billion in a new factory with a planned powder production capacity of 100 t/year, expected to open in early 2020.

Osaka Titanium has been manufacturing titanium low oxygen powders using gas atomisation since 1994, primarily for use in sputtering targets, liquid crystal displays and in Metal Injection Moulding (MIM). As the adoption of metal AM grows, however, it has seen both domestic and international customers express their need for a safe and reliable system for the delivery of high quality alloy powders for use in AM. The company stated that it has seen the highest demand for titanium alloy powder from the aerospace and medical industries. As such, it will aim to secure aerospace quality certification to AS9100 for the new factory as soon as is possible.

Along with the new factory, Osaka Titanium Technologies has established a new team, the AMPM Team, to combine sales and technology for accelerated market development and expansion of the company's alloy powder activities. One key area in the company's development of higher performance titanium powder is the use of its in-house manufactured titanium sponge material as feedstock, which could offer heightened control over powder quality.

www.osaka-ti.co.jp

Carpenter announces acquisition of LPW Technology

Carpenter Technology Corporation, Philadelphia, Pennsylvania, USA, has acquired LPW Technology Ltd for approximately $81 million. LPW develops and supplies advanced metal powders and lifecycle management solutions to the metal Additive Manufacturing industry. LPW is based in Widnes, Cheshire, UK, and has additional processing operations near Pittsburgh, Pennsylvania, USA.

Tony R Thene, Carpenter's President and Chief Executive Officer, stated, "Our aggressive development in key aspects of Additive Manufacturing demonstrates our commitment to build on our industry-leading position in this space. The acquisition combines LPW's metal powder lifecycle management technology and processes with our technical expertise in producing highly engineered metal powders and additively manufactured components."

Carpenter stated that lifecycle management technology is becoming increasingly important to understanding how materials behave before, during, and after production in Powder Bed Fusion (PBF) Additive Manufacturing. Understanding powder behavior will continue to be critical as AM becomes more widely adopted and implemented across various industries.

"LPW's innovative platforms and enabling technology further solidify Carpenter's position as a preferred provider of end-to-end next generation Additive Manufacturing solutions," commented Phil Carroll, LPW's founder. "I'm extremely proud of the accomplishments we've achieved at LPW and I'm excited to be part of Carpenter's continued growth and leadership in AM."

Carpenter's AM portfolio also includes recent investments in Puris, a titanium powder producer; CalRAM, a leader in Electron Beam and Laser Beam Powder Bed Fusion AM services; and the construction of an Emerging Technology Center in Athens, Alabama, USA. The company stated that these recent acquisitions and investments represent a significant force positioned to capitalise on the rapid growth of the AM industry.

www.cartech.com
www.lpwtechnology.com

LPW Technology's headquarters in Widnes, Cheshire, UK (Courtesy LPW Technology)

BeAM partners with PFW Aerospace for industrialisation of Directed Energy Deposition

BeAM, Strasbourg, France, is partnering with PFW Aerospace GmbH, Speyer, Germany, to qualify a Ti6Al4V aerospace component for a large civil passenger aircraft. In addition, this collaboration will focus on industrialising the Directed Energy Deposition (DED) Additive Manufacturing process to manufacture series components.

PFW states it has been keeping track of technological developments and the market for AM processes for four years, prior to partnering with BeAM. The company is a tier one supplier of systems and components for all civilian Airbus models, as well as the Boeing 787 Dreamliner. Its status as a build-to-spec developer and experience in qualifying components and processes gives PFW the ability to establish designs for AM and to perform qualifications. The two companies are working closely to test the applicability of the DED process to currently machined titanium components and complex welding designs.

In the DED process, focused thermal energy is used to fuse materials by melting them as they are deposited, making it possible to give complex characteristics to semi-finished products or intermediate construction. The results are near net shape geometries, which can reduce material expense as well as scrap volume by over 70%, having a sustainable effect on process cost effectiveness. PFW reported that it is striving to create a process combining the cost-effective manufacturing of geometrically simple intermediate products, and jobs with complex, additive characteristics.

As part of the partnership, PFW has acquired a Modulo 400 machine from BeAM. The Modulo 400 incorporates a glove box design which makes it possible to fulfil aerospace requirements for overall atmospheric values for O_2 and H_2O. System technology and process management are now being further developed in close cooperation between the companies, with an eye to meeting industrial production requirements.

www.beam-machines.com
www.pfw.aero

Aerospace flange in Ti6Al4V. Built using DED, heat treated and partially machined (Courtesy BeAM)

Generation Growth Capital acquires 3rd Dimension Industrial 3D Printing Co.

Generation Growth Capital Fund III, LP, (GGC), a private equity firm based in Milwaukee, Wisconsin, USA, has acquired 3rd Dimension Industrial 3D Printing Co., Indianapolis, Indiana, USA. 3rd Dimension is an industrial precision metal Additive Manufacturing solutions provider, and is reported to serve several large customers in the aerospace, consumer branded goods, automotive and industrial sectors.

Bob Markley, founder and part owner of 3rd Dimension, will continue to manage the company following the acquisition. "I am excited to be partnered with GGC for 3rd Dimension's next phase of growth," he commented. "During my search for the right partner, it became apparent that GGC was well aligned with my goals and could offer more than just access to capital after the transaction."

"Their team's background in manufacturing provides significant strategic advantages," he continued. "They speak the same language and understand the business model. I believe this partnership will greatly benefit 3rd Dimension's customers as we expand and invest in new equipment and technologies."

"We were extremely impressed by 3rd Dimension's capabilities and customer base and look forward to working with Bob Markley to build a best-in-class Additive Manufacturing platform," stated John Reinke. "We have already begun our investments in new facilities and equipment to provide enhanced services to 3rd Dimension's customers. The team is excited to see what the future holds for the growth of this business."

www.generationgrowth.com
www.print3d4u.com

VBN Components launches new cemented carbide for metal Additive Manufacturing

Drill bits in Vibenite 480, produced in collaboration with Epiroc

VBN Components AB, Uppsala, Sweden, has launched a new cemented carbide for metal Additive Manufacturing, the hard metal Vibenite® 480. The alloy is said to be corrosion resistant as well as extremely heat and wear resistant, and its suitability for metal AM is expected to enable the manufacturing of industrial tools and components in complex shapes, while reducing the environmental impact of their production.

Ulrik Beste, PhD Materials Science and Tribology and CTO of VBN Components, stated, "It is a particular kind of joy for me, as a material developer, to introduce such ground-breaking news within the area of hard metals. We turn the page in the book of Swedish material history." Vibenite 480 is based on metal powder produced through large-scale industrial gas atomisation, and combines the toughness of Powder Metallurgy high speed steels (PM-HSS) with the heat resistance of cemented carbides. To reflect this combination, the new group of materials is named hybrid carbides.

The material has a carbide content of ~65%, making it tougher than regular hard metals and therefore suitable for the production of more complex details. According to VBN, the material is aimed at applications where steel would normally be used, but where a switch to hard metal could increase production efficiency and geometrical complexity. This could mean that metal cutting tools which today are manufactured by machining steel bars could be replaced by the hybrid carbide and run with higher speed, thanks to higher heat resistance.

In addition to enabling the production of more complex shapes, Vibenite 480 is said to allow the production of much larger objects in a single piece than is possible using conventional hard metal manufacturing techniques. This adds to the number of possible usage areas and offers new opportunities for the production of prototypes.

"We have learned an enormous amount on how to 3D print alloys with high carbide content and we see that there's so much more to do within this area," stated Martin Nilsson, CEO of VBN Components. "We have opened a new window of opportunity where a number of new materials can be invented."

The material is well-adapted for products with extreme demands on wear and heat resistance, such as tools for thermoforming, die casting, cutting and woodworking. Rock drilling is another application where VBN Components has reportedly already begun a collaboration with Swedish company Epiroc.

www.vbncomponents.se

Authentise teams up with Autodesk to enable seamless AM workflow

Authentise, a provider of data-driven workflow tools for AM, is collaborating with Autodesk to release an integration that enables the use of Autodesk's Netfabb software with Authentise's additive workflow management tools.

As part of the integration, users of Authentise products can load geometries directly into Netfabb easily, using Autodesk's cloud-based Forge developer platform. Saving files edited in Netfabb back into Authentise is said to be equally simple, allowing what Authentise describes as a seamless AM workflow from quoting to CAD editing, version control, scheduling, and real-time, data-driven monitoring. The integration is available to those customers who subscribe to both Authentise's Additive Accelerator and any version of Autodesk Netfabb.

Andre Wegner, CEO of Authentise, commented, "While we have proven our open approach with third-party algorithm integrations in the past, this is the first time we are working to craft a joint customer journey. We are proud to be doing so with Autodesk."

www.authentise.com
www.autodesk.com

Trumpf adds high-strength tool steel processing and green laser functionality for AM

Trumpf, Ditzingen, Germany, has announced a range of new capabilities and highlighted new applications for its metal Additive Manufacturing technology. The company stated that its latest TruPrint 5000 machine can preheat to 500°C, allowing the production of high-strength tool steel. Trumpf also introduced a green laser option allowing the processing of pure copper and precious metals, as well as showcasing new applications in tool and mould making, medical devices and the jewellery industry.

Tool and mould makers frequently work with carbon tool steel 1.2343, an extremely hard and wear-resistant material that dissipates heat particularly well. However, this material is extremely challenging to process using Additive Manufacturing due to its propensity to crack during manufacturing.

"The laser beam melts the component surface, which subsequently cools back down to room temperature. The components weren't able to withstand this temperature drop, and cracks formed," explained Tobias Baur, Trumpf's General Manager Additive Manufacturing. To address this issue, the substrate plate of the TruPrint 5000 Laser Beam Powder Bed Fusion (LB-PBF) system is preheated to 500°C, reducing the temperature drop following laser melting. "The material quality and surface of carbon steels are significantly better than without preheating, preventing fractures in the components," he stated.

Preheating also offers advantages for titanium alloy medical prostheses and implants produced using AM, Trumpf stated. "When the ambient temperature drops too sharply, the parts warp and we have to rework them. In addition, we often require support structures that are difficult to set up and take down," Baur added. Preheating the substrate plate is said to reduce stress, improve processing quality and, in many cases, eliminate the need for support structures. It can also reduce the need for downstream heat treatment, as well as making titanium alloys processed by AM more resilient and implants more durable as a result.

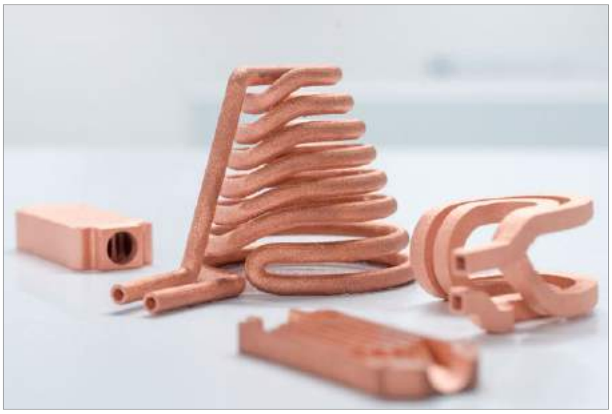
It was stated that using a green laser with a pulse function makes it possible to print pure copper and other precious metals. "Conventional systems use an infrared laser as the beam source, but its wavelength is too long and it can't weld highly reflective materials such as copper and gold," Thomas Fehn, Trumpf General Manager Additive Manufacturing, explained. "This can be done with laser light in the green wavelength spectrum."

Using a green laser connected to its TruPrint 1000 metal AM machine, Trumpf has been able to additively manufacture pure copper and gold components

According to Fehn, this will open up a wider range of applications for metal AM, for example in the electronics and automotive industries. The capabilities offered by the green laser could also be especially lucrative in the jewellery industry, he added, as the AM process wastes significantly less material than conventional milling or casting processes.

www.trumpf.com

By heating the substrate plate, high-carbon steels or titanium alloys can be additively manufactured without cracking or severe warping



The Additive Manufacturing of pure copper has a number of potential applications in plant engineering and construction, among other industries

Altair acquires simulation software company SIMSOLID

Altair, Troy, Michigan, has announced its acquisition of structural analysis software company SIMSOLID Corporation. SIMSOLID works on full-fidelity CAD assemblies to provide fast, accurate, and robust structural simulation without requiring geometry simplification, clean-up or meshing, using underlying technology based largely on the work of company co-founder Dr Victor Apanovitch, a former professor at Belarus Polytechnic University.

The SIMSOLID computational engine is said to use novel and unpublished mathematics based on extensions to the theory of external approximations. It controls solution accuracy using multi-pass adaptive analysis, making it fast and memory efficient. The software is reportedly capable of rapidly solving large and complex assemblies.

The ability to quickly solve large assemblies and complex lattice-based parts, without meshing or geometry simplification, could offer significant time savings when designing parts for AM. Because complex lattice structures can be analysed very quickly, Altair states, users can focus on engineering decisions rather than on model preparation. Speaking on the acquisition, James Scapa, Altair's Founder, Chairman and CEO, stated, "We believe SIMSOLID is a revolutionary technological breakthrough which will have a profound impact for product design. It's incredibly fast, accurate and robust and we believe a game changer for our industry."

Dr Uwe Schramm, Altair's CTO, explained, "We are very serious about solution accuracy. Others have tried to accelerate the interface between CAD and simulation by degrading the mathematical robustness. It is our feeling that by rapidly moving forward with the methods in SIMSOLID and expanding them across applications we can have a real effect on how design gets done while maintaining our high standards for computational excellence."

www.simsolid.com
www.altair.com/SIMSOLID

PyroGenesis completes construction of new metal powder production facility

PyroGenesis Canada Inc., Montreal, Canada, has completed the construction of its new facility for the production of metal powders for Additive Manufacturing. The facility houses a new plasma-based atomisation unit, inventory storage and logistics operations and will be dedicated to the production of plasma atomised Ti-6Al-4V powders, primarily targeting the aerospace and biomedical industries.

Massimo Dattilo, Vice President of PyroGenesis Additive, stated, "We are very excited about having completed this milestone. It puts PyroGenesis squarely on the map as a quality supplier of Ti-6Al-4V powder for the AM industry. In parallel, we are also investigating other materials which can be produced with our other reactors, currently in our main facility."

"This next logical step of incorporating some of the previously announced improvements into a cutting-edge facility is now complete," added P Peter Pascali, President and CEO of PyroGenesis. "After investing over $2.5 million into this facility, all that remains is to incorporate post-treatment equipment for it to be a stand-alone facility."

The new facility is ISO 9001:2015 certified and is expected to be AS9100D (aviation, space and defence) certified by the end of 2018. Upon receipt, PyroGenesis will then pursue ISO 13485 for the production of medical devices.

www.pyrogenesis.com

Uddeholm produces first test melts at new AM powder plant

Uddeholm, a voestalpine company headquartered in Hagfors, Värmland, Sweden, has completed installation at its new powder production plant, dedicated to the production of metal powders for Additive Manufacturing. The investment in the new plant was approved and announced in May 2017, and Uddeholm stated that the first test melts have now been produced.

Uddeholm entered the Additive Manufacturing market with the release of its first metal powder product, AM Corrax® stainless steel powder, in June 2017. The company stated that its investment in the new plant strengthens its position as a leading provider of high-performance tool steels.

The plant comprises a brand new 1,450 m² facility in Hagfors, and is the first new building to be constructed on the Uddeholm site since 1981. It will accommodate melting and atomisation equipment as well as offering space for raw materials handling, an automatic sieving station, a packing station and office space.

Powder production will be carried out in a vacuum induction melting, close-coupled atomiser with a total melt capacity of 500 kg. Using this system, melt is poured through a ceramic nozzle and atomised into powder using a high-pressure nitrogen stream; a new gas distribution system has also been installed in close proximity to the building to provide the atomiser with high-pressure nitrogen.

Testing was expected to conclude this month, with the company set to officially begin production soon after. The new facility significantly expands Uddeholm's powder produ ction capacity, but the company added that preparations for future expansions are already in place.

www.uddeholm.com

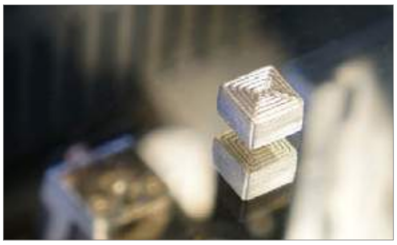
Fraunhofer IKTS develops Fused Filament Fabrication for hardmetals

Researchers at the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) in Dresden, Germany, report that they have adapted the Fused Filament Fabrication (FFF) process for the Additive Manufacturing of hardmetals. Hard tools, produced from hardmetals consisting of the metal binders nickel or cobalt and the hard phase tungsten carbide, are required in forming technology, metal-cutting and process engineering.

Cutting, drilling, pressing and punching tools made from hardmetals have conventionally been extruded, metal injection moulded or produced using uniaxial or cold isostatic powder pressing. However, although these methods can achieve a high degree of hardness, they often require complex and expensive post-processing steps to achieve net shape.

AM enables the production of components with complex geometries with minimal post-processing, but has traditionally been limited in terms of the hardness and component size which can be achieved. Both metal Binder Jetting and plastic 3D printing have been successfully used at IKTS with selected hardmetal compositions; however, the metal binder content and resulting hardness, as well as the size of these components, has been limited.

According to the IKTS, FFF could enable economical and customisable production of even harder tools for the first time. Originating in the plastics processing industry, FFF was initially adapted for ceramics and composite materials at IKTS. Depending on the material's structure, a reduced grain size and binder content can be used to specifically increase the hardness, compressive and flexural strength of hardmetal filaments.



Hardmetal sample with a complex geometry produced on a standard FFF AM system

Dr Johannes Pötschke who heads the Hardmetals and Cermets group at IKTS, explained, "The filaments can be used as semi-finished products in standard printers and, for the first time, make it possible to print hardmetals with a very low metal binder content of only 8% and a fine grain size below 0.8 µm, and thus allow extremely hard components with up to 1700 HV10."

www.ikts.fraunhofer.de

voestalpine completes run-up phase for new metal powder facility

voestalpine Group's High Performance Metals Division, based at sites in Kapfenberg and Mürzzuschlag, Austria, states that it has completed the run-up phase for a new metal powder production facility which will produce powders for Additive Manufacturing. The new facility forms part of a wider, ongoing investment in technology development at the Kapfenberg site, expected to reach around half a billion euros by 2021.

The launch of the AM powder facility follows the division's opening of a pilot plant in 2016, and the group stated that in future, it expects each of its external partners as well as its own global AM centres to be supplied with powders from Kapfenberg. Franz Rotter, Member of the Management Board of voestalpine AG and Head of the High Performance Metals Division, stated, "We are one of only a few suppliers worldwide able to offer a complete value chain in the metal Additive Manufacturing sector — covering everything from powder and design through to the final metal part."

In summer 2018, a new chemical laboratory was opened at Kapfenberg with the aim of enabling the ongoing optimisation of material production and processing at voestalpine Böhler Edelstahl. An in-house competence centre for digitalisation was also established to provide a training and development space, with an apprentice workshop applying digitally-supported training concepts, and an electronics and automation laboratory has been set up with a focus on process control, mechatronics, robotics and IT technology.

voestalpine's new Additive Manufacturing powder production facility in Kapfenberg, Austria (Courtesy voestalpine Group)

voestalpine High Performance Metals Division employs a workforce of around 3,800 and is a leading global provider of high-performance materials and special forgings for the aerospace sector. Its products are used in structural and undercarriage parts, engine components, and door segments in all major models of aircraft, including Airbus, Boeing, Embraer and Bombardier.

www.voestalpine.com

Xi'an Bright Laser Technologies adds Quintus Hot Isostatic Press to its AM facility

The QIH48 URC installed at BLT's metal Additive Manufacturing facility in Xi'an, China (Courtesy Xi'an Bright Laser Technologies Co., Ltd.)

China's Xi'an Bright Laser Technologies Co., Ltd. (BLT), a metal Additive Manufacturing service provider located in Xi'an, Shaanxi Province, has installed a Hot Isostatic Press from Quintus Technologies, Västerås, Sweden, at its Additive Manufacturing facility. BLT operates just under one-hundred systems for laser-based Additive Manufacturing and repair at its 40,000 m^2 facility, and is capable of additively manufacturing parts in more than fifty materials, including titanium and aluminium alloys, superalloys, and stainless, die and high-strength steels.

Quintus's model QIH48 URC® press is equipped with the company's patented Uniform Rapid Cooling, which combines traditional HIP with heat treatment in a single system. The integrated materials densification process, known as High Pressure Heat Treatment, is said to produce parts with improved fatigue and ductile properties to satisfy critical performance requirements in industries ranging from aerospace and automotive to medical and energy.

"We chose to work with Quintus Technologies because the company has more than fifty years of history in the application of high pressure in sheet metal forming and advanced material densification," stated Dr Xue Lei, General Manager, BLT. Quintus specialises in the design, manufacture, installation and support of high pressure systems. The company has delivered more than 1,800 of its systems to customers across the globe within industries including aerospace, automotive, energy, and medical implants.

The Quintus HIP system installed at BLT features a hot work zone of 375 mm and 1200 mm in height; an operating temperature of 1400°C; and pressure of 30,000 psi. "The QIH 48 URC offers several time-saving and quality advantages," added Dr Xue Lei. "The streamlined High Pressure Heat Treatment process enables us to serve our customers with shorter lead times. The press's programmable temperature distribution and high precision can avoid thermal stress deformation caused by temperature change and prevent cracking. In addition, there is no need to clean or dry parts after cooling."

"We are very pleased to be working with a company that has such expertise in Additive Manufacturing in China," commented Jan Söderström, CEO of Quintus Technologies. "Our collaboration brings together two leaders that are committed to advancing technology development and product innovation in the AM field."

Xi'an Bright Laser Technologies Co. was established in 2011 and benefits from over twenty years of metal AM research gained by its founding team. The company currently employs over 400, of which 30% are said to hold advanced degrees. Along with cooperating with several renowned enterprises in various areas in China, BLT has established long-term relationships with global aerospace companies such as Airbus and Safran. BLT is focussed on continuous invention and innovation, which is reflected in 155 patent applications related to metal AM technology.

www.quintustechnologies.com
e.xa-blt.com

Xi'an Bright Laser Technologies operates almost one-hundred laser-based AM systems at its 40,000 m^2 facility

Aperam looks to acquire Germany's VDM Metals

Aperam S.A., Luxembourg, has proposed the acquisition of VDM Metals Holding GmbH, Werdohl, Germany. The company filed a form CO notification with the European Commission for the proposed acquisition in October 2018.

Aperam supplies stainless, electrical and speciality steels globally, and serves customers in over forty countries. VDM Metals is a producer of high-performance metals and metal powders for a range of applications and industries.

The acquisition is currently in Phase II review by the European Commission, with a decision set to be made by April 16, 2019, at the latest. The initial Phase I review was said to have raised issues regarding a reduction in competition in the supply of nickel alloys, which both companies produce.

Recently, Aperam signed a Memorandum of Understanding with metal powder producer Tekna, Quebec, Canada, for the joint development of high-quality spherical metal powders for Additive Manufacturing. VDM Metals currently supplies a wide range of superalloy powders, corrosion resistant alloy powders, cobalt-chrome alloy powders and more for the metal AM industry.

www.aperam.com
www.vdm-metals.com

Authentise adds Prosper3D quoting engines to its AM software

Automation software company Authentise, Mountain View, California, USA, which produces data-driven workflow tools for Additive Manufacturing, has partnered with Prosper3D, Tel Aviv, Israel, a provider of quoting solutions for AM service bureaux, to offer Authentise customers access to a greater range of workflow management tools.

As part of the agreement, Authentise customers will be able to access Prosper3D's quoting engines through the Authentise Additive Accelerator interface. This will enable them to receive accurate Prosper3D quotes in addition to printability assessments, rendering, automatic traveller creation, file conversion and more for every geometry uploaded to the system.

Access to the Prosper3D quoting algorithm will be offered on Authentise's internal quoting tools, which are based on data drawn from AM machines. The integration can also be accessed via Authentise's 3Diax modular platform.

Ilan Sidi, CEO of Prosper3D, stated, "We are proud to work with Authentise to bring our quoting algorithms to additive customers. For too long, service providers in the area have wasted time and money generating inaccurate quotes. This partnership broadens the reach of our advanced quoting tools."

"This partnership shows once again how the industry can be accelerated by being open," commented Andre Wegner, CEO of Authentise. "Our customers can now choose to switch quoting algorithm at zero switch cost – they don't even need to learn a new software."

"In the end, the customer and the industry benefits because competition makes products evolve faster and they know they're always getting best-in-class. We're not afraid of competition – we invite it. Our partnership with Prosper3D proves that," he concluded.

www.authentise.com
www.prosper3D.com


Let's build anything together.
No, really, it's up to you. By partnering with GE Additive, your factory comes equipped with an increased level of choice, flexibility and design freedom. Now, you can create products that are stronger, lighter and more efficient. Which means, the next thing you make could be anything. Let's build anything together. Learn how to transform your factory into an Anything Factory at ge.com/additive.
GE Additive

Lockheed Martin first to be certified for Additive Manufacturing safety by UL

Lockheed Martin, headquartered in Bethesda, Maryland, USA, has been named as the first organisation to be certified to UL 3400, a set of safety guidelines addressing hazards associated with Additive Manufacturing facilities, by global safety science company UL. The certification was issued to Lockheed Martin's Additive Design and Manufacturing Center (ADMC) in Sunnyvale, California, USA.

UL published UL 3400, 'Outline of Investigation for Additive Manufacturing Facility Safety Management', in 2017. Balu V Nair, UL's AM Lead Development Engineer, stated, "Employers, employees, local regulators as well as insurance companies who have to underwrite Additive Manufacturing facilities, were not fully aware of the inherent material and technology risks. Safety is designed rather than built," he continued. "Not a single standard or statutory guideline was available that specifically focused on AM. Other standards and guidelines were developed for conventional manufacturing processes. We decided to address this industry need by developing a set of guidelines with exclusive focus on additive manufacturing."

UL 3400 takes into consideration three layers of safety: material, equipment and the facility as a whole. The guideline references applicable standards from the US's Occupational Safety and Health Administration, the National Fire Protection Association, UL and ASTM International, among others. The guideline was created with the global market in mind and covers the potential hazards and risk mitigation measures required for the safe functioning of the facility.

Lockheed Martin's ADMC is said to be unique among the company's additive facilities. Focused on space applications, it aims to bridge the gap between materials research and the manufacturing floor to enable engineers to design and produce superior satellite parts faster and at lower cost.

Thomas Malko, VP of Engineering & Technology at Lockheed Martin Space, stated, "Lockheed Martin built the first 3D printed parts bound for deep space on the Juno spacecraft and we've been at the forefront of Additive Manufacturing ever since. This facility builds on our sixty years of Silicon Valley research and decades of satellite manufacturing expertise, so we can launch lighter, more affordable products faster. Lockheed Martin's ultimate goal is to build satellites in half the time and cost, and this facility will accelerate that capability."

www.lockheedmartin.com

www.ul.com/am

Tekna inaugurates expanded metal powder production facility

Tekna recently inaugurated its expanded second plant in Sherbrooke, Canada

Metal powder manufacturer Tekna Plasma Systems Inc., Sherbrooke, Quebec, Canada, has officially inaugurated its expanded second plant and its new manufacturing infrastructure. The result of a $5.5 million investment by the company, the expansion has doubled its metal powder production facilities to support the major growth of its activities.

The additional space created will reportedly be used for the immediate and future deployment of new metal powder production units, the introduction of new research infrastructure and the relocation of part of its administrative staff. Rémy Pontone, Tekna's Vice President, Sales and Marketing, stated, "This investment will enable us to follow and support the growth of our clients through our existing products and to launch new innovative products on the industrial market."

Luc Dionne, Tekna CEO, added, "This expansion, which is part of our five-year growth plan, will increase our annual metal powder production capacity to over 1,000 tonnes. Our world-class manufacturing infrastructure and our accreditations in terms of the strictest quality standards make Tekna a reliable partner that our clients can count on to ensure their current and future success."

Tekna manufactures metal powders for Additive Manufacturing, Metal Injection Moulding (MIM), Hot Isostatic Pressing (HIP) and thermal spray, including Ti64 titanium alloy powder, aluminium powder, tantalum powder and molybdenum powder. It also produces a range of turnkey plasma systems for the production of metal powders.

In August 2018, the company revealed plans to invest up to $128 million over the course of its five-year plan to expand its global manufacturing output and boost its research and development capabilities, in a project benefiting from $33 million in financing from the Canadian government.

www.tekna.com

Z3DLAB releases enhanced nano-structured titanium powders

A comparison between the characteristics of ZTi-Powder and ZTi-Med with Ti-6Al-4V and Ti according to ASTM values (Courtesy Z3DLAB SAS)

Z3DLAB SAS, Montmagny, Val-d'Oise, France, has released its new nano-structured titanium powders, enriched by 1% nano-zirconium, for use in metal Additive Manufacturing. Founded in 2014, the company specialises in advanced non-structured materials for Additive Manufacturing, and believes that its new titanium powders provide better characteristics than standard titanium powders.

The company's ZTi-Powder® range comprises nano-structured TA6V & zirconium powders with an ultimate compressive strength of 1482 MPa, a compressive yield strength of 1100 MPa, an ultimate tensile strength of 1035 MPa and micro hardness of 441 HV.

ZTI-Med®, a range of nano-structured titanium & zirconium powders, is designed to solve the stress shielding effect in medical implants, having an elastic modulus GPa of 35. ZTI-Med has an ultimate compressive strength of 1030 MPa, a compressive yield strength of 630 MPa and an ultimate tensile strength of 950 MPa.

According to Z3DLAB, the above material properties were achieved for parts produced in a standard titanium Powder Bed Fusion (PBF) Additive Manufacturing process, with none of the parts undergoing any design alterations. Madjid Djemaï, Z3DLAB CEO, stated, "We are pleased to make available the 1% enhanced nano-ceramic, with better results to what we obtained back in 2015 with 5%."

"This will reduce resistance to change to its minimum and facilitate rapid adoption by both the medical and other industries," he added. "The ZTi Family is here to replace the old titanium and bring new enhanced characteristics. A family of advanced material specifically designed for AM."

www.z3Dlab.com

Aurora Labs partners with Fortescue on metal AM for mining industry

Aurora Labs Limited, Bibra Lakes, Western Australia, has signed a non-binding term sheet with subsidiaries of Fortescue Metals Group, a global leader in the iron-ore industry with integrated operations across three mines sites in the Pilbara region of Western Australia.

The agreement comprises an Industry Partner Program, with the opportunity for Aurora to work with Fortescue on the company's metal Additive Manufacturing technology to demonstrate the potential for application of Aurora's Rapid Manufacturing Technology (RMT) in the mining industry. The venture could progress to Aurora developing technology or processes that may reduce production and operation costs in the mining and resources sectors.

David Budge, Managing Director of Aurora Labs, stated, "We're very excited to sign a preliminary agreement with Fortescue and pursue the opportunity to apply Aurora's Rapid Manufacturing Technology to the mining sector. Fortescue are an ideal industry partner for us and they are at the forefront of technological advancements in the mining sector."

"We are building our Industry Partner Program with VEEM, DNV-GL, Advisian and Fortescue and it's great to see some of Australia's largest companies are keen to explore our technology," he continued. "We see this as validation of what we are developing and it acknowledges the high potential that 3D printing has in transforming how parts are created and optimised."

Aurora Labs' Rapid Manufacturing Printer 1 (RMP1)

www.auroralabs3d.com
www.fmgl.com.au

AP&C to offer aluminium alloy F357 powder

AP&C, a GE Additive company, headquartered in Montreal, Canada, has announced that it will begin production of aluminium alloy F357 powder in the first quarter of 2019, with customer deliveries expected from April 2019. The alloy is known to have good weldability, with high strength and toughness offering a good corrosion resistance and heat conductivity.

The demand for Aluminum F357 alloy is said to be increasing, particularly from customers in the aerospace and automotive sectors. The alloy powder will be produced using AP&C's proprietary Advanced Plasma Atomisation (APA™) at its recently expanded facility in Saint-Eustache, Canada. This new, automated plant offers a full production capacity of 1,000 tons.

Aluminium shares similar characteristics with titanium, and aluminium alloy F357 powder is said to have the same quality signature as APATM titanium powders – good processability, high flowability, high packing, low porosity and high purity – which are all required by the Additive Manufacturing industry to enhance performance and reliability of the aluminium printing process.

"It's great to add aluminium F357 to our portfolio. Our customers have been asking us to provide aluminium solutions to address the challenges they currently experience. We are confident we've developed a solution that solves these challenges," stated Alain Dupont, President & CEO, AP&C.

The final analysis to determine the content of carbon and sulphur within a metallic matrix, F357

"The modular cell-based structure of our new plant in Saint-Eustache allows us to respond quickly to the additive industry's demands as it rapidly evolves," he added.

www.ge.com/additive

VDMA developing Additive Manufacturing roadmaps for Smart Factory

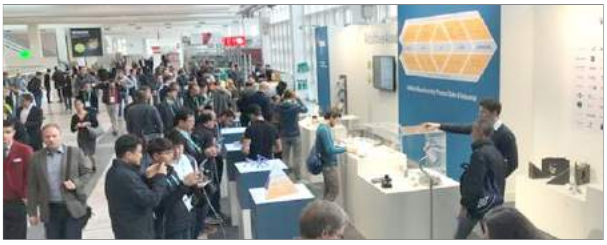
Member companies of the Additive Manufacturing Association of the VDMA, Germany's Mechanical Engineering Industry Association, have developed new detailed roadmaps for Additive Manufacturing which outline, step-by-step, the path to the development of the Smart Factory.

The VDMA Additive Manufacturing Association is comprised of around 150 member companies and research institutes covering all steps of the AM value chain, from design software to construction, system control, building and consumable materials, to AM systems for diverse technologies in metal and plastic AM. Member companies also include suppliers of post-processing and automation solutions and air purification and vacuum conveyor technology.

Dr Markus Heering, Managing Director of the VDMA AM Association, stated, "Our roadmaps are firmly built on the ground of comprehensive industrial experience." In the roadmapping process, companies representing each step in the value chain have shared their perspective on the current state of technology and on potential future developments, enabling a clarification of priorities for those technology developers and users that participated, while also enabling participants to reach an agreement about standardised terms and interfaces during this process. The members of the VDMA AM Association stated that they are convinced of the potentials for series production using Additive Manufacturing, and there is said to be a high degree of willingness within the association to come to agreements for the purpose of fast industrialisation. "Against this background, our discussion process has developed a very special dynamic," commented Rainer Gebhardt, Project Manager of the VDMA AM Association. "If you look at it closely, you will find already today hotbeds for comprehensive automation and a consistent in-process quality control. We need to make them available to industrial users as quickly as possible."

The project participants identified the post-processing of AM parts as being most in need of development to enable series production. "Only automation of the various work steps will allow for economical and sustainable production with Additive Manufacturing technologies," stated Christoph Hauck, Chairman of the Board of the VDMA AM Association and Managing Director of MBFZ Toolcraft GmbH. "It is here in particular that research and development need to be advanced so as to strengthen the competitive position of AM technologies. The experience gathered as well as integration of traditional manufacturing technologies all offer a large potential for optimisation."

The VDMA AM Association reported that it has identified a cross-process need for R&D in the developed roadmaps. Many problems in materials logistics, the EHS area, data processing, and process standardisation would be virtually impossible for a single company to tackle independently; in order to address these issues, the involvement of research associations bringing together the experience and know how of diverse areas and industries is of key importance.


The VDMA presented its AM roadmaps at Formnext 2018

"We are convinced that our roadmaps provide an accurate summary of the work schedule for the next years," stated Heering. "Now, politically responsible persons of vision and innovative fellow campaigners from diverse sectors are needed for us to quickly work through this programme. We need to watch out so that we will not waste our good starting position and then watch the innovation train leave without us."

https://am.vdma.org

AutoAdd project looks at integration of AM in automobile series production

Five companies and two research institutes recently took part in AutoAdd, a project to examine the 'Integration of Additive Manufacturing Processes in Automobile Series Production', with a focus on Laser Beam Powder Bed Fusion (LB-PBF) technology. The project ran from June 1, 2015, to May 31, 2018, and was funded by the German Federal Ministry of Education and Research (BMBF) under its 'Photonic Process Chains' framework.

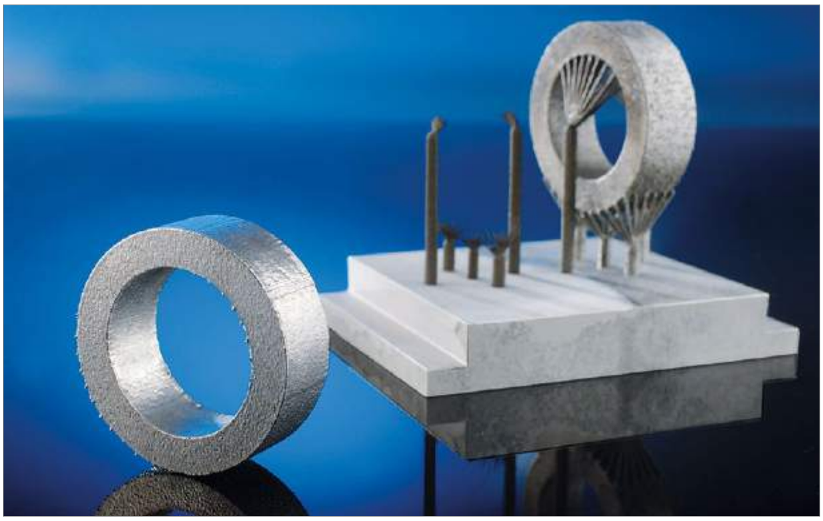
The full list of project partners included:

- BMW AG, Munich, Germany
- Daimler AG, Ulm, Germany (Project coordinator)
- Fraunhofer Institute for Laser Technology ILT, Aachen, Germany
- GKN Powder Metallurgy, Radevormwald, Germany
- Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
- netfabb GmbH, Lupburg, Germany
- Trumpf Laser- und Systemtechnik GmbH, Ditzingen, Germany

BMBF's Photonic Process Chains framework funds research projects looking to integrate photon-based manufacturing processes such as metal Additive Manufacturing into product planning to develop flexible, hybrid manufacturing conceptual designs which the industry can use to produce individualised, complex products more efficiently than previously possible.

The AutoAdd project was set up with the aim to ease the adoption of AM by the automotive industry within three years. The project partners focused on integrating the LB-PBF process into the automotive mass production environment to create a hybrid process chain and thus reduce unit costs. BMW Group and Daimler defined the requirements for an automotive Additive Manufacturing process chain, while AM machine maker Trumpf and research institute Fraunhofer ILT developed the LB-PBF plant technology.

The result was a potentially production-ready design as well as a modular system architecture which could, for example, enable the use of multiple laser beam sources and interchangeable cylinders. In addition, the project team developed automatable post-processing concepts for support structure removal, and analysed novel scalable materials produced by GKN Powder Metallurgy.



A test piece with supports removed through a wet-chemical process (Courtesy Fraunhofer ILT)

To conclude the project, Karlsruhe Institute of Technology (KIT) evaluated the new factory designs using a simulation model to visualise an exemplary conventional process chain, in which engineers at the wbk Institute for Production Science were able to design various possible LB-PBF plant concepts with methods such as cost or benchmark analysis enabling a comparison of new and previous approaches from both a technical and economic point of view.

The results of the three-year joint project were said to be impressive. Because modular cylinders and the use of wet-chemical immersion baths can now be used to remove batches of components in the post-processing step, the entire process chain can be automated and non-productive time saved, increasing the overall profitability. The AutoAdd project team has also developed common metrics for evaluating LB-PBF manufacturing equipment and identified them for the most popular equipment manufacturers as part of a large-scale benchmarking exercise.

By using standardised benchmark jobs with different test specimens, industrial users can now calculate transferable key figures with which they will be able to find the most economical system for their purposes. In addition, the reproducibility of the mechanical properties of metal AM parts – one of the most important challenges which must be overcome to make the technology ready for series production – was demonstrated and evaluated in several state-of-the-art facilities.

At the conclusion of the project, the members stated that the integration of an economical AM process chain in automotive mass production can now be considered possible. In 2019, a further project partly based on the results of AutoAdd will follow, dealing with the in-line integration of AM processes to implement the process chain designed on the project.

www.bmbf.de

DMG MORI invests in Indian Additive Manufacturing software developer

DMG MORI has announced that it has taken a 30% stake in the Indian company, INTECH, a developer of software for Additive Manufacturing, machine learning and artificial intelligence.

INTECH is reported to be a pioneer in metal Additive Manufacturing in India. The firm already supplies software solutions for DMG MORI's LASERTEC SLM machines and for other products as well as customers using powder bed technology. Its new OPTOMET software, for example, automatically calculates optimal process parameters, simplifying programming and resulting in improved surface quality as well as reproducible component properties.

Employing more than sixty software specialists and technology experts, INTECH was founded in 2012. It supplies not only innovative software solutions but also additively manufactured prototypes into the aerospace, medical, automotive and toolmaking sectors, as well as mechanical engineering. The company's staff has more than 30 years' metallurgical experience gained in the foundry business and over 25 years of machining and quality control expertise.

Christian Thönes, Chairman of the Executive Board of DMG MORI AG commented, "With INTECH we are strengthening our global footprint in India and accelerating our innovation in additive manufacturing. Right first time is our motto, which means producing the first good part quickly. We are actively pushing ahead with integrated solutions along the whole generative manufacturing process chain."

DMG MORI is taking a 30 per cent stake in Indian additive manufacturing specialist, INTECH (Courtesy DMG MORI)

Sridhar Balaram, CEO of INTECH added, "Leveraging synergies is key and our collaboration with DMG MORI is a perfect fit of hardware and software. OPTOMET can also be applied to other key technologies within additive manufacturing, such as directed energy deposition and binder jetting. We believe this software is a game-changer for the whole of the additive manufacturing market."

www.dmgmori.com

OR LASER demonstrates its metal Additive Manufacturing in dental sector

OR Laser, a Coherent, Inc. company, showcased its range of industrial laser based Additive Manufacturing equipment at this year's Formnext exhibition. The company's booth was dedicated to highlighting how its metal AM platforms can be applied within a complete production workflow, with a specific focus on how this is already happening within the dental sector.

The company displayed a range of manufacturing systems at its booth, most notably the Creator direct metal Additive Manufacturing machine, the Creator RA and the Creator hybrid, which were displayed alongside the EVO Mobile and Cube systems to allow visitors to fully understand their capabilities and how they can fit into their own production environments.

The company's continued focus on advancing the capabilities of the Creator series of machines is said to have resulted in a refined metal powder bed Additive Manufacturing system, which last year added hybrid subtractive capabilities. The latest development is the Creator RA, which increases functionality of the Creator platform with the capability to process reactive materials such as titanium and aluminium. The RA system is reported to offer a cost/performance ratio that makes producing AM parts in reactive materials more accessible to industry.

To illustrate the real world potential of the Creator platforms, the company demonstrated a working application for its AM hardware within a dental production workflow. This revealed the entire digital process through the use of connected data and equipment, including a 3D scanner, the App Suite of CAM processing software, the Creator itself and ancillary equipment.

The dental market is one sector where the Creator has already penetrated with a great deal of success. The unique selling points of the Creator platform are an essential driver for this, notably its small footprint, with the intentional ability to fit easily through a standard doorway. The performance of the machine in terms of its reliability and the quality of the parts that are produced in dental-specific materials are said to be further factors resulting in the company's success in this market.

www.or-laser.com

Air Liquide and Additive Industries launch partnership for reliable gas supply

Air Liquide and Additive Industries have announced plans to intensify their long term relationship and enter into a professional partnership. The move will see Air Liquide adding their solutions for supply and storage of shielding gasses used in Additive Industries MetalFAB1 systems during the Additive Manufacturing process.

It was stated that a dedicated infrastructure blueprint for the MetalFAB1 system will enable Additive Industries customers in demanding markets such as aero-space, automotive, medical and high tech equipment to increase both the quality and safety of the AM process as well as post processing.

"We are proud to team up with Additive Industries to provide the optimum solution at a customer site to create the perfect environment for their production processes", said Diederick Luijten, Managing Director IM Benelux of Air Liquide.

"On our continuous quest to improve the performance of our systems while offering our users a fully integrated solution, we have identified the gas infrastructure for argon and nitrogen as an often overlooked but important piece of the puzzle," added Daan Kersten, CEO of Additive Industries.

"Because of our partnership with Air Liquide, we now can offer a blueprint to our customers to guarantee a reliable gas storage and supply as well as a higher level of safety, our number one priority," concluded Kersten

www.additiveindustries.com
www.ariliquide.com

Submitting news..

Please contact Paul Whittaker:
paul@inovar-communications.com

Mitsubishi Electric reveals new Dot Forming Technology for metal Additive Manufacturing

Mitsubishi Electric Corporation, Tokyo, Japan, has reportedly developed a new technology for high-precision metal Additive Manufacturing. Known as 'Dot Forming Technology' (DFT), the process combines laser, CNC and computer aided manufacturing (CAM).

According to the company, DFT produces metal components with few voids at high speed, employing a laser wire Directed Energy Deposition (DED) process which fuses materials as they are deposited. The company stated that it believes this new process has the potential to raise productivity in a wide range of applications, including the near net shape manufacture of aircraft and automobile parts, and build-up repairs.

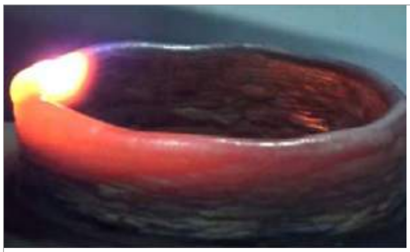
A key focus of DFT's development has reportedly been on avoiding the part deformation which can occur during DED. During DED, heat generated by a laser and heat from the just-deposited material are transferred to the deposition base. If the laser is continuously irradiated, the temperature of the deposition base rises, and new molten material added to this base can take more time to solidify, causing the shape of the part to collapse under its own weight.

To prevent this outcome, Mitsubishi Electric stated that its new technology uses a unique pulsed laser and CNC technology with minimised heat input, to help ensure adequate cooling time. Further, the new DFT technology also synchronously controls the supply of wire feedstock and shield gas, and the position and moving speed of the laser irradiation point. This means high temperatures are limited to a point-like narrow area, making it possible for the antioxidant action of the shield gas to spread across the entire high-heat area, suppressing oxidation. The production of complex parts is further supported by the use of special-purpose CAM, which automatically generates forming paths corresponding to the Dot Forming Technology.

Mitsubishi Electric stated that it expects to launch a commercial version of the system in 2021.

www.mitsubishielectric.com

Examples of dot forming technology (Courtesy Mitsubishi Electric)




Consecutive forming (high heat accumulation) | **Dot forming technologies (high heat accumulation)**

A comparison between part deformation in consecutive forming and dot forming technologies (Courtesy Mitsubishi Electric)

3YOURMIND releases revised version of Additive Manufacturing Part Identifier

3YOURMIND, Berlin, Germany, has released what it describes as a completely revised version of its Additive Manufacturing Part Identifier (AMPI). This tool automatically checks part databases to detect which components could be good businesses cases for Additive Manufacturing, or for switching from traditional to Additive Manufacturing.

The analysis performed by the tool consists of both technical and economic aspects, and is based on metadata of individual components, such as material selection, quality and production requirements or, optionally, specifications from CAD programs. 3YOURMIND believes the AM Part Identifier could make it easier for companies to enter into Additive Manufacturing, and helps to reduce the time and cost involved in identifying suitable components for AM adoption.

Stephan Kühr, 3YOURMIND's CEO, stated, "Working closely with customers, we added two new ways to find AM suitable parts: first, it's now possible for any employee to suggest items for AM by feeding them directly into AMPI. Second, by enabling newly arriving print orders to be screened prior to being placed, companies can ensure the items are a definite fit for AM before moving into production."

One of the new features of the revised AM Part Identifier is its Use Case Screening function. According to 3YOURMIND, every employee in a company – whether involved in design, procurement or production – can now check the economical and technical feasibility of components for AM using a clearly structured and digitised process.

Dominik Lindenberger, AM Part Identifier Product Manager, 3YOURMIND, stated, "The value the new Use Case Screening offers directly affects employees' workflow. Designers, for example, can run new parts through our screening process and check whether they are potential AM parts before they even open a CAD program."

Following Use Case Screening on potential AM parts and assemblies, relevant 3D models can be transferred into 3YOURMIND's other tools for an end-to-end AM workflow.

The full suite of tools included in the company's Enterprise platform includes fully-automated printability analysis, component optimisation, material selection and price calculation, the placement of print jobs in the production workflow, and comprehensive data analysis for optimising AM.

3YOURMIND's software solutions also include the On-Demand Production network, where customers can access external AM capacities from selected service providers around the world for the production of the identified components.

www.3YOURMIND.com

PostProcess Technologies expands into Europe with first international office

PostProcess's DECI Duo Support Removal system

PostProcess Technologies Inc., Buffalo, New York, USA, a provider of automated and intelligent post-processing solutions for Additive Manufacturing, has opened its first international office and launched its product line in Europe. The company has previously operated exclusively in North America.

PostProcess Technologies International will be led by Bruno Bourguet, formerly Global Head of Sales for HERE, a digital map company acquired by a consortium of German automotive companies. Its first office is located in Sophia-Antipolis, near Nice, France.

Jeff Mize, PostProcess CEO, stated, "The additive space is rapidly growing, our customers are global leaders across every major industry, and they are eager for automated post-printing solutions in Europe as well. Customers value the unparalleled consistency of results they are able to achieve with our technology. It is simply not replicable or scalable without a software-driven solution. Once they achieve consistent quality results, the demand quickly spreads worldwide."

"While we have an immediate solution to automate post-printing for support removal and surface finish, the real power of the PostProcess technology is its capability to enable digital manufacturing in a factory 4.0 environment," added Bourguet. "There is high interest from companies in Europe in our solutions and the role that automated post-printing plays in unleashing the power of 3D printing."

PostProcess's solutions integrate software, hardware and chemistry designed specifically for Additive Manufacturing, to create what it states are unique, transformative results. Its software operating intelligence has been built by benchmarking more than 500,000 parts produced using all AM technologies, and it stated that it is continuing to learn from a growing installed base of machines.

"Our solutions are used across all 3D printer technologies for both high-volume custom part production or one-off prototypes," added Bourguet.

www.postprocess.com

Aurora Labs S-Titanium Pro sees growing interest in research and academia

Aurora Labs Ltd, Bibra Lake, Western Australia, reports that sales of its Aurora Labs S-Titanium Pro metal Additive Manufacturing system are increasing, with three orders having been placed in the second half of 2018. The company has seen increasing academic and research interest in the system, especially from universities and R&D facilities, which it states is in large part due to the system's comparatively low acquisition cost of €55,000.

The Aurora Labs S-Titanium Pro has three modes – Selective Laser Melting, Selective Laser Sintering and Directed Energy Deposition

The Aurora Labs S-Titanium Pro offers a build volume of 200 x 200 x 250 mm and has the ability to additively manufacture structures in a wide range of materials, including but not limited to titanium, stainless steels, Inconel and bronze. It offers three modes – Selective Laser Melting, Selective Laser Sintering and Directed Energy Deposition – and includes specific parameters developed for manufacturing products with titanium.

A key feature of the system is its open approach to parameters and materials, which gives the user the freedom to select any combination of parameters and materials from third party companies. This is also of special benefit to universities and research organisations.

An Aurora Labs S-Titanium Pro system was recently acquired by Rey Juan Carlos University in Madrid, Spain. Speaking on the acquisition, Joaquin Rams, a researcher at the university, stated, "I consider the flexibility of the Aurora Labs S-Titanium Pro system perfect for academic use, as it allows modifying many parameters including types of powders and even mixtures of powder, which is not commonly seen in metal 3D printing systems."

Engineering company Hyon Engineering GmbH acquired an Aurora Labs S-Titanium Pro system in August 2018. Odon Szinyi, HYON Engineering, commented, "As an engineering firm, we develop products for the automotive, aerospace, transport and medical industries."

"The Aurora Labs S-Titanium Pro will be used to print parts for customers and the ULC.EVs (ultra-low-consumption electric-vehicles) we are developing. It was the right choice for us due to the large build volume and it has excellent value for money considering 3D printers of this size and abilities often cost over more than a quarter million euro."

www.auroralabs3d.com

Markforged ships its hundredth metal Additive Manufacturing system

Markforged, Watertown, Massachusetts, USA, reports that it has now shipped over one-hundred of its Metal X metal Additive Manufacturing systems to customers globally. The company further stated that it expects to more than double that number by the end of 2018.

The Metal X began shipping in March 2018, and is said to enable large-scale manufacturers to produce functional prototypes, tools and fixtures, injection moulds and end-use parts in metal. By printing metal powder bound in a plastic matrix, Markforged claims to have eliminated certain safety risks associated with traditional metal Additive Manufacturing, while enabling new features such as closed-cell infill for reduced part weight and cost.

Customer Russell Beck, who along with Jim Teuber is Founder of Re3DTech, Chicago, Illinois, an AM sevice bureau which uses Markforged systems to produce parts for a large number of global and local customers, stated, "Markforged – especially the Metal X – accelerated our ability to serve a higher level of the industry. We're educating more and more companies everyday on the power of additive. Customers can see the performance of the machines in an actual manufacturing environment, and it's incredible to watch them hold a Markforged-printed part for the first time. With Markforged, we nearly always exceed their expectations, and we don't need hazmat suits or a million-dollar machine to do it."

"Demand for affordable, strong, and safe metal 3D printing has never been greater," added Greg Mark, CEO and Founder of Markforged. "Markforged is drastically reducing the barriers to entry and opening up additive to more and more businesses every day. We can't wait to see what 2019 has in store."

www.markforged.com

FIT Additive Manufacturing offers spare parts on demand

FIT's 'Spare Parts on Demand' service aims to guarantee the availability of discontinued spare parts

During Formnext 2018 in Frankfurt, Germany, November 13–16, 2018, FIT Additive Manufacturing Group, based in Lupburg, Germany, presented its latest solution aimed at the Additive Manufacturing of industrial spare parts. The company's 'Spare Parts on Demand' (SPOD) aims to guarantee the availability of discontinued spare parts at reasonable costs to end-users.

As the majority of parts requiring replacement are conventionally manufactured and have already passed through an approval process, it is not possible to simply create an additively manufactured copy of a component for printing on demand. Using SPOD, FIT AG converts the designs for conventionally manufactured spare parts into AM parts in a six-step process. Based on a pull-system, the SPOD solution then stores data models of spare parts ready to be additively manufactured on demand when required, reducing inventory storage costs.

An example use case of FIT AG's SPOD is the production of the left sandbox housing for the brake systems on a train for Deutsche Bahn. As the manufacturer of this part ceased production, Deutsche Bahn risked train failure as parts in service continued to wear and near the end of their lifespan. In order to offer replacement parts on demand, FIT AG re-engineered the component for AM and additively manufactured it from titanium using Electron Beam Melting. The AM replacement is reported to have passed all tests performed to date.

Carl Fruth, Founder and CEO at FIT Additive Manufacturing Group, stated, "We are perfectly aware that SPOD will not yet mean the perfect solution for every spare part. Nevertheless, it's our goal to avoid storage issues, e.g. storage costs, delivery delays, or waste."

fit.technology

Sciaky to deliver hybrid EBAM system to aerospace parts manufacturer

Sciaky, Inc., Chicago, Illinois, USA, a subsidiary of Phillips Service Industries, Inc. (PSI), states that a "prominent Southeast Asian aerospace parts manufacturer" has purchased a dual-purpose Electron Beam Additive Manufacturing (EBAM®) and EB Welding System. The hybrid machine, which is reported to be the only one of its kind, will be customised with special controls to switch from AM to welding quickly and easily.

The aerospace parts manufacturer will use the system to additively manufacture metal structures, as well as weld dissimilar materials and refractory alloys for these structures and other aerospace parts. Delivery of the system is scheduled for the second quarter of 2019.

"Sciaky is excited to work with this innovative company," stated Scott Phillips, President and CEO of Sciaky, Inc. "This strategic vision will allow this manufacturer to reduce operating costs by combining two industry-leading technologies into a single turnkey solution. No other metal 3D printing supplier can offer this kind of game-changing capability."

Sciaky's EBAM systems can be used to produce parts ranging from 203 mm (8 in) to 5.79 m (19 ft) in length. EBAM is also reported to be the fastest deposition process in the metal AM market, with gross deposition rates ranging from 3.18-11.34 kg (7-25 lbs) of metal per hour.

Sciaky's systems also incorporate IRISS® (Interlayer Real-time Imaging and Sensing System), a real-time adaptive control system that can sense and digitally self-adjust metal deposition with precision and repeatability. According to Sciaky, this innovative closed-loop control is the primary reason that its systems are able to deliver consistent part geometry, mechanical properties, microstructure and metal chemistry.

Sciaky's EB Welding Systems are able to meet rigid military specifications for the manufacturing of items such as airframes, landing gear, jet engines, guided missiles and vehicle parts. They incorporate an internal moving EB welding gun with multi-axis motion, providing beam access for unusual joint configurations.

www.sciaky.com

An Electron Beam Additive Manufacturing system produced by Sciaky

Quintus HIP installed at US-based Lake City Heat Treating

A Hot Isostatic Press (HIP) produced by Quintus Technologies, Västerås, Sweden, is to be installed at heat treatment specialist Lake City Heat Treating (LCHT), Warsaw, Indiana, USA. The investment in the new system will allow the company to meet demanding customer turnaround requirements, by integrating the application of high pressure and heat treatment in a single unit.

Lake City Heat Treating is installing the new HIP at its facility in Warsaw, Indiana

HIP parts offer improved fatigue and ductile properties, enabling them to satisfy the critical performance parameters of the aerospace and medical device industries. The QIH 122 URC® model is the third Quintus HIP to be added to LCHT's production portfolio, and its incorporated quenching capability with controlled cooling rates up to 200°C per minute, is believed to make it the first of its kind to be installed in North America.

Jan Söderström, CEO of Quintus Technologies, stated, "Quintus HIPs are recognised as offering the best quality on the market. Our presses are the only systems that can combine traditional Hot Isostatic Pressing with heat treatment in the same cycle, in a process known as High Pressure Heat Treatment. With high-speed quench rates approximating those of vacuum cooling, this innovation increases throughput and lowers costs."

The new Quintus HIP has a capacity of 900 kg per load, significantly larger than Lake City's existing systems. Combined with the efficiencies of High Pressure Heat Treatment, this increased load will enable the service provider to offer its aerospace and medical customers shortened lead times, while focusing on continued growth in production.

Lake City's new HIP system features a work zone of 660 mm in diameter and 1,750 mm in height; an operating temperature of 1400°C; and pressure of 2,070 bar. It will be housed in a recently completed addition to LCHT's facility.

"Lake City has been using Quintus HIP systems for the last 25 years," added Söderström. "The company has been a pioneer in using combined HIP and heat treatment cycles to maximise material properties. With the new QIH 122 equipped with quenching capabilities, Lake City will have exceptional possibilities to continue to supply the medical implant and aerospace industries with high quality parts."

www.quintustechnologies.com

www.lakecityheattreating.com ■

Italy's largest AM bureau adds XJet Carmel system

BEAMIT SpA, Fornovo di Taro, Italy, said to be the country's largest Additive Manufacturing bureau, has purchased an XJet Carmel 1400 Additive Manufacturing system from XJet, Rehovot, Israel. The system, which uses XJet's proprietary NanoParticle Jetting™ (NPJ) technology, is also said to be the first XJet machine installed in Italy.

The acquisition of a XJet Carmel system expands the company's capabilities from metal Additive Manufacturing to include ceramic Additive Manufacturing for the first time. Mauro Antolotti, BEAMIT President, stated, "Our customers have experienced the numerous benefits AM production brings to metal parts and many of them would love to see that in ceramics too."

"XJet's NPJ technology provides a combination of detail, density and design freedom not previously afforded by other methods of ceramics manufacturing, so it feels like now is the right time for us to make this move," he added.

Gabriele Rizzi, Sales Manager, BEAMIT, stated, "BEAMIT has thrust itself into working with this new emerging technology as a competitor to traditional casting processes. One of our next joint development programmes with an aeronautical customer will be based on this interesting technology when applying metal alloys." NPJ uses a liquid dispersion process said to provide unique benefits in mechanical and geometric properties, resulting in high quality parts and a high degree of design freedom.

BEAMIT holds ISO 9001 and EN 9100 certifications in automotive, medicine, avionic/aerospace and racing, and stated that ensuring high part quality is central to its operations. "As Italy's leading AM service bureau, we have partnerships with the most prominent companies in the biomedical, aeronautic, aerospace, racing and industrial sectors, similarly key universities and research institutions," stated Rizzi. "As such, it's imperative we produce items of the highest quality. After reviewing parts produced using XJet technology we were extremely impressed with levels of precision and detail on the parts. Near net shape was another crucial factor as the more time we can take off post-processing the better the process we have, giving our teams confidence to go for more complex and sophisticated parts designed for AM."

www.xjet3d.com

www.beam-it.eu ■■■

Innovation by Matsuura

Hybrid Additive Manufacturing

Seamless Metal Laser Sintering & Milling Process

LUMEX Avance-25

Build Volume:

(D)250mm x (W)250mm x (H)185m
(D)250mm x (W)250mm x (H)300m *

(* Option)

HOLLOW — **COMPLEX GEOMETRY**
3D Cooling Channels
Internal Features

POROUS — **VARIABLE DENSITY**
Gas Venting
Gas Assist

NO EDM — **LAYER MACHINING**
High Aspect Features
Reduced EDM Processing

MILLING — **PROFILE MACHINING**
High Accuracy
Precision Finished Parts

TIME — **TIME SAVING**
One Process Manufacture
Reduced Lead Times

The ***Matsuura LUMEX Avance-25*** is the world's first hybrid powder bed fusion machine. The combination of additive technology and ***Matsuura's*** 80 years of subtractive high speed milling technology into one seamless process, enables the production of complex, high accuracy molds and parts in a method that has never been possible, nor imagined. Further adding to ***Matsuura's*** expertise in the Hybrid metal AM field, this technology is now available on the new ***Matsuura LUMEX Avance-60*** possessing the largest powder bed platform available on the market.

LUMEX Avance-60

Build Volume:

(D)600mm x (W)600mm x (H)500m

The Matsuura Avance-60 the largest hybrid powder bed platform on the market.

More information at www.lumex-matsuura.com and matsuurausa.com

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Nanogrande brings 'metal particle assembly' to Additive Manufacturing market

Nanogrande, Montreal, Quebec, Canada, officially launched its new Additive Manufacturing system at Fabtech, November 6-8, 2018, in Atlanta, Georgia, USA. According to the company, the new MPL-1 metal AM system is said to use a patented process which makes it possible to assemble metal particles of different sizes, shapes and types.

Juan Schneider, Nanogrande's president and founder, stated, "Current 3D printing technologies are limited in their ability to layer particles smaller than 20 µm," he explained. "We are the first to achieve uniform layering and controlled packing density of metal particles below five microns."

Nanogrande was the first company to introduce a nanoscale AM machine, capable of assembling particle layers as thin as 1 nm using metals, oxides, waxes and polymers. The technology is said to have applications in a number of fields, including photonics, life sciences, micro fluidics, micro rapid prototyping, mechanical microstructures, micro-optics and maskless lithography.

www.nanogrande.com

Short course on Atomisation for Metal Powders set to run in 2019

Atomising Systems Ltd and Personal Development Advanced Courses (PERDAC), a division of CPFResearch Ltd, will hold their popular short course on atomisation for metal powders for the twelfth time in 2019. The two-day course will take place from March 14-15 in Manchester, UK.

The course will consist of presentations from John Dunkley (Chairman, Atomising Systems Ltd), Dirk Aderhold (Technical Director, Atomising Systems Ltd), Tom Williamson (Research Engineer, Atomising Systems Ltd), Rajeev Dattani (Applications Specialist, Freeman Technology) and Andrew Yule (Emeritus Professor, University of Manchester).

A combination of up-to-date practical information and theory, the course is aimed at engineers working in both metal powder production and R&D. The programme includes expanded coverage of Additive Manufacturing and modern powder analysis methods.

www.atomising.co.uk

www.cpfresearch.com

Formnext 2018 sees 25% visitor growth, sets new records

Formnext 2018, held in Frankfurt, Germany, November 13–16, 2018, saw a 25% increase in visitors throughout the four-day event compared to the previous year's figures. According to the exhibition organisers, Mesago Messe Frankfurt GmbH, the exhibition was attended by a record 26,919 individuals. A total of 632 exhibitors from thirty-two countries, covered the full process chain including a wide range of production machines alongside software, post-processing, materials development, materials testing, consultancy services, part qualification solutions, data management and more.

Drawing 49% of its audience from outside Germany, the organisers stated that Formnext attracted specialists and managers from many of the leading companies, including representatives from OEMs and suppliers in the sectors of aerospace, automotive, oil & gas, medical technology, dental technology, mechanical engineering, construction and architecture.

Sascha F Wenzler, Vice President for Formnext at event organiser Mesago Messe Frankfurt, stated, "Formnext has undergone exceptional development. With its unparalleled level of innovation, the event provided a vibrant trade fair experience for everyone involved. In the context of an extremely dynamic sector, Formnext provides a road-map for the evolution of cutting-edge manufacturing industries."

A number of business deals and machine sales were concluded during the exhibition, which provides newer companies with an opportunity to meet important investment and business partners, as well as enabling long established companies to form new connections in the industry. In addition to networking on the exhibition floor and throughout the programme of supporting events, 850 industry experts also attended the TCT conference @ Formnext for in-depth technical and business discussions on the global AM industry.

Also held during Formnext 2018 was the first transatlantic 'AM Standards Forum', organised in conjunction with the U.S. Commercial Service. Here, experts from Europe and the United States discussed international developments in production standards.

Formnext 2019 will be held from November 19–22, 2019, in Frankfurt, Geremany.

www.formnext.de

Sandvik expands production capacity for Additive Manufacturing

Sandvik has substantially increased its capacity for metal Additive Manufacturing by installing several new Renishaw RenAM 500Q quad laser machines, the company reports. Sandvik is also initiating further collaboration with Renishaw, based in Gloucestershire, UK, in areas such as materials development, AM process technologies and post-processing.

Its capacity expansion follows the announced investment of SEK 200 million in a new plant for the manufacturing of titanium and nickel powders for AM, which will complement Sandvik's existing Osprey™ powder offering to include virtually all alloy groups of relevance today. The new multi-laser RenAM 500Q machines will expand Sandvik's existing lineup, which includes systems from EOS, Concept Laser, Arcam and ExOne.

When it comes to Additive Manufacturing, no two use cases are the same – the optimal balance of weight, strength, hardness, thermal characteristics, flexibility, geometric complexity, surface finish and other characteristics vary from one application to the next. Sandvik is said to work across the entire value chain, from component selection, AM-design and modelling, through material choice/development and optimal printing process, – to post-processing, testing and quality assurance.

Kristian Egeberg, President of Sandvik Additive Manufacturing, stated, "We refer to our process as 'Plan it. Print it. Perfect it.' Printing is only one of seven steps you need to master to obtain a perfect AM component. So, you have to think beyond printing to get the best possible value from Additive Manufacturing."

While much attention in the AM arena focuses on revolutionary designs, the company asserted that innovation at material level is equally important. With its Osprey metal powders, the company has the in-house capability to produce the market's broadest portfolio of alloys, coupled with the metallurgical expertise to customise the best material for every application. "We work closely with our customers to tailor alloys in line with their exact requirements, even for small-batch print runs," added Annika Roos, Head of the Powder Division at Sandvik. "Not only do we match the alloy to the purpose, we can also optimise the particle size for the chosen printing process."

www.home.sandvik
www.renishaw.com

Sandvik has purchased several new Renishaw RenAM 500Q quad laser Additive Manufacturing machines (Courtesy Renishaw)

Tekna and Aperam sign MoU on spherical powders for AM

Tekna, a supplier of plasma induction systems and metal powders based in Sherbrooke, Quebec, Canada, has signed a Memorandum of Understanding (MoU) with Aperam, Luxembourg, to jointly develop high quality spherical metal powders for use in Additive Manufacturing and Metal Injection Moulding (MIM).

The industrial partnership will see the production of spherical powders of nickel superalloys and steels, and is expected to benefit from the existing knowledge, expertise and industrial facilities of both Aperam and Tekna.

Luc Dionne, CEO of Tekna Plasma Systems, commented, "This agreement is a major step in Tekna's growth strategy in the markets of Additive Manufacturing. Tekna is proud to team up with Aperam, a partner whose dynamism, innovation and reputation are widely recognised in the industry."

Timoteo Di Maulo, CEO of Aperam, added, "We are very proud of today's agreement with Tekna, which is part of our strategy to further transform our business and address the next generation needs of our customers through new technologies. This collaboration also enables us to further consolidate our leading position in the Nickel alloys and speciality steels markets."

Aperam is a global provider of stainless, electrical and speciality steel, and is organised across three primary segments: Stainless & Electrical Steel, Services & Solutions and Alloys & Specialties. The company has 2.5 million tonnes of flat stainless and electrical steel capacity in Brazil and Europe.

www.aperam.com
www.tekna.com

GKN Aerospace's new aero-engine repair facility centres on Additive Manufacturing

GKN Aerospace has officially opened its repair and research facility for aero-engine systems in Johor, Malaysia. The establishment of the new site was announced during Farnborough Air Show in July 2018, and GKN Aerospace has reportedly invested $30 million in the site and in its equipment and technologies.

Research at the facility will centre on the application of Additive Manufacturing technology to engine parts repair. It will initially focus on servicing engine low-pressure compressor (LPC) components for CFM56-5B, CFM56-7 and V2500 and will be operational in 2019. GKN Aerospace stated that it expects the facility to complement its existing component repair facility in San Diego, California, USA, to meet growing demand in the Asia Pacific region.

Joakim Andersson, CEO of GKN Aerospace Engine Systems, stated, "We are proud to extend our global presence with this new site in Malaysia. This new facility highlights our commitment to support our customers in Asia. This will definitely lead to exciting growth opportunities. We thank the Government of Malaysia for the excellent collaboration and for supporting and facilitating our decision to locate in their country"

The company stated that the expansion to Asia is an important aspect in its long-term growth strategy and global operating model. GKN Aerospace already operates six facilities in the region, delivering wiring systems, transparencies and services in China, India, Singapore, Thailand and Turkey. This latest expansion marks the Engine Systems division's first site in the Asia-Pacific region.

GKN Aerospace to establish £32 million Global Technology Centre in United Kingdom

GKN Aerospace, along with Greg Clark, the UK's Secretary of State for Business, Energy and Industrial Strategy, also revealed plans for a new Global Technology Centre in Bristol, UK. The new centre - funded by a £17 million commitment from GKN Aerospace and a £15 million commitment from the UK Government through the Aerospace Technology Institute - is expected to open in 2020.

The 10,000 m^2 facility will host three-hundred engineers, and will include collaborative space for research and development with universities, the UK's CATAPULT network and GKN Aerospace's UK supply chain. The centre will focus on Additive Manufacturing, advanced composites, assembly and the implementation of industry 4.0 processes to enable high-rate production of aircraft structures. The facility will serve as a base for GKN Aerospace's technology partnership in the Airbus' 'Wing of Tomorrow' technology programme as well as new AM programmes.

The Bristol centre joins a growing list of GKN Aerospace Centres of Technical Excellence around the world. Each centre has a unique technology focus - with some covering AM, thermoplastics or smart aero-engine systems - and is supported and linked by a clear digital strategy. Hans Büthker, Chief Executive of GKN Aerospace, commented, "GKN Aerospace can trace its engineering heritage back to the 18th century, and we are proud of our role as a leading player in the UK's world leading aerospace sector."

"The GTC will ensure we continue to develop new technologies that deliver for our customers, making aircraft more sustainable and economical. It will also support our 4,000 strong workforce in the UK, ensuring they remain at the cutting edge of the global aerospace industry. The GTC is a great example of the UK's industrial strategy at its best: with industry and the government coming together to invest in the technology of the future."

In addition to GKN Aerospace and the Aerospace Technology Institute, collaboration partners at the new GTC include: the Advanced Manufacturing Research Centre (AMRC), Additive Industries B.V., ANSYS UK Limited, ATS Applied Tech Systems Limited, Centre for Modelling & Simulation, Digital Catapult, KUKA Industries UK Limited, Manufacturing Technology Centre, Materialise UK Limited, National Composites Centre, PXL Realm, Thales UK Limited, University of Bath, University of Bristol and University of Sheffield.

www.gknaerospace.com

GKN Aerospace held the official opening of its repair and research facility for aero-engine systems at the beginning of October 2018

Digital Metal launches fully automated metal AM production concept

Digital Metal, Höganäs, Sweden, has launched what it describes as a fully automated 'no-hand' production concept for the series production of components using metal Binder Jetting technology. In this concept, the majority of the process steps involved in part production will be handled by a robot, eliminating most manual work involved and thus increasing productivity.

The robot will feed the printer with build boxes, which will then be moved for post-treatment in a CNC-operated depowdering system combined with a pick-and-place robot. There, the remaining metal powder will be removed and recycled, and the parts placed on sintering plates before being moved by the main robot to the sintering furnace for combined debinding and sintering, in batches or for continuous production.

Ralf Carlström, General Manager at Digital Metal, stated, "Most AM technologies show a very low level of automation. Our aim is to change that. With the new no-hand production line, our customers can further improve their productivity and lower the production costs."

"Almost all manually intensive work can be eliminated and, in addition, the powders removed in the cleaning machine can be recirculated in the process, thus minimising waste," he continued. "As we see it, the Digital Metal technology is now applicable for the serial production of high-volume components."

Digital Metal's DM P2500 system uses Binder Jetting technology and is currently in use for the production of parts in series of up to 40,000 components. In 2018, the company signed a number of delivery agreements with major European automotive and aerospace companies. "We believe there is a huge potential for our unique technology," added Carlström. "Not only is it very fast and cost-effective, it is also able to create complicated and highly detailed designs with wide material choice."

www.digitalmetal.tech

A production line of Digital Metal's DM P2500 metal Binder Jetting systems

Euro PM2019 heads for the Netherlands, issues Call for Papers

Euro PM2019 heads to Maastricht (Courtesy EPMA)

The EPMA has issued a Call for Papers for Euro PM2019, the association's annual Powder Metallurgy Congress and Exhibition, taking place in Maastricht, the Netherlands, October 13-16, 2019. According to the EPMA, Euro PM2019 is set to feature a world-class technical programme as well as a 5000 m^2 exhibition, showcasing the latest developments from the global PM Supply Chain

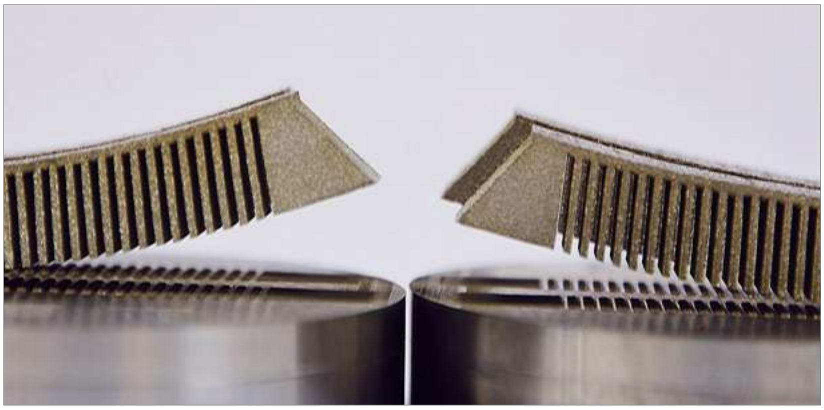
The Euro PM2019 Congress and Exhibition, along with social events such as the welcome reception and congress dinner, is expected to provide excellent networking opportunities for those within the PM industry.

The conference programme of plenary, keynote, oral and poster presentations will focus on all aspects of Powder Metallurgy, including PM structural parts, Additive Manufacturing, hard materials and diamond tools, Hot Isostatic Pressing, Metal Injection Moulding, new materials, processes and applications.

Authors are invited to submit abstracts of papers for presentation in the Technical Programme. These should be of original and unpublished work, with all abstracts submitted using the EPMA's online submission form by no later than January 23, 2019. The EPMA states that abstracts must be between 100-150 words in length and give sufficient information to allow the Technical Programme Committee to evaluate the proposed presentation.

www.europm2019.com

Fraunhofer ILT showcases VCSEL pre-heating for Additive Manufacturing



The component preheated with VCSEL (right) has significantly less distortion than the component not preheated for the exposure process

Fraunhofer Institute for Laser Technology (ILT), Aachen, Germany, showcases a new metal Additive Manufacturing process in which the component in the powder bed is heated with laser diodes to reduce distortion, enabling the production of taller parts in new materials.

Laser Beam Powder Bed Fusion (LB-PBF) Additive Manufacturing can produce internal stresses caused by temperature gradients in the generated component. In the laser spot, temperatures above the melting point prevail, while the rest of the component cools rapidly. Depending on the geometry and material, this temperature gradient can lead to cracks in the material. To avoid this, the component is usually heated from below via the substrate plate. However, with taller structures this may not be sufficient. As part of the Digital Photonic Production (DPP) research campus, a funding initiative of the German Federal Ministry of Education and Research (BMBF), Fraunhofer ILT and RWTH TOS Chair are working together with their partner Philips Photonics to develop solutions for this task.

Developed as part of this project, titled DPP Nano, the new heating process uses an array of six vertical-cavity surface-emitting laser bars (VCSEL) of 400 W each, installed inside the process chamber. By emitting infrared radiation at 808 nm, this array can heat the device from above to several hundred degrees Celsius during the build process. The bars can be controlled individually, making sequences in different patterns possible, and the heating process is monitored using an infrared camera.

To test the VCSEL heating technique, project engineers have constructed parts in Inconel 718 which it is reported demonstrated significantly reduced distortion, with the component being heated up to 500°C. The use of VCSEL heating reduces the thermal gradient, and by extension the internal stresses, making it possible to produce taller parts with a minimised risk of distortion or cracking.

The new method also offers opportunities for the Additive Manufacturing of particularly difficult materials, and the project engineers expect to begin testing with titanium aluminides in the near future. For this material, the component will be heated to approximately 900°C using the VCSEL method.

Titanium aluminides are commonly used in components for turbomachinery, such as in the hot gas section of turbochargers. In addition to turbomachinery, the process also opens up new potential applications in other industrial sectors where thermally induced stresses in AM processes have to be reduced.

www.ilt.fraunhofer.de

Valuechain receives Innovate UK funding to support AI for AM

Software company Valuechain, Daresbury, UK, has received £960,000 in funding from UK Research & Innovation towards the development of Artificial Intelligence (AI) within its Additive Manufacturing production control software, DNAam.

Launched in July 2017, DNAam was developed in collaboration with Airbus UK to standardise aerospace AM production processes and enable scalability in the aerospace sector. This project looks to further develop the platform to integrate AI which can optimise AM processes by analysing multiple data sources.

Tom Dawes, Valuechain CEO, stated, "Through our collaboration with Airbus UK we have developed DNAam into the global market leading production control solution for aerospace AM. With this project, we are looking to be able to model big data captured from multiple sources such as ERP systems; AM plant, equipment and sensors; and material analysis software; to understand correlations between powder properties, plant / sensor parameters, part complexity and production builds and generate AM optimisation insights."

The development is expected to see Valuechain build on its long-standing partnership with UK-based AM company, FDM Digital Solutions, to open an Innovation Centre at FDM's facility, where the technology developed through the Innovate UK funding will be trialled prior to commercialisation.

www.valuechain.com

Additively manufactured spray head wins German Design Award 2019

SMS Group GmbH, Düsseldorf, Germany, has been named as winner in the German Design Award 2019's Industry category for a metal additively manufactured spray head. The spray head, the product of a joint development effort by the group's Forging Plants Department, Additive Manufacturing Project Team and simulation technology experts, is used to cool dies in forging presses and is significantly smaller, lighter and more efficient than conventionally manufactured spray heads.

The German Design Award is given annually by the German Design Council to recognise innovative products and projects and the German companies or individuals behind them. Axel Rossbach, Research and Development Extrusion and Forging Presses, SMS Group, stated, "Winning the Design Award makes us extremely proud. It is recognition of many teams within SMS Group whose work is characterised by a highly interdisciplinary approach."

"The spray head is a milestone innovation marking a new era in the design of plant and machine components, enabled by the game-changing potential of 3D printing and function-optimised design," he continued. "The design of a machine part is today no longer limited by the constraints imposed by conventional – process-optimised – forming and machining techniques. Supported by latest software and computer technology, we can now give a component exactly the design that fulfils its designated function in the best possible way."

"Another important aspect is that we have used new materials," he added. "Therefore the Award honours not only a new design, but above all the new way of thinking lived within SMS Group, which has materialised in a global approach to Additive Manufacturing."

Rossbach described the spray head as an example of how, in the digital age, different disciplines can interact, and of the opportunities Additive Manufacturing may hold in store. The component features flow-optimised channels to cool dies specifically and as-required in each individual case. Die areas subjected to intensive heating are cooled at a correspondingly – precisely calculated – higher rate than areas which are less hot.

"Although the spray head is only a small component, it nevertheless ideally represents the potential of Additive Manufacturing," Rossbach explained. "The innovative manufacturing methods enabled by 3D printing form the basis for Industry 4.0. The example of the 3D printed spray head makes this clear and measurable. Made of plastics, it weighs only one tenth of what a conventional one would weigh. A 3D spray head made of metal weighs up to 70% less. It is less expensive, more efficient and can be easily customised and instantly produced."

This provides multiple advantages for drop forging operations. Drop forging presses are continuously being optimised with a view to achieving the shortest cycle times and maximum service life for dies. Spray heads for cooling and lubricating dies perform a key function in the forging process, as without spray cooling dies would not be able to withstand the constant and extremely high stress which acts on them during operation.

Spray heads are introduced between the open dies awaiting the next forging stroke. According to SMS Group, the new AM spray head does not only provide a reduction in part weight and cost, but also reduces wear to the supporting arms used to introduce the spray heads between the dies. Due to the significantly lower mass of the component, cycle times for the process can be shortened.

The company stated that it also plans to additively manufacture current-conducting elements and sensors into the spray heads in future, making it possible to actuate the valves electrically and generate condition messages for the systems. Robert Banse, a member of the R&D Project Team at SMS Group, commented, "We are in no way restricted by any manufacturing constraints. Therefore we can adopt a creative technological approach to designing and start out from the function the component is going to perform. In other words: We develop the perfect design for the function at hand, knowing that it can be produced in the 3D printer."

www.german-design-award.com
www.sms-group.com

SMS Group's spray head for forging plants, produced using metal Additive Manufacturing (Courtesy SMS Group GmbH)

Titanium wheel created using EBM Additive Manufacturing

The HRE3D+ wheel was produced on two Arcam EBM machines, the Q20 and Q10 (Courtesy HRE Performance Wheels)

GE Additive has partnered with HRE Performance Wheels on the production of what it states is the first titanium wheel manufactured using Electron Beam Melting (EBM) Additive Manufacturing. Known as HRE3D+, the prototype wheel is said to demonstrate the future potential of wheel technology and how advanced materials such as titanium can be used to create complex designs.

According to the partners, the goal of the HRE3D+ project was to test the capabilities of AM in a practical application, to create a highly-sophisticated wheel design using a potentially challenging material such as titanium.

In the production of a traditional aluminium Monoblok wheel, 80% of material is removed from a forged block of aluminium to create the final product. Using EBM AM, only 5% of the material is removed and recycled during production, making the process far more cost efficient. Titanium also has a much higher specific strength than aluminium and is highly corrosion resistant.

The project involved an intensive design collaboration between HRE's staff in Vista, California, USA, and the GE AddWorks team in Ohio, USA. Using design cues from two existing models of HRE wheels, the wheel was redesigned for AM and produced on two Arcam EBM machines – the Q20 and Q10 – in five separate sections, then combined into one using a custom centre section and titanium fasteners.

Speaking on the results of the project, Alan Peltier, HRE President, stated, "This is an incredibly exciting and important project for us as we get a glimpse into what the future of wheel design holds. Working with GE Additive's AddWorks team gave us access to the latest additive technology and an amazing team of engineers, allowing us to push the boundaries of wheel design beyond anything possible with current methods. To HRE, this partnership with GE Additive moves us into the future."

Robert Hanet, Senior Design Engineer, GE Additive AddWorks, added, "HRE prides itself on its commitment to excellence and superior quality in the marketplace. It was a natural fit for AddWorks to work on this project with them and really revolutionise the way wheels can be designed and manufactured."

www.ge.com/additive
www.hrewheels.com

Additive Manufacturing for Aerospace and Space Forum heads to London

The Additive Manufacturing for Aerospace and Space Forum, organised by the International Quality and Productivity Center (IQPC), will be held from February 26–28, 2019, at the Hilton Wembley, London, UK. The event will be chaired by Paul Evans, Head of Manufacturing Technologies and Process, Airbus Group, and Jason Gilmore, New Product and R&D Technical Lead, Airbus Defence & Space. Airbus Defence & Space will also host attendees for a site visit to its Space Systems facility and the European Space Agency's ExoMars Rover Test Yard.

The conference is designed to offer a platform to tackle the roadblocks of industrial digitisation and ensure the industry benefits from opportunities offered by high-value manufacturing, both internationally and in the UK.

The current list of confirmed speakers is as follows:

- Dr Paul Unwin, Chairman, UK Additive Manufacturing Strategy Steering Group
- Steven Catt, AM Technical Lead, Thales UK
- Advenit Makaya, Advanced Manufacturing Engineer, European Space Agency
- Dr Rob Scudamore, Vice Chair AM UK & Associate Director, Group Manager – Joining Technologies, Additive Manufacturing, TWI
- Andy Schofield, Manufacturing & Materials Strategy and Technology Director, BAE Systems – Air
- Richard Minter, Chief Expert – Airframe, European Aviation Safety Agency
- Sébastien Messé, Additive Manufacturing Chief Engineer, Safran Landing Systems
- Dr Katy Milne, Chief Engineer – DRAMA , Digital Engineering Group, Manufacturing Technology Centre
- Claude Sarno, Head of Packaging Design Office, Thales Avionics

Further information on the conference agenda and registration details are available via the forum website. Registration is available at early-bird discounted rates until January 26, 2019.

www.additivemanufacturing.iqpc.co.uk

MELD's Additive Manufacturing technology wins at R&D 100 Awards 2018

MELD™ Manufacturing Corporation, Christiansburg, Virginia, USA, has been named as a winner in the R&D 100 Awards 2018 for its MELD™ Additive Manufacturing technology. Now in their 56th year, the independently judged awards honour the one-hundred most innovative technologies introduced in the past year across five major categories – Analytical/Test, IT/Electrical, Mechanical/Materials, Process/Prototyping, and Software/Services and Other.

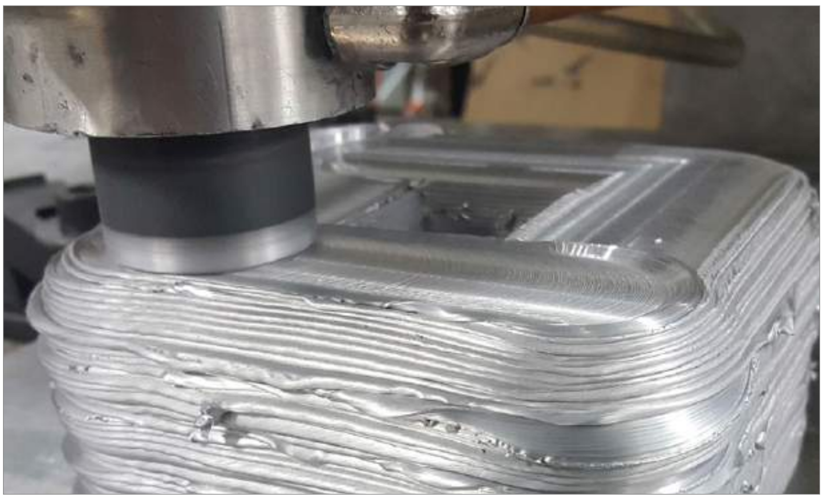
MELD Manufacturing Corporation was launched in April 2018 as a spin-off of Aeroprobe Corporation, and holds more than a dozen patents for MELD, a solid-state process which can be used to manufacture, repair, alter and join parts using a wide range of feedstocks, including metal powders and rods. It can also be used with metal chips generated as the waste material in other manufacturing processes.

The MELD process is reported to deposit material at least ten times faster than fusion-based metal AM processes and is expected to find applications in a range of areas including the automotive, aerospace, defence and turbomachinery industries, with the company offering machine sales in addition to contract manufacturing and consulting services. Since its launch, the technology has received the Rapid + TCT innovation award and won the SAE Create the Future Design Contest, been selected by the US Army as part of its inaugural Army Expeditionary Technology Search (xTechSearch), and been awarded funding by the USA's Strategic Environmental Research and Development Program (SERDP) to support research into its use as a method for recycling battlefield scrap metal for repairs and manufacturing in the field.

"Our mission with MELD is to revolutionise manufacturing and enable the design and manufacture of products not previously possible," explained Nanci Hardwick, MELD CEO. "MELD is a whole new category of AM. For example, we're able to work with unweldable materials, operate our equipment in open-atmosphere, produce much larger parts than other additive processes, and avoid the many issues associated with melt-based technologies."

The winners of the R&D 100 Awards were announced in a special ceremony on November 16, 2018, during the annual R&D 100 Conference at the Waldorf Astoria in Orlando, Florida.

www.meldmanufacturing.com



MELD is a solid-state process which can use a wide range of materials as feedstock, including metal powders and rods

The Barnes Group Advisors partners with TransMachine Additive

The Barnes Group Advisors (TBGA), Pittsburgh, Pennsylvania, USA, is partnering with TransMachine Additive (TMA), Winston-Salem, North Carolina, USA, a division of TransMachine Technologies, to provide strategic leadership for the company, with Laura Ely serving as President of TMA, and TBGA providing technical support via the Technical Excellence Resource Model (TERM). The TERM will allow TMA access to TBGA's technical expertise for application development, without the overheard burdens of a large business.

"We are excited to support TMA's growth via the TERM concept," stated John Barnes, Managing Director, The Barnes Group Advisors. "It is a great opportunity to leverage our diverse experience in Additive Manufacturing to reduce risk and accelerate time to profitability." The objective of the collaboration is said to be to build on TMA's aim to provide AM products by Electron Beam Melting (EBM), in an agile, cost-effective and customer-focused environment.

Barry Leonard, CEO of TransMachine Additive, commented, "I've always had a vision to expand our high quality, precision manufacturing presence in the US. With our investment in EBM Additive Manufacturing and the industry leading business and technical expertise of The Barnes Group Advisors, that dream is rapidly becoming a reality."

TMA reported that it is ready to support customer programmes ranging from early application development to serial production. Full product solutions are said to be available, with project management including delivery of fully finished parts. TMA operates out of an ITAR-registered production facility, using an Arcam Q20plus and Arcam A2X system, and plans to be AS9100 certified by early 2019.

www.trans-machine.com/additive
www.thebarnes.group

What can you achieve with Renishaw additive manufacturing?

Renishaw multi-laser AM systems open the door to a new world, bringing more applications within reach of AM technology.

RenAM 500Q has four efficiently applied high power lasers that reduce cost per part, while advanced sensors and systems ensure unparalleled processing conditions to deliver consistent class leading performance, build after build.

Unlock your potential and explore the possibilities with Renishaw advanced multi-laser additive manufacturing.

For more information visit www.renishaw.com/multi-laser

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AVIMETAL PM

ISO 9001 | ISO 13485:2016

Powder Solutions for Metal AM

Main Powders

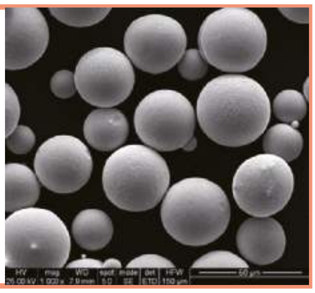
Titanium: Ti CP, Ti64 Gr5/Gr23, BT9, BT20, Ti6242, Ti4822, Ti2AINb, NiTi50
Nickel: IN718, IN625, IN713, Hastelloy X, Hastelloy C276, Waspaloy
Cobalt: CoCrMoW, CoCrMo, CoCrW, HA 188
Stainless Steel: 316L, 17-4PH, 15-5PH
Die Steel: 1.2709(MS1), Corrax, H13, S136
Aluminium: AISi10Mg, AISi7Mg
Refractory Metal: W,Mo, Ta, Nb, Cr, Zr

Additional alloys are available upon request

Advanced Atomization System for Metal Powder Production

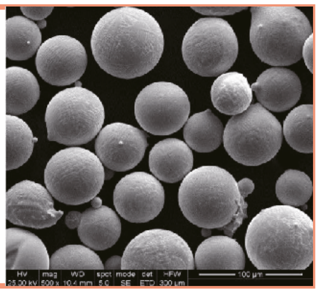
Ti64 Gr5

15-45μm



IN718

15-45μm



Powder Characteristics

Controlled chemistry
Spherical shape
High flowability
High apparent density
High purity and applied to aircraft engine

Capacity

Powder 600t/a
Powder Atomization System 30units/a

Particle size range(min/max)

0-20μm
15-45μm
15-53μm
20-63μm
45-106μm
53-150μm

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America Makes appoints new Education and Workforce Director

America Makes, Youngstown, Ohio, USA, the US's National Additive Manufacturing Institute, has appointed Josh Cramer as its new Education and Workforce Director. Cramer previously served as the Director of Educational Programs at the SME Education Foundation, monitoring, promoting and evaluating all of its major programmes. In addition to those duties, he served for a time as the Interim Executive Director of the Foundation.

Other positions held by Cramer during his five-years with the SME Education Foundation included Director of K-12 Educational Programs and Senior Educational Program Officer. Prior to joining the SME Education Foundation, he was Director of School Engagement, Eastern Region for Project Lead The Way (PLTW), a nonprofit organisation for PreK-12 students and teachers across the USA which is designed to develop in-demand knowledge and skills through pathways in computer science, engineering, and biomedical science.

Rob Gorham, Executive Director, America Makes, stated, "We are very excited to welcome Josh to our team. Josh brings a unique fresh perspective, a dynamic energy, and the essential skill sets required of the Education and Workforce Director for America Makes."

"We look forward to Josh leveraging this experience and that as a teacher to promote and further the America Makes mission to develop and grow a workforce capable of supporting the growing and evolving additive manufacturing industry," concluded Gorham.

www.americamakes.us

Alfa Romeo Sauber F1 and Additive Industries extend AM technology partnership

The Alfa Romeo Sauber F1 team has announced that it is extending a three-year Technology Partnership with Additive Industries to five years. Recently, the Alfa Romeo Sauber F1 team took delivery of its third MetalFAB1 system within one year, and expanded its second system with an additional build chamber (or Additive Manufacturing Core) to expand its productivity.

Frédéric Vasseur, Team Principal Alfa Romeo Sauber F1 Team and CEO Sauber Motorsport AG, stated, "We are pleased to be extending our current partnership with Additive Industries, and to introduce a third MetalFAB1 3D printing system to our facilities."

"Not only do we aim to develop our production of parts for Formula One further, but we are also expanding our competences and activity in our third-party businesses," he continued. "Building on the successful collaboration we have had so far, we look forward to working with Additive Industries and making further progress in our shared projects."

Christoph Hansen, Head of Technical Development at Sauber Engineering AG, added, "After an in-depth evaluation of all systems we found Additive Industries' MetalFAB1 to be the only true industrial system available on the market. Their level of integration and automation allowed us to implement the technology very fast and with only a small team of experts."

"Moreover, the MetalFAB1 system is easy to use and has high consistency across the build chambers and between systems, this allows us to schedule the workload flexibly over the 3 systems," he concluded.

Daan Kersten, CEO of Additive Industries, added, "For Additive Industries, this partnership extension with the Alfa Romeo Sauber F1 Team confirms the acceleration in industrial AM that we are aiming for."

"Repeat sales in such a short time are the best compliment for our team, both for the system design and 3D metal printing process but also for our customer support team which works closely with the Alfa Romeo Sauber F1 Team to reach the highest productivity in the market today. We are both proud and grateful for such a partnership," he concluded.

www.additiveindustries.com
www.sauberf1team.com

Alfa Romeo Sauber F1 has extended its partnership with Additive Industries from three years to five (Courtesy Alfa Romeo Sauber F1)

3D Systems appoints new leader of software business

3D Systems, Rock Hill, USA, has announced that Radhika Krishnan has been appointed as Senior Vice President and General Manager of its software workflow business, reporting directly to Vyomesh Joshi, President and Chief Executive Officer. In her role, it was stated that Krishnan will focus on realising 3D Systems vision to radically transform Additive Manufacturing by driving higher levels of simplicity, automation, and collaboration through software.

Krishnan joins the company from the Lenovo Datacenter Group where, as Vice President and General Manager of the Software Defined Infrastructure business, she built teams from scratch, launched multiple products, and drove rapid growth. While at Lenovo, she was a member of the senior leadership team managing a globally diverse organisation across multiple functions. Prior to Lenovo Datacenter Group, Krishnan held leadership roles in software product development as well as go to market at Nimble Storage, NetApp, Cisco and HP.

Radhika Krishnan has been appointed as Senior Vice President and General Manager of 3D Systems' software workflow business

"Software is core to the 3D Systems' strategy and enables us to help transform customers' manufacturing environments," stated Joshi. "We plan to double down on software and continue to build out the industry's leading portfolio to provide our customers with world-class solutions that address even the most complex and unique production workflows. Radhika brings tremendous experience and a proven ability to seamlessly incorporate emerging technologies into solution offerings that deliver scale for the business and greater ease of use for the customer. We're excited to have Radhika in this key leadership role as we take our software portfolio forward."

3D Systems recently unveiled an updated end-to-end software portfolio. The portfolio now provides an unprecedented level of automation to accelerate design and production processes for customers giving them a competitive advantage to create and bring new products to market faster.

www.3dsystems.com

APWORKS announces new Chief Product Officer

APWORKS, Taufkirchen, Germany, has appointed Jon Meyer as new Chief Product Officer, effective immediately. In his new function, Meyer will be responsible for the strategic and technical development of series Additive Manufacturing applications at the company.

Meyer's move to APWORKS follows more than ten years at Airbus, where in his recent position as Technology Roadmap Owner Additive Manufacturing Processes he was globally responsible for defining the vision and strategy for technology within Airbus, serving the wide range of technology needs and applications within civil and military aircraft, helicopter, and satellite products. Prior to that, Meyer was leading the central research and technology team responsible for the development of Additive Manufacturing within Airbus Group, where he is said to have developed a strong technical expertise in a wide range of AM technologies, with a focus on Powder Bed Fusion and Directed Energy Deposition.

As Chief Product Officer, Meyer will strengthen APWORKS' management team, bringing wide-ranging technical experiences and strategy expertise. Together with APWORKS team, he will devote considerable time and effort to pursuing the development of independent product innovations with significant added value for manufacturing.

www.apworks.de

3rd Dimension expands AM capacity with MetalFAB1 system

3rd Dimension Industrial 3D Printing Co., Indianapolis, Indiana, USA, placed an order for a MetalFAB1 system from Additive Industries, Eindhoven, the Netherlands, during the Additive Industries partnership event at the recent Formula 1 race in Austin, Texas. The company has a racing background and stated that it recognises the advantages of the MetalFAB1 in terms of precision and high level of automation to reduce lead times.

"Our client base demands large quantities of high quality products," stated Bob Markley, President and CEO of 3rd Dimension Industrial 3D Printing. "As we have moved into full-scale production, we have realised the need for drastically faster additive equipment and the Additive Industries four-laser system provides the solution our customers need."

"I have looked at many additive solutions to add to our existing equipment and have not only been impressed with the technical prowess of Additive Industries, but also their innovative and modular solution," he continued. "With this machine, we can add capacity as needed, as well as ensure that all of the machines are of the same specification. This really is unique in the industry and positions us well for continued growth."

Shane Collins, General Manager of Additive Industries North America, added, "3rd Dimension understands how to do series production with Additive Manufacturing and integrates subtractive processes to create the highest quality parts for automotive, aerospace and consumer applications.

The deal was confirmed at the F1 race in Austin, Texas, USA. Left to right: Shane Collins and Daan Kersten, Additive Industries, Bob Markley, 3rd Dimension, and Jonas Wintermans, Additive Industries

This combination is essential to drive this technology forward. Moreover, 3rd Dimension, like Additive Industries, is collaborating closely with its customers to continuously improve the products. That makes a great fit between both our companies."

www.additiveindustries.com
www.print3d4u.com

EPMA names winners in its 2018 Powder Metallurgy Component Awards

During the opening Plenary Session at the Euro PM2018 Congress and Exhibition, Bilbao, Spain, October 14–18, 2018, the European Powder Metallurgy Association (EPMA) revealed the winners of its 2018 Powder Metallurgy Component Awards. The awards are open to companies who manufacture components made by various Powder Metallurgy processes including metal Additive Manufacturing.

The award in the Additive Manufacturing category was presented to Rosswag GmbH, Pfinztal, Germany, for its Forgebrid® process. The production method combines open die forging and Laser Beam Powder Bed Fusion (LB-PBF) processes, benefitting from the advantages offered by each process. To manufacture a component, a basic body is conventionally forged and machined to produce a plane surface. Onto this surface, the functionally optimised section of the component is added using LB-PBF.

Using this combined method enables Rosswag to preserve resources and thus save production costs, in addition to reducing machining time and the consumption of coolants and lubricants. Moreover, the material remnants produced during sawing and forging of the component base can be recycled into metal powder for use in the Additive Manufacturing process.

Rosswag stated that the forged component area offers excellent mechanical-technological properties, especially with regard to fatigue strength. The complex segments of the part, produced by metal AM, are then manufactured in such a way as to add value which could not be achieved by conventional manufacturing. The hybrid production process is therefore an ideal method to meet safety requirements and still achieve functional optimisation of the component.

The winner in the PM Structural Component category was Gevorkyan, s.r.o, Vlkanová, Slovakia, for a driving flange designed in cooperation with a leading power tools producer. According to its designers, the part is brand new and has never been produced using any other technology. The part was originally developed for CNC machining from conventional bars, however, by adopting PM technology for its production, Gevorkyan stated it was able to achieve a significant reduction in price in comparison to machining.

In the Hot Isostatic Pressing (HIP) category, the development of a near-net shape component for use in the nuclear power sector was the winner. The component, a reactor coolant pump impeller, has a large dimension and complex geometry, which both pose significant production challenges.

The award for a metal injection moulded component was presented to AMT PTE Ltd, Singapore, for its one piece nozzle for automotive applications. The judges stated that the MIM nozzle featured a good finish with complex internal channels and was manufactured in a sustainable and economical way. The product was said to have opened up an entirely new application for MIM process capability, and AMT stated that it was the most complex part that it has produced to date.

www.edelstahl-rosswag.com
www.epma.com



Winners in the other EPMA award categories - Top: PM Structural Component. Middle: HIP Award. Bottom: Metal Injection Moulding (Courtesy EPMA)

Rosswag GmbH received the Additive Manufacturing award for its Forgebrid® component (Courtesy EPMA)

Stratasys offers insight into its new 'Layered Powder Metallurgy' technology

Stratasys, based in Minneapolis, Minnesota, USA, and Rehovot, Israel, has released further details of its new metal Additive Manufacturing platform currently being developed and designed for short-run metal applications. First unveiled earlier this year, the Additive Manufacturing platform is based on Stratasys' 'Layered Powder Metallurgy' (LPM™) technology, and is said to make production of metal parts quicker, easier and more cost-effective.

The company stated that it believes this technology will be of special interest to the Powder Metallurgy community. LPM is reported to offer improved efficiency and cost savings using standard Powder Metallurgy alloys, with high accuracy and controlled shrinkage, as well as extremely fast throughput. Developed internally over the past several years, Stratasys' platform incorporates the company's proprietary jetting technology. The first material to be made available for the system will be an aluminium alloy.

"We note that current approaches to 3D printing metal parts leave a lot to be desired – including slow post-processing, painstakingly intricate support removal, and hours of machining and grinding. Combined with the high cost of AM powders, this means each part is expensive, with a total cost of ownership that is too hard to justify," stated Rafie Grinvald, Director of Product Marketing and Management, Stratasys.

"Our new platform is being designed to transform the current metal Additive Manufacturing landscape – presenting a viable alternative to typical production methods – and helping customers dramatically reduce the costs of creating reliable, consistent production-grade, metal parts for short-run applications."

The LPM™ solution includes a three-step Additive Manufacturing process combining traditional PM with Stratasys' PolyJet™ ink-jet technology. The process includes printing of boundaries with proprietary thermal ink, powder dispensing and spreading, followed by compaction of the powder layer to achieve high density and controllable shrinkage.

The system aims to directly address the needs of customers who require production of pilot-series parts, small-batch manufacturing during product ramp-up and end-of-life, as well as customised, lightweight, complex parts. The offering is said to be ideal for such markets as automotive, aerospace and defence.

www.stratasys.com

Stratasys's LPM process combines both ink jetting and powder compaction (Courtesy Stratasys)

Sigma Labs launches updated PrintRite3D software

Sigma Labs, Inc., Santa Fe, New Mexico, USA, a provider of quality assurance software under the PrintRite3D® brand, launched the newest configuration of its PrintRite3D software during Formnext 2018 in Frankfurt, Germany, November 13–16, 2018.

The updated software incorporates PrintRite3D Sensorpak® 4.0 hardware and PrintRite3D Inspect® 4.0 software. Using the new hardware requires no sensors within the build chamber; all sensors are now said to be coaxial to the laser optics, eliminating concerns over gas flow disruptions or space limitations inside the build chamber. In addition, Sigma Labs' new client-server architecture enables multiple machines to be connected to the system as clients on one server, and upgraded data acquisition and data processing hardware provide faster processing of data, with the results now displayed in real-time during the build.

New features of the Inspect 4.0 software include melt pool spectral data evaluation capability. Sigma Labs states that it has developed a physics-based methodology for characterising and analysing spectral data and optimising optics hardware and sensors to monitor spectral regions of interest and validate thermal signatures of interest. New tools have been incorporated which allow the measurement and reporting of melt pool relative temperature as well as Thermal Energy Planck (TEP) in-process quality metric, used for thermal signature identification.

John Rice, CEO of Sigma Labs, stated, "Our latest PrintRite3D suite of products presents a significant value proposition to OEMs and manufacturers, as it is designed to increase production yield of 3D metal manufactured parts and to shorten time to market, removing a major hurdle that has been affecting manufacturers."

www.sigmalabsinc.com

Betatype uses AM to produce unique titanium watch strap

Betatype Ltd, London, UK, recently teamed up with luxury watchmaker Uniform Wares to design and develop a woven T5 titanium alloy watch strap using metal Additive Manufacturing. The strap is part of Uniform Wares' PreciDrive M-Line watch collection and reportedly includes a unique clasp that is as strong as a metal bracelet, but light enough to feel like fabric on the wearer's wrist.

The strap, built on a Renishaw AM250, is comprised of more than 4,000 links that interlock with each other to form a strong, lightweight structure. Unlike in traditional mesh straps, each link is also asymmetrical, meaning that each side of the strap has a differing bend radius. This allows it to be fitted easily over the hand, while remaining flexible enough to be secure on the wrist.

Uniform Wares had previously created a mesh bracelet for their watches using conventional manufactured methods, wherein a large machine weaved steel cable into the mesh pattern, which was then cut to size and working parts welded onto it.

The strap also features a new type of directional clasp design featuring microscopic 'teeth' that have been integrated into the inside of the clasp, which interlocks with the weave of the strap itself. According to the company, this design element could only have been achieved using this unique AM production approach, rather than more traditional methods of welding separate pieces together.

"Every element of the bracelet has been engineered exactly as it needs to work," stated Michael Carr, Creative Director at Uniform Wares. "The radius at which it curves, the flexibility and stiffness at each point – every link incorporates fine adjustments. It represents bespoke engineering at every point."

Betatype's optimised LPBF process is also said to have used the least amount of material possible, producing little to no waste in the manufacturing of the T5 titanium strap. After manual finishing, the final strap was said to be extremely strong and much lighter than a traditionally-made Milanese mesh bracelet, and weighing just 10.5 g (0.37 oz).

The strap will be available in a natural matt finish with selected references from Uniform Wares' PreciDrive collection and will be sold via the Uniform Wares website and select retailers, including Porter and Nordstrom. Uniform Wares reported that it is currently in discussion with Betatype about future projects, with Carr stating, "We plan to incorporate what we've learned into other aspects of our product. Whatever we decide to do next, we'll start with the design based on the knowledge of the additive process."

www.betaty.pe
www.uniformwares.com

The woven titanium alloy watch strap was produced for Uniform Wares' PreciDrive M-Line watch collection (Courtesy Uniform Wares)

US-based Military AM Summit

The Defense Strategies Institute's 3rd Military Additive Manufacturing Summit & Technology Showcase will be held from February 6–7, 2019, at the USF Health, CAMLS Education Institute in Tampa, Florida, USA. The event aims to bring together experts and key-policy makers across military services, defence agencies and civilian organisations.

This year's summit is set to focus on the latest techniques and innovations being developed to further various AM processes, as well as the technology's current levels of capability, in order to deliver increased flexibility on the battlefield. The organisers stated that according to recent reports, the aerospace and defence Additive Manufacturing market is expected to surpass $4 billion by 2023, and is projected to increase 23.2% annually over the next five years.

Manufacturers across a broad spectrum of industries including automotive, aerospace, high-tech and medical products are all now either piloting or using Additive Manufacturing technologies and the US Military has for some time been taking advantage of developments in AM, which has been integrated into several aspects of the military services, in particular for the production of spare parts in the field of combat.

The 2019 Military Additive Manufacturing Summit will detail how, through the use of AM, the military is able to enhance its sustainment capabilities, minimising the costs associated with the purchase, transport and storage of additional resources. Panels during the event will explain how the military logistics supply chain has become more efficient through the implementation of expeditionary printing methods and various cutting-edge AM innovations, producing a more self-sufficient and agile force in austere and contested environments.

www.militaryam.dsigroup.org

CECIMO publishes online course on Additive Manufacturing

The EU's MachinE Tool ALliance for Skills (METALS) project, coordinated by CECIMO, the European association for the Machine Tool and Additive Manufacturing industry, has concluded with the release of a free online course on the fundamentals of Additive Manufacturing. The course includes a total of twenty-seven learning units divided along three main subject areas – knowledge on AM, work-process and entrepreneurship – covering both technical and soft skills needs in Additive Manufacturing.

The METALS project is the result of a comprehensive partnership spanning Germany, Italy and Spain, involving key stakeholders in AM workforce development, from industry and vocational training institutes to local training regulators and research bodies. The aim of the project was to increase the competitiveness of the European machine tool industry by providing the sector with the skills needed to benefit from new disruptive technologies.

Following the completion of surveys, workshops and interviews with a number of European machine tool experts, the project partners concluded that in the portfolio of innovative technologies in the machine tool sector, AM is a key area for training since it is on the verge of industrialisation. The online AM learning course, which is available in English, German, Italian and Spanish, intends to support AM workforce development.

The project also aimed to raise policymakers' awareness about the importance of AM skills for the European advanced manufacturing sector. METALS developed a position paper which called on Vocational Education and Training (VET) regulatory bodies in Europe to develop robust training programmes for AM-skilled workers, and for relevant national accreditation agencies to give priority to AM skills in their respective systems. The paper also called for further promotion of the attractiveness of VET and to increase funding at the disposal of VET institutes for the purchase of necessary technical equipment in the field of Additive Manufacturing.

Filip Geerts, CECIMO's Director General, stated, "Training and education are important elements for the industrialisation of additive technologies in Europe, which is the objective of CECIMO. With METALS, learners will be able to access relevant online knowledge at no cost and start building their competences to interact with AM."

metals.mobil-lernen.com
www.metalsalliance.eu
www.cecimo.eu

Registration opens for 2019 Additive Manufacturing Users Group Conference

The Additive Manufacturing Users Group (AMUG) has opened registration for its 2019 Education & Training Conference, to be held in Chicago, Illinois, March 31–April 4, 2019. The AMUG Conference is open to owners and operators of industrial Additive Manufacturing technologies, and aims to bring together engineers, designers, technicians, supervisors, plant managers and educators from around the world to share expertise, best practices, challenges and application developments in AM.

Now in its 31st year, AMUG stated that it is adjusting its 2019 conference programme to deliver more training and hands-on experiences. Paul Bates, AMUG President, stated, "As the AM community evolves, so will AMUG. We are excited to present the new programme with the goal of continuing to act on our mission of educating and advancing the uses and applications of Additive Manufacturing technologies."

The 2019 event will include technical sessions and hands-on workshops designed to help users take full advantage of AM technology. As part of this greater focus on training, the group has also introduced a new Training Lab, which it stated will offer an engaging training environment where tools for AM are the focal point of discussions.

The conference agenda is expected to contain more than 150 presentations and hands-on workshops, as well as the fifth annual Innovators Showcase. The showcase takes the form of an on-stage interview where attendees will have the opportunity to get to know an innovator in the industry and discover insights from their experiences. For 2019, the special guest will be Professor Gideon Levy, consultant for Technology Turn Around.

The five-day event includes the two-night AMUGexpo and a number of popular networking receptions

Throughout the conference, AMUG's Innovators Award, Technical Competition and DINO Awards will be announced, recognising successful applications of Additive Manufacturing and contributions to the industry as a whole.

www.amug.com

Triditive aims to accelerate AM research & training

Triditive, Gijón, Spain, is partnering with the University of Las Palmas de Gran Canaria and the University of Oviedo MediaLab to drive research and training programmes at its Scaladd AM Centre, a facility housing multiple Triditive AMCell Additive Manufacturing systems. Triditive intends for Scaladd to form the largest AM platform for mass manufacturing, and will provide companies access to its AM production capacity in metals and polymers, as well as technology and services provided by partners of Triditive. The company has previously stated that it expects the centre to have a production capacity of up to 30,000 parts a month by the close of 2018.

According to Mariel Diaz Castro, Triditive CEO, "Companies that do not want to invest in 3D printing capacity or do not have yet the knowledge themselves, can then purchase capacity on one of the AMCell machines at Scaladd."

Triditive's new partnership with the University of Las Palmas and University of Oviedo aims to increase collaboration, communication and research in new processes and technologies in the AM of metals and polymers, and to facilitate development of the skills and training for use in factories of the future.

"We share a common goal of attempting to implement new training methods that may be implemented by universities, but also providing the manufacturing industry with new professionals with skills in AM. This technology will help the manufacturing industry to innovate and to be more competitive," added Castro.

Triditive's AMCell systems utilise BASF's Ultrafuse 316LX metal-polymer filament. The machines can operate largely unsupervised during the whole production process, reducing human labour and intervention to a minimum.

www.triditive.com

GE Additive helps Callaway Golf optimise putter head design

Callaway Golf Company, Carlsbad, California, USA, a leading manufacturer of golf clubs and equipment, has signed a consultancy agreement with GE Additive's AddWorks team to help it harness the potential of Additive Manufacturing. The first project resulting from the agreement is a redesigned Odyssey R-Ball Prototype putter head.

As part of its product innovation strategy, Callaway uses a range of manufacturing techniques to produce clubs and equipment that reflect the different aesthetic and acoustic tastes of professional and amateur golfers in different world regions. The reworked Odyssey R-Ball Prototype putter was originally developed as a tour-preferred model in Japan, and its design offers an acoustic signature unique to that local market. Callaway's goal was to see how Additive Manufacturing could change that acoustic signature, while retaining the preferred shape and performance.

For this putter head, it was found that the best way to optimise acoustics was to add a complex geometry that would have made it difficult to produce by conventional casting methods. GE Additive's Addworks engineering consultants worked with Callaway's design and engineering teams to apply Additive Manufacturing design practices and build upon the already-proven design. The team refined existing designs to ensure all features were self-supported or easily supported during the AM build, and topology optimisation was used in conjunction with acoustical mapping to create the optimal design.

The AddWorks team has equipped Callaway with knowledge on additive processes and provided assistance on materials selection, along with developing parameters and testing protocols to achieve desired material properties. It has also helped Callaway discover and identify other parts that are potentially suitable for production in the future.

"Additive Manufacturing is a new tool which is quickly going beyond the aspirational phase, and into the functionalisation phase of the technology. Callaway needs to learn how to use this tool well, because it is inevitable that 3D printing of production parts is going to happen – it is the production method of the future," stated Brad Rice, Director – R&D, Advanced Engineering at Callaway.

"We chose to work with GE Additive to partner with experts that represent best-in-class within the industry. GE Additive brings the total package to the table, offering end-to-end solutions; from printing machinery, raw materials, consultancy and build software," he added.

"In terms of innovation and technology leadership in their sector, Callaway stands head and shoulders above the rest. This project has allowed us to add value to Callaway's business goals," commented Chris Schuppe, General Manager, AddWorks, GE Additive. "We're also taking away many new learnings from our first project together, especially around aesthetics. We have also used additive technology to create an acoustic map, which is certainly a first for us. We're looking forward to driving more successful projects with Callaway, as they continue their additive journey," he added.

www.cmp.callawaygolf.com/
www.geadditive.com

GE Additive has helped Callaway develop its latest Odyssey putter head (Courtesy GE Additive)

Additive Industries launches its fifth Additive Manufacturing Design Challenge

Additive Industries, Eindhoven, the Netherlands, has launched its fifth Additive World Design for Additive Manufacturing Challenge. The annual challenge is aimed at increasing the number of examples available of highly effective design for metal Additive Manufacturing, encouraging the technology's application across a wider range of industries.

Competing in two categories, both professionals and students are encouraged to enter the challenge by redesigning an existing, conventionally manufactured component for metal Additive Manufacturing. A professional jury will evaluate all submitted designs to assess whether they make the most of the distinctive features and freedom AM has to offer.

Partners of the Design for Additive Manufacturing Challenge are consumer 3D printer manufacturer Ultimaker, Altair Engineering, Autodesk and CECIMO, the European Association of the Machine Tool Industries. All six challenge finalists will be invited to Additive World Conference in Eindhoven, March 20, 2019, with the winners to be announced during the Additive World Awards Dinner.

Daan AJ Kersten, Additive Industries Co-founder and CEO, stated, "We are looking forward to this fifth anniversary edition of the Challenge, with inspiring (re)designs to eliminate manufacturing difficulties, reduce the number of parts, and minimise assembly or lower logistics costs."

Entrants must register before February 1, 2019. Prizes will include software licences, an additively manufactured award, and the latest Ultimaker 3D printer.

www.additiveindustries.com

IUPUI'S School of Engineering and Technology wins Praxair grant for metal AM research

The School of Engineering and Technology at IUPUI (a partnership between Indiana and Purdue universities, USA) has announced that Praxair Surface Technologies has awarded one of six TruForm AMbition grants to a project led by Dr Jing Zhang, Ph.D., Associate Professor of Mechanical and Energy Engineering. The aim of the in-kind grant is to support the growth of Additive Manufacturing in the academic community, targeting North American universities involved with metal AM.

Praxair Surface Technologies is a supplier of metal powders for AM, offering cobalt, copper, iron, nickel and titanium-based alloys to the industry. "This AMbition grant helps support collaboration within the industry, which is important as we push to accelerate metal AM adoption," stated Andy Shives, Praxair Surface Technologies's AM Business Manager.

Zhang will collaborate with Praxair Surface Technologies, the U.S. Army Research Laboratory (ARL), Argonne National Laboratory, Brookhaven National Laboratory and Changwon National University in South Korea to develop Additive Manufacturing of Alloy 718, which is used to fabricate military vehicle engine components.

"Through this grant and a Cooperative Research and Development Agreement with ARL, IUPUI will work closely with the team to develop a new methodology to optimise the metal AM process via combined ICME (integrated computational materials engineering) and targeted experimental validation," Zhang explained. "The goal is to maximize the performance of AM alloys used for U.S. Department of Defense applications, in both normal operating and high strain-rate and ballistic conditions."

praxairsurfacetechnologies.com
www.engr.iupui.edu

EPMA PM Thesis Competition 2019 now open for submissions

The European Powder Metallurgy Association has launched its 2019 Powder Metallurgy Thesis Competition, sponsored by Höganäs AB, and is now accepting entries via its website. The deadline for submissions is April 24, 2019.

This competition is open to all graduates of a European University whose theses have been officially accepted or approved by the applicant's teaching establishment during the previous three years. Theses, must be classified under the topic of Powder Metallurgy (which includes metal Additive Manufacturing), are judged by an international panel of experts drawn from both academia and industry.

The aim of the competition is to develop interest in and to promote PM among young scientists at European academic institutions and to encourage research at undergraduate and postgraduate levels.

The PM Thesis competition winners will be awarded prizes of €750 and €1,000 for Masters and Doctorate levels respectively. In addition, each will receive complimentary registration to the Euro PM2019 Congress & Exhibition as well as the opportunity of having their work published in the scientific journal *Powder Metallurgy.*

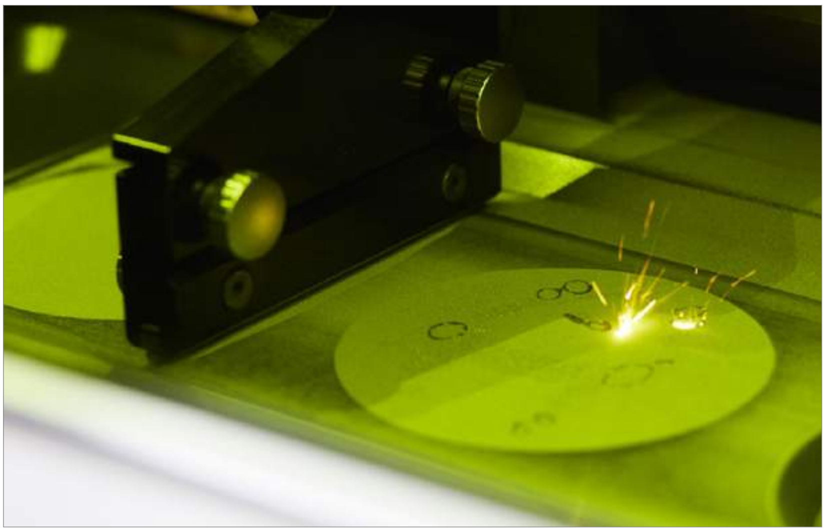
www.thesiscompetition.epma.com
www. epma.com

Russia's Conmet employs Trumpf technology for the production of custom craniomaxillofacial implants

In the conventional manufacturing of craniomaxillofacial implants, the surgeon must cut the implant out of a perforated titanium plate during an operation, while the patient is under anaesthetic, and then shape it to size in the operating room. This can lead to time pressure and added stress for the surgeon, potentially leading to variations in the quality of fit.

The production of personalised patient implants prior to surgery using metal Additive Manufacturing has been one of the most successful applications for the technology to date. One user of metal Additive Manufacturing in the production of patient implants is Conmet, a market leader in the field of craniomaxillofacial surgery and implantology based in Moscow, Russia. The company is currently using TruPrint 1000 AM systems produced by Trumpf, Ditzingen, Germany, to manufacture implant components for markets in the Commonwealth of Independent States (CIS) and will soon be supplying elsewhere in Europe.

Conmet uses Trumpf's TruPrint 1000 AM system to produce customised craniomaxillofacial implants



A view of the build chamber during component manufacture on Trumpf's TruPrint 1000

Conmet first began investigating Additive Manufacturing for the production of implants around a decade ago. At the time, however, the technology was still insufficiently mature for such applications. Andreas Margolf, Project Manager for Additive Manufacturing at Trumpf, commented, "Conmet asked various machine-tool suppliers to produce benchmark parts but wasn't happy with the quality."

In 2017, following a wide range of significant developments in Additive Manufacturing technology over the past decade, the company made the decision to reinvestigate the technology and approached Trumpf to find out how far it had evolved. "We set up a second meeting in Ditzingen," Margolf continued. "Over the course of two days, our experts answered all their questions on Additive Manufacturing, while our machines produced the benchmark parts."

This time, Conmet was sufficiently impressed by the quality of parts and the design of the system, all of which met its requirements. "Trumpf is the only supplier on the market for 3D printing that develops its own lasers and all the optical components," Margolf added. "Trumpf also has a wealth of experience in the areas of machine tools and services. That means we're able to assist Conmet with any aspect of the process."

The right machine with the right process parameters

The first task for Trumpf's team was to determine the right machine for Conmet, along with the relevant process parameters for the production of medical implants. According to Trumpf, it soon became clear that the ideal setup was Trumpf's TruPrint 1000 AM system. This machine is especially compact and could therefore be comfortably installed in Conmet's existing production facilities.

Equipped with a 200 W fibre laser, developed in-house by TRUMPF, the machine is highly suitable for use with the titanium alloys generally used to produce medical implants.

Trumpf also assisted Conmet in fine-tuning the focal diameter at which the laser beam hits the powder bed. "Our tests showed that reducing the focal diameter to 30 µm improves the surface smoothness of the implants by around 20%," Margolf explained. "This makes the process slower and slightly more expensive, but reduces the cost of post-processing the surface."

Conmet currently produces sixty implants a month with the TruPrint 1000 AM system, and compared to conventional machining methods the process saves 40% in production costs

A 40% reduction in production costs

Conmet has now been operating the TruPrint 1000 at its Moscow production facilities since the beginning of 2018 for the production of dental components and craniomaxillofacial implants. These products are marketed in the CIS region and in Europe. To manufacture the implants, hospitals provide Conmet with the CT data of the patients who require them. The company's engineers then design the implant, in consultation with the surgeon, before additively manufacturing it on the TruPrint 1000. "We currently produce sixty implants a month with the TruPrint 1000, and we're planning to increase our output by 10%," stated Nadeschda Morozova, Project Manager at Conmet.

The implants produced are said to be of an especially high quality overall, as well as being substantially cheaper than conventionally manufactured implants. "Compared to conventional machining methods such as turning and milling, the new process saves us 40% in production costs," Morozova reported.

In the near future, the company stated that it intends to begin production of custom-fit spinal fixation devices using AM. The company also has plans to manufacture mass-produced prosthetics with the TruPrint 1000. For this, it will once again opt for Trumpf technology with a TruPrint 3000, which features a larger build chamber.

Medical devices produced by Conmet are said to offer a high degree of reliability and repeatability in line with European standards. Since Trumpf supplies not only the AM machine but also the associated products, including substrate plate, software and process parameters, it was stated that the implants produced are highly congruent.

In addition, Trumpf Moscow provides a local service partner and Russian-speaking technicians to support Conmet wherever necessary. "It's not just about the customer buying equipment from us; we also want to see them earn money," Margolf added. "Conmet's success with Additive Manufacturing shows we're on the right track!"

Providing solutions for the full laser-based manufacturing chain

Trumpf offers production solutions for a number of fields in the machine tool and laser sectors. The company is currently focused on increasing connectivity in the manufacturing industry through its consulting, platform and software offers.

In its laser technology business division, the company provides high-performance CO_2 lasers, disk and fibre lasers, direct diode lasers, ultrashort pulse lasers and marking lasers and marking systems. Its product range also includes laser systems for cutting, welding and surface treatment of three-dimensional components, as well as high-power laser systems with an extreme ultraviolet light spectrum for the semiconductor industry. This wide-ranging and in-depth experience of laser technology has positioned the company well to drive forward metal AM technology, alongside its knowledge of mechanical engineering and industrial digitalisation.

Trumpf manufactures AM systems based on two laser-based processes: Laser Beam Powder Bed Fusion (LB-PBF) and Laser Metal Deposition (LMD). As a laser and machine manufacturer, the company stated that it can support customers across the entire process chain, offering comprehensive solutions for the industrialisation of AM, as well as robust and reliable machines for the series production of metal additively manufactured parts.

With a staff of about 13,400, the company generated sales of nearly €3.6 billion for the 2017/18 fiscal year. The company has a development ratio of over 9% and remains an independent, family-owned business, which is represented by over seventy global subsidiaries in Germany, France, the UK, Italy, Austria, Switzerland, Poland, the Czech Republic, the USA, Mexico, China and Japan.

www.trumpf.com

Binder Jet metal Additive Manufacturing: Process chain considerations when moving towards series production

With the launch of a number of new systems targeting the series production of components, Binder Jetting is generating a high level of interest in the world of metal Additive Manufacturing and beyond. In the following report, Sebastian Boris Hein, Claus Aumund-Kopp and Bastian Barthel of Fraunhofer IFAM review the main process considerations and production steps in the Binder Jetting of metals as related to series production, highlighting both the advantages of the technology and the challenges that it poses.

Binder Jetting is an Additive Manufacturing process that promises some interesting benefits, technologically as well as economically. Despite originally being developed in the early 1990s [1], other powder-based Additive Manufacturing technologies have gained higher visibility in recent years, in particular Powder Bed Fusion processes employing laser (LB-PBF) or electron beam (EB-PBF) energy sources. These processes are also more widely distributed in the industrial environment.

When comparing Powder Bed Fusion processes with Binder Jetting, there are several basic advantages for the Binder Jetting process. As it makes use of a liquid binder instead of high-energy electro-magnetic radiation, there is no melting of the material, which can lead to internal stresses and distortion. Therefore, no support structures are required, a wider selection of materials is possible - including non-weldable materials - and the building of closed layers above loose powder areas, and thus the stacking of parts, is enabled.

As the surrounding powder does not stick to the part as with a melt, the undersides of part features show the same surface qualities as the upsides. Therefore, parts can be designed differently and design features that would not be achievable by Powder Bed Fusion processes can be realised (Fig. 1). The main drawbacks are to be seen in the sintering step; one factor is the non-isotropic shrinkage, the other the potential for distortion during sintering due to the weight of the part and friction with the sintering setters (Fig. 2), which can limit the maximum part size.

Fig. 1 Sections of circular nozzles, upper part by Binder Jetting without support structures; lower parts by LB-PBF with varying amounts of internal support structures

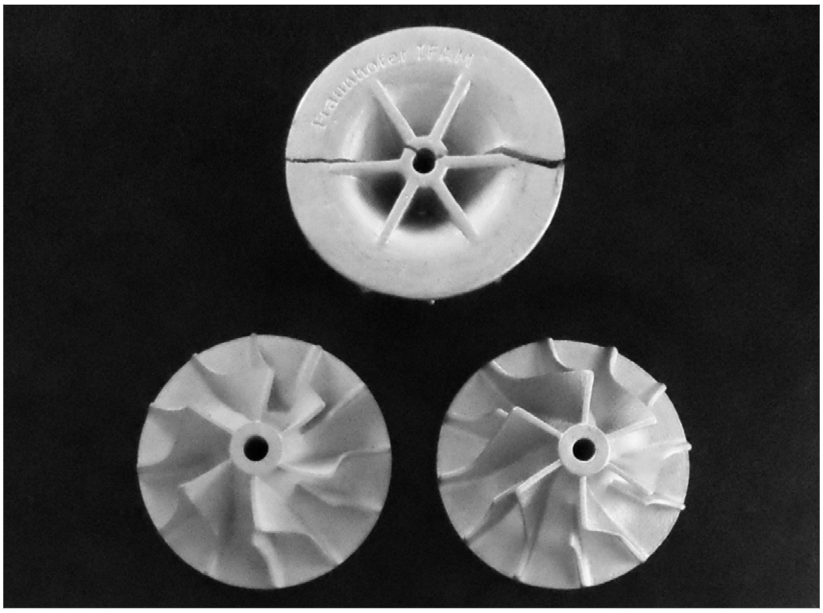


Fig. 2 Turbine wheels made by binder jetting, upper part broken due to high cooling rates after sintering; lower left part with significant distortion; lower right part with less distortion

Aside from technological aspects arguing for or against the use of either AM process, Binder Jetting is especially interesting for companies that already make use of sintering, and therefore have experience with the process step. The process is well established, and the material properties of parts made by Binder Jetting are close to conventional sintered parts, such as those produced by Metal Injection Moulding. Thus, prototypes and small series parts show comparable properties to production series parts.

Still, when considering implementing a technology such as Binder Jetting, which is unproven for volume production, the decision not only comprises technological factors, but also everything that surrounds the technology. Awareness of the complete process chain is, therefore, essential as the basis for decision-making. This is the motivation for this article; to broaden the discussion of the Binder Jetting process beyond the core part building process. Independent of machines or machine manufacturers, certain points have to be addressed in the process chain and an understanding of interdependent process factors has to be created.

Fig. 3 shows a general description of all relevant process steps for the Binder Jetting process of metals, based on commercially available materials. Underlying all process steps is the control of the process, which can take on various forms, depending on each process step itself. In the following, all process steps will be considered and discussed, including possible challenges, important impacts of specific factors on the overall process and control aspects. No claim is made that descriptions are complete, and further factors may be missing. Nonetheless, the intent of this article is to raise awareness of the whole process chain and to stimulate discussions on all process areas.

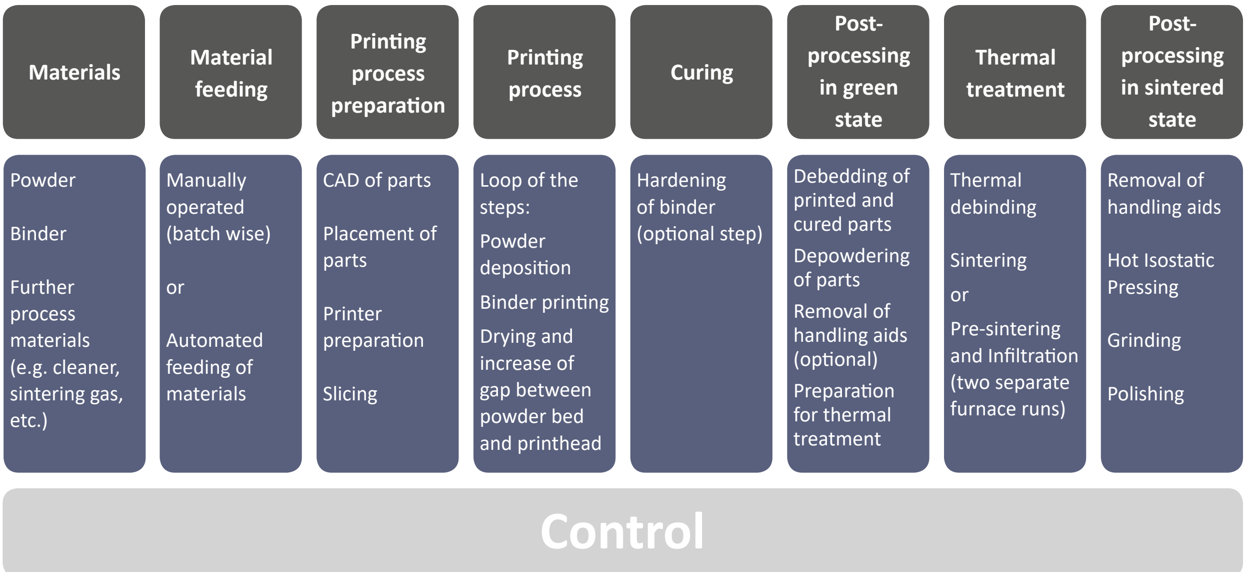


Fig. 3 Overview of all process steps in the Binder Jetting process

Material considerations in Binder Jetting

Materials of relevance to the complete Binder Jetting process chain may include more than just the materials associated with the build process, namely metal powder and binder. They may further comprise materials for cleaning or post-processing – for example mechanical machining, grinding, shot blasting, etc. After sourcing, materials have to be stored properly, according to safety guidelines and in a way that excludes property changes. Such changes may be of a chemical nature, for example in the case of reactive chemicals, or a separation of powders that would destroy a homogeneous or statistical mixture of differently sized powder particles, affecting final part quality and reproducibility.

With regard to their respective effects on the processability, handling and final quality of the parts, powder and binder have the biggest influence. The powder characteristics determine several factors that have a direct effect on important part properties. For example, particle size, particle size distribution and particle morphology determine characteristics such as apparent density, tap density and powder flowability. These in turn influence powder bed density [2] and possible anisotropies, which are directly responsible for the sintering behaviour, including achievable density [3, 4], also influenced by the intrinsic material properties, and shrinkage behaviour [5], though this may also depend on the part orientation in the building chamber. The binder is also crucial for further processing steps and their robustness, as it gives strength to the green parts and thus their handling capabilities. Additionally, the binder can influence achievable sintering densities due to its burnout properties and associated residuals that may interact with the solid material during thermal treatment. There is also the interaction of binder and powder to be considered. The wettability of the powder with the binder and the binder viscosity, which influences droplet size and capillary effects, also have an impact on the accuracy of the build, for example in the sharpness of edges.


Fig. 4 Turbine wheel made of 316L via binder jetting

As powder and binder have such a major influence, control aspects become very important. With regard to the binder, any changes in composition, for example due to chemical reactions or solvent evaporation, must be prevented prior to starting the build process. The same applies to powder and knowledge of powder characteristics. Therefore, analytical tools should be implemented to monitor material quality in order to assure reliable series production.

Material feeding

The feeding through of materials is one aspect of Binder Jetting that is seldom considered in research environments, but it is an important aspect when it comes to production. Usually, a Binder Jetting system is loaded manually with powder, and binder is filled into a reservoir. In the case of high production volumes, multi-machine operations, or when safety concerns regarding open powder handling come into play, a closed, automated material feeding system may be necessary. In such a case, the influence of these systems on material quality has to be considered. If, for example, the powder is stored in larger quantities and distributed by pneumatic feeding, this may affect the particle distribution due to de-mixing. Again, the monitoring of material properties becomes important.

Fig. 5 Ring-shaped injection nozzle made of 316L via Binder Jetting

The build process: planning and implementation

Design and placement

Having solved the question of the material feeding strategy, the build process has to be planned. This includes various stages, beginning with a review of the part design. Using CAD, parts must be designed along process specific guidelines, which vary from those of other AM technologies. Such guidelines should take all process limits and material properties into account. Process limits are set by all process steps, not only by the properties of the Binder Jetting machine (resolution, size of building chamber, etc.). The possible size of feasible channel structures are influenced by the powder characteristics and the strategy for depowdering. Distortion of part features may occur during sintering, which is closely linked to wall thicknesses, while automated handling may require sufficiently strong handling features. A further question may arise regarding the placement of the as-built parts in the sintering furnace: do the parts have a flat surface that can be placed directly on sintering trays or is a separate sintering support necessary to avoid distortion? Such a support would have to be designed and built, preferably in the same job. In order to be able to prepare thorough and reliable design guidelines, a complete understanding of the whole process is required.

Having designed the parts, they must be placed virtually in the build chamber, taking factors such as an anisotropic shrinkage into account. Depending on how the parts are placed, a direction-dependent size factor may have to be used to scale the parts.

Machine preparation

After placing all parts for the build job, physical preparation of the AM machine follows. This may vary considerably depending on the build and include specific steps aside from a sufficient material supply. The settings for the build job have to be chosen (for example, layer thickness, binder saturation, powder deposition settings, drying time, etc.), the powder bed prepared and possibly several system checks performed.

The final step before starting the build job is slicing, in which the virtual model of the build chamber is transformed into slices of the chosen thickness and combined with the build parameters.

Build step 1: Preparation of the powder layer

The Binder Jetting build process consists of three steps that are carried out in a repeating loop until the build job is finished. The first step is the deposition of the metal powder layer that includes the setting of the layer height, spreading of powder (either by a moving, vibrating container above the build chamber or by drawing powder from an adjacent powder reservoir), smoothing and compacting the layer by use of a doctor blade, roller or similar tool.

The method of powder spreading and the type of smoothing tool influence the characteristics of the powder layer [6]. In spreading the powder via a moving reservoir above the powder bed, the powder can be distributed evenly on the powder bed prior to smoothing.

Drawing the powder from an adjacent reservoir leads to a higher powder build-up at the beginning of the powder bed that slowly decreases over the distance to the end of the bed. The amount of powder build-up and the type of tool determine the pressure distribution in the powder and, with that, the compaction of the powder layer. Ideally, the compaction should be homogeneous in the powder bed to minimise anisotropy.

Build step 2: Binder deposition
The second step of the build is the deposition of binder into the powder bed. Position and amount of binder are set during build job preparation. The binder viscosity has to fit a window, given by the nozzle. Build accuracy is determined by the nozzle resolution and the droplet size, as well as the powder characteristics and the aforementioned interaction of powder and binder.

Build step 3: Drying
The third step of the build loop is a drying step, during which the binder solvent is evaporated to a certain point that prevents the following layer from shifting during powder smoothing. In addition, the powder bed is heated to a set temperature, which is crucial to guarantee uniform conditions for all layers and shorten the build time.

Between the binder deposition and the drying step, a setting time for the binder may be required in order to ensure sufficient time for the binder to soak into the powder layer and enable adhesion to the layer below.

Control aspects during a build may become complex. It is important to make sure that each layer is processed properly, as even one defective layer can make the complete part unusable. Regarding the build environment, measures against the contamination of equipment and personnel have to be taken, including safety aspects relating to the use of powder such as proper ventilation and atmosphere control, the use of explosion proof filters, etc.

Curing
The curing of the binder is a step that is optional depending on the employed binder system. It may be a completely separate process, in which binder components react to form a polymeric structure that provides mechanical strength. Alternatively, it may simply consist of a drying step, through which a previously dissolved polymer provides cohesion in the green part. Other concepts, as implemented in polymer Binder Jetting, make use of chemically reactive binder components such as acrylates and induce a reaction during the build process (for example by UV radiation), which leads to a polymerisation. From a production point of view, omitting a separate step is favourable, but such concepts are not yet established for the Binder Jetting of metals. When considering binder concepts, factors such as processing strategy (including necessary equipment), processing time, mechanical strength and burnout properties have to be taken into account.

Fig. 6 Sintered part, broken during depowdering due to low green part strength

Post-processing in the green state

The post-processing of green parts is a crucial step in the overall process. Independent of the employed AM system, this always includes debedding and depowdering of the green parts. Strategies for these steps have to be adjusted to the part geometry; simpler geometries may be easily handled and depowdered by tapping, brushing and/or compressed air blasting, but depending on geometric features such as channels or fine undercuts, and the powder's flow characteristics, these measures may not suffice. Other approaches, such as controlled vibration or immersion and ultrasonic excitation, may be necessary. Of course, the success of a defect-free depowdering strongly depends on the green part strength (Fig. 6). Improved binder stability may therefore enable the use of more intense depowdering measures, making certain geometries realisable.

Furthermore, the removal of handling aids, especially in the case of automated part handling, may be done in the green state. In any case, the green parts have to be prepared for the following thermal treatment by placing them on sintering trays, with or without a separating agent, or in combination with geometry-specific shrinkage supports.

Control measures taken during post-processing directly correlate with final part quality. Also, treating green parts and freeing them from unbound powder has to be done in closed surroundings to prevent the uncontrolled release of powder. Excess powder and removed powder has to be further treated in order to be reusable; this includes powder recovery, possibly drying, sieving, verifying its original particle size distribution and refeeding.

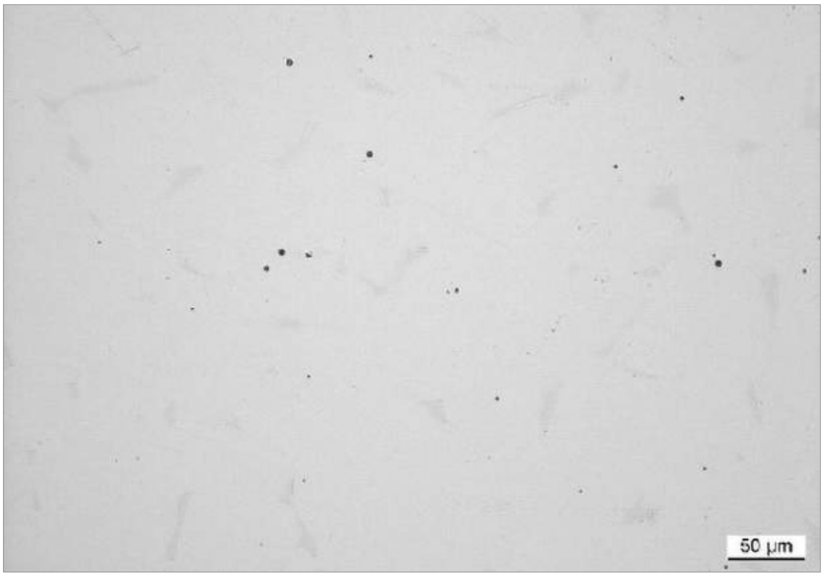


Fig. 7 Light microscopy image of a polished section of binder jetted and sintered 316L

Thermal processing

Debinding

Thermal processing can be divided into phases, with the first being thermal debinding. This is a thermal decomposition of the organic binder in a manner that does not damage the part and leaves behind as little residual material as possible. This requires detailed knowledge of the binder's thermal behaviour in a specific atmosphere, especially regarding degradation behaviour, which is often quite complex and requires several holding steps and slow heating. The in-line monitoring of decomposition products in the furnace would be a sensible method for quality control.

Depending on the basic approach of the Binder Jetting process, thermal debinding is either followed by a sintering step to achieve high densities, usually directly after debinding in the same furnace run, or by pre-sintering to achieve parts with specific porosity that is filled by infiltration with a lower melting point material (e.g., bronze) in a separate furnace run.

Sintering

Sintering in general is a heat treatment applied to a powder compact in order to impart strength and integrity by diffusion processes. The temperature used is below the melting point of the major constituent of the material. The two selectable parameters are the time-temperature profile and the atmosphere or process gas, both of which have a significant influence on the sintering process and must be chosen depending on the material and the processed powder.

Among other things, the atmosphere is responsible for heat conduction and removal of the decomposed binder and can interact with the material. Hydrogen, for example, has a reductive effect, which leads to a higher density in stainless and low-carbon steels, and changes to the chemical composition and mechanical properties of medium-carbon steels, which are decarburised. It is also possible to sinter under vacuum, so that no gas-filled pores can arise, which could expand again during a heat treatment after Hot Isostatic Pressing.

The time-temperature profile is usually divided into three sections: heating, holding and cooling. The heating process includes the debinding step and is limited in its speed by heat conduction and part size in order to ensure a homogeneous temperature distribution in the green/brown part, which in turn leads to a uniform start to densification. The start of densification depends directly on the particle size and particle morphology, which also influence the required holding temperature and holding time. For finer powders, lower temperatures and a shorter holding time can be selected compared to coarser powders in order to achieve similar densities. During cooling, it is important to avoid large temperature gradients that can cause residual stresses. Current work mostly focuses on sintering and, for specific materials, relative densities of more than 99.5% can be reached for 316L stainless steel (Fig. 7).

Sintering equipment with the proper monitoring of temperature development and distribution is rather expensive, but a crucial part of the process chain. The quality of processing materials, especially the gases, is also of great importance. Furnace installation requires considerable effort, as demands on operational safety are high.

Post-processing in the sintered state

Mechanically, sintered parts are considerably more stable than green parts. Therefore, the removal of handling aids that would be too difficult to remove in green state may instead be carried out after sintering. Further treatments may include Hot Isostatic Pressing, calibrating via coining, or machining processes such as grinding, turning, milling and polishing in order to achieve the desired part finish.

Further control aspects

Several control aspects have been mentioned for specific process steps, such as special analytics and in-line monitoring for quality control purposes, but also controlling the necessary process environment with regard to safety.

In a production environment, further controls may need to be implemented. First of all, incoming goods inspection of all consumable materials is indispensable to ensure reproducibility. This requires different processes for each material,for example chemical analysis or powder characterisation. Other quality control measures may include SOPs (standard operation procedures) for all manually performed tasks, documentation and data storage. In order to prevent production downtimes, spare parts have to be in stock and the logistics of materials, parts and consecutive process steps have to be managed. This also includes the reuse of materials and waste management.

Conclusion

When considering the implementation of a relatively new series production process, many factors have to be taken into account. Aside from existing challenges regarding Binder Jetting technology, there are many more aspects surrounding the build process that could have an even greater impact on series production within the process chain. It is hoped that with this article, awareness of these aspects is raised, as discussions about the technology are usually limited to the advantages, disadvantages, possibilities and challenges of the build process. There is no doubt that this technology will be applied in the future, but we also see the need to shed light on all process aspects in order to prevent unnecessary setbacks in the implementation of Binder Jetting. The sooner more people are aware of challenges in the entire process chain, the sooner solutions for specific challenges will be developed.

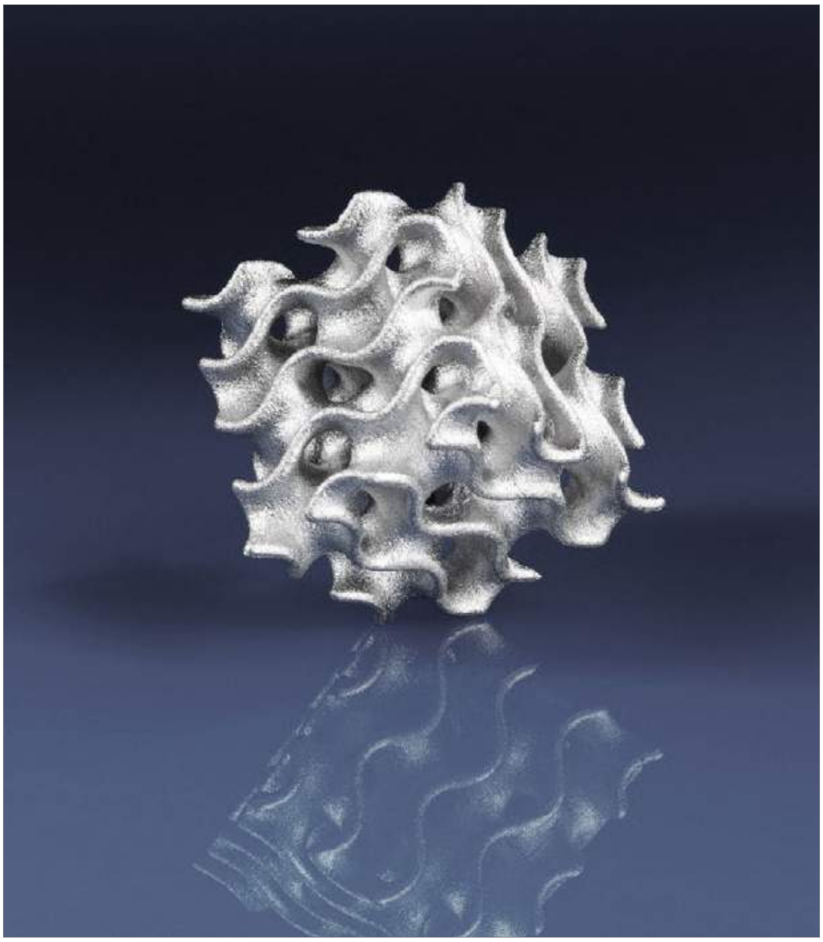


Fig. 8 Gyroid structure made of 316L via Binder Jetting

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Simple and standardised X-ray CT testing in metal Additive Manufacturing

X-ray Computed Tomography (CT), also widely known as MicroCT, is a proven method for not only checking the structural integrity of additively manufactured (AM) parts - for example for unwanted porosity - but also for checking a build's dimensional accuracy. The main advantage of the technique is of course the non-destructive nature of the assessment; however, there are also many misunderstandings about the capabilities and complexity of the technology. Prof Anton du Plessis and Dr Jess M Waller review the application of CT testing in relation to metal AM and highlight the advantages of a move towards standardised test methods.

Most metal Additive Manufacturing engineers have heard of CT scanning and seen exciting 3D X-ray images. Some have even used the technique, and some use it extensively. However, whenever the topic is mentioned, a combination of the following is often heard from AM engineers:

- It costs too much
- It takes too long
- It's too complicated
- Does it really help?
- It's too variable in quality
- It's too variable in cost and time
- It's too 'fancy' and not for production
- Which defects matter or are rejectable?
- What is the critical initial flaw size for metal AM parts that must be reliably detected?
- How reliable is the technique for detecting deeply embedded flaws?
- I've characterised the defect state, i.e., defect sizes, types, orientations and distributions, but what about microstructure-dominated failure mechanisms?
- I've heat treated or subjected my part to Hot Isostatic Pressing, thus closing the pores as revealed by before and after CT. Do I still need to be worried?

All of the above leads to one unfortunate result: engineers are not using the awesome power of CT to improve Additive Manufacturing, despite its availability. First, take a step back and look again at the first few comments in the list above. It sounds very much like a description of metal AM you may have heard few years ago, doesn't it? The exciting news is that all the above issues are now either resolved or significant

Fig. 1 A sample is mounted onto the turntable in the X-Ray CT scanner at Stellenbosch University's CT facility

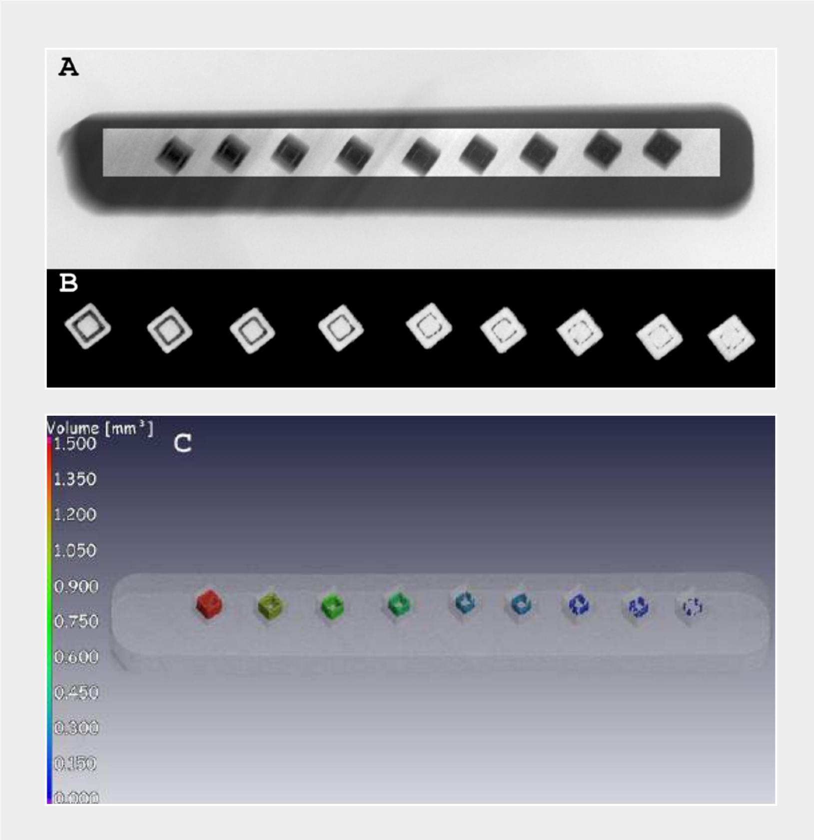

Fig. 2 Intentionally-designed cavities in a Ti-6Al-4V test part, produced by Laser-Beam Powder Bed Fusion, taken from [26]. Shown here are (A) an X-ray projection image with region contrast enhanced, (B) a microCT scan slice image in horizontal plane and (C) a 3D rendering including porosity/defect analysis showing cavities colour-coded by volume

progress has been made towards resolving them, and microCT is taking its place as the method of choice to inspect AM parts. This article explains why and how, whilst also reviewing current CT standardisation efforts and resources.

How does X-ray CT work?

Fig. 1 shows a sample being loaded in an industrial X-ray CT system. When X-rays are projected through and around a sample, they form a 'shadow' image, or X-ray image, of the object on a digital detector. This is essentially the same as a doctor's office X-ray and, for industrial parts, is known as digital radiography. This method is very useful to check for unexpected features: cracks, pores or inclusions. While detection of these features may not necessarily be grounds for part rejection, their detection may warrant archiving as a quality record, or review by a material review board or cognizant engineering organization to determine final disposition of the part.

However, radiography provides limited contrast and a strictly two dimensional view. By recording images from many angles as the object rotates, a CT scan is recorded and full 3D data are generated. After recording the images, a back-projection algorithm calculates the X-ray density at each point in the object. This results in much higher contrast images than radiographs (but many more of them!), with full 3D information – location, width, pore to surface distance, etc., as demonstrated in Fig. 2. In high value parts subject to fracture critical requirements, more rigorous and comprehensive CT analysis may be required, including characterisation of flaw shape, orientation relative to principal stresses, nearest neighbor pore to pore distances, and determination of the probability of detection (POD) for a given flaw size [1,2,3]. In advanced CT applications, extreme value statistics can be used to predict the fatigue strength and service life of an object by describing the defect population and determining the most critical defect distribution. This, in turn, can simplify the CT scan by determining the minimum volume that needs to be inspected to ensure the required CT precision [4]. A typical X-ray image is shown in Fig. 2(a) with a rectangular area of interest contrast-enhanced to show the presence of intentionally designed cavities (white areas inside darker area). The subsequent full microCT scan in Fig. 2(b) shows in a slice image the same cavities in much higher contrast (with inverted contrast – pore spaces are black and material is white). Fig. 2(c) shows a transparent 3D rendering of the square pore spaces, with colour coding based on volume (processed microCT data).

Computed tomography is known by many names and can be used in different ways, which might make it seem complicated. X-ray CT, microCT, nanoCT, microtomography, CT scanning, X-ray microscopy; all are effectively the same technique. As with all technologies, some types of equipment are suited to specific types of samples while others are better suited for other types of samples. However, the major point often overlooked is the processing of the 3D data – the handling, processing and analysis of 3D data sets was until recently the biggest hurdle to use the technique effectively. With today's high-spec computing workstations with multiple CPUs, high-end graphics cards, solid state drives and large amounts of RAM available, the analysis of large amounts of CT data becomes more efficient and much more useful, especially when using dedicated software for the purpose. Examples in this article are produced using Volume Graphics VGSTUDIO Max 3.2 with workstations using dual-core CPUs, NVidia graphics cards and 64–128 GB RAM. Scans here reported are performed at the Stellenbosch CT facility [5] and in all cases can be performed with a typical commercial microCT system with microfocus X-ray source capability up to 225 kV. Higher voltage systems and macro¬scale CT systems are also available and applicable for larger and denser AM parts (where microCT starts to be limited, as will be discussed below), but these are less widely available than microCT. For many applications, it is cost-effective to make use of the growing number of microCT service providers available globally.

What are the technology's uses in AM?

MicroCT has proven to be useful for checking the structural integrity of AM parts, i.e., to check for unwanted porosity or other flaws introduced during build. It is also used to check the dimensional accuracy, as parts may warp or otherwise build inaccurately – and microCT is the only way to create a full 3D model of a complex part with hidden or challenging geometries [1,6,7,8]. The need to develop new CT standards for measurement of internal features in AM parts using existing CT standards on a basis (E1570 [9], E1695 [10], VDI/VDE 2630 [11], WK61161 [12] and WK61974 [13]) was recently identified as a key NDE standardisation need in the United States [14]. Namely, current CT metrology state-of-the-art needs to be tailored to evolving AM part inspection requirements, including measurement of small or intricate AM features, and verification of the form and fit of lattice structures [14]. In its current form, the main advantage of the CT technique is the non-destructive nature of the assessment: this means that the dimensional accuracy and internal integrity can be assessed and the part approved or rejected based on pre-determined criteria [3], depending on the criticality of the application, i.e., as a quality control tool [15,16,17]. Despite many newer applications of the technology, this is still the most valuable application of microCT in AM. It is clear that this will become indispensable as AM moves more and more towards production and such quality control becomes essential, especially for high-value and structurally critical parts such as those for medical or aerospace applications.

What are the limits?

Not everything can be scanned, much like not everything can be additively manufactured. The physical size limits are typically based on the size of the CT cabinet; however, this is not the most critical consideration. The major point is that as the sample gets bigger, the resolution gets poorer due to field-of-view limits, and with this comes increasing likelihood of image artefacts such as beam hardening due to the larger amount of material that needs to be penetrated by the X-ray beam. Due to complex parts with varying densities and the fact that a cone beam geometry is often used, some image artefacts are almost always present in obtained images. Fan beam geometries are sometimes used to eliminate artefacts but these scans take more time to acquire, and therefore are not well suited to high-throughput inspections. In general, the smaller the sample, the better the results due to both above reasons – better resolution and fewer artefacts. There is no hard rule for 'high-quality data' vs 'poor-quality data' and, in reality, anything can be scanned - the results simply degrade as the part gets bigger.

"...as the sample gets bigger, the resolution gets poorer due to field-of-view limits, and with this comes increasing likelihood of image artefacts such as beam hardening due to the larger amount of material that needs to be penetrated by the X-ray beam..."

Choice of resolution is one of the misunderstandings of the technique in general, as the same part can be scanned at either 30 or 100 µm, for example, but the detail seen at 30 vs 100 µm is not the same. Smaller pores are visible at higher resolution, which can make it seem like the part has more porosity, but this is not the case necessarily. For one-to-one comparisons, one must compare scans of similar parts at the same resolution, ideally with the same scanner settings and the same contrast, and obviously with the same image analysis method. This is exactly where standardised workflows, which have recently been introduced in our group at Stellenbosch University, can support the wider and improved adoption of the technique for Additive Manufacturing.

Besides resolution vs sample size, some material types are simply too radiodense to scan, and this 'impossibility' is again not a hard threshold, as the quality of the scan data degrades as the part becomes larger. In general, steel (which is strongly X-ray absorbing due to heavier atomic mass atoms) is challenging to scan, and therefore microCT using typical laboratory CT systems is better suited to lighter metals. When steel parts are small (solid parts up to 8 mm, or multiple wall thickness up to 8 mm total in line with the X-ray), the method works reasonably well using typical

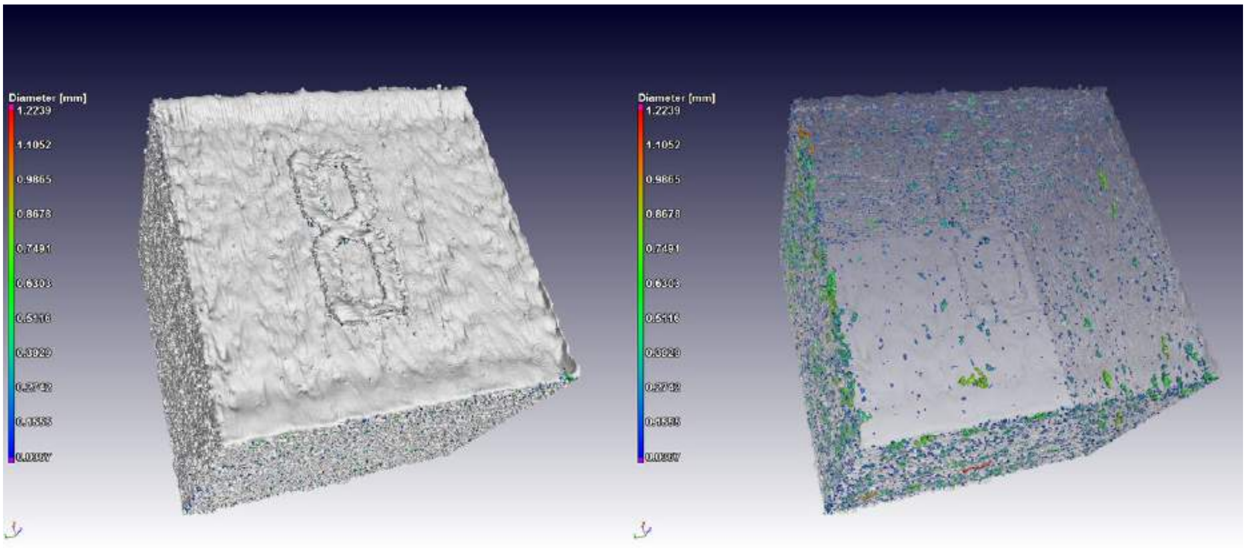

Fig. 3 Coupon cube sample showing porosity mainly around the edges, attributed to contour scanning error. Laser-Beam Powder Bed Fusion sample of Ti-6Al-4V, using standard method [20]. Pores are colour coded by diameter, the front facing surface with number 8 is the top surface of the cube – this shows the pores are mostly located around the vertical cube edges

microfocus sources up to 225 kV. For larger steel parts or heavier metals, higher voltage systems may be the only solution. Otherwise, low-quality images may be sufficient to get an idea of structural integrity, without detailed quantitative evaluation. On the other hand, Ti-6Al-4V parts up to 200 mm can be scanned on 225 kV systems with full quantitative evaluations, to give an idea of the sample sizes possible. All examples shown in this article are for Ti-6Al-4V.

As shown above, the scan quality is influenced by resolution, part size and material type, all affecting the presence of image artefacts and affecting the detectability of small flaws. Of course, many other factors also affect the quality of the obtained images – increasing image averaging reduces inherent noise, but makes scan times longer. Scanning multiple samples together is sometimes possible, but puts a limit on the best possible resolution that can be obtained. Using shorter image acquisitions and less averaging allows much faster throughput but increased noise in images. Despite all of these complex considerations, there are some general guidelines or best-practice methods that can be followed [9,18]. The acquisition of good images and subsequent analysis for a specific purpose might sometimes seem like an art more than a science, understood only by skilled experts. This brings us to an important point: if you scan the same part at different service facilities, do you get the same answer? Up to now, this was not the case. Luckily, standardisation has now arrived in this industry, despite the above challenges.

In addition to part complexity and size, which directly affect CT inspect-ability, other part characteristics may place added demands on the requisite precision and rigour of the CT

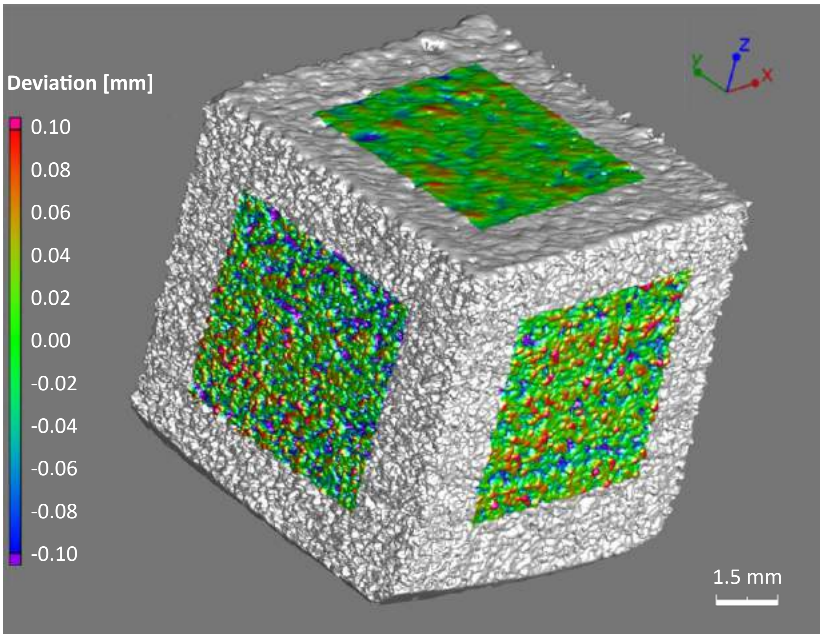

Fig. 4 Surface roughness using microCT, showing three surfaces with colour-maps indicating the top surface is much smoother

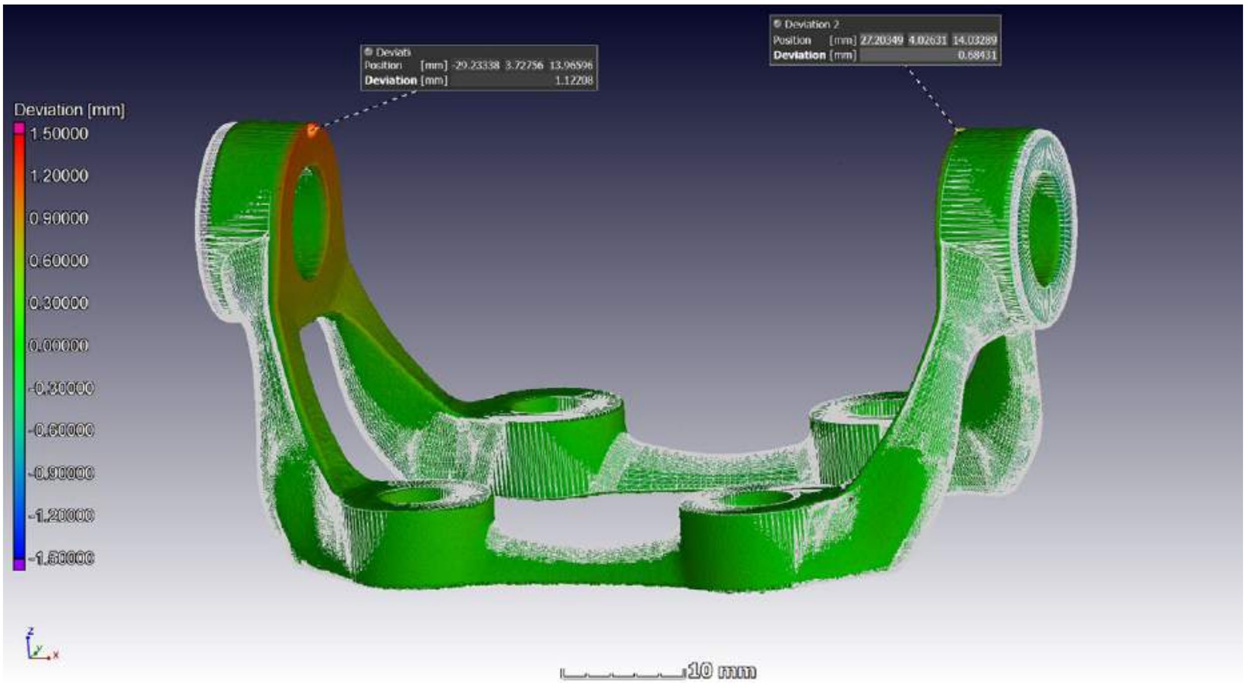

Fig. 5 Example of bracket warping – CAD variance more than 1 mm (CAD file shown in wireframe, actual part with colour coded variance)

technique used. The combined effect of these characteristics is denoted 'AM risk' [16]. Simply put, high AM risk parts require the use of highly reliable and precise CT techniques, possibly including other NDE methods to ensure complete coverage of all part surfaces and volumes. Part characteristics contributing to 'AM risk' ranked in order of importance are 1) the inability to perform adequate proof testing based on the anticipated design stress state, 2) the inability to remove the as build surface from all fatigue-critical surfaces, 3) the inability to access and improve surfaces interfacing any sacrificial supports, 4) the presence of thin (< 1 mm) walls and protrusions, and 5) the presence of critical regions requiring sacrificial supports. In such cases, the onus placed on CT can be extreme, and can result in situations where it is difficult, if not impossible to inspect a part by CT or other means.

Lastly, since location-dependent properties in as-built AM parts are affected by complex interactions between defect-dominated and microstructure-dominated failure mechanisms [19], the interaction between defects and microstructure needs to be better understood. Until this understanding matures, in addition to characterising the defect state as revealed by CT or other NDE, the need to characterise the microstructure as revealed by metallography, fractography, etc., is highlighted if AM parts with desired location-specific properties are to be produced.

Standardised CT test methods

Standardised test methods were proposed recently and implemented in a round robin test [20-26]. These methods simplify the workflow, with the ultimate aim of improving the quality of AM processes and parts. The first standard test method involves a simple 10 mm cube as the coupon sample. Such a small coupon sample is already used in many optimisation processes for AM and should therefore be simple to incorporate in existing optimisation workflows. The idea is that, for a given sample size (i.e., 10 mm), a fixed resolution can be used for the scan. Coupled with some general guidelines on scan parameters, a precise image analysis workflow can be generated where human input is minimal, resulting in a standard test method. For this 10 mm cube, a simplified workflow results in a detailed porosity analysis [26]. This result is not only a quantitative evaluation of the porosity, which can act as feedback for process optimisation, but also the 3D distribution, location and shape of pores can assist in understanding the root cause of problems in the manufacturing process and, therefore, allowing much faster correction of the real problem compared to past trial and error methods. In the example shown in Fig. 3 there is a contour scanning error, a reasonably well-known in-process laser or electron beam scanning error, which can be fixed by reducing the space between contouring and hatch scan lines. This type of information can therefore be used to optimise the process for each new type of powder or process, qualify a process for production, or check process parameters on a regular basis to ensure quality builds.

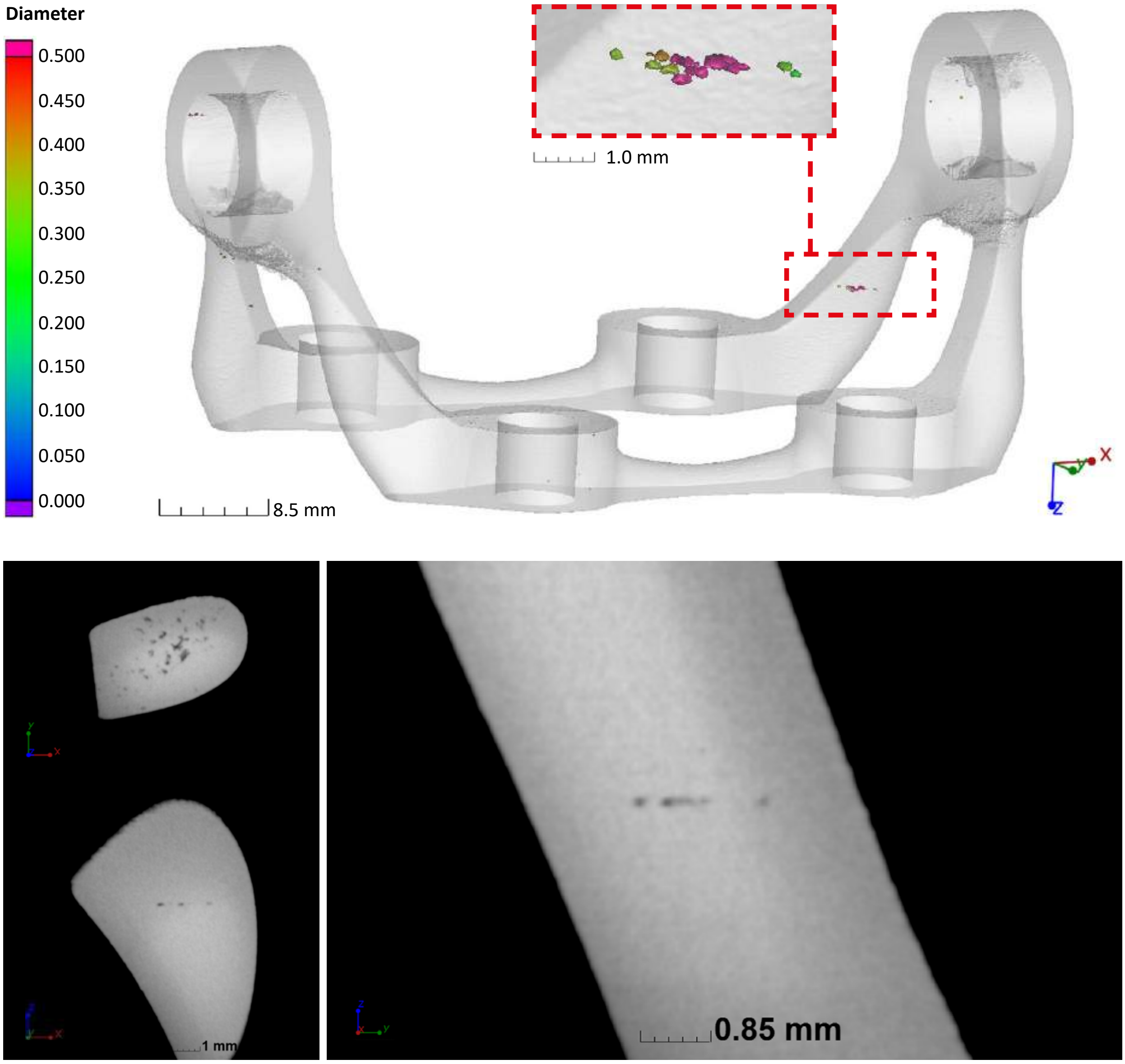

Fig. 6 Layered flaw found in complex part shown here in multiple microCT views

It is important to realise that the analysis workflow is simplified and semi-automatic, removing almost all possible human bias from the process.

The next standardised method involves using the same 10 mm cube (no additional scan is required) and measuring the total volume accurately using microCT data, then measuring the mass of the cube, thereby obtaining a mean CT-density value. While the Archimedes density measurement method is well known, this CT-density method holds some advantages, especially for typical as-built AM surfaces, which might trap air bubbles in a water-Archimedes test, or when open pores may result in water filling large internal cavities, resulting in improper Archimedes measurements. It is also very simple and not much effort when the CT data are already available. The added benefit is that, when an irregular density value is found, the images may help to understand why this is the case and therefore better understand the problem. This standardised image analysis workflow, which is described in detail in [21], is also entirely automated.

Evaluation of surface roughness is also possible using microCT data, using the same 10 mm cube. A standard workflow [22] was proposed for this purpose and an example is shown in Fig. 4, which shows the top surface is much smoother than the vertical surfaces, as expected for Laser-Beam Powder Bed Fusion parts. The colour-map shows deviation of the actual surface from the mean plane representing the surface. Output of the deviation values allows calculation of an Sa value, which expresses, as an absolute value, the difference in height of each point compared to the arithmetical mean height of a surface. The main benefit of this process is the simplicity and the possibility to assess build quality in multiple ways (porosity content, density, and roughness) using only one scan of a coupon sample. The use of a standard workflow also ensures high reproducibility.

Besides using small coupon samples for optimising and characterising the general build quality, quality inspection of real (typically complex-shaped) parts is equally important. Here we demonstrate a topology optimised bracket, which was used in a round robin production test, i.e., the same set of parts were produced in different LB-PBF systems and the resulting parts all analysed using the standardised microCT workflows [20,23]. The result shown in Fig. 5 is an example of one such bracket compared to its design; in this case, warping of the vertical sections inwards by more than 1 mm is seen on the left side.

Shown in Fig. 6 is an example of unexpected porosity found in a section of a sample as shown in various microCT views. Besides unexpected porosity, which can have several causes or manifestations (gas porosity, keyhole porosity, chained porosity, surface breaking porosity, skipped layers, etc.), microCT can help to identify other issues in AM parts as part of a quality inspection [1,7,8]:

- Lack of fusion (lack of penetration between a deposited layer and the previously deposited substrate)
- Inclusions (dense particles, e.g., from contamination of the powder or build chamber, or segregation of species upon cooling from the melt)
- Unconsolidated or trapped powder (unfused feedstock stuck inside lattice structures or internal cavities inside complex parts)
- Cracks (hot tear, cold cracking, delamination)
- Surface flaws (notches, stair stepping, spatter, sag, balling, worm track, contour separation)

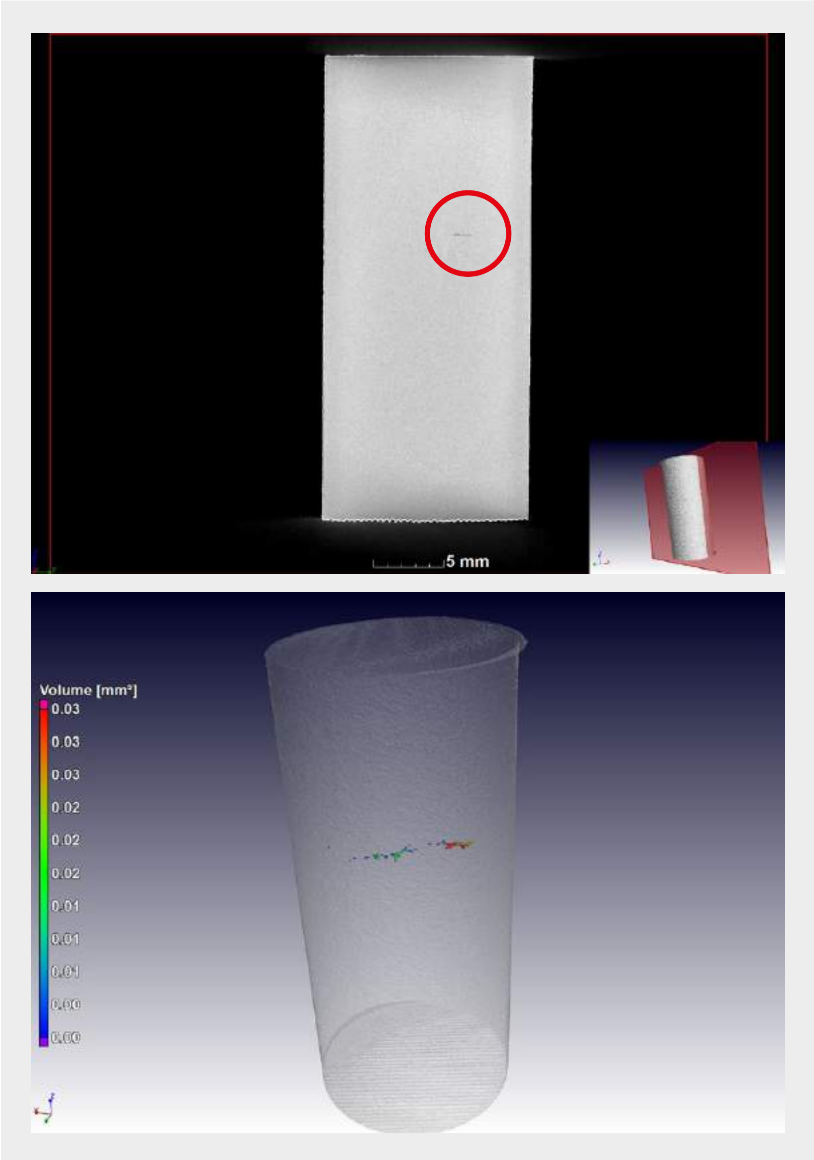

Fig. 7 Witness specimen analysis of quality of build, showing a layered stop-start flaw in this case

As mentioned in the previous section, resolution is limited by sample size. Therefore, a large part cannot be evaluated to the same detailed resolution as a smaller part. One way to help overcome this problem is to also scan a witness specimen, in this case a small vertically-built cylinder, built alongside the complex part. This allows high-resolution scanning of the witness specimen, and an assessment of the general quality of the build. In addition, since the witness specimen is a fixed dimension, CT scan parameters and the resulting workflow can be refined and standardised across different AM processing platforms, or for different pieces of equipment within a given AM processing platform.

The logic for the witness specimen is that many types of flaws may occur across the entire build – one such flaw is a stop-start flaw, which is a layered flaw induced when the system stops and is restarted. This was intentionally induced in the example shown in Fig. 7.

The above-mentioned standard workflows for porosity content, density, and roughness are supple-

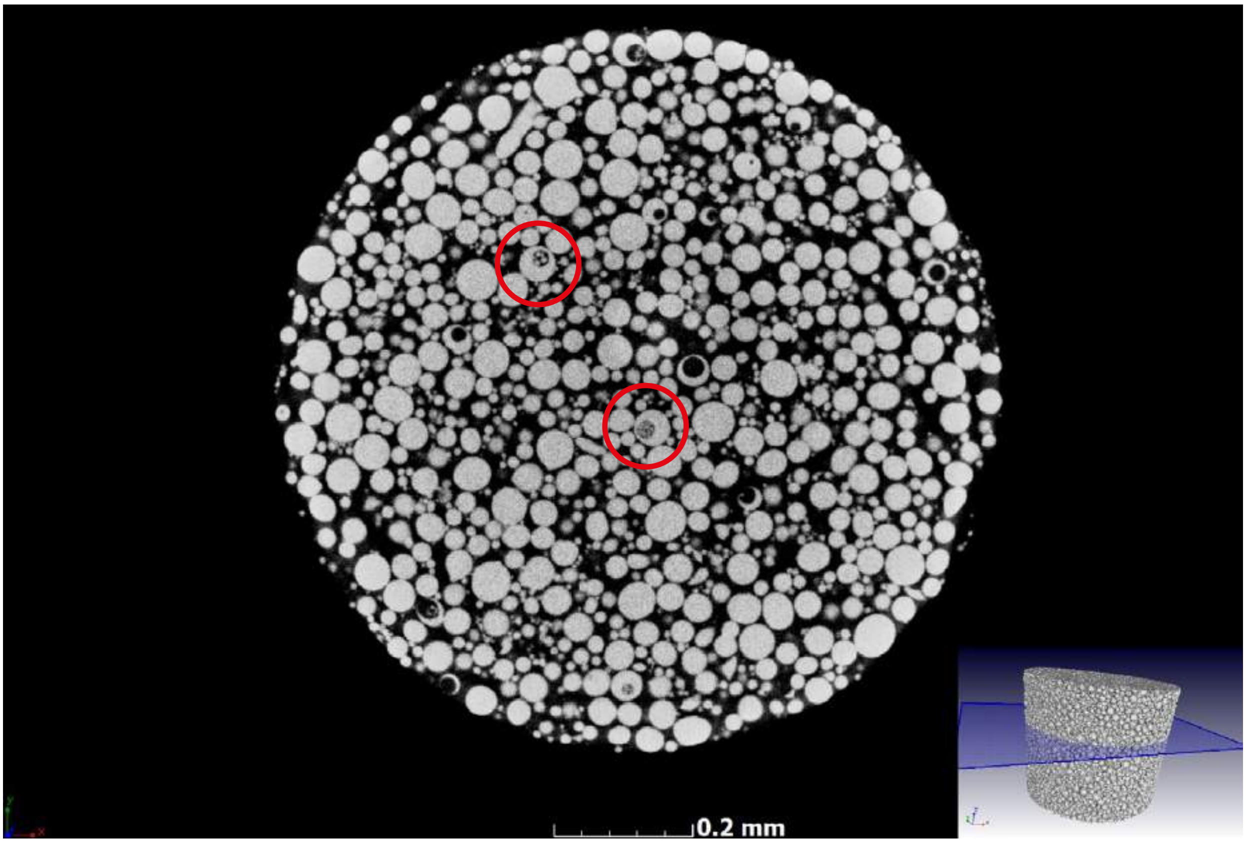

Fig. 8 Powder analysis showing a typical cross sectional view of gas atomised Ti-6Al-4V powder. The red circles show powder particles which contain pores filled with finer powder particles

mented by a standard workflow for analysing metal powder by high-resolution microCT (e.g., from different suppliers). The standard workflow is described in [24], with an interesting result from one specific Ti-6Al-4V powder batch shown in Fig. 8. In this case the gas atomised powder is mostly spherical (round in the slice image), with some gas porosity inside particles as shown by the round black areas. What is interesting here is the presence of fine powders trapped inside cavities inside particles, indicated in two cases by red circles. This indicates the presence of 'powder inside powder', i.e., fine powders trapped inside pores in larger powder particles! There is simply no other way to see this than by microCT.

The standardised methods discussed above are useful because the fixed sample sizes (a 10 mm cube, a vertically-built witness cylinder, or a fixed tube diameter of metal powder) allow a uniform CT scan resolution, which effectively allows simplified and exact scanning and image analysis steps to be followed. Additionally, the image analysis steps in the workflows are mostly automated, minimising the influence of human bias or image analysis errors in the process. The end result is a simpler and more easily reproducible method, even for less experienced analysts. When using a service provider for this analysis, the transparency in the workflow allows a simpler and lower price structure. This addresses the issue of 'CT takes too long' and 'CT costs too much', while also ensuring useful and reproducible results, not simply 'fancy' results.

The cube porosity analysis (scan plus analysis, entire job) takes a maximum of four hours, with typical service providers charging $150 per hour, to give an idea of an approximate cost.

Conclusion

It is clear that microCT is a powerful ally for Additive Manufacturing. By using the power of microCT, not only can quality inspections improve the success rate of critical parts, manufacturing processes can be improved and problems eliminated sooner in the fastest possible time, even during powder feedstock screening and acceptance.

While the detection of unwanted porosities or inconsistencies using microCT has been well known for some time, its wider use has been lagging in this industry due to costs and quality variances, which are not always transparent or easily understood. With the incorporation of standard methods and best-practice workflows, easier usage and improved interpretation of CT results is made possible.

Not mentioned in this article are the multitude of other applications and emerging methods of using microCT to the benefit of AM research and eventually industrial production: these are discussed in detail in a recent comprehensive review article [25]. The use of the standardised methods in the round robin production test is also reported in detail in [20]. Descriptions of the standardised methods and videos showing every step are available at www.protocols.io.

It is clear that metal Additive Manufacturing is an immensely promising field, and this will be amplified even more once microCT is adopted and widely used as the leading test method for quality inspection and process optimisation. There is a bright and exciting future for both these technologies.

Application of the described workflows will also help to surmount some of the more difficult technological hurdles that remain. Those hurdles relate to knowledge of the critical initial flaw size, detection of deeply embedded flaws, reliability of detection, effect-of-defect (including understanding effect of closed porosity after post-processing), and developing a clearer understanding of the role of defect-dominated versus microstructure-dominated failure mechanisms. However, to tackle these more entrenched issues, part variability due to differences in porosity, density, surface roughness, and feedstock must be controlled first. The workflows described herein are central to that task.

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Resources and references

Standardised method descriptions and workflow videos are available on protocols.io: www.protocols.io/researchers/anton-du-plessis/protocols. The review paper is open access and available here: www.liebertpub.com/doi/abs/10.1089/3dp.2018.0060

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Formnext 2018: The global AM industry addresses 'the bigger picture' for true industrialisation

From November 13-16, 2018, the Additive Manufacturing world congregated in Frankfurt, Germany, to attend the year's final and arguably most significant international exhibition on the technology. Occupying more than 37,000 m^2 of floor space, Formnext 2018 attracted nearly 27,000 visitors - an increase of more than 25% on the previous year - and over 600 global exhibitors. In this report, *Metal AM*'s Emily-Jo Hopson covers some of the news and developments out of Formnext, and looks at how they reflect an industry turning its focus toward productivity and efficiency for true industrialisation.

Since its launch in 2015, Formnext has seen significant year-on-year expansion and solidified its status as the leading international trade fair for Additive Manufacturing. Each year, the show attracts both engineers and management from a wide range of world-renowned companies including leading OEMs and suppliers in the aerospace, automotive, oil and gas, medical, dental, mechanical engineering and the construction and architectural industries. Whilst the industry's leading players dominated the event's two halls, Formnext's organisers once again provided an essential platform for start-ups and other lesser-known AM companies to gain significant exposure before a truly global audience.

As has now come to be expected, Formnext was host to a number of major industry announcements, business deals and machine sales which will set the course for the continued development of the AM industry over the coming twelve months. However, while former events have seen companies competing to announce 'the world's biggest machines' with 'the world's largest number of lasers,' the focus at Formnext 2018 was on how such a machine – however exciting the technology it offers – should fit into the overall workflow of a functioning production line, and how such production lines can find a place in the global industrial landscape. Throughout the event, companies sought to demonstrate how they were tackling this question through a combination of machine launches

Fig. 1 Formnext 2018 attracted nearly 27,000 visitors from around the world – an increase of more than 25% on the 2017 event (Courtesy Mesago / Klaus Mellenthin)

Fig. 2 ExOne's new X1 25PRO system, launched during Formnext, is designed to combine the capabilities of the Innovent+ system with series production performance

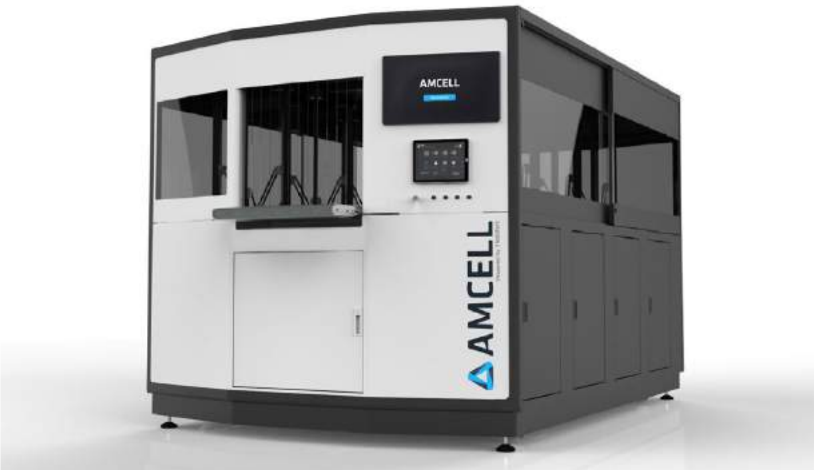

Fig. 3 The AMCell metal Additive Manufacturing system uses BASF's Ultrafuse 316LX filament

and updates, software integrations, development programmes centred on the 'factory of the future' and more.

In other words, Formnext 2018 was the exhibition for 'the bigger picture', at which the focus was widened from single machine to functioning production line. Exhibits, discussions and product launches leaned heavily toward increased productivity and efficiency (through faster production, decreased waste, integrated process steps, etc), cost-per-part affordability, factory integration, modularity and more. An increasing rate of adoption and collaboration throughout the industry could also be observed. As has been visible at most industry events throughout 2018, the concept of the 'digital factory' or 'smart factory' was highlighted by many companies as key to the success of AM as a mature production technology. Major players such as EOS, SLM Solutions, GE Additive and Trumpf, to name just a few, were keen to demonstrate their plan to implement a truly digital, automated workflow soon, with many having established pilot digitalised production lines since 2017.

It would be difficult to cover every announcement from the metal AM industry at Formnext in this report; the list is extensive, ranging from peripheral solutions to major product launches. Those announcements which are not included here can be found in this magazine's Industry News section. Here, we will focus on some of those developments which were the most highly reflective of the industry's maturation toward real-world productivity.

Machine makers target productivity at volume

ExOne's X1 25PRO™: MIM powder capability for volume production

During Formnext, The ExOne Company, North Huntingdon, Pennsylvania, USA, announced its newest system, the X1 25PRO (Fig. 2). Combining the capabilities of ExOne's small-scale Innovent+™ machine with series production capacity, the new X1 25PRO is said to be positioned to address the needs of Metal Injection Moulding, Powder Metallurgy and other manufacturing customers seeking a larger platform solution for the manufacture of parts in a production environment.

The new system offers the ability to produce high quality parts from a variety of materials including: 316L, 304L, and 17-4PH stainless steels; Inconel 718 and 625; M2 and H11 tool steels; cobalt chrome; copper; tungsten carbide cobalt and many other types of powder. Speaking on the system's launch during the exhibition, Rick Lucas, ExOne's Chief Technology Officer, stated, "We are pleased to bring the new X1 25PRO to market to satisfy the needs of the industry for high quality, functional, production-

Fig. 4 3D Systems announced the DMP Flex 350 and DMP Factory 350 at Formnext

volume parts. ExOne has a pioneering legacy of being on the cutting edge of introducing materials and processes using Binder Jetting."

"We currently have machines installed in customer facilities in more than twenty countries around the globe, and we are proud to bring innovations like the X1 25PRO to realisation," he continued, adding: "This is the first of two machines that we are introducing by the end of the first half of 2019, utilising our state-of-the-art, patent pending MIM powder processing machine technologies. We believe these new production machines will be the most flexible and highest performing Binder Jetting machines in the market."

Triditive: Hybrid and automated Additive Manufacturing with AMCell®

Triditive, an Additive Manufacturing machine maker based in Gijón, Spain, presented its AMCell, a hybrid and automated Additive Manufacturing machine said to be capable of producing up to 10,000 parts per month using BASF's Ultrafuse 316LX filament (Fig. 3). Enabled by its control software and remote monitoring, the integrated system is aiming to make Additive Manufacturing a viable solution for high-volume manufacturing, 24/7.

According to Mariel Diaz, Triditive CEO, "The green parts printed with AMCell using BASF's metal filament solution meet the geometric and surface quality requirements for mass manufacturing of final parts. The controlled build chamber environment in the AMCell and its optimised extrusion process achieve part porosities similar to those that are typically obtained from Metal Injection Moulding technology."

AMCell's automated manufacturing of large batches and use of Ultrafuse 316LX is said to greatly ease material handling processes by eliminating the potential hazards inherent to metal powder-based AM processes. The automatic load and consumption control of Ultrafuse 316LX filament spools allows the system to operate largely unsupervised throughout the production process, and reduces human labour and intervention to a minimum during production, though the green parts produced must undergo debinding and sintering in line with BASF's widely used Catamold MIM feedstock.

3D Systems: Latest additions to the DMP platform unveiled

3D Systems, South Carolina, USA, announced the latest additions to its DMP metal Additive Manufacturing platform - the DMP Flex 350 and DMP Factory 350 (Fig. 4). These systems are designed for the volume metal AM of critical components for industrial applications such as aerospace, healthcare, and transportation. In addition to these systems, the company introduced a new aluminium alloy material – LaserForm® AlSiMg0.6(A).

These latest launches follow relatively close on the heels of the announcements of the DMP Flex 100 in June 2018 and the DMP Factory 500, developed in partnership with GF Machining Solutions, in September 2018. The new DMP Factory 350 and DMP Flex 350 are said to provide a strategic migration path that enables customers to grow their business by transforming the way they design and manufacture parts. These are systems engineered for robust, repeatable 24/7 metal part production for R&D, application development and production, and the DMP platform's

Fig. 5 Desktop Metal has expanded the capabilities of its Production System. Shown in the upper image is the build unit, with the dedicated sintering furnace below

design enables customers to scale from the Flex 350 to the Factory 350 as their production needs evolve.

The DMP Flex 350 was described by 3D Systems during the show as the successor to its ProX DMP 320 machine, enabling more efficient production of very dense, pure metal parts and incorporating improved gas flow technology for more uniform part quality across the entire build area. Additionally, the new system offers an improved build productivity of 15% over the previous model, facilitating faster times to market at lower total operation costs. For enhanced ease-of-use for demanding production environments, the DMP Flex 350 can be field upgraded to the DMP Factory 350. The DMP Factory 350 combines the same features and advantages of the DMP Flex 350 with integrated powder management. The DMP Factory 350 also includes real-time process monitoring via 3D Systems' DMP Monitoring and allows customers to analyse and optimise parameters for higher quality final parts.

Desktop Metal: An enhanced Production System for high-volume AM

Desktop Metal, Massachusetts, USA, announced several major advancements and expanded capabilities to its Production System, the company's metal Additive Manufacturing machine developed for the mass production of complex metal parts (Fig. 5). The company also displayed a range of metal AM parts produced on the new system. The installation of the first Production System is scheduled for the first quarter 2019 at a Fortune 500 company which was among Desktop Metal's early 'Pioneer customers', the first wave of companies to place orders for its systems, with additional installations set to follow at major automotive and metal parts manufacturers throughout 2019 and broad customer availability expected in 2020.

Ric Fulop, CEO and co-founder of Desktop Metal, commented during Formnext, "As we continue to expand our list of global customers and partners, with companies turning to the game-changing technology available with the Production System and installations set to begin rolling out in the coming months, Desktop Metal is looking to further shift the industry beyond prototyping to now include full-scale metal manufacturing."

Powered by what Desktop Metal calls its Single Pass Jetting technology, the Production System is said to offer a 'one hundred times speed improvement over any laser-based system.' Since it was first introduced, the technology and capacity of the Production System have expanded to include accelerated build speeds of up to 12,000 cm^3 per hour; a 225% larger build volume of 750 x 330 x 250 mm; two full-width print bars, advanced powder spreaders and an anti-ballistic system that work to spread powder and print in a single quick pass across the build area; and the use of 32,768 piezo inkjet nozzles that enable binder chemistries to build parts from a wide range of metals - including tool steels, low-alloy steels, titanium and aluminium - at a rate of three billion drops per second.

Fig. 6 The first Concept Laser M Line Factory systems will be delivered to customers in Q2 2019

The Production System also offers an industrial inert environment, including gas recycling and solvent recovery, to safely additively manufacture reactive metals in mass production, and the capability to build more than 60 kg of metal parts per hour.

The parts exhibited by Desktop Metal at its stand included a mass-produced batch of Milwaukee Tool spauger bits, which feature a complex geometry traditionally requiring multiple manufacturing steps to produce. Producing each individual bit conventionally involves twenty time-consuming process stages, including milling, turning and grinding. Using the Production System, Desktop Metal has been able to reduce the number of steps to four, and can produce as many as 1,400 spauger bits for every four-hour build.

GE Additive: Concept Laser M Line Factory systems to ship Q2 2019

While GE Additive did not bring a major machine launch to Formnext, the company announced during the show that the first Concept Laser M Line Factory systems will be delivered to customers in the second quarter of 2019 (Fig. 6). Since GE Additive's acquisition of Concept Laser in December 2016, the M Line Factory's design architecture, system and software have undergone extensive review and redesign in line with established GE processes and beta testing with selected customers. Jason Oliver, President & CEO of GE Additive, stated, "The positive impact the M Line Factory can have on our customers' operations and their bottom line is huge. It's important we provide technologically advanced systems that are reliable and add value to our customers. M Line Factory delivers on those commitments."

The M Line Factory automates both upstream and downstream stages of the production process and provides interfaces to conventional manufacturing methods in the form of automation, interlinking and digitalisation. As Additive Manufacturing transitions from a prototyping to a production technology, the demand for machines increases, as does the demand on production floor space and the number of operators required to run production lines. Existing standalone machine solutions can limit economical series production, but GE is confident that the M Line Factory's modular machine architecture can offer outstanding automation and reliability, driving economical and scalable series production on an industrial scale.

GE added that during detailed rig testing and lifetime testing, a number of areas were identified for improvement and have since been incorporated into the system, including improved in-machine architecture and automation; a scalable modular system design; an increased build volume of 500 x 500 x up to 400 mm^3 (x,y,z); and a modularised onboard software architecture offering superior exposure strategies and real-time, in-situ process monitoring; and enhanced process control &

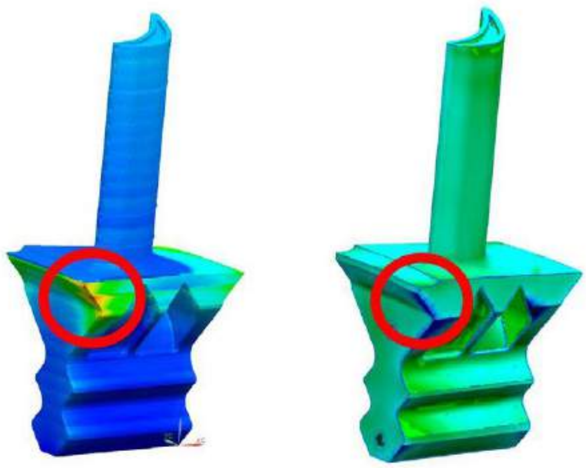

Fig. 7 Siemens' Simcenter 3D AM Process Simulation tool shows how the predicted distortion (on the left) is confirmed by the comparison of the real-world part to the original CAD data on the right

thermal stability to enable the control of key process variables that can dictate part quality.

Part production, as well as the set-up and dismantling process, takes place in two independent machine units which can be operated separately from one another or combined depending on each customer's preference. This enables production processes to run in parallel rather than sequentially, thereby reducing downtime considerably and increasing the availability and output quantity of the process chain.

New software releases aim to speed design and enhance production management

Siemens: Additive Manufacturing process simulation for improved accuracy

Throughout 2018, Siemens has made a number of significant announcements regarding its activities in AM, from the news that its metal AM gas turbine burner has completed its first year of operation, to the successful testing of new applications such as a metal AM gas turbine pre-mixer, to its £27 million investment in a new Materials Solutions facility for AM in Worcester, UK (see page 7), to the development of a new advanced depowdering system, the SFM-AT800S, in partnership with Solukon Maschinenbau GmbH. During Formnext, the company showcased the integrated AM solutions it offers under the tagline 'Industrialize Additive Manufacturing'. Siemens sought to highlight its ability to tailor its solutions portfolio to its customers' respective industries, from automotive to mechanical engineering, using an apparently seamless development process chain suitable for use with all common AM processes and systems, which covers steps from part design to the creation of build exposure paths on an associative database.

The main announcement from Siemens was the addition of a new, integrated process simulation tool designed specifically for Laser Beam Powder Bed Fusion (LB-PBF) AM. The Simcenter™ 3D AM Process Simulation tool uses a digital twin to simulate the build process prior to building a part, anticipating distortion within the process and automatically generating the correct geometry to compensate for those distortions (Fig. 7).

The ability to simulate part distortion during LB-PBF is key to the fabrication of 'first time right' components, and a necessary step if manufacturers are to achieve the efficiencies required to fully industrialise metal Additive Manufacturing. The new tool is integrated into the Powder Bed Fusion Process Chain in the Siemens PLM Software Additive Manufacturing portfolio, providing a guided workflow to the user that allows for the assessment of distortions, the prediction of recoater collisions, prediction of areas of overheating, and other important feedback about the build process. It offers the ability to iterate on a solution between the design and build tray set-up steps of the workflow, and the simulation step. The simulation data created then feeds into the digital thread of information gathered by the system, which informs each step of the build process. This enables the system to develop pre-compensated models and to feed those seamlessly back into the model design and manufacturing processes without additional data translation.

3YOURMIND: Product scheduling software for fully-integrated and automated AM

3YOURMIND GmbH, Berlin, Germany, announced the launch of its latest product, titled the Agile Manufacturing Execution System (Agile MES), a production scheduling platform developed to manage the scheduling and prioritisation of additively manufactured parts. The initial features showcased during Formnext were what the company refers to as Smart Part Prioritisation and Agile Production Scheduling. According to the company, the most significant improvement for AM service managers on the production floor is provided by a data based recommendation engine; when AM jobs are created, the system automatically suggests which parts to assign and when to assign them.

The company stated that it has "an aggressive road-map" in place to develop the Agile MES further based on the requirements of its customers. Stephan Kühr, Co-founder of 3YOURMIND, explained, "Our next priority is to create a strong direct connection from the Agile MES to individual machines. The collection of the real-time production data will further enable accurate production tracking and quality assurance. We are determined to generate a fully integrated and automated platform that can serve as the data infrastructure for the factory of the future."

AddUp and ESI Group: Distortion Simulation AddOn for metal AM

Fives and Michelin joint venture AddUp, Clermont-Ferrand, France, announced during Formnext the forthcoming availability of a Distortion Simulation AddOn, developed jointly with ESI Group, Paris, France. This module, specifically designed for metal Additive Manufacturing, is designed to enhance the functionalities of the AddUp Manager software for the definition and production tracking of parts. The Distortion Simulation AddOn is set for commercial launch in Spring 2019.

As founding members of France's SOFIA project (Solution pour la Fabrication Industrielle Additive métallique – Industrial Metal Additive Manufacturing Solution), initiated in 2016 and sponsored by Bpifrance, AddUp and ESI Group stated that they have shared a "common vision of metal Additive Manufacturing" since their first meeting. At a time when the industrialisation of AM is drawing closer to reality, both companies noted that simulation based on material physics, which ensures an in-depth understanding of material processes and behaviour, is one of the key components to improving the competitiveness of the AM process.

The optimisation of process parameters is a crucial stage in the AM process; manufacturers, according to their specific applications, must be able to focus available machine times either on production or on process

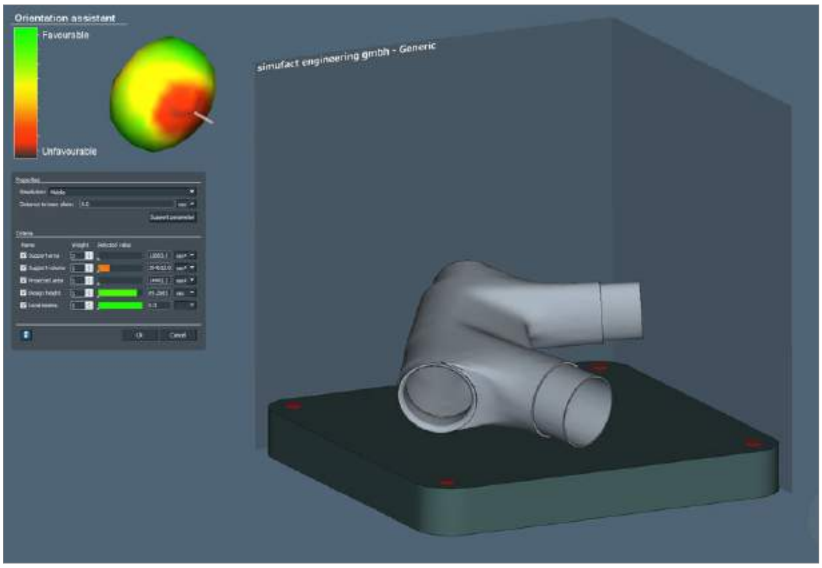

Fig. 8 Simufact Additive 4's orientation assistant helps to determine the best build orientation

optimisation. Traditionally, production validation has primarily meant producing parts, then assessing their conformity. Introducing a simulation tool all too often limited expert users and required multiple feedback loops between different functions, creating discontinuity over the digital chain. By integrating simulation directly in the preparatory stages of the AM process, the new Distortion Simulation AddOn is said to bring continuity to the technology, while the AddUp Manager's user interface is designed to be both intuitive and stable, offering a good working environment in which to define simulation parameters, particularly for staff who are not experts in this field.

Simufact Additive 4: Simulation for the entire AM process chain

Simufact, an MSC Software Company headquartered in Hamburg, Germany, released Simufact Additive 4 - the newest generation of its solution for the simulation of metal Additive Manufacturing processes - during Formnext (Fig. 8). This scalable, practitioner-oriented simulation solution is designed to predict distortion, stress and temperature effects, and help to optimise build preparation, build simulation and subsequent steps in the AM process chain, including steps such as heat treatment, build plate removal, support removal and Hot Isostatic Pressing.

The software helps to identify the best build orientation, predict and completely compensate final part distortion automatically below a given threshold, optimise support structures automatically, identify overheated or not sufficiently heated zones and predict manufacturing issues such as cracks, shrinklines, and recoater contact before they occur. Users can also view the effects of preheated base plates or build spaces, and achieve more accurate simulation results for fully-nested base plates and build spaces.

Dr Gabriel McBain, Simufact's Senior Director Product Management, stated, "Our new version 4 underlines our ambitions to provide the best overall process simulation package – concerning speed, accuracy, functionality, and usability." Another focus point for the new release is to strengthen process chain capabilities, he added; "Our open software concept allows interfacing with third party solutions in the AM process chain, such as OEM build preparation software – Renishaw's QuantAM is an example – and Materialise Magics."

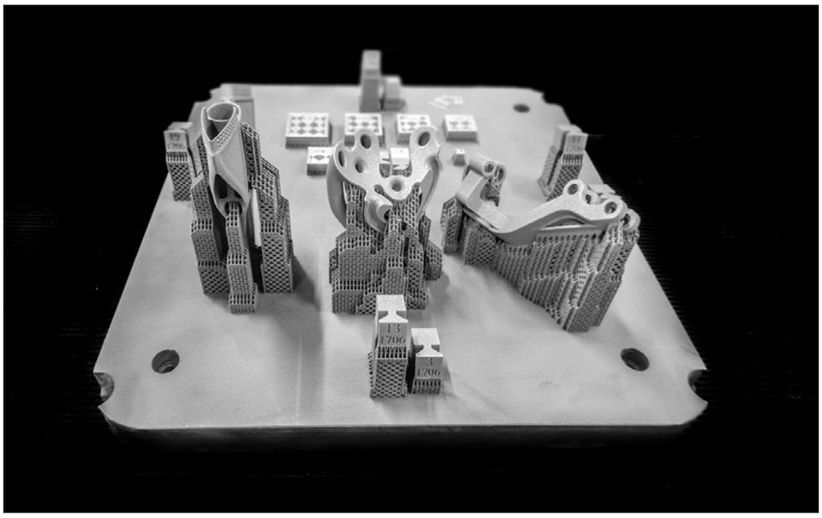

Fig. 9 Metal additively manufactured parts with support structures generated in Materialise Magics

Fig. 10 This mesostructural femur bone implant was designed in ParaMatters and shows the potential of biomimicry

Materialise Magics 23: Enhanced metal AM functionality

Materialise NV, Leuven, Belgium, introduced the latest edition of its Magics software for AM: Magics 23 (Fig. 9). The updated software offers integrated simulation capabilities and automated support generation for metal Additive Manufacturing, and is said to offer improved ease-of-use while giving users more control. By offering more control and better integrated features, the company stated that its updated software allows users to process large data sets faster, spend less time on data preparation, and benefit from reduced powder consumption. Part quality has also been improved using fillets, which can be generated on a single edge.

Materialise Magics 23 also introduces Data Matrix Label, a labelling feature that converts alphanumeric data from standard additively manufactured labels into a data matrix code that can be applied to individual parts. These smart tags are smaller and can be read by conventional data matrix scanners. Machine-readable tags are said to reduce human error and further automate the post-production process, supporting mass customisation.

Stefaan Motte, Vice President and General Manager of Materialise's Software Division, stated, "With the introduction of Magics 23, we offer integrated automation features for metal 3D printing, including simulation and automatic support generation. This allows users to drive down cost by optimising their machine operations and reducing the number of build fails, all within their trusted Magics environment."

ParaMatters: CogniCAD 2.0 topology optimiser for lightweighting

ParaMatters Inc., Ventura, California, USA, a provider of software for generative design, autonomous topology optimisation, parts consolidation and lightweighting, made available its second generation CogniCAD 2.0 platform during Formnext. Usable as both a cloud-based service and enterprise solution, CogniCAD 2.0 is the company's second generation holistic, agnostic generative design solution. The tool works by first importing CAD files into the platform, and then defining loading and design criteria. Users can 'within minutes' obtain generative designs verified by built-in Finite-Element Analysis (FEA), ready for Additive Manufacturing in both STL and STEP formats. The platform is said to be capable of automatically generating ready-to-build, high-performance, lightweighted AM structures for aerospace, automotive and other mission-critical applications.

"We are taking full advantage of the convergence of advanced topology optimisation techniques, computational geometry, infinite computing power in the cloud and artificial intelligence to deliver the most powerful, affordable and impactful tool that unleashes the full potential of design for Additive Manufacturing," commented Avi Reichental, ParaMatters Co-founder and board member. CogniCAD 2.0 also offers unique mesostructural design capabilities, which are available as a design service and can be used to create biomimicry or 'nature inspired' design for optimal structural infills, which can be mission-critical for certain

Fig. 11 A conventional Mini Cooper suspension trailing arm (left) and optimised one weighing 48% less, designed in ParaMatters (Courtesy ParaMatters, Techniplas and XponentialWorks)

AM processes (Fig. 10). "We are transforming the entire design-to-manufacturing process by making it possible for our cloud service to autonomously generate high-quality, CAD-agnostic and ready-to-manufacture, optimised lightweighted designs in minutes to a few hours," explained Dr Michael Bogomolny, the company's Chief Technology Officer and Co-founder.

The company is engaged in several complementary strategic partnerships. Among those customers and partners ParaMatters has made public are Ford, Volkswagen, GE, Renishaw, Techniplas, Stanley Black & Decker and AlphaStar. It also stated that it is developing advanced algorithms designed to enhance the overall digital thread and Additive Manufacturing capabilities. This includes a new cloud-based, generative design platform that automatically compiles lightweight and metamaterial lattice structures on-demand, based on size, weight, strength, style, materials and cost as specified by designers or engineers. "Our proprietary generative engine automatically delivers high performance and quality designs with minimal user input," added Dr Bogomolny. "As a result, the entire design cycle is compressed from days to hours, and the quality of generative designs raised compared to what can be achieved manually" (Fig. 11).

Strategy, adoption and collaboration on the journey toward industrialisation

GE Additive: Software strategy aims to simplify AM process

The Additive Manufacturing industry employs what seems like a vast array of build preparation tools, technologies, interfaces and licenses, which can create an additional layer of complexity for design engineers to manage and navigate when taking a part from CAD design to build job. A lack of interoperability due to conflicting interfaces, file types and user experiences can result in costly mistakes and delays for both the design engineering community and machine operators. During Formnext 2018, GE Additive outlined its software strategy, which centres on simplifying the AM process and enabling an interoperable workflow. The vision, according to the company, is to create a common experience through a secure, intuitive tool that reduces design iterations and speeds up the time taken to build a good additively manufactured part, according to the designer's original intent.

The company stated that improving the build preparation workflow for AM, and lowering barriers to the technology's adoption, will require: a simplified and secure build preparation workflow spanning the entire design-to-build process; the provision of interoperable build preparation services to CAD providers; high

Fig. 12 Trumpf is integrating its digitalisation and other industry 4.0 solutions in its TruPrint series of AM machines

speed and accuracy, coupled with iterative thermal compensation; improved slicing performance; and the availability of an off-machine build processor.

As part of its wider software strategy, GE Additive announced at Formnext several partnership agreements with leading AM software vendors Autodesk, PTC, Siemens PLM Software and Vera Security, through which it hopes to accelerate its development of interoperable, secure workflow solutions. The company also initiated a collaboration agreement with Dassault Systèmes. "We acknowledge that the industry needs to improve overall interoperability for design engineers," stated Lars Bruns, Software Leader, GE Additive. Working with partners will enable GE to integrate build preparation services directly into the tools of design engineers, thereby saving time, reducing errors and enabling more accurate builds, while accelerating the adoption of AM through secure access to GE Additive machines.

Through its Formnext exhibit, the company actively sought feedback from its customers and end-users through interactive demos, and announced that it is recruiting interested parties to participate in beta testing through its Software Advisory and Technical Preview programme. "Feedback is a critical activity in the development of any software system, which is why we are demonstrating our current capabilities in Frankfurt," stated Bruns during the show. "Over the next eight months, we're seeking customer input from our users to help us inspect, adapt and iterate ahead of our commercial launch." This end-user and customer feedback will expand upon extensive ongoing internal GE user research, combined with advanced technical modelling capabilities developed by both GE Additive's GeonX team for simulation (following the company's acquisition of GeonX in November 2017), and by GE Global Research teams for distortion compensation.

Volkswagen adopts metal AM technology from Additive Industries

It was announced during Formnext that Germany's Volkswagen Group, one of the world's largest automotive producers, has signed a long-term partnership with Additive Industries to additively manufacture advanced tooling and spare parts using the company's metal Additive Manufacturing technology. It was reported that in September 2018, Additive Industries, Eindhoven, the Netherlands, had installed its latest fully-automated and integrated MetalFAB1 system at Volkswagen's facility in the group's hometown of Wolfsburg, Germany, with the first products now having been successfully produced after intensive training of the Volkswagen team.

"We see great potential for 3D metal printing of a broad range of car parts and tooling and have joined forces in Volkswagen internally to increase our facility seven fold to be prepared for the digital future," stated VW's Klaus-Jürgen Herzberg. Oliver Pohl, VW Department Manager, added, "The investment in the most modern 3D printing equipment allows us to continue to be front-runners in toolmaking and give our craftsmen access to the latest technology."

"For Additive Industries, the partnership with Volkswagen, the world's largest car maker, is a confirmation of our strategy to accelerate industrial Additive Manufacturing and focus on innovators in their markets," commented Daan Kersten, CEO, Additive Industries. Jan-Cees Santema, Sales Director Europe for Additive Industries, continued, "We are proud to work closely with the Volkswagen team in Wolfsburg to execute on our roadmap for manufacturing excellence and expansion of the metal Additive Manufacturing footprint."

Trumpf reveals its approach to industry 4.0 and metal Additive Manufacturing

Trumpf, Ditzingen, Germany, demonstrated how the use of connected metal Additive Manufacturing machines can boost transparency in digitalised factories. Trumpf has already employed digitalisation and other industry 4.0 solutions in its workflows for other manufacturing technologies, and stated that it is now transferring these solutions to its TruPrint series of AM machines for workflow optimisation.

In November, to enable Formnext attendees to experience the advantages of connected manufacturing first hand at its booth, Trumpf displayed its TruPrint machines connected to a Manufacturing Execution System (MES) and a

Fig. 13 The EOS stand at Formnext 2018: GKN Powder Metallurgy announced a strategic partnership with EOS at the event (Courtesy Mesago / Thomas Masuch)

smart ordering platform. These two solutions offer employees mobile, real-time access to the machines' process data and pending orders, and facilitates planning and paperless management of production, which boosts transparency, flexibility and ultimately manufacturing productivity.

"Trumpf is a leader in Industry 4.0," stated Tobias Baur, Trumpf General Manager Additive Manufacturing with responsibility for technology. "We also show how the 3D printing process chain can be completely digitalised - from tender preparation to printed component."

To establish additive technologies in industrial manufacturing, Trumpf is continuing to focus on ensuring that its systems are highly reliable and efficient. "Otherwise, 3D printing methods can't compete with conventional technologies such as milling and casting," stated Thomas Fehn, Trumpf General Manager Additive Manufacturing with responsibility for sales.

Trumpf brings more than fifty years of experience in machine tools to the table, and is somewhat unique as an Additive Manufacturing machine maker in that it offers all components of the technology under one roof: laser beam sources, optics, machines and post-processing technologies such as milling. "We have everything you need for 3D printing," added Fehn. "This is highly advantageous when industrialising these processes because we have access to the technologies that best fit our customers' needs."

In order to fully utilise Additive Manufacturing as a mass-production technology, Trumpf stated, AM systems must be automated. It is for this reason that the new TruPrint 5000 incorporates an automated process start, reducing manual system preparation activities, as well as saving time and improving both quality and productivity.

GKN Powder Metallurgy and EOS form technology partnership to industrialise metal Additive Manufacturing

GKN Powder Metallurgy, the world's largest producer of sintered metal parts, announced a strategic partnership with EOS, long recognised as a global technology leader at the forefront of the industrial Additive Manufacturing of both metals and polymers. In a panel discussion at Formnext, the two companies revealed that together they have designed a new, high-productivity process for laser-based metal Additive Manufacturing that they believe will reduce production time by 70% and overall cost by up to 50%.

"We're thinking differently about what's possible in manufacturing; metal 3D printing and rapid prototyping have become a formidable part of our business," stated Peter Oberparleiter, CEO of GKN Powder Metallurgy. "This collaboration makes laser metal 3D printing a viable

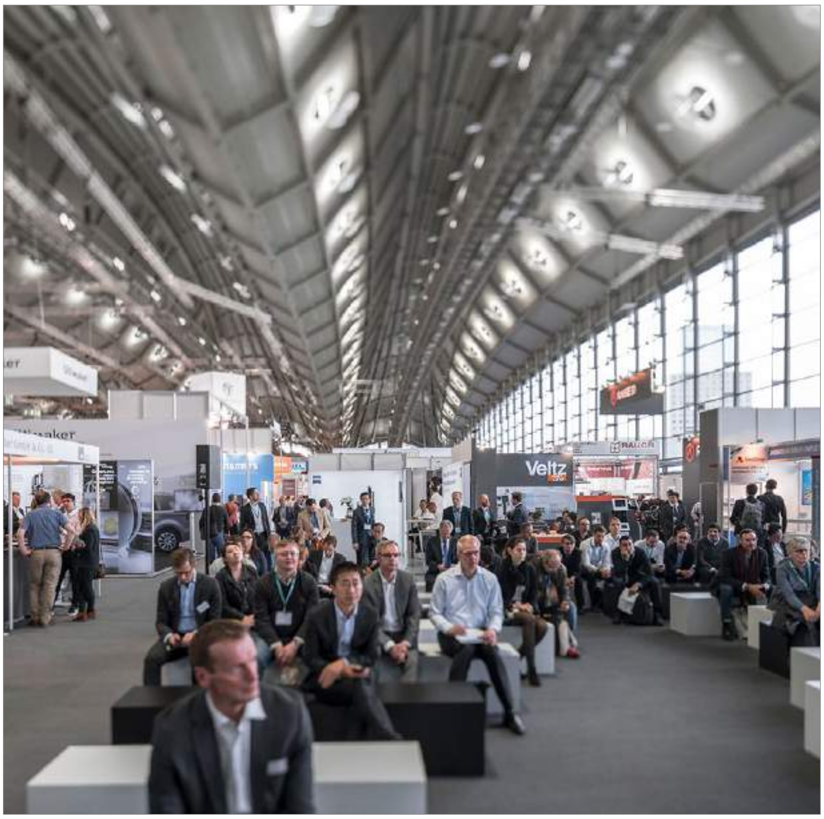

Fig. 13 With its rapid expansion, the Formnext exhibition will for 2019 move from Hall 3 at Messe Frankfurt to the larger halls 11 and 12 (Courtesy Mesago / Klaus Mellenthin)

long-term solution for manufacturers across the board that require fast delivery turnaround and could benefit from the high degree of design freedom that comes with laser 3D printing. Our customers will be able to produce higher quality parts faster than ever before, with absolutely no tooling."

It was stated that the combination of an innovative metal powder from GKN, EOS StainlessSteel 316L VPro, and EOS's unique process and Additive Manufacturing expertise, make it possible to create high-performance parts designed for end-use at scale.

"In order to expand our footprint in the automotive industry, we were looking for a strong partner with a high level of expertise in the field of steels and typical industry grade materials, combined with a proven track record of further industrialising technologies together with customer applications," stated Dr Adrian Keppler, EOS CEO. "We found a perfect partner in GKN Powder Metallurgy. Based on this partnership, our customers will benefit from higher build speeds and lower material costs resulting in significantly optimised cost -per-part. This is going to lower the entry barrier and will enable completely new application fields."

Conclusion

Whilst this report does not hope to cover all of the innovations in productivity and efficiency presented during Formnext – including new peripheral technologies for post-processing and more – it is clear from this sampling that the industry recognises the need to enhance the productivity and efficiency of metal AM technology if it is to compete as a production technology at volume. It is no longer enough to produce the most enticing or the most exciting new Additive Manufacturing technology; those companies with an eye on industrialisation must now be ready to prove their machine's capabilities in a factory setting. Likewise, software companies must increasingly gear their solutions toward interoperability and time saving for the production workflow.

If at Formnext 2017 metal AM began the shift from hype to reality, then it was at Formnext 2018 that the industry set about addressing that reality. It has become increasingly clear over the course of the year that large segments of the wider industrial community are ready to embrace metal Additive Manufacturing as a production technology, but that significant challenges remain for its use in serial parts manufacturing. In addition to promoting its adoption, the AM industry must now be ready to facilitate that adoption by making available factory-ready technologies across the entire process chain, from design to finishing. Recent decisions to adopt metal AM technology by major companies such as Volkswagen indicate that efforts in this area offer significant rewards for the industry.

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Formnext 2018: International forum reviews standards for Additive Manufacturing

Organised by the U.S. Commercial Service in Dusseldorf, Germany, the Additive Manufacturing/3D Printing Standards Forum took place on November 14, 2018, in Frankfurt, Germany, at the Formnext trade fair. As Dr Georg Schlieper reports, the event brought together leading experts from industry, research institutions, standards developing organisations, professional societies and government to address key themes focused on standards development in AM technologies. This included progress on international standards development for AM and how the use of these standards can help the industry achieve its potential.

The importance of industrial standards for an emerging industry such as Additive Manufacturing is widely recognised. Standards are needed for a variety of purposes. Among other things, they facilitate and harmonise communication between suppliers and customers, determine and document the requirements for materials and products, define test methods and resulting protocols, and ensure safe procedures that are consistent with ethical principles, gentle on the environment and as safe as possible for the health of the workforce and end users. Besides industry and trade, standards are also referenced by government regulatory agencies and certifying bodies in their regulations and procedures. In a globalised industry, all standards should be harmonised at an international level.

In order to bring the AM industry closer to this goal, a standards workshop was held on November 14, 2018, during Formnext in Frankfurt, Germany, attended by high-level experts from Standards Developing Organisations (SDO), government and industry. The Additive Manufacturing Standards Forum was chaired by Terry Wohlers, President of Wohlers Associates, who opened the half day event by welcoming the audience and introducing the topic. Opening statements were then made by John McCaslin, Minister Counselor for Commercial Affairs and Regional Senior Commercial Officer, US Commercial Service at the US Embassy in Berlin, and Dr Thomas Zielke, Head of Division Technology Transfer at the German Federal Ministry for Economic Affairs and Energy.

Fig. 1 Participants at the AM standards workshop, held during the Formnext exhibition in Frankfurt, Germany (Courtesy Sascha Wenzler)

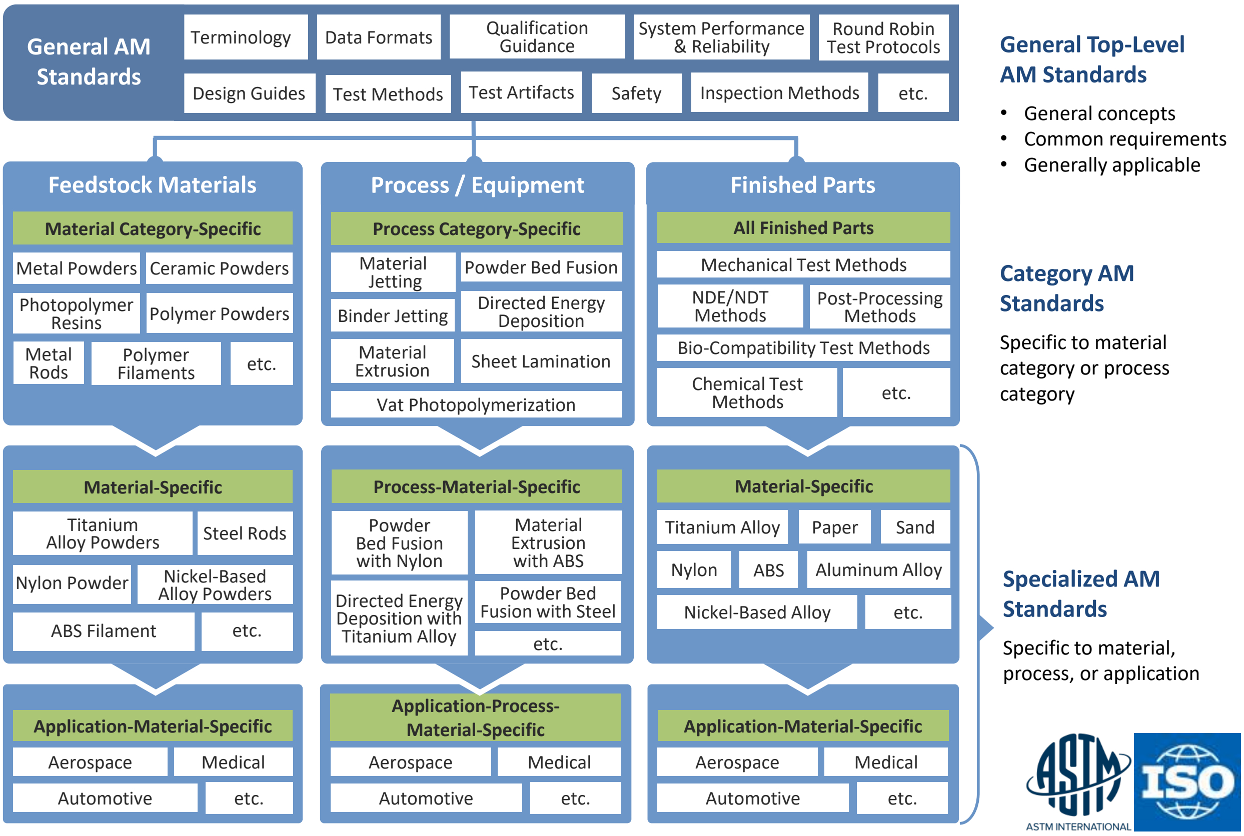

Fig 2 Structure of AM standards (Courtesy NIST)

NIST describes the importance of AM standards

Kevin Jurrens, Deputy Chief of the Intelligent Systems Division of the U.S. National Institute of Standards and Technology (NIST), gave a U.S. federal government agency perspective on Additive Manufacturing standards as well as a broader summary of AM standards development activities across the multiple SDOs. NIST supports innovation in the American industry by developing test methods, measurement tools, performance measures and scientific data. The role of NIST is to identify consensus needs and priorities for standards through workshops, industry meetings, outreach events, etc. The institute carries out scientific research to develop the technical basis for standards and disseminates research in collaboration with the private sector and academic organisations. NIST is active in standards committees, often in a leadership role, initiating the development of technical standards, preparing strategic plans and supporting coordination, facilitation and communication among standards groups.

Examples of measurement science for Additive Manufacturing, one of the major competencies of NIST, are the development of methods to characterise the powder bed density and recyclability of metal powders, methods to characterise built materials and the generation of sound databases in round robin studies and variability analyses. NIST operates an Additive Manufacturing Metrology Testbed (AMMT) that allows it to monitor and control the powder bed-based AM process in-situ in order to robustly predict part quality. These investigations are used to generate reference data and find correlations between process parameters, process signatures and part quality to enable the intelligent design of control devices.

Reference data are used for computer modelling to improve model inputs and validate model outputs in terms of temperature, microstructure, residual stresses, etc. X-ray Computer Tomography (CT) is used to assess the part quality and to characterise the machine performance. NIST has also developed the architecture of an AM Information System including metrics, information models and validation models. A public AM Material Database (AMMD) has been launched, populated with round robin data. Further activities of NIST are focused on product definition and tolerance representation for AM and fundamental principles of AM design rules.

Standards bodies relevant to AM

ASTM International and ISO

A number of standards bodies are involved in or have work that is relevant to Additive Manufacturing. Two leading SDOs on an international level, ASTM International and the International Organization for Standardization (ISO), have agreed on a formal collaboration between their Technical Committees ASTM F42 and ISO TC 261 focusing on AM Standards. The various sectors of AM Standards such as terminology, test methods, materials and processes, quality specifications, design, environment and health and safety are addressed by several subcommittees (ASTM) and working groups (ISO). The guiding principles and specific procedures for the cooperation of ASTM and ISO are defined in the 'Joint Plan for Standards Development'. The goal is that the resulting AM standards, issued under the dual-logo of ISO and ASTM, will be used all over the world and there will be no need for future harmonisation. According to Kevin Jurrens, this is the first time that these standards bodies have agreed upon such a close and in-depth cooperation.

To gain an overview of the large number of standardisation tasks for AM technology, the table shown in Fig. 2 is helpful. The general top-level standards refer to general concepts, common requirements and are generally applicable. Below these are the standards for raw materials, processes and the characterisation of finished products. These are followed by standards for special materials and applications.

The European Committee for Standardisation

The European Committee for Standardisation (CEN), with its Technical Committee CEN/TC 438, has so far adopted ISO standards without any change, so that there is currently no need for harmonisation. These EN ISO/ASTM standards are adopted for use by all EU member countries, thereby strengthening collaboration on standards and facilitating commerce.

SAE International

Other standards bodies focus their activities on special sectors of AM. SAE International, formerly known as the Society of Automotive Engineers, was represented during the forum by John Clatworthy. The organisation has established a committee on Aerospace Material Specifications for Additive Manufacturing (AMS-AM), with subcommittees for metals and polymers. The first four material specifications (AMS7000–AMS7003) were issued in June 2018 (Table 1) and relate to Laser Beam Powder Bed Fusion (LB-PBF) Alloy 625.

Standard	Title	Type
AMS7000	Laser-Powder Bed Fusion (L-PBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni -21.5Cr -9.0Mo -3.65Nb Stress Relieved, Hot Isostatic Pressed and Solution Annealed	Final Material Spec
AMS7001	Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 62Ni -21.5Cr -9.0Mo -3.65 Nb	Powder material spec
AMS7002	Process Requirements for Production of Powder Feed-stock for Use in Laser Powder Bed Additive Manufacturing of Aerospace Parts	Powder Processing Spec
AMS7003	Laser Powder Bed Fusion Process	Process Spec

Table 1 SAE's committee on Aerospace Material Specifications for Additive Manufacturing (AMS-AM) issued its first four material specifications (AMS7000–AMS7003) in June 2018 (Courtesy SAE)

American Society of Mechanical Engineers

The American Society of Mechanical Engineers (ASME) standards committee Y14.46 works on Geometric Dimensioning & Tolerancing (GD&T) requirements unique to AM. The objective is to specify free-form complex surfaces and internal features, lattice and support structures, as-built assemblies, properties depending on the build-direction, multiple and functionally gradient materials, etc. GD&T is the language for communicating the specification of geometric tolerances and design intent from the designer to the manufacturing and quality engineers. The ASME Y14 committee has developed several GD&T standards in the past and can build on long-standing experience in this field. A draft standard, ASME Y14.46 Product Definition for AM, was issued for trial use in 2017.

Another standards committee, ASME B46, is concerned with the classification and designation of surface qualities. The committee has begun a preliminary work item on surface attributes and corresponding characterisation methods that are relevant to components made by AM technology. The topic is still in the early stages of discussion; there is currently no consensus on some details and several open questions need to be answered with further research. For example, it must be investigated whether the usual

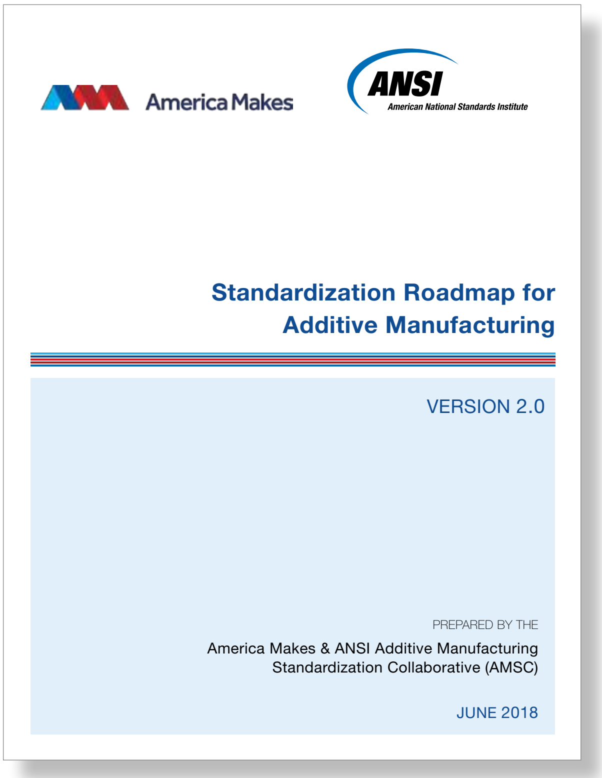

Fig. 3 The 'Standardization Roadmap for Additive Manufacturing' Version 2.0 was published in June 2018 and is available as a free download from the ANSI website

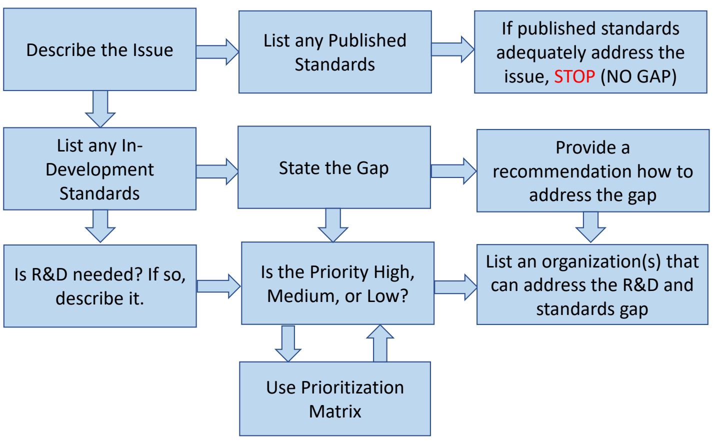

Fig. 4 Process flow for describing issues and gaps in standards (Courtesy ANSI)

roughness parameters (R_a, R_t) are suitable for describing the roughness of the sometimes complex surfaces of AM parts.

American Welding Society

The American Welding Society (AWS) develops specifications for the fabrication of metal components using Additive Manufacturing. This work is focused on the requirements for the repeatable production of metal AM components by technologies including Powder Bed Fusion and Directed Energy Deposition (DED) from raw materials in either metal powder or wire form. The current draft covers design requirements for AM components, fabrication requirements, AM machine and procedure qualification, inspection requirements and AM machine operator performance qualification.

The growing AM standards landscape poses a risk of overlapping work and duplication of efforts. When standards committees work independently, there is potential for inconsistencies or even contradictions, resulting in conflicting standards which may create ambiguity and confusion. To avoid this, intensive communication, coordination and liaison among the various organisations involved is indispensable. After all, the resources available for standards development are limited.

Additive Manufacturing Standards Collaborative

In order to pool resources for standardisation, the Additive Manufacturing Standards Collaborative (AMSC) was initiated in March 2016 with the purpose of coordinating and accelerating the development of standards for AM technology, which are consistent with the needs of stakeholders and facilitate the growth of the AM industry. The initiative was supported by the American National Standards Institute (ANSI) through a cooperative agreement with America Makes. Jim McCabe, Senior Director at ANSI, outlined the following overarching goals of the project:

- Facilitate the development of a consistent, harmonised and non-contradictory framework of AM standards and specifications
- Develop a standardisation roadmap describing the current and desired future standards landscape: what's published, in development, or needed
- Drive coordinated activity among AM standards developing organisations and avoid duplication of efforts
- Inform industry decision-making vis-à-vis resource allocation for standards participation
- Provide subject matter experts to work with SDOs

It was noted that AMSC itself is not developing standards. Phase 1, a 'Standardization Roadmap for Additive Manufacturing' was released in February 2017. Version 1.0 was replaced by Version 2.0 in June 2018. In this 268 page booklet (Fig. 3), which is available as a free download on the ANSI website, a comprehensive review is given of the standards requirements for AM, existing and needed standards. The roadmap identified ninety-three gaps (needed standards), of which eighteen were classified as high priority, fifty-one as medium priority and twenty-four as low priority. Research is required for sixty-five standards that are to be developed. A list of standards that are directly or peripherally related to the issues described in the roadmap has been published under the title 'Standards Landscape', which is also available as a free download.

The roadmap defines the topic areas for standardisation in five basic groups:

- Design
- Process and Materials
- Qualification and Certification
- Non-destructive Evaluation
- Maintenance and Repair

Each basic group is divided into subtopics, which in some cases are further subdivided. We will not go further into detail to avoid overwhelming our readers. Those who are interested in more details can read them in the AMSC Roadmap.

Planned future activities of ASMC are related to further promoting the roadmap and meeting with SDOs to track progress in standardisation. An online table of progress on the gaps in standards is planned and ASMC will also approach other industry sectors beyond aerospace, defence and medical with workshops to encourage them to participate in the standards committees.

Conclusion

The workshop featured speakers from both sides of the Atlantic. Europe's contribution to the standards activities was represented by Benjamin Hein, of the German Institute for Standardisation DIN and Secretary of ISO TC 261 'Additive Manufacturing'. He stressed the importance of cooperation for consistent international standards and predicted that these will increasingly replace national standards. "A globalised world needs worldwide standards," he said. "They enhance efficiency and quality, promote trade and make products safe and environmentally friendly." DIN estimates that the German industry alone saves €17 billion each year thanks to standardisation and fully supports the joint activities of ASTM and ISO.

Hein emphasised that using standards saves R&D and production costs, and that standards provide users and researchers with fundamental expert knowledge that can be used to gain a competitive edge and expand networks. Further, standards facilitate market access and help dismantle barriers to trade, thereby promoting economic growth throughout the world. Conforming to standards shows a commitment to quality, enhancing customer trust, increasing product safety and lowering liability risks.

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Resources and useful links

National Institute of Standards and Technology
www.nist.gov

America Makes - National Additive Manufacturing Innovation Institute
www.americamakes.us

ASTM International
www.astm.org

ISO - International Organization for Standardization
www.iso.org

CEN - European Committee for Standardization
www.ce.en

SAE International
www.sae.org

The American Society of Mechanical Engineers
www.asme.org

American Welding Society
www.aws.org

Formnext 2018: How the growth of metal AM is driving changes to the metal powder landscape

Whilst machine builders once again dominated Formnext 2018, the world's metal powder producers have also become an increasingly important part of the event as the industry evolves towards serial production. In the following report, Toby Tingskog highlights some of the major events in the world of AM-related metal powder production in 2018, along with a number of trends that became apparent as a result of conversations with producers in the exhibit hall.

Formnext 2018 was, as anticipated, the key event for the Additive Manufacturing industry this year. The floor space was dominated by the major machine manufacturers, with plenty of smaller support companies displaying their solutions for powder handling, screening, testing, etc. Naturally, without metal powder it would be impossible to produce parts using the Powder Bed Fusion technologies which form the core of existing metal AM applications, so it is interesting to follow the developments in this area, to understand the trends in the market and to consider what the supply situation will be in the future – will there be a metal powder shortage, or perhaps over-supply? Will prices come down? Not counting OEMs, some thirty different metal powder producers/sellers exhibited at this year's show, offering a range of perspectives in this area.

There were a couple of relatively major events in the AM metal powder industry this year, one of which was Carpenter Technology's purchase of AM powder specialist LPW Technology. The Carpenter–LPW development was announced only a few weeks before Formnext, allowing little time for integration ahead of the show; the large LPW booth displayed a Carpenter logo, but there was no separate Carpenter Technology booth. Integration is now reported to be underway with an emphasis on servicing current customers at both companies. The Summer 2018 issue of *Metal Additive Manufacturing* magazine (Vol. 4 No. 2) gives a detailed overview of LPW's activities and its new facility dedicated to AM powder.

Carpenter Powder Products is one of the largest producers of gas atomised powder with a full range of alloys, including titanium following its

Fig. 1 Formnext was once again the global meeting point for the metal AM industry in 2018 (Photo Mesago / Mathias Kutt)

acquisition of Puris LLC in 2017. It will be interesting to see how the combination with LPW works out; CPP-LPW will without doubt be a powerful powder supplier, with substantial production capacity.

Höganäs AB's acquisition of H.C. Starck's Surface Coating Powder Division (STC) was completed in March 2018. This is an interesting combination of a very high volume automotive and industrial metal powder producer with a more specialised powder company which primarily produces powders for thermal spray applications. STC has Vacuum Induction Melting (VIM)-based production technology and expertise in finer powder fractions, and it has been indicated that there was little overlap in the product portfolios. Höganäs intends to grow the AM business and will, it has stated, invest as needed for additional capacity. With Höganäs in the AM powder market, it is expected that there will be a further expansion of the supply base in the direction of higher volumes and lower costs.

Höganäs AB's main competitor in the automotive powder business is the closely-named Hoeganaes Corporation (formerly the US subsidiary of the Swedish firm) and today part of GKN Powder Metallurgy. GKN announced in February 2018 that it intends to divest GKN Powder Metallurgy within twelve to eighteen months. GKN Powder Metallurgy has also announced a cooperation with HP Inc on its new metal Additive Manufacturing system, the HP Metal Jet, to produce high-volume industrial and automotive parts and, at Formnext, a strategic partnership with EOS was also announced.

GKN occupied a large booth at Formnext which primarily promoted its AM part manufacturing; however, it is expected that GKN Powder Metallurgy will continue to target AM powder sales following the divestment, given recent investments in AM powder-related R&D and the resulting range of AncorAM powders specifically designed for Additive Manufacturing, including AncorTi CP and AncorTi 6Al4V, as well as nickel and ferrous-based materials.

Metallurgical companies move into the powder business

The business for wrought high alloys steels is dominated by a handful of companies with deep metallurgical expertise. A few of these have also been in the powder business: Carpenter Technology, Sandvik AB, Aubert & Duval, Erasteel and Boehler-Uddeholm. The latter two companies primarily produce PM high speed steel for internal use.

An interesting trend is that such metallurgical companies are now interested in the powder business for AM and are building new facilities as a result. They are also taking the step to learn more about the technology, offering build parameters for their powders and even forward integrating with in-house AM part production.

This has to be seen as good news for the AM industry, since more metallurgical knowledge will help establish new advanced applications and accelerate acceptance.

"...metallurgical companies are now interested in the powder business for AM and are building new facilities as a result. They are also taking the step to learn more about the technology, offering build parameters for their powders and even forward integrating with in-house AM part production..."

However, it is less positive news for anyone looking to start a new powder company: pre-established metallurgical companies can support customers technically, develop new alloys and expand production capacity by building large plants. The cost of an atomiser - or five - is insignificant compared to a typical rolling mill with large-scale melting.

In February this year, Sandvik announced a $25 million investment in Sweden to build a new powder facility with VIM atomisers for nickel alloys and titanium alloys. This will be complementary to the Osprey plant in South Wales, UK, which has high-volume production of Metal Injection Moulding and AM powders and may add aluminium alloys in 2019. Sandvik also has a corporate R&D centre with a significant number of AM machines. At Formnext, Sandvik's Osprey metal powder business co-exhibited with Sandvik's Additive Manufacturing business, which offers both development support and manufacturing services for external clients as well as in-house application development.

Boehler Edelstahl has two VIM atomisers with 250 kg and 500 kg melting furnaces. This is impressively supported by EOS, SLM Solutions, Renishaw and Trumpf AM machines. A patented 50-57 HRC tool steel, developed for AM, is already available (Böhler W360). Perhaps we'll see cheaper and better alternatives to the standard maraging 300, 18% Ni now used extensively in AM. Several nickel alloys are also available from Boehler.

VDM Metals is a leading metallurgical company producing nickel-based superalloys. Not historically a powder producer, VDM now has a VIGA system and will focus on Ni alloys including its own speciality alloys, such as VDM Powder 780, a 718-type alloy with 100°C higher operating temperature. Build parameters are developed by

VDM with partners. Nickel alloys are of course used for high-value parts and are excellent candidates for AM, and the opportunity is there for metallurgical companies to leverage alloy know-how with Laser-Beam Powder Bed Fusion expertise to come up with unique solutions for their customer base.

From thermal spray to Additive Manufacturing

As mentioned earlier, Höganäs AB is now in the thermal spray business via STC and is leveraging this towards AM. The two main thermal spray companies are Metco and Praxair Surface Technologies; Metco, the first company to commercialise thermal spraying, is now owned by Oerlikon – a company that has emerged as a major force in the world of metal Additive Manufacturing.

One natural attraction of AM for thermal spray companies is that the Laser Powder Bed size 15-45 µm is also a standard size for plasma spray and High Velocity Oxygen Fuel (HVOF) spray coatings. Consequently, thermal spray companies have appropriate atomising and screening expertise as well as good procedures for recycling off-size powder.

Oerlikon AM exhibited both metal powders and AM parts at Formnext, the latter as a result of its acquisition of AM part producer citim GmbH two years ago. The company has expanded its powder production with a new plant in the USA that operates VIM atomisers with 250 kg and 1000 kg capacity, as well as a titanium atomiser. All are aimed primarily at AM.

Praxair has a considerable business in AM powder. The company has several large VIM atomisers that supply high-end TS alloys such as CoNiCrAl – perfect for IN718 and other advanced alloys. Additionally, Praxair has a titanium gas atomiser with a patented nozzle for making alloys with high yield and in-house AM facilities to support the development of AM materials.

Titanium

Ti-6Al-4V and other alloys manufactured with the Plasma Atomised Wire (PAW) process have gained wide acceptance in the AM industry. AP&C and Tekna were both at Formnext, the former as part of GE Additive. Both companies have or will increase production capacity significantly and it can be expected that these French-Canadian companies will see more local competition from PyroGenesis, which now has a production atomiser installed and is offering powder from stock. It was reported that PyroGenesis has an atomiser dedicated to Ti-6Al-4V to provide the best quality powder without cross contamination and the company has also developed good controls over particle size distribution and can tailor runs from MIM to laser to electron beam

AM processes. This can increase the effective capacity of in-size yields over other PAW processes. Further systems are reportedly planned to expand the alloy offering.

Sino-Euro Materials Technologies (SMT) makes titanium alloys and Inconel with a high-speed Plasma Rotate Electrode Process (PREP) machine. The powder has a considerably finer size than traditional PREP and can be used for electron and laser beam PBF applications. The powder quality is extremely high and, arguably, better than PAW. The starting material for this powder is bar rather than wire, adding flexibility and lowering raw material cost.

Praxair remains the only high-volume producer of gas atomised titanium alloys. Several companies with Electrode Induction Melting Inert Gas Atomisation (EIGA) systems were at Formnext and offered titanium alloys, but no particular emphasis on EIGA titanium powders was observed, so it may be that much of this powder goes through OEMs.

Speciality producers

The metal powder business has always had a number of speciality producers that make powder for different market segments. Many of these have now turned their attention to AM to satisfy the need for alloys and powder types not covered by the larger producers or even OEMs. Some examples include:

- Turkey's SentisBIR, which makes cobalt alloys and is offering powders for the AM of dental parts
- Hereaus, which makes precious materials and several speciality alloys. Heraeus is offering AM powders to complement its product line, as well as Scalmalloy. Hereaus has several types of LB-PBF machines as well as Arcam EBM systems.
- Kymera International is the umbrella company for three major powder producers; ECKA Granules, SCM Metal Products and ACuPowders. Whilst its traditional market is Powder Metallurgy, Kymera is now offering the AM industry copper and Cu alloys, bronze, brass and aluminium alloys. It also supplies tin and zinc powder, but it is somewhat unlikely that these will ever account for significant AM tonnage.
- US Metal Powders (USMP) is producing inert gas atomised aluminium alloy powder from its Poudres Hermillon operation in France, including AlSi10Mg and 6061. Custom alloy chemistries can be made and the powder size is tailored to LB-PBF as well as -30 µm powder for Binder Jetting.

China and Japan

CNPC Powder in China has set up a large powder plant with nine atomisers and a capacity of 3000 Mt per year. Equipment includes VIGA and EIGA atomisation to cover all alloys from stainless steels and nickel alloys to aluminium and titanium. The range is impressive, and we could see volume shipments begin in 2019.

The December 2018 issue of *PIM International* magazine includes an extensive list of Chinese powder producers, which are in many cases expanding from MIM to AM powder.

Japan was represented by Sanyo Specialty Steel and Osaka Titanium Technologies, who shared a booth. Sanyo has VIGA for stainless steel and nickel alloys, whilst Osaka Titanium has several titanium powder production technologies. The company is a high-quality titanium sponge powder producer and has expanded with EIGA atomisation. As an integrated producer, Osaka Titanium may have some advantages over pure atomising companies.

Conclusions

The most positive trend is that more companies are taking AM seriously and investing money and R&D resources accordingly. We can expect significant developments on the alloy side as well as in powder quality.

The powder supply situation is very good – from an end user perspective. The capacity in place now, plus the increases over the next year, can easily cover any need for the foreseeable future. Perhaps the greater challenge is to pick a supplier from the increasing number of AM powder producers and distributors.

Entering the AM powder market as a new producer is becoming more difficult, with an increasingly crowded field of manufacturers that now include metallurgically competent suppliers; there are some market opportunities in underserved alloys systems, but even these are in the sights of current powder producers.

Some softness in powder prices was also discussed at Formnext. Prices are now driven downwards by a higher degree of competition, as well as increased direct selling by powder producers which is reducing price mark-ups by middlemen. However, truly low powder prices will only arrive when consumption increases and larger and more rational production units can be used; the AM powder volume currently remains very low compared to Powder Metallurgy markets. Interestingly, the prices of powders used in Binder Jetting are low, since the technology can piggyback on a > 12,000 ton/year MIM market. Many more Formnext exhibitions will come and go before we see this kind of volume in metal Additive Manufacturing.

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ABSTRACT SUBMISSION DEADLINE: APRIL 15, 2019

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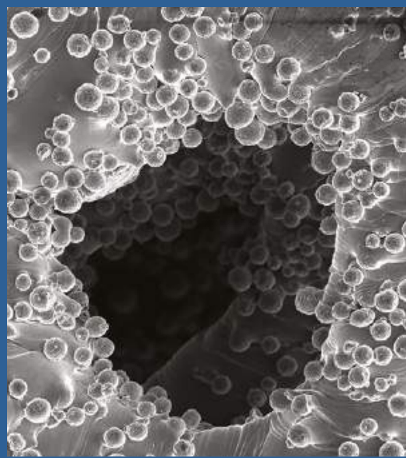

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How residual stress can cause major build failures, and what you can do to prevent it

Anyone who starts out on their own evaluation of the opportunities presented by metal Additive Manufacturing will soon stumble across the phrase 'build failure'. Whilst there can be many causes for a failed build, which of course comes at a significant cost in terms of both material wastage and machine time, residual stress is often at the top of the list. As Olaf Diegel and Terry Wohlers explain, residual stress can be both anticipated and managed though a combination of basic design rules, process settings and post-build heat treatment.

Residual stress is one of the most common causes of catastrophic build failures in metal Additive Manufacturing. A recent LinkedIn post by Alexander Liu, a well-known metal AM trouble-shooter from Temasek Polytechnic in Singapore, demonstrated this problem with the failed build of a topology-optimised bracket. The parts kept detaching from the build plate or ripping away from the support material. It was caused by considerable residual stress within the parts.

What is residual stress?

Similarly to welding, metal Additive Manufacturing induces a substantial amount of stress on parts. This is one of the principal reasons why support material is often needed. This residual stress, as well as stress concentrations, must be relieved through heat-treatment after the build and before parts are removed from the build plate.

Residual stresses remain in a solid material after the original causes of the stresses have been removed. In itself, residual stress is not always a bad thing, and can sometimes be desirable. Shot peening, for example, imparts beneficial compressive residual stresses into metal parts. Residual stress is also used in toughened glass to allow for the large, thin, scratch-resistant glass used in smartphones. Unintentional residual stress in a designed structure, however, can cause it to fail prematurely and becomes problematic.

Many factors can cause residual stress in a part, but the chief one is controllable through design. Residual stress is a result of temperature

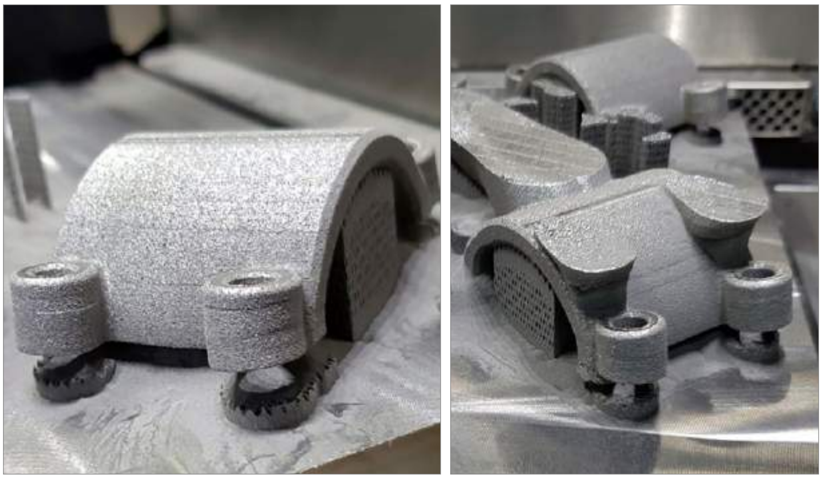


Fig. 1 Examples of parts detaching from the build due to residual stress (Courtesy Alexander Liu)

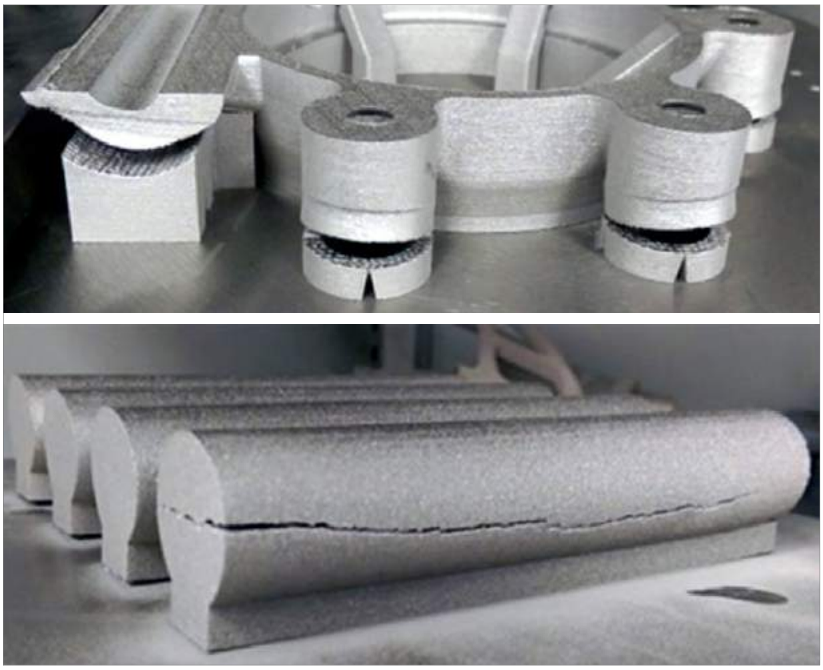


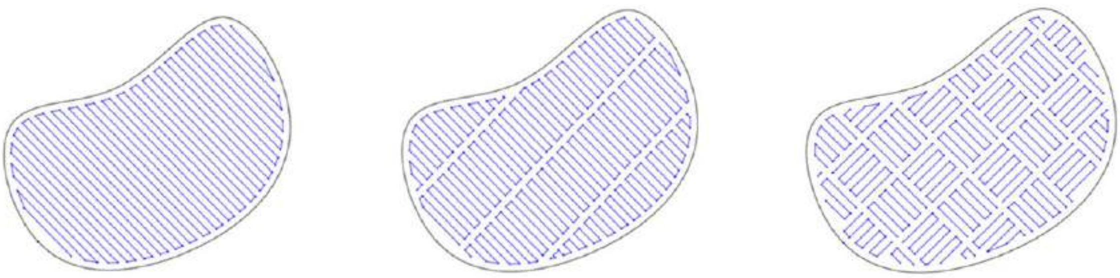
Fig. 2 Examples of the catastrophic effect residual stress can have on parts (Courtesy Renishaw)

gradients from the surface to the centre of an AM part during cooling. It can have a particularly severe impact on parts with large masses of material, as the material inside the mass cools slower than the material on the outside, inducing stress in the part.

Within the metal AM process itself, strategies can be employed to reduce the formation of residual stress. As discussed in the Summer 2018 issue of *Metal AM* magazine, the hatching strategy used can play a significant role in reducing residual stress. Smaller chessboard hatch patterns will, for example, create less residual stress than bigger ones, or than large meander type patterns. However, they will also slow down the process somewhat. Rotating each hatch scan, usually by 67° for each layer, can also prevent stress from building up vertically, compared to scan strategies that occur one on top of another. As with almost everything in metal AM, it can be a compromise to choose between a scan strategy that minimises stress versus maximising speed.

Survival of the part through the AM build process, without cracking or separating from the build plate or support material, is key. The first step after removing the build plate from the AM system is to stress relieve the parts in a furnace. In this process, the parts are slowly heated up so that they reach a specific temperature, with the thicker sections of a part reaching that temperature at the same speed as the thinner sections. Once that temperature has been reached, the parts are soaked at that temperature to ensure equilibrium has been reached. The parts are then slowly cooled, again with the goal of the thick and thin sections of the parts cooling at the same rate so that new residual stresses are not introduced.

From a design perspective, engineers can do a lot to reduce the risk of residual stress in a part during fabrication. This, in turn, reduces the risk of build failures, and reduces the need for heat treatment after the build has finished.



Meander hatch pattern
High build rate
Higher residual stress
Suitable for small/thin parts

Stripe hatch pattern
Medium build rate
Medium residual stress
Suitable for large parts

Chessboard hatch pattern
Slow build rate
Lower residual stress
Suitable for large parts

Fig. 3 Laser scan strategies for reducing residual stress

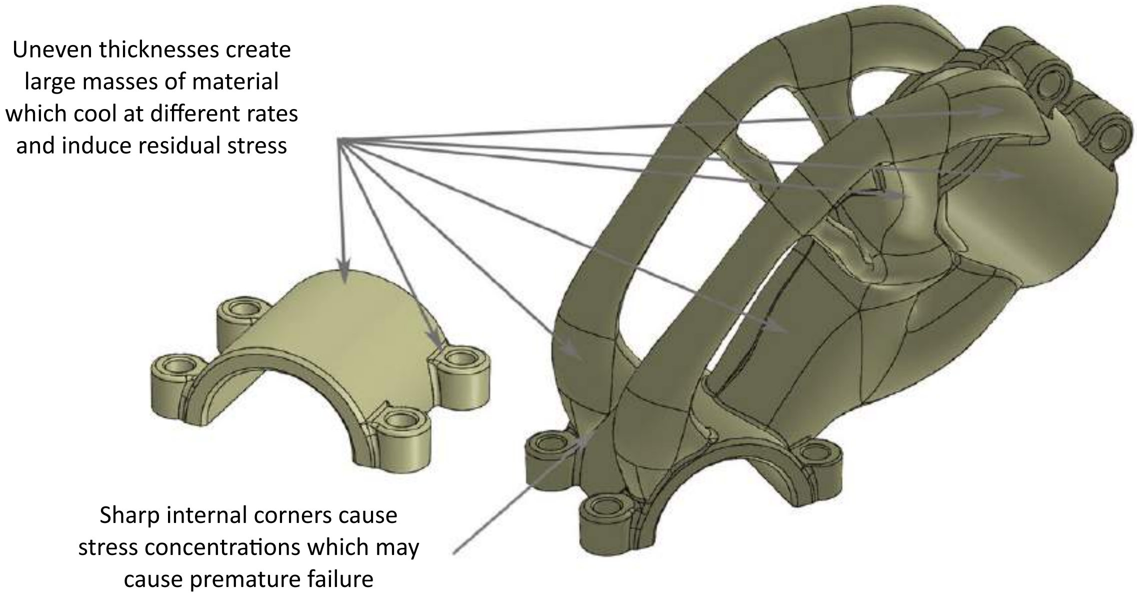


Fig. 4 Some of the problems identified in the original bracket and clamp designs

Designing to minimise residual stress

The original bracket was designed as a topology-optimised part made up of two pieces: a small clamp, and the main bracket. A topology-optimised part, however, does not automatically make it suitable for metal AM. In this case, the main part included large masses of material and uneven thicknesses, resulting in substantial stress. It also included several sharp internal corners that caused stress concentrations, likely causing premature failure of the part.

One of the most fundamental design guidelines that applies to many manufacturing methods, including injection moulding, casting, and AM, is to use an even wall thickness wherever possible. In Additive Manufacturing, this simple technique can have an even greater impact than with other manufacturing methods.

On the smaller clamp part of the bracket, a simple technique of removing unnecessary material and using ribs to maintain mechanical integrity was used to achieve an even wall thickness of 3 mm for the main body of the clamp. This is a common wall thickness used for light- to medium-duty casting applications. The ribs are 2 mm in width, which prevents an uneven thickness forming where the ribs join the cylinder. Also, the four bolt-hole lugs were shelled and ribbed to prevent them from becoming an area of residual stress. Depending on the specific application of this bracket, the nominal 3 mm thickness could be increased or decreased as necessary. All internal corners of the clamp were filleted to avoid the formation of stress concentrations.

For the main part of the bracket, the topology-optimised version was used as the design source for a parametrically designed CAD version. The clamp ends of the brackets were redesigned in a way similar to the previously described clamp. The thick centre member was split into three lofted members of even wall thickness, and the centremost of these members was designed as a U section for extra rigidity. All thicknesses were kept to 3 mm. Also,

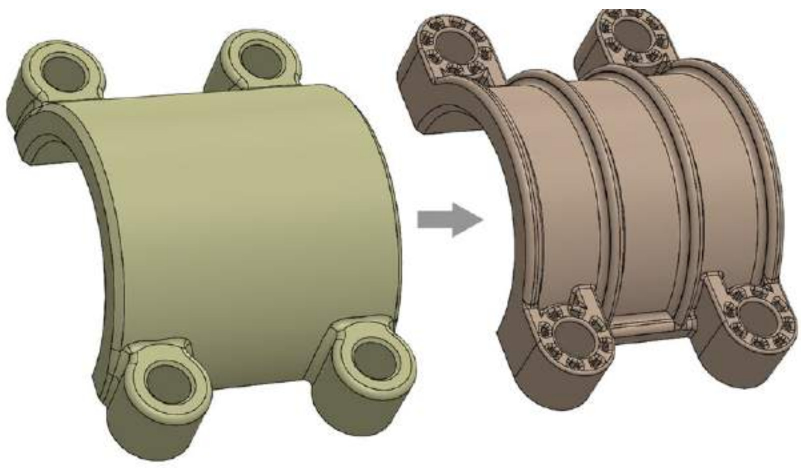


Fig. 5 The original design (left) and new design (right). The new design has an even wall thickness and no areas where stress can build up. It also weighs 25% less

Fig. 6 Original topology-optimised bracket (left) and new bracket (right) with relatively even wall thicknesses in all locations. The new design weighs 53% less than the original bracket

every internal corner was filleted to avoid the risk of stress concentrations at the joints.

The new design was successfully built in two different orientations without any lifting off the build plate or breaking away from the support material. The smaller clamp was built in both horizontal and vertical orientations. The larger bracket was built in one orientation with one of the clamps in the horizontal position, and in a second orientation with both clamps at an angle to achieve a lower build height.

Conclusions

When designing parts for production by AM, it is important to constantly consider techniques that avoid residual stress. Applying techniques such as keeping to an even wall-thickness and avoiding large masses of material can have a dramatic impact on the ability to successfully manufacture metal parts.

Reducing the residual stresses that can build up in a part can also greatly reduce the need for heat treatment after the build is complete. Also, avoiding large masses of material, as described in a previous issue of *Metal AM* magazine, has a substantial impact on reducing the time and cost of manufacturing a part. The example in this article clearly demonstrates that it is not practical for conventionally designed parts - even if they employ modern design techniques such as topology optimisation - to always perform well in an AM environment. Design for AM is not a choice, but rather an absolute necessity to make best use of the true power of Additive Manufacturing.

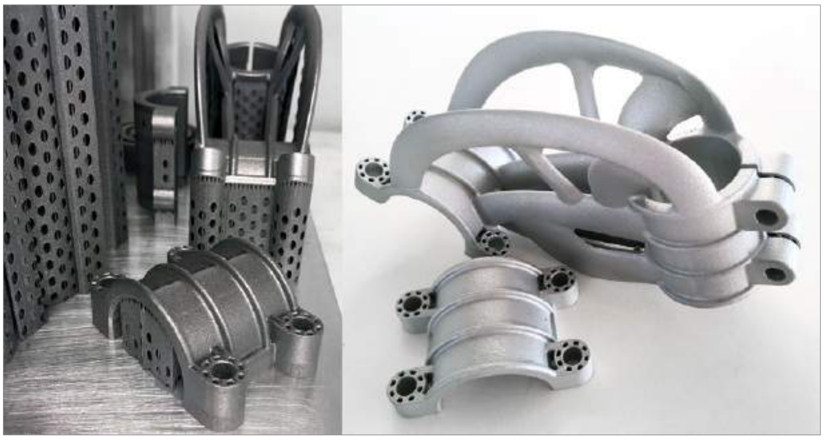


Fig. 7 Parts still attached to build platform with support material (left), and parts after post-processing and shot-peening (right)

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Arcast: Applying advanced melting and atomisation expertise to the production of a new generation of metal powders

Arcast Inc., based in Oxford, Maine, USA, is today emerging as a leader in advanced melting and metal powder atomisation technologies, with a diverse international customer base. As *Metal AM* magazine reports, the company provides processing solutions for some of the most challenging alloys, as well as offering through its new venture, Arcast Materials, a range of commercially-produced metal powders.

In 2005 in the US state of Maine, Rayland O'Neal established O'Neal's Manufacturing, a machine shop specialising in components and fabrications for the radio frequency broadcast equipment industry. After some years of initial success, it became apparent that this sector had fully matured and orders were becoming harder to come by. It was around this time that O'Neal had a conversation with his old school friend, Sasha Long, who had been working in the UK in the field of specialist vacuum furnaces and melting systems. Long had identified this as a field of burgeoning interest and activity, and persuaded O'Neal that this was an area of manufacturing that was worthy of further investigation.

It quickly became apparent that the capabilities and machining skills acquired in the RF equipment business could be transferred to the manufacture of certain kinds of metallurgical process equipment. As a result, Arcast Inc. was incorporated in 2010 by O'Neal, and Long followed shortly after in partnership as its two principals.

Early success in specialist melting systems

Initially, the company strove to establish and develop a niche range of products focused on specialist metal melting furnaces. It was fortunate to win some small but important early contracts for custom metallurgical equipment from a number of prestigious customers that included NASA and Los Alamos National Laboratory. It was this business, plus valuable development grants from the National Science Foundation and some remaining work for its RF customers, that provided initial cashflow and allowed the company to survive.

Fig. 1 View inside an Arcast atomisation chamber

Fig. 2 Part of the Arcast team in front of one of the company's atomisers at the Royce Translational Centre in Sheffield, UK, including Rayland O'Neal (far right) and Sasha Long (second from right)

Fig. 3 A line of arc melters in assembly at Arcast

In 2009, Arcast sold its first Arc 200 cold-crucible arc melting system. The company had identified a need for such systems from various research establishments and universities investigating and developing new metal alloys. Whilst there were a few existing systems available at that time, Arcast sought to provide equipment with greater versatility and adaptability, introducing several innovative features that were not available from other manufacturers. Since then, the Arc 200, the smaller Arc 50 and, more recently, the larger Arc 500 have proven very popular with a number of high-profile customers around the world. Arcast is now firmly established as a leading manufacturer of this kind of arc melting equipment.

In addition to arc melters, Arcast has also designed and supplied melt spinners and splat cooling devices to both research and industrial users interested in bulk metallic glasses.

Gas atomisation technology

While reaping the rewards of its growing sales of arc melting systems, Arcast had its sights set firmly on an even greater prize: the development of gas atomisation systems for the production of metal powders. Even before its incorporation, Arcast's management team had significant experience in the design and manufacture of metal atomisation systems and were therefore fully aware of the growing interest in metal/alloy powders for manufacturing processes such as Metal Injection Moulding, Hot Isostatic Pressing and, more recently, Additive Manufacturing.

The company states that designing and developing its own technology and systems in-house has been key to its success in creating equipment that can accommodate a wide range of feedstocks. It is also claimed that Arcast's proprietary technology and designs deliver higher operating efficiencies than competing systems.

Arcast supplies gas atomisers that are based on both conventional, ceramic-contained melting and 'clean', contactless melting regimes. During 2015 and 2016 the company supplied three industrial scale atomisers, one for Uddeholm, Sweden, the world's oldest steel-maker in continuous production; the other two for a US metallurgical conglomerate.

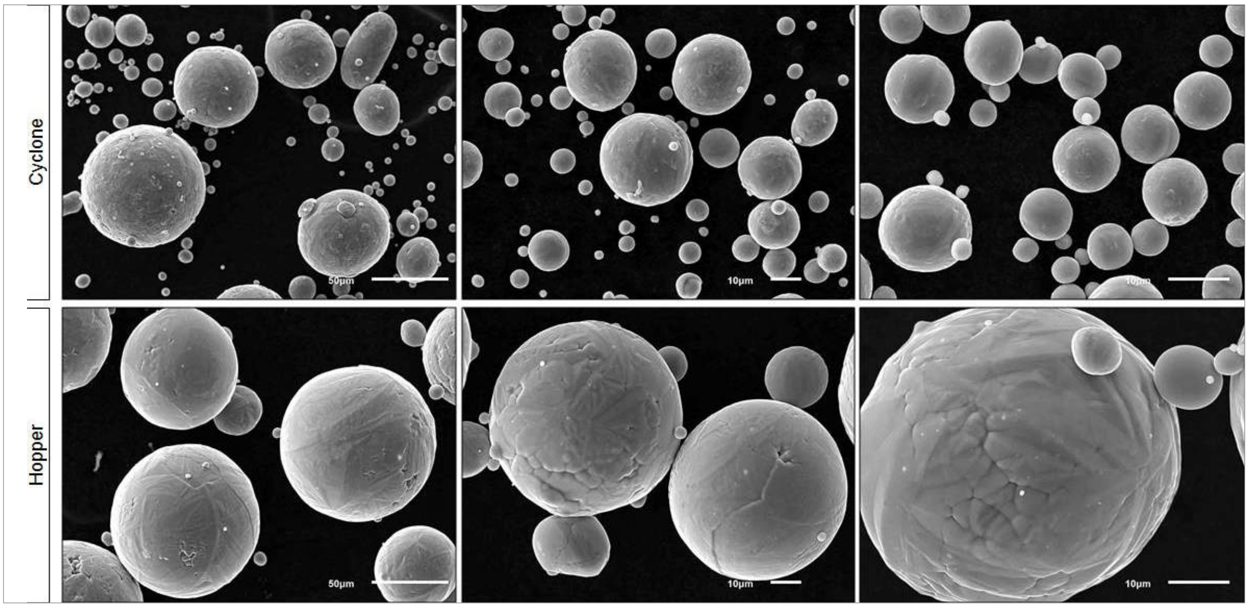

Fig. 4 SEM image of spheroidal Cristal Metals Ti metal powder AR3-20170609.02 (Courtesy Cristal Metals)

Long told *Metal AM* magazine, "Along with the conventional ceramic-lined close-coupled and induction drip melt rod feed [EIGA type], we offer a range of cold crucible and 'contact free' melting and atomising methods using plasma/arc and induction techniques. One of these methods is what the company calls a tube feed plasma/arc melting system. This allows a wide range of feedstocks to be directly melted and atomised without contamination and in an inert atmosphere."

Tony Deacon, Arcast's Contracts Manager, stated, "Arcast spent years developing its gas die/jet designs - close-coupled, free-fall and others - to give the most efficient and effective powder production. We continue to improve these designs to increase robustness and efficiencies. Combined with our gas heater and chamber designs we produce very high-quality powder that is low in satellites and with good particle size distributions."

Arcast's latest research or pilot atomiser, the VersaMelt, can accommodate four kinds of interchangeable melting capability within a single system package. The first of these was supplied to the Catholic University of Louvain, Belgium, in 2018.

A move to materials supply and collaboration with Cristal Metals

In 2018, Arcast took the decision to form a separate company, Arcast Materials, that commercially produces metals and alloys in both powder and other product forms. Arcast Materials focuses on specialty and niche alloys and toll work for customers. Deacon told *Metal AM* magazine, "In recent years, we have been assisting customers in refining materials like hafnium and titanium sponge. In particular, we have been working closely with Cristal Metals [Ottawa, Illinois, USA] to take its pre-alloyed titanium material and turn this directly into high-quality spherical powder, with very little increase in oxygen or nitrogen, typically ≤ 200-400 ppm O and < 10-40 ppm N when using standard industrial argon supplies. In fact, our process reduces undesirable elements such as hydrogen and sodium by more than 99%."

"Through its own process, Cristal Metals can create a wide range of titanium alloys directly. This ensures that there is a homogeneous alloy in the resulting material. By combining the capabilities of both companies, we have a direct route to creating high-quality custom alloys to supply the fast-growing requirements of downstream Powder Metallurgy

"By combining the capabilities of both companies, we have a direct route to creating high quality custom alloys to supply the fast-growing requirements of downstream Powder Metallurgy processes..."


Fig. 5 Detail view of an Arcast inert gas atomiser

processes. There is now no longer a need to create multi-ton ingots with multiple VAR stages and then draw this down to rod or wire to create custom titanium or similar alloy powders," stated Long.

The direct atomisation of materials such as this offers the most efficient and the cleanest method to produce spherical powder in bulk quantities. The flexibility of alloys using the Cristal Metals process and the additional flexibility of the Arcast process gives, it is claimed, an unprecedented range of economically viable spherical alloy powders. "With our continued work with Cristal Metals we can offer high quality customised alloy powder with the most direct processing route in the industry. Because we can also process scrap directly, we can drive the cost down on standard composition powders," explained Deacon.

Beyond the work done with Cristal Metals, Arcast has been working with a number of industrial customers and partners to process materials using its atomisation capabilities. Long stated, "Core to the materials business is an atomising process that can receive a wide range of metal feedstock and produce fine powder from reactive alloys such as titanium while avoiding ceramic contamination - all with very low gas usage. This process produces powder equal to or possibly better than that produced from wire plasma atomisation but with a much more flexible feedstock range. This means materials like boron alloys, titanium aluminide, or the direct processing of sponge can be performed. Brittle, or non-ductile materials can be processed because there is no need to pre-cast rod or draw wire. The process typically gives an as atomised D50 of 40 µm and a D90 of 90 µm when processing conventional titanium alloys. The process can be tuned to change these values and certainly with some other difficult to handle materials we have produced finer distributions." Fig. 6 shows a typical distribution of Ti-6Al-4V produced using Arcast's technology.

"Often Arcast is speculatively asked if we can process certain challenging materials, for example titanium, tantalum, shape memory alloys and tungsten alloys. With confidence we can say yes. This is usually met with a pause and moment of silence, and then 'oh, ok, well we have a requirement for x or y…' and the conversation begins. Although our customers are often surprised, it is a pleasure

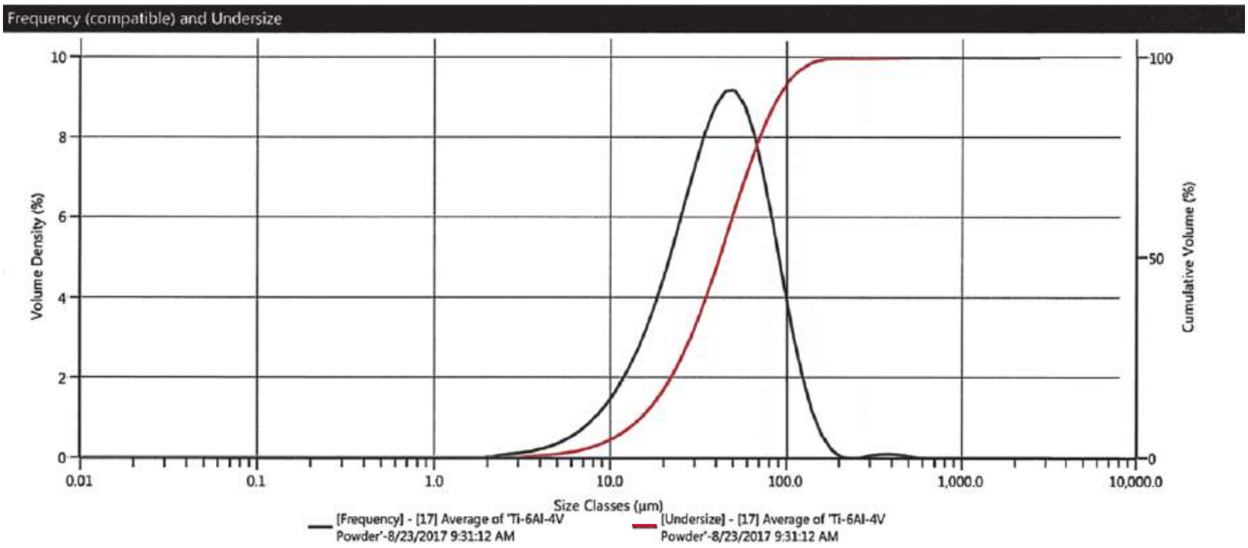

Fig. 6 A typical distribution of Ti-6Al-4V produced by Cristal Metals and Arcast

to be able to address the needs of our customer's most challenging requirements. This capability helps us grow product lines, along with growing the supply and production of the more conventional metal powder and castings," explained Long.

Looking ahead

In 2018, Arcast completed the purchase of 10,000 ft^2 additional freehold factory space. "This is sufficient to accommodate our near-term expansion plans for both Arcast Inc. and our new materials company, but even now we must seriously contemplate adding more factory space in the near future," stated Deacon.

"The short-term objective is to have three full-time production atomisers and one experimental atomiser operational to meet current demand. Additionally, a production alloying furnace and small-scale continuous casting furnace will supplement our capability. The new laboratory will have a new Scanning Electron Microscope and equipment for analysing composition, size and morphology. To complement the technical capability we are completing the quality management system and audits to allow ISO9001 and AS9100 certification for this new division."

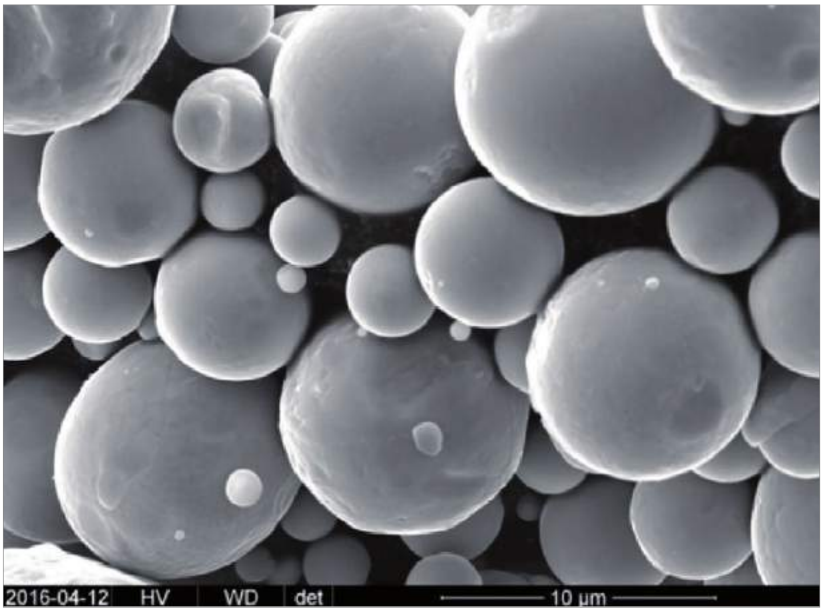

Fig. 7 Steel alloy powders produced using Arcast technology

"After years of working with different customers and developing novel methods for processing metal and powder we have amassed a comprehensive range of capabilities. If we don't have an off-the-shelf solution, we can usually create an adaptation that will solve the problem. We believe this will be the strength of a material processing company, being born from a R&D and equipment supply company," concluded Long.

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Additive Manufacturing in Aerospace: Highlights from the AMA 2018 international conference in Bremen

Much of metal Additive Manufacturing's recent success has been driven by the aerospace sector, where demanding applications have propelled progress in all aspects of the technology, from process stability and quality to part design and materials. Together, these advances are enabling metal AM to meet the next challenge: that of wider serial production. As the University of Bremen's Christian Kober reports, it was this challenge that formed the central theme at this year's International Conference on Additive Manufacturing in Aerospace.

After a successful first conference in 2016, over 130 participants from more than fourteen countries came together in Bremen, Germany, from September 19–20, 2018, for the International Conference on Additive Manufacturing in Aerospace (AMA).

Whilst around a third of the attendees came from research institutes, the majority of participants consisted of representatives from numerous companies in the space and aerospace industries. Among those were global players including Airbus, Boeing, Ariane Group and MTU Aero Engines, AM machine manufacturers such as EOS and Trumpf, and a number of small to medium-sized enterprises in the relevant fields.

More than twenty presentations were given over the course of the two-day event, all of them on the theme 'Challenges of AM Serial Production'. These were complemented by a small exhibition and a poster presentation session where each poster's authors presented their topic in a four-minute talk. This was followed by a longer poster session, in which detailed discussions with other participants were encouraged.

The conference programme was organised into five sessions addressing the process chain for AM serial production, AM-related lightweight design, part testing and quality assurance, high-production rate AM technologies, and data handling and simulation-driven solutions.

Given its central theme of AM for serial production, the conference programme was structured with a clear industrial focus. However, with

Fig. 1 The International Conference on Additive Manufacturing in Aerospace (AMA) took place in Bremen, Germany, a leading city for aerospace engineering for more than a hundred years (Image courtesy Flughafen Bremen)

Fig. 2 Conference Chairman Prof Dr V Ploshikhin, University of Bremen, welcomed delegates to the conference

a technology such as Additive Manufacturing, applications that are currently in serial production are a rarity. Much development is still necessary to bring the technology to maturity as a production tool, so it is unsurprising that nearly half of the presentations at AMA 2018 did not come from industry, but rather from universities and research institutes. This enabled the audience to gain insight from a number of perspectives, from organisations which, however different, are all dealing with a very similar field of problems and goals. OEMs, suppliers, start-ups, software engineers and researchers, each with their own point of view, each offered valuable contributions by sharing the methods they have used to address these problems and achieve these goals.

Today, a small number of additively manufactured space and aerospace parts are qualified and certified for serial production for use by OEMs. However, while today this is in most cases based on single-part qualification, the process itself must be qualified in order to be competitive in the future. Over the course of the conference the different aspects of the AM process, challenges in terms of serial production and approaches for qualification were all presented, with talks covering topics from single part examples to company roadmaps, and from additively generating features for given structures to algorithms capable of automatically calculating hundreds of designs within minutes.

Highlighting the state of the art in AM

The conference was opened with a short welcome from Conference Chairman Prof Dr V Ploshikhin, University of Bremen (Fig. 2), followed by a video message from Senator Martin Günthner, Ministry of Economic Affairs, Labour and Ports, Bremen. Next, the first keynote lectures were presented by Dr Joachim Schmidt, Premium Aerotec, Germany, and Raphael Salapete, Ariane Group, France, who offered insights into the state of the art as relating to the serial production of aerospace parts and applications for rocket engines.

This first overview presented many of the benefits and improvements achievable by Additive Manufacturing. The integration of functionality into a single part, and thus the possibility to appreciably decrease the required manufacturing steps, is one of the great advantages of the technology. Furthermore, the secondary effects of Additive Manufacturing adoption were highlighted; for example, when a hydraulic component is additively manufactured in a flow-optimised design the pressure requirements may be lower, leading to the development of smaller and lighter pumps and pipes. Effects such as these are not typically taken into account in today's evaluations of the process, but have the potential to create sweeping improvements across the aerospace industry.

Furthermore, the results of the 'Next Generation AM' project have been highly promising with regards to the industrial automation of - in this case - powder bed-based Additive Manufacturing processes. A pilot scenario was created by Premium Aerotec GmbH, Daimler AG and EOS in which a robot automatically unloads an AM machine and transfers the build plate to a furnace for subsequent heat treatment. It is then optically measured or 3D scanned before being transferred robotically to a saw for separation from the build plate. In automated solutions such as this, the downtime of machines, particularly Laser Beam Powder Bed Fusion (LB-PBF) machines, can be significantly reduced.

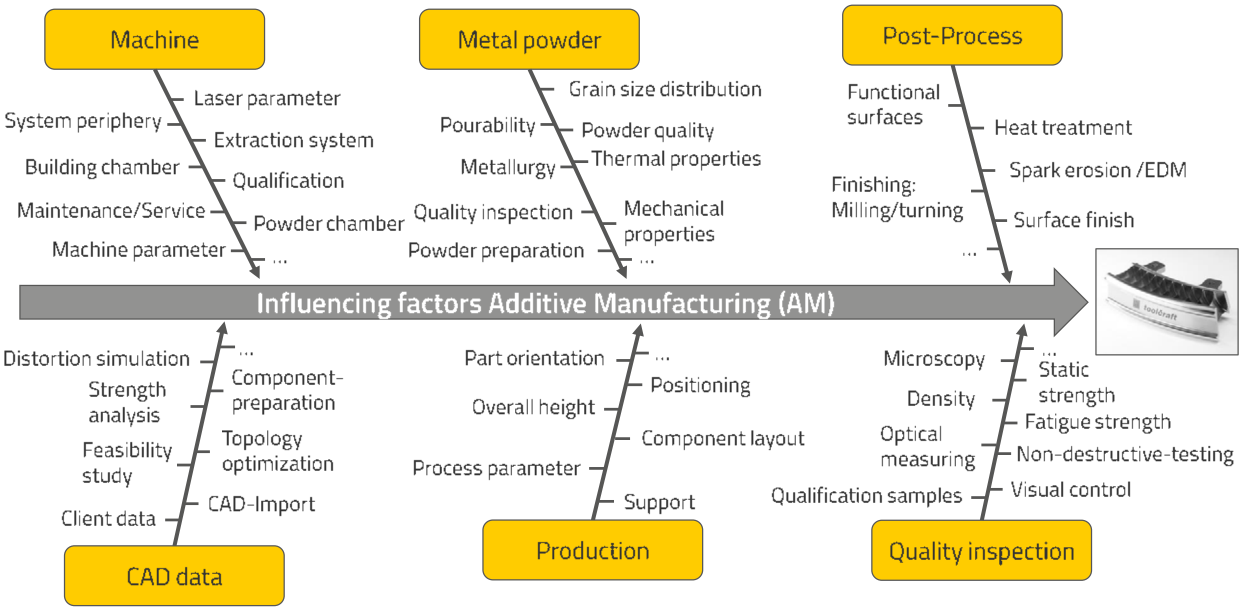

Fig. 3 Toolcraft's Christoph Hauck highlighted the complexity of the AM process chain

The challenges of serial production

The first conference session dealt with the process chain for AM serial production and was opened with a keynote lecture by Christoph Hauck, CEO of Toolcraft, a German-based AM components supplier. Hauck offered insights into the challenges and changes posed by such a complex and rapidly evolving technology (Fig. 3), along with a new application case study.

This was followed by two presentations from Emmanuel Muzangaza, Manufacturing Technology Center (MTC), UK, and Philipp Bruckbauer, Airbus DS, Germany, which showed the numerous hurdles and steps involved when parts are qualified or new materials implemented into the aerospace industry's process chain.

All three speakers highlighted that the current absence of universal standards for AM complicates the process of qualification in general. Today, numerous extensive physical tests have to be carried out that take material, part and process into account. Particularly in the early stages of development, where simple samples such as tensile specimen and elementary geometries are built, no specifications are defined. The result is that a broad field of tests must be undertaken, since the influences in the process are so numerous.

Understanding both the material science and the technology behind metal AM is essential to ensure that materials are safe, reliable and durable. Nevertheless, the involvement of different industries and, therefore, the development of robust and meaningful standards would be of benefit to the whole Additive Manufacturing community.

AM and lightweight design

The second conference session dealt with lightweight design and how Additive Manufacturing is influencing this field. This session was opened with a keynote presentation by Dr Jens Telgkamp, Head of Additive Manufacturing Research & Technology at Airbus Operations GmbH, Germany, who outlined the usage of Additive Manufacturing at Airbus.

A presentation by Michael Süss, from the Technical University of Dresden, then gave a good overview of the influence of parameters and material on optimisation algorithms. His talk was based on the well-known FCRC-Bracket, and showcased the results of the latest optimisations and how this would change if the material was not Ti-6Al-4V but, for example, an aluminium alloy. He also pointed out how important the right boundary conditions are. For the FCRC bracket, for example, the real failure load was nearly four times higher than the one predicted in 2012. With optimised algorithms, a version of the bracket was created that was 75% lighter than the original machined bracket, significantly exceeding that of the previous 13% weight reduction.

Many participants were impressed by a presentation from Dr Moritz Maier, ELISE GmbH, Germany, who spoke about the company's development of 'technical DNA', an algorithm that automatically develops sophisticated geometries based on defined boundary conditions. Unlike regular algorithms, 'technical DNA' is able to generate numerous different designs for a fixed loading condition within

Fig. 4 Tim Domagala, Materialise, Belgium, presented a case study on the AM of parts for a two-mirror telescope used on satellites (Image ©TNO)

minutes, each optimised to another 'secondary boundary condition' such as necessary support volume during build up, mass, overhanging surfaces, etc. This development is reported to enable a drastic reduction in iterative costs by up to 99% compared to standard development methods.

The session was closed with a talk by Klaus Hoschke, Fraunhofer EMI, Germany, which dealt with the enhancement of robustness and damage tolerance in lightweight structures. For this, EMI researchers have introduced mesostructures where functional lattices replace bulk material. Furthermore, the concept of failsafe designing was taken into account, and it was concluded that an optimised structure should focus more on robustness, rather than on stiffness alone. Additionally, mesostructures can effectively improve the reduction of stress concentrations.

Testing and quality assurance

In the third session, Part Testing and Quality Assurance, Evangelos Chatzivagiannis, MTC, UK, drew the audience's attention to the challenges posed by the quality demands of the aerospace industry when dealing with Additive Manufacturing. One of the main points of the presentation was that aerospace standards for Additive Manufacturing are today well-developed but heavily overlapping, and that understanding common requirements will help suppliers. Furthermore, a wide range of equipment is currently needed for new product introduction, some of which is quite expensive.

Tim Domagala, Materialise, Belgium, followed with the presentation of a case study on the AM of parts for a two-mirror telescope, an optical instrument used on satellites (Fig. 4). Here, the main challenges were the required geometric accuracy, the need to withstand heavy vibrational and shock loads during the start of the carrier rocket's launch, and the surface treatment of complex inner structures. To prove the quality of the otherwise inaccessible surfaces after post-processing, a second part was generated which could be opened. The project members are confident that they will have a TRL5 demonstrator by the end of the project.

Vibrational loads, in the broadest sense, were also addressed in a talk given by Prof Dr Gianni Nicoletto from the University of Parma, Italy. His topic was fatigue testing aimed at the qualification of metal parts produced by LB-PBF. Since Additive Manufacturing can be quite expensive, due among other factors to the high cost of metal powders, an investigation was carried out with 'mini specimens'. It was shown that specimens with dimensions of

22 x 7 x 5 mm, with a round notch with r = 2 mm in the middle, generated in different orientations, lead to fatigue results comparable to regular-shaped specimens. Additionally, the influence on fatigue of different surface treatments, compared to the as-built surface, was determined.

Maximilian Raab, APWorks GmbH, Germany, spoke on the plasma electrolytic polishing of complex Ti-6Al-4V parts and its geometric applicability. A complex test specimen showed various different surface situations, most of which could be satisfactorily polished. However, he reported that small features of less than 0.5 mm tended to disappear during polishing.

In the last presentation of the session, Tim Wischeropp, Fraunhofer IAPT, Germany, spoke on 'Six Sigma Methodology for Increased Process Stability in AM.'. This method was developed in order to optimise a process with numerous parameters without exceeding the number of necessary experiments. Several participants were very pleased to see that this method had found its way to the Additive Manufacturing industry.

Fig. 5 A highlight of day one was a panel discussion with experts from various fields of metal Additive Manufacturing

Panel discussion: 'The effects of defects,' future challenges and new opportunities

One of the highlights of day one was a panel discussion at the close of the sessions. Here, experts from various fields of metal Additive Manufacturing participated in a discussion moderated by Dr Jens Telgkamp, Airbus, Germany, and Joerg Sander, Hensoldt Sensors, Germany. The members of the panel were Dr Remedios Carmona, Airbus, Germany, and Dr Guy Larnarc and Dr Raphael Salapete from Ariane Group, France, who together represented the OEMs.

The supply chain industries were represented by Joachim Zettler, APWorks, as well as Gerd Weber and Dr Joachim Schmidt, both from Premium Aerotec. A research-oriented perspective was provided by Prof Dr Christoph Leyens, a Professor at Technical University of Dresden (GER) in the field of Materials Science and Director of the Fraunhofer Institute for Material and Beam Technology (IWS), and Prof Dr Vasily Ploshikhin, a Professor at the University of Bremen in the field of Additive Manufacturing Simulation. The final participant was Volker Thum, Managing Director of the German Aerospace Industries Association (BDLI).

The discussion of problems and challenges between the panel members led to a topic which could be called 'the effects of defects.' Questions asked by the panel included: What circumstances cause what kind of defects? Which defects are causing problems and which are tolerable? And do we really need the 'perfect' part?

To answer these questions, a better and more sophisticated understanding of the material science at play in Additive Manufacturing is necessary. As Prof Leyens stated, "In other technologies, mankind needed thousands of years to come to where we are today, and Additive Manufacturing has just started."

It is important to recognise at this stage the impressively high technological level that has already been reached in this field. But in general, it is recognised that people still need to gain more trust in the technology. In conventional manufacturing methods such as casting or machining of sheet metal, one finds defects such as pores, anisotropies in the material properties and distortions, but 'no one cares' - or rather, these things are taken into account throughout the whole process chain.

In Additive Manufacturing, on the one hand, engineers and designers have only little experience; on the other, topics such as pores, surface roughness and fatigue are handled with great care. One of the major tasks for the industry is to gain a deeper understanding of aspects such as the influence of specific primary and secondary process parameters and post-processing steps on material properties. It must also be clarified which post-processing steps are really necessary: for example, is a heat treatment step needed in addition to a HIP-process to guarantee that the part will be as expected, and how can a certain quality be guaranteed?

The last point in particular addresses machine manufacturers, as it is recognised today that two different machines may not produce parts of the same quality.

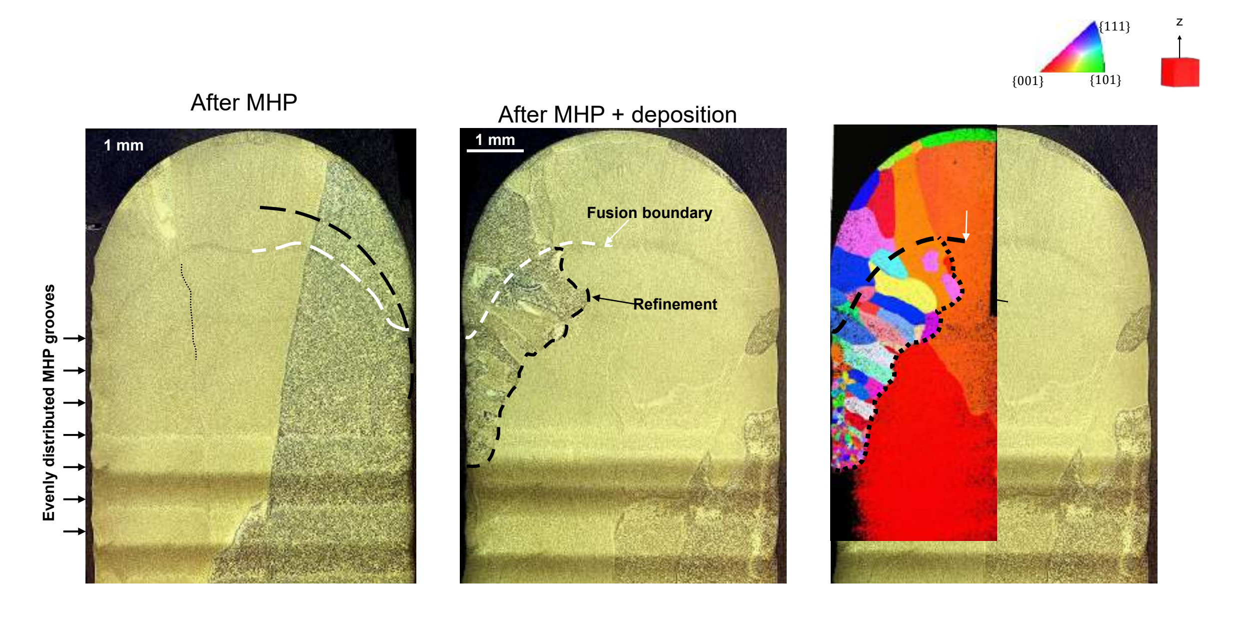

Fig. 6 Jan Roman Hönnige, Cranfield University, UK discussed spatially tailored mechanical properties in Ti-6Al-4V wire-arc additively manufactured components. The tailoring of mechanical properties was achieved by rolling and, in a second approach, machine hammer peening to increase surface hardness

This fact is rather unique in Additive Manufacturing technologies and a big hurdle on the way to (effective) serial production. The reason for this is that Additive Manufacturing not only produces a part, but the material as well.

Furthermore, most of the materials that are today used in AM are not designed for the AM process. Instead, they have their origin in die or investment casting, meaning that some alloying elements in the used powders exist to improve on the casting process, but may be useless for laser, electron-beam or arc-based Additive Manufacturing processes.

Scalmalloy® (AlMgSc) is an example of a material developed specifically for metal Additive Manufacturing and, according to Zettler from APWorks, "This material is really shaping business cases." In Laser Beam Powder Bed Fusion, this alloy forms an excellent microstructure and therefore has very good mechanical properties. This leads to a high potential, for example, in sophisticated lightweight structures, enabling the effective usage of this technology where profitable business cases are possible.

"...most of the materials that are today used in AM are not designed for the AM process. Instead, they have their origin in die or investment casting, meaning that some alloying elements in the used powders exist to improve the casting process..."

In general manufacturing scenarios, business cases are hard to create when Additive Manufacturing technologies are used to replace conventional ones. Weight reduction, and thereby mass reduction, in combination with function integration is an important aspect of improving economic competitiveness. Combined with a material which is optimised for additive technologies, the benefit can be maximised. However, while key to the future of AM, the development of optimised materials from scratch is a long and costly procedure. A suggested approach for short term applications is, therefore, to tailor existing alloys to the specific process and application required.

In addition to exploiting the full competitive advantages of AM in terms of geometric freedom and functional integration, the concept of the 'digital spare part' can offer a very lucrative business model. In the automotive industry, for example, countless different spare parts exist for hundreds of vehicle types and models. Today, a lot of money is spent on the storage and logistics of such spare parts. With further improvements to AM technology, the way spare parts are handled, stored and produced could completely change.

While the automobile industry is one offering very large volumes of parts, the space industries part quantities are smaller by orders of magnitude. However, in rocket applications such as the Ariane 6 project, Additive Manufacturing is enormously decreasing lead times – especially during the development phase. This is one of the major aspects that will help the Ariane Group to compete against organisations such as SpaceX.

For large scale parts, it may be more likely that wire-based AM technologies will prevail over powder-based technologies. Today, powder deposition / powder-based Directed Energy Deposition (DED) technologies are already being used to add features to existing structures. This adding of functionality increases the competitiveness of otherwise conventionally manufactured parts, and these hybrid methods are established technologies that are used in turbine engines today.

Fig. 7 Prof Dr Christoph Leyens, Technical University of Dresden & Fraunhofer IWS, speaking at AMA2018

Hybrid processes, high production rates and digital security

The second day of the conference opened with a series of keynote lectures by Prof Dr Christoph Leyens, Technical University of Dresden & Fraunhofer IWS, Dr Claudio Dalle Donne, Airbus, Germany, and Georg Fischer, Gefertec, Germany. They talked about the possibility of adding features to existing structures, enabling the cost- and material-efficient production of complex rocket engine parts.

Demanding materials such as nickel-based alloys were also discussed, and the concept and potential of Directed Energy Deposition technology was presented in detail, including gas shielding when manufacturing titanium and the potential for manufacturing large parts using DED - first from the researcher's point of view and then from the perspective of an OEM and from the supply industry.

High production rate technologies were also addressed, commencing with a presentation by Jan Roman Hönnige from Cranfield University, UK. This presentation discussed spatially tailored mechanical properties in Ti-6Al-4V wire-arc additively manufactured components, and the according process integration. This tailoring of mechanical properties was achieved by rolling and, in a second approach, machine hammer peening. Using this method, it was possible to achieve recrystallisation of the surface and increase the surface hardness (Fig. 6).

A two-scale approach for the faster prediction of part distortion in Directed Energy Deposition processes with the goal of dealing with large-scale components was presented by Dr Fabien Poulhaon, ESTIA, France. This approach is based on the inherent strain method, known from welding and powder bed Additive Manufacturing simulations. Results from simulations like this can be used to calculate necessary oversizes for machining. The last talk in the session was held by Dr Thomas Gilles from IRT Saint Exupéry, France., who presented work undertaken on processing maps for DED processes, as well as giving a detailed overview about the influence of key process parameters.

In the final session of the conference, digital topics around Additive Manufacturing were addressed. The first talk of this session was given by Scott Zimmerman, Concurrent Technologies Corporation, USA, on cybersecurity. This topic in general is very important in the field of Additive Manufacturing and Industry 4.0, for example when dealing with the concept of digital spare parts or the 'digital twin'.

One of the most important points was that all levels of personnel in an organisation must be trained to avoid security weaknesses. Alexander Morrison, MTC, UK, spoke about the data framework for Additive Manufacturing, approaches to handling the large amount of generated data and how this can be used as a 'learning

Fig. 8 The AMA conference provided numerous opportunities for networking as well as learning

factory', based on the current, public funded project DRAMA, which aims to lead, among other things, to decreased risks when starting with Additive Manufacturing technologies by creating a 'decision support system' (DSS).

The final two presentations of the conference were given by Dr Patrick Mehmert, Simufact Engineering GmbH, Germany, and Dr Enrique Escobar di Obaldia, Ansys Germany GmbH, who highlighted the latest developments in the field of Additive Manufacturing simulation and how it can be used, for example, to compensate process-specific distortions or identify 'hotspots' during the build process.

Conclusion

What is clear from this year's conference is that we have barely scratched the surface in terms of our understanding of the full potential for AM in aerospace and space. Beyond the technology's major advantages such as lightweighting, the integration of functionality into a single part - significantly reducing manufacturing steps - is proving to be one of the great advantages of AM. This alone has the potential to drive innovation across the aerospace industry.

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Euro PM2018: The influence of powder characteristics on processability in metal Additive Manufacturing

Technical papers presented at the Euro PM2018 conference, organised by the European Powder Metallurgy Association (EPMA) and held in Bilbao, Spain, October 14-18, 2018, addressed issues related to the influences of chemical contamination and powder characteristics on processability in metal Additive Manufacturing. In the following report, Dr David Whittaker reviews four presented papers that touched on each of these issues.

EURO PM2018 CONGRESS & EXHIBITION

Framework development for the cleanliness assessment of metal powders for use in Additive Manufacturing

A contribution from Cameron Blackwell, Steven Hall, Jason Dawes and Nick Brierley (The Manufacturing Technology Centre (MTC), UK) described the development by the MTC of a framework for the cleanliness assessment of metal AM powders [1]. To date in AM, research has been largely focused on both improving the AM process itself (reducing production time and introducing in-process monitoring, for example) and on the post-processing of AM components and subsequent validation and testing of processed components. Until recently, less focus has been placed on the analysis of the material input, with little thought given to the assessment of cleanliness. At present, there are no established methods for the assessment of powder cleanliness and the task remains non-trivial.

As AM machines and auxiliary equipment move further towards closed loop systems throughout the component production chain, the ability to assess the cleanliness of metal powders becomes more pertinent. Chemical contamination of a powder batch can occur during all stages of its lifetime. There are common types of contamination that occur during specific stages and these are detailed in Table 1.

Whilst standards exist to analyse the cleanliness of components manufactured by PM processes, there are currently no standards to assess the cleanliness of metallic powders. Methods commonly used to assess powder cleanliness currently include

Fig. 1 Euro PM2018 took place at the Bilbao Exhibition Centre, BEC (Photo © Andrew McLeish / Euro PM2018)

Contaminant	Common stage of introduction	Common origin causes	Approximate size range
Refractory materials	Powder production	Processes that use crucibles, nozzles or tundish filters - in-process touching can induce stripping of material [5]	µm - mm
Steels	Powder production; AM operation	High temperature powder impinging on atomiser walls can strip material, atomisers are often made from stainless steel; From deterioration of base plates and build chamber during builds	µm - mm
Alloy cross-contamination	Powder production; Handling; AM machine operation	Inadequate cleaning between powder uses; Cross-contamination due to powder recycling methodology and improper cleaning	µm
Raw material contamination	Powder production	Impure raw material	< µm - µm
Polymer material	Handling	Degradation of container materials e.g. bags, seals, brushes, sieves, and introduction into bulk	µm - mm
Biological containment	Handling	Powder left open to environment due to improper storage conditions	µm - mm
Al-Si-O fibrous materials	Handling	From degradation of container materials, such as rope seal	µm - mm
Oxide film	Handling; AM machine operation	Formation after improper storage and handling; Non-optimised running conditions leading to formation of oxide layer	< µm - µm
Morphological contaminants	AM machine operation	After multiple recycles agglomerates can build up and shards can be produced by sintered power	µm
Brass	AM machine operation	Material breakdown due to wear and tear and introduction into bulk	µm

Table 1 Typical contaminant types found in metal powders and their common origins [1]

optical microscopy, scanning electron microscopy and various chemical analyses.

Standard analysis of powder cleanliness can primarily focus on interstitial ingress into the powder chemistry. The oxygen, nitrogen, carbon, hydrogen and sulphur levels within a powder are commonly analysed as part of other testing for quality assurance. Testing is commonly performed using Inert Gas Fusion – Infrared and Thermal Conductivity Detection (IGF), alongside Induction Coupled Plasma – Optical Emission Spectroscopy or Mass Spectroscopy (ICP-OES or ICP-MS) for the analysis of other elements. However, as these techniques require prior selection of elements to be analysed, they cannot be used in isolation to determine cleanliness. Due to this, these analyses only provide definition of chemical variance from the nominal composition and, as such, do not provide information on foreign material contamination or information on the potential origin of the contamination.

Further to these chemical analyses, it is common to assess powder cleanliness via visual inspection or optical microscopy. This allows contamination to be categorised by its size, shape and colour. This analysis is often complemented by analysis using Energy Dispersive X-ray Spectroscopy (EDS) on an SEM. This provides analysis of size, shape and chemistry, key factors in determining the potential severity of the presence of a contaminating particle in a powder batch. A number of organisations have begun to use automated SEMs to not only identify contamination occurrences in metal powders, but also quantify the level (semi-quantitatively) of contaminating particles present in a powder batch. The use of an automated SEM allows a standardised cleanliness assessment method to be developed, which is operator-independent.

Sampling methodology is dictated by the total amount of the material to be represented and subsequently influences the sample size. Sample size is further defined by the analysis technique used to interrogate the material, as this presents a limit to the amount of material analysed due to issues of practicality and detection resolution. Due to the potentially catastrophic nature of a minute amount of contamination in a powder being used within PM applications, and the spatially localised nature of contamination, a limited sample size is not desirable when performing cleanliness assessments. However, considering the size range of potential contamination as detailed in Table 1,

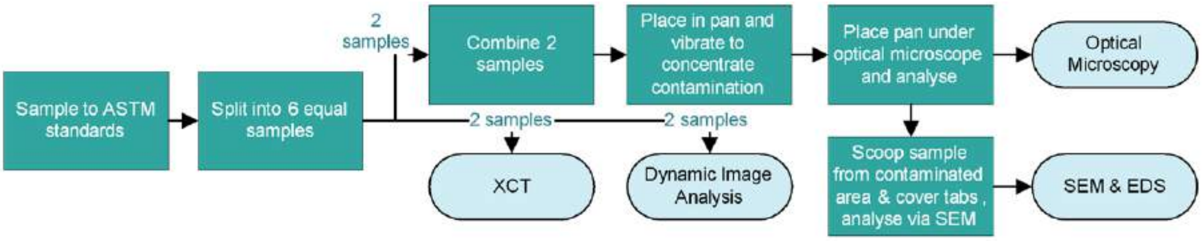

Fig. 2 Proposed workflow for large sample cleanliness assessment [1]

	Increasing detection limits and sample size →			
	SEM & EDS	**Optical Microscopy**	**DIA**	**XCT**
Est. minimum contaminant size	< 1 µm	≈ 10 µm	≈ 10 µm	≈ 30 µm
Surface area / mass scanned per sample	< 1 g / ≈ 2 cm^2	150g / ≈ 100 cm^2	25 g	40 g
Contaminant identification method	Morphology, chemistry	Morphology, visible colour difference	Morphology	Radio-density (chemistry & density)

Table 2 Suggested operating parameters for large sample cleanliness assessment as used in the analysis within the reported study [1]

a high level of detection resolution is needed to capture all types of possible contamination. In order to circumvent these two conflicting concepts, metallic powder cleanliness assessment should use a variety of techniques in order to assess the full range of potential contamination occurrences, whilst still analysing a relevant and practical sample size.

Developed from knowledge gained from the study of many metallic powders for AM and considering the need for a larger sample size for analysis, the reported study has sought to understand the current capability of cleanliness assessment using large sample sizes. The MTC has proposed a workflow, detailed in Fig. 2, using optical microscopy (OM), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDS), dynamic image analysis (DIA) and X-ray Computed Tomography (XCT). Table 2 defines basic operating parameters for each of these analyses. This assessment should be performed alongside other powder characterisation analysis, such as size, shape, flow and chemistry analysis, using ICP-OES and IGF for instance, for overall chemical specification and performance validation.

To maximise the value of these cleanliness analyses, a comparison must be made between different analyses and samples using a global classification system. Using such a system allows a comparative level assessment to be made of each contamination type, providing a framework for future cleanliness and quality assurance assessments. The system that the MTC has proposed, as detailed in Table 3, classifies contamination based upon its chemistry and its morphology. It is important to make both levels of distinction as both give insights into the origin of the contamination. An example of this would be finding stainless steel foreign metallic contamination. If this were spherical, this raises the possibility of alloy cross-contamination occurring sometime within the powder lifecycle; however, if it were

Contaminant class									
I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**
Contaminant category									
Biological/polymer materials		Ceramic		Foreign metallic		Bulk non-conformance		Bulk surface non-conformance	
Highly elongated	Irregular	Highly elongated	Irregular	Spherical	Irregular	Elongated	Irregular	Surface contamination	Surface oxide

Table 3 Proposed contamination classification system [1]

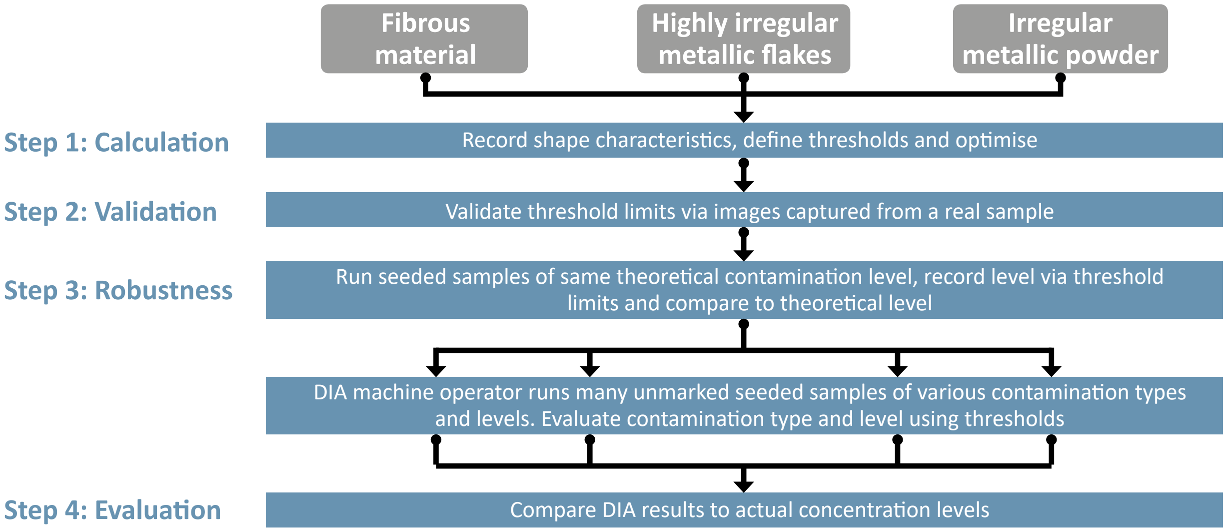

Fig. 3 Workflow used to develop threshold limits for use in DIA contamination assessments [1]

an irregular shard-like particle, then this may be due to degradation of the atomiser or AM machine components.

The reported study did not look to provide contamination severity levels, but rather to put forward a proposed classification system to allow the assessment of comparative levels of various contamination types. Significant further work is needed to compute severity levels, which should take into consideration contamination type and size, and which would vary in accordance with alloy and component end-use sector.

SEM/EDS is the key analysis technique for the system, although this is closely linked to optical microscopy, due to the sampling methodology used in the workflow. OM analysis allows the identification of contamination based on size, shape and colour. In order to capture all contamination within a large sample, the authors have suggested that the powder be placed in a wide tray and, using a vibratory and rotating sifting action, contamination will segregate and concentrate in one area given sufficient sifting time. The area surrounding the area of concentrated contamination is where OM analysis should be conducted, the concentrated area sitting centrally within it, and all contamination occurrences imaged and mapped. Once OM analysis has been conducted, the powder in the concentrated area should then be loaded onto an SEM stub for manual or automated analysis. Contamination should first be identified by either a contrast difference to the bulk material in the electron-backscatter image, or by a variation in morphology. Each contamination instance should then be imaged (to a practical extent for contamination classes VII and VIII (Table 3)) and chemical analysis should be performed via EDS.

Dynamic image analysis (DIA) is currently used to perform size and shape analysis of particulate material. Given its evaluation of shape, it was chosen as a detection technique for the assessment of contamination based on morphological differences from the bulk. DIA allows the assessment of a large powder sample (Table 2) in a fast and automated way. In order to do this in an automated fashion, there is a level of development needed. DIA machines record particulate shape characteristics using various measurands, e.g., sphericity, aspect ratio and convexity amongst others. A user can specify shape characteristic threshold limits, which can be used to automatically calculate the volume percentage of material between these limits. If a user develops threshold limits using size and shape characteristics unique to different contamination types, an automated detection and calculation of comparative contaminant level may be developed. It is important to note that standard two-camera based systems do not provide a user with an explicit number of contamination instances within a sample due to the counting algorithms used to correlate measurements between the two cameras. However, these data can still serve to provide comparative level assessments between samples.

To develop shape characteristic threshold limits, the MTC has undertaken work as detailed in Fig. 3, using three samples with different morphological properties to simulate highly elongated, highly irregular and irregular contamination occurrences, and was able to develop threshold limits to define highly elongated and highly irregular particles. Using the thresholds developed, the MTC was able to automatically semi-quantitatively assess the level of contamination classes I-VI. DIA is now used in conjunction with OM and SEM-EDS to corroborate findings to a larger scale sample size.

The use of X-ray Computed Tomography has been explored for cleanliness assessment of powder feedstocks as a complementary technique allowing larger sample characterisation compared with SEM. The MTC study was therefore to look at the use of polychromatic XCT with a large sample for the analysis of a known possible contamination within powder. A known example of possible

Sample name	Virgin powder	Controlled contamination		Possible contamination source
		Type	Quantity [wt.%]	
MS1_Ti64	MS1	Ti64	0.5	Contamination through sieving equipment, tools, gloves or AM machine that are previously used with Ti64
MS1_Oxi	MS1	TiO_2, Al_2O_3	< 0.5	Production batch with titanium oxide and aluminium oxide inclusions
Ti64_MS1	Ti64	MS1	0.5	Breakage of the steel recoater blade or contamination from AM machine
Ti64_ZrO_2	Ti64	ZrO_2	0.5	Breakage of ceramic recoater blade

Table 4 Type and amount of controlled cross-contamination [2]

contamination was that of tungsten particles found within Ti-6Al-4V. These contamination instances are a similar size to those of the bulk material and so an analogous tungsten alloy powder of size range < 75 µm was mixed into 40 g of Ti-6Al-4V powder in a split sample arrangement. Such samples were scanned in a set-up that produced a 22.5 µm voxel size. Contamination occurrences were identified by eye and, for each, a Region Of Interest (ROI) volume was selected manually. The volume was then extracted for size analysis. This manual analysis could be automated; however threshold levels need to be developed and so, for the reported study, manual analysis was used. The extracted volumes were then compared to the associated size fraction of the tungsten powder to assess applicability of the use of large scale samples in this system. The measured size of contaminant, in fact, correlated well with the sieved size fraction of powder and therefore this set-up shows promise for the identification of tungsten contamination in Ti-6Al-4V in a large sample sizes with regard to contaminant size analysis.

The authors' overall conclusion was that the proposed contamination assessment framework should be developed in order to perform cleanliness assessments of metal powder. A holistic approach, using various measurement technologies, must be applied to perform a full assessment of metal powder cleanliness, due to the variety of contamination sources, measurement sample sizes and detection limits.

The demonstrated technologies that currently show promise for cleanliness assessment are optical microscopy, SEM-EDS, DIA and XCT. Cleanliness severity levels for each contamination type, alloy and component end-use sector must be developed within the wider scientific and industrial community.

Development of a reliable method for contamination detection in raw metal powders for AM

A second paper continued on the theme of contamination detection in raw metal powders for Powder Bed Fusion (PBF) AM. This paper came from an Italian academic consortium comprising Eleonora Santecchia, Paolo Mengucci and Gianni Barucca (Universita Politecnica delle Marche), Andrea Gatto, Elena Bassoli and Lucia Denti (Universita di Modena e Reggio Emilia) and Federica Bondoli (Universita di Parma) [2].

Currently, major technical limitations for metal AM relate to the lack of specific qualification standards for AM parts and feedstock materials. Raw powders for Additive Manufacturing are subjected to potential contamination through the full supply chain, from production to the storage and usage (AM) steps. In the reported study, the challenge of cross-contamination detection in feedstock powder materials was addressed. Various scenarios of contaminants and contamination sources during the production and sintering processes were taken into account and batches of two powders, having the typical compositions of Ti-6Al-4V (EOS Ti64) alloy and maraging steel (MS1) and containing a controlled cross-contamination, were prepared. The contamination was detected using SEM and EDS techniques and a statistical treatment of the collected data allowed quantification of the cross-contamination.

Controlled contamination was introduced to the powder samples following assumptions concerning damage to the PBF equipment (i.e. breaking of the recoater blade), cross-contamination of the powder taking place in the Additive Manufacturing equipment (i.e. the same PBF machine used for different powders) and cross-contamination during powder production or transportation (i.e. sieving equipment, tools or gloves used for different powders). The inspected scenarios are summarised in Table 4.

Scanning electron microscopy observations were performed on a field emission SEM equipped with microanalysis for the energy dispersive spectroscopy (EDS) inspections. Powders were accurately spread and attached on stubs for SEM; three stubs for each cross-contamination condition were characterised.

The chemical compositions of the pure and contaminated powders were checked by collecting three EDS spectra on areas at the same low magnification (200 x), using 20 keV accelerating voltage. Deconvolution of the elemental peaks was used in order to resolve peak overlaps and

	Ni	Co	Mo	Ti	Al	Cr
MS1	17-19	8.5-9.5	4.5-5.2	0.6-0.8	0.05-0.15	≤ 0.5
MS1_Ti64	15.4±0.3	10.8±0.1	3.5±0.2	1.50±0.2	0.05±0.01	0.15±0.03
MS1_Oxi	15.3±0.2	11.2±0.1	3.9±0.2	0.9±0.1	0.06±0.03	0.25±0.06

	Cu	C	Mn	Si	P	S	Fe
MS1	≤ 0.5	≤ 0.03	≤ 0.1	≤ 0.1	≤ 0.01	≤ 0.01	Bal.
MS1_Ti64	0.14±0.06	-	0.08±0.04	ND	ND	0.06±0.04	Bal.
MS1_Oxi	0.11±0.04	-	ND	ND	ND	ND	Bal.

Table 5 Comparison of elemental concentrations (wt.%) in the MS1 samples (pure and contaminated) [2]

	Al	V	Zr	O	N
Ti64	5.50-6.75	3.50-4.50	-	< 0.20	< 0.05
Ti64_MS1	5.4±0.1	3±0.1	-	ND	ND
Ti64_ZrO_2	5.6±0.3	3±0.1	0.3±0.1	ND	ND
	C	**H**	**Fe**	**Y**	**Ti**
Ti64	< 0.08	< 0.015	< 0.30	< 0.005	Bal.
Ti64_MS1	-	ND	ND	ND	Bal.
Ti64_ZrO_2	-	ND	ND	ND	Bal.

Table 6 Comparison of elemental concentrations (wt.%) in the Ti64 samples (pure and contaminated) [2]

quantitative analysis was performed by the EDS software. In order to ease the detection of the contamination particles, the backscattered electrons (BSE) signal was used together with EDS elemental maps. The low atomic weight of Ti- and Al-based oxides, in the MS1_Oxi samples, resulted in a high BSE contrast and, therefore, contaminant particles in these samples were spotted using SEM-BSE micrographs only.

Quantification of contamination was performed by collecting fifty micrographs for each stub and the elemental map for each position, looking for the major contamination element, i.e., Ti in MS1_Ti64, Fe in Ti64_MS1 and Zr in Ti64_ZrO_2.

The scanning electron microscope working parameters were kept constant for all of the investigations and can be summarised as: (i) 60 µm aperture (beam spot), (ii) 500 x magnitude, (iii) 8.3 mm working distance and (iv) 15 keV accelerating voltage. The latter parameter was chosen in order to achieve an optimised balance between the EDS signal and the BSE contrast/brightness for SEM imaging. The contaminant particles spotted on each micrograph/map were counted and a statistical procedure was then applied, in order to define a calculated contamination. Firstly, the frequency of contaminant particles µ is calculated as in the equation:

- µ = Counted Contaminant Particles / Inspected Area

The total area of the stub is known to be 122.6 mm^2. The total contaminant particles (TCP) number on the overall stub area is therefore given by:

- TCP = (µ · 122.6)

Therefore, the calculated contamination (CC) is obtained as the ratio between the contaminant particles and the total number of virgin powders particles on the stub:

- CC = TCP / TOT

The nominal compositions, as well as the EDS quantification results of the data acquired from MS1 and Ti64-based powders samples, are reported in Tables 5 and 6, respectively.

With reference to the MS1_Oxi samples, the average concentrations reported in Table 5 show no remarkable variations that could be linked to the TiO_2 and Al_2O_3 contaminations. On the other hand, the average Ti concentration in the MS1_Ti64 samples is higher compared with the nominal and MS1_Oxi values, suggesting higher concentrations of titanium.

The vanadium concentrations in Table 6 are below the nominal values in all the samples. Despite the same amount (wt.%) of contamination in the Ti64-based samples, no iron was detected or quantified (Table 6) while a clear signal for zirconium, corresponding to 0.3 wt.%, was obtained, as shown in Fig. 4. Here, two representative spectra, collected on areas of the Ti64-based contaminated samples, are reported in the form of de-convoluted peaks with the background already subtracted. While the peak corresponding to the Lα characteristic energy of zirconium is excited by the electron beam (Fig. 4(b)), no peaks related to iron are observed in the Ti64_MS1 spectrum (Fig. 4 (a)). A feasible explanation for this result can be achieved by accounting for the density of the contamination particles under consideration, i.e., 8.0-8.1 g/cm^3 for MS1 and 5.8 g/cm^3 for ZrO_2.

By collecting the elemental map of the major contamination element, namely that with the highest percentage, it is possible to accurately highlight the cross-contamination powder particles. During the first scan, the mapped element is shown on many points of the micrograph, but, when a very high concentration is detected in a certain area, the software uses this information to adjust the detected chemical element amount on the overall frame area.

For the MS1_Oxi samples, the high BSE-signal contrast, given by the very low atomic weight of the contaminant particles, was sufficient to distinguish

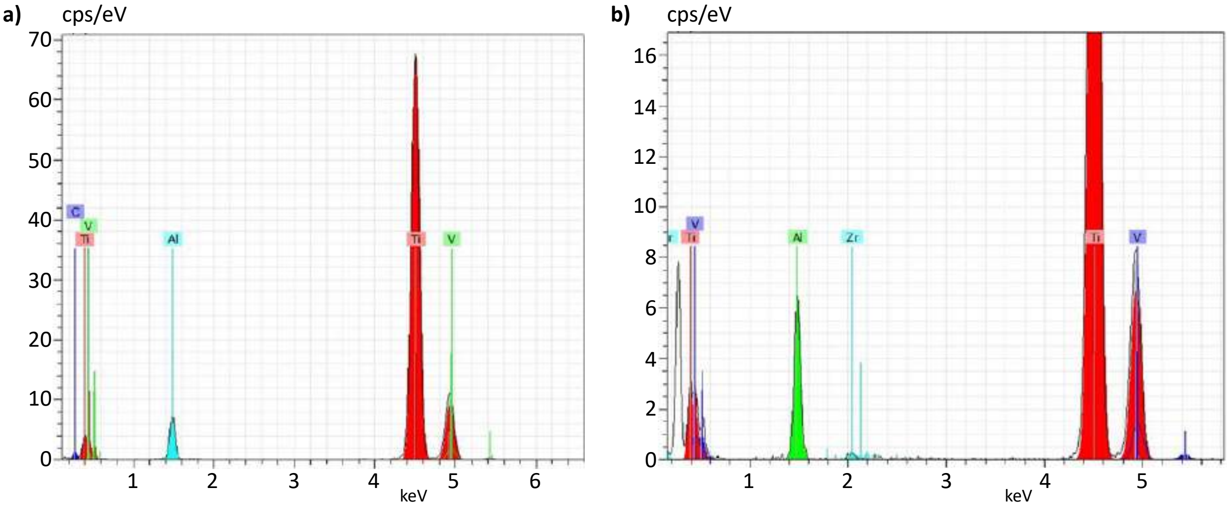

Fig. 4 Representative EDS spectra for the Ti64_MS1 (a) and Ti64_ZrO_2 (b) samples [2]

them from the virgin powders, without the aid of elemental maps. However, the composition of each contaminant particle still needed to be verified using EDS point analysis. The EDS spectrum confirmed that the major elements in the contaminant particles were aluminium, titanium and oxygen. Other unindexed peaks corresponded to Fe, Ni and Mg.

Table 7 shows the average values of calculated contaminations obtained for all the inspected samples. The lowest level of average calculated cross-contamination is given by the samples having an unknown cross-contamination level, or rather MS1_Oxi. Results on specular samples, namely MS1_Ti64 and Ti64_MS1, are of particular interest. The average calculated contamination value of the MS1_Ti64 samples was almost two times higher than that of the Ti64_MS1 samples. Given that the density values of the two virgin powders correspond to 8.0-8.1 g/ cm^3 for MS and 4.41 g/cm^3 for Ti64, in order to obtain the same amount of 0.5 wt.% of cross-contamination, a lower number (approximately a half) of MS1 particles is required. This explanation also justifies the high level of calculated contamination obtained for the Ti64_ZrO_2 samples, as zirconia has a density equal to 5.81 g/cm^3. This larger number of zirconia particles leads to a higher number of nuclei of characteristic X-ray signal generation. This is particularly remarkable for the EDS spectra collected from large areas, or rather those used for the chemical composition quantification (Fig. 4).

Sample	Average Calculated Contamination (10^{-3})
MS1_Ti64	7±1
MS1_Oxi	1.8±0.5
Ti64_MS1	2.7±0.2
Ti64_ZrO_2	6±2

Table 7 Calculated contamination (CC) values obtained for all of the samples [2]

A systematic approach for understanding powder influence in powder bed-based AM

The next paper turned the attention to the influence of powder physical characteristics, as opposed to chemical contamination, on processability in powder bed-based Additive Manufacturing. This paper came from Silvia Vock, Solomon Jacobs, Burghardt Kloeden, Thomas Weissgarber and Bernd Kieback (Fraunhofer IFAM, Dresden, Germany) and Michael Haertel (AM Metals GmbH, Germany) [3].

The reported study introduced an approach for the systematic assessment of powder influence along the process chain. As a first step, a database was evaluated in order to identify suitable characterisation techniques and parameters for the reliable and sensitive detection of powder quality changes. In future applications, the continuously growing database would serve as a source for the predictive modelling of process and part properties, based on measured powder characteristics. It was anticipated that this would pave the way for efficient quality control and accelerate the development of process windows for new powder materials.

The authors proposed that powder can be characterised on different levels. On the one hand, the individual particles can be characterised by their morphology, size distribution, composition (main elements and impurities), moisture content on the particle surface and their individual particle density, for instance. On the other hand, physical properties of the powder describe the collective behaviour of the particle assembly, such as the packing of the particles (apparent density, tap density) and the mechanical behaviour of the particle assembly when it is forced to move (flowability). All of these characteristics contribute to a specific process behaviour represented, for

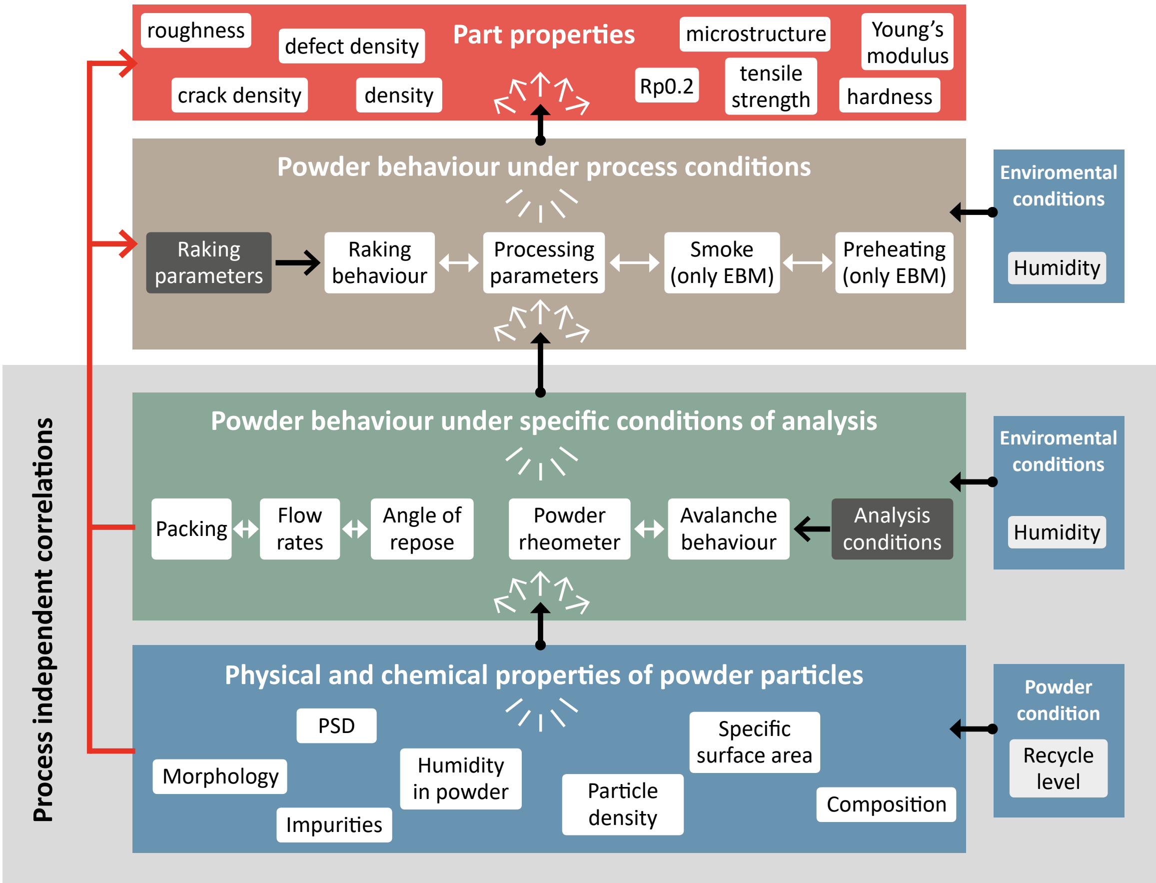

Fig. 5 Schematic of the database, capable of tracking the influence of powder along the PBAM process chain [3]

instance, by the raking quality and the optimum processing parameters (e.g., the necessary volume energy) and finally will translate into the part properties.

In order to be able to track the powder influence along the complete process chain, a comprehensive database must contain all of the significant characteristics of each chain link. The necessary inputs for such a database are schematically shown in Fig. 5.

Also, powder reuse is not a straightforward issue. The powder quality after use can depend on factors such as build time, the heat evolved during the build and the part surface area in direct contact with the powder. Further, an established method for powder recovery includes sieving of powder from the build platform and remixing it with virgin powder, so that there is a sufficient amount of powder for the next build jobs. This procedure is not repeated after each build job, but only when the powder volume drops below a certain limit. It is advisable to allow the operator to classify the powders with regard to how heavily they were exposed during the process (heat, time, contact surface) and how much they are diluted with virgin powder. Ten so-called recycling levels (RL) are defined as classes, ranging from virgin powder (RL=0) to very heavily exposed and more than ten times reused powder (RL=10).

Humidity is an environmental condition, which can affect several parameters describing powder behaviour. Humidity can be measured in the ambient air, but also in the powder itself (e.g., by thermogravimetric methods).

Archiving all of the defined parameters in a single source repository enables the application of meaningful statistical evaluation tools, data mining and visualisation, and facilitates data sharing and comparison with project partners.

Fraunhofer IFAM characterised powders in the database, using both standard and dynamic methods. In relation to standard characterisation, particle size measurements were carried out using a laser diffraction device and apparent and tap densities were determined according to DIN ISO 3923/2 and DIN ISO 3953, respectively. The Hausner ratio HR is the ratio between the tap density TD and the apparent density AD: HR=TD/AD. An HR value close to unity means that the powder cannot be further consolidated and hints towards good flowability. The larger the value, the lower the powder's flowability rating will be. The Hall and Gustavsson flowabilities were measured according to DIN ISO 4490 and DIN EN ISO 13517, respectively.

Dynamic flowability measurements were conducted using an FT4 Powder Rheometer from Freeman Technology. This device measures the rheological properties of powders in an analogous manner to fluid rheometry. Blades are rotated and moved downwards through the powder at a blade velocity specified in the test programme. During measurement, both the vertical force and the torque are detected and the total energy is derived. Based on this, the following parameters can be defined:

- Basic Flowability Energy BFE (mJ): the energy required to move the blades anti-clockwise downwards through the powder, high stress mode
- Specific Energy SE (mJ/g): the energy required to move the blades clockwise upwards through the powder, low stress mode
- Stability Index SI: measure of the energy change after repeated test procedures (down and up movement of the blade)
- Flow Rate Index FRI: measure of the energy change rate, when the blade velocity is varied
- Aerated Energy AE (mJ): flowability energy at a defined air velocity
- Aeration Ratio AR: factor by which the BFE is reduced by aeration at a defined air velocity
- Normalised Aeration Sensitivity NAS (s/mm): measure of sensitivity of the powder to the introduction of air
- Pressure Drop PD (mbar): pressure drop across the powder bed at a defined applied normal stress at a defined air velocity
- Compressibility CPS (%): percentage by which the bulk density has increased with an applied normal stress

To date, the database consists largely of powders for Laser Beam PBF (LB-PBF). The inclusion of the coarser EBM powders has now begun and will continue. The majority of powder types consist of Al-based alloys. Cu-, Ti-, and Fe-based alloys are also included. The powders are available in virgin form and in varying recycling levels.

With the current status of the database, it is possible to address the following queries:

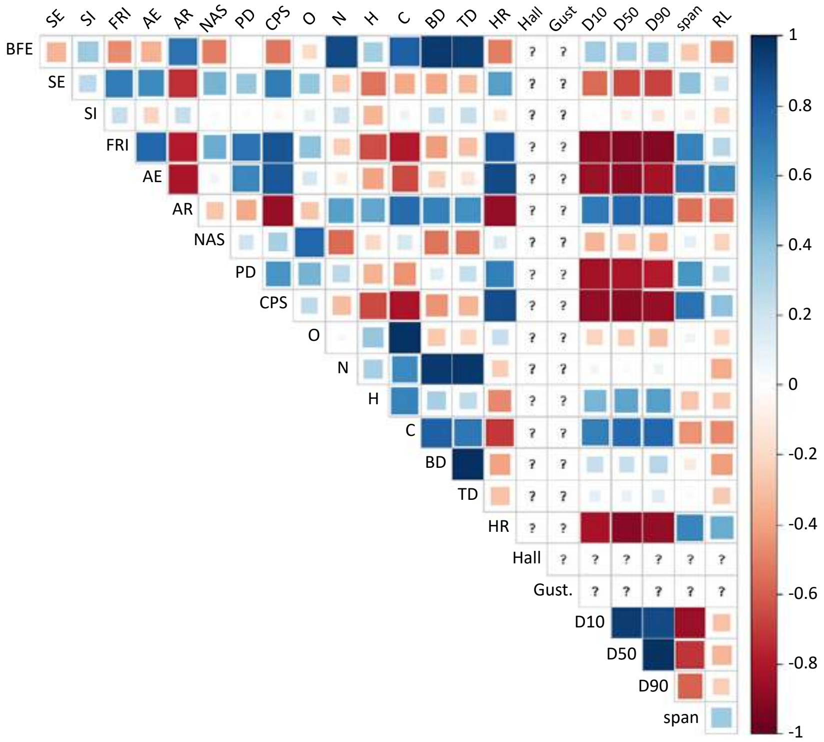

Fig. 6 Correlation matrix for the complete database. The question marks denote where correlation cannot be defined due to an insufficient amount of data [3]

- Which powder characterisation technique and which parameters are most suitable for identifying changes in powder quality?
- How are the measured parameters correlated with one another?
- Which powder characteristics are affected by recycling?

Fig. 6 shows a correlation matrix of the complete database based on the Bravais-Pearson correlation coefficient. The intensity of the colour represents the strength of the correlation, whereas the colouring itself denotes the type, i.e., the sign of the correlation. In the upper (left) part, the rheometer characteristics are shown. In the middle part, the characteristics, as determined by standard analytics, and, in the lower (right) part, the particle properties (D10,D50, D90, span) can be found. The last column represents the powder condition (recycling level).

Focusing on the correlation strength, the plot readily reveals the parameters which are most sensitive to powder quality changes, i.e., variations in D10, D50, D90 and span. In the case of the standard characteristics, strong correlation (correlation coefficient > 0.8) occurs only for the Hausner ratio. Bulk density and tap density show only weak correlation (correlation coefficient < 0.5). Hall flow and Gustavsson flow could only be measured for well-flowing powders; therefore, the available data do not allow for a calculation of the correlation coefficient. In the case of the powder rheometer, the FRI, AE, PD and CPS can be identified as parameters strongly correlated with the powder quality. The basic FT4 Rheometer parameters BFE and SE show only weak (BFE) or medium (SE) correlation with D10, D50, D90 and span. Interestingly, the sign of the correlation is opposite for these two parameters. A physical explanation for this could be that more cohesive and thus loosely packed powders are more easily moved during the downward movement of the rheometer blades. In the case

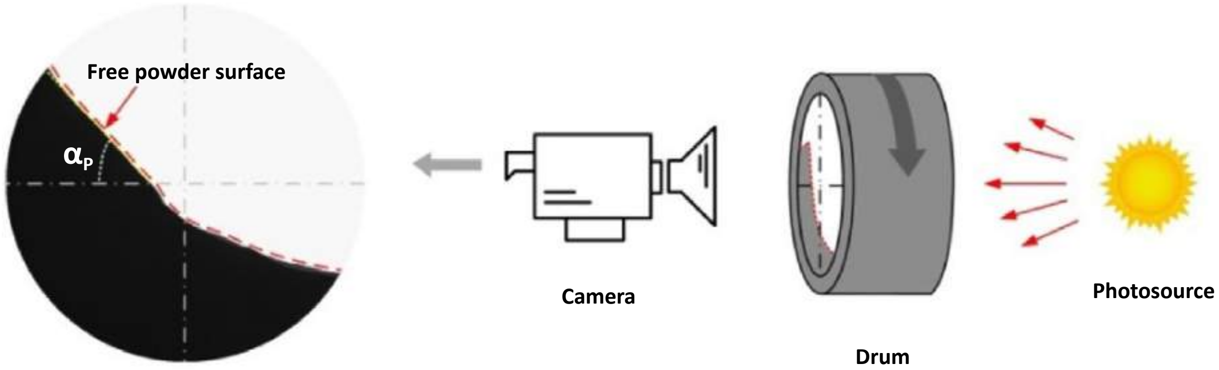

Fig. 7 Schematic of the GranuDrum™ technique [4]

of the SE measurement, the blades move upward and the energy needed for powder displacement is mainly influenced by the cohesive forces between the powder particles rather than their packing properties.

The correlation between measured parameters and the recycling level RL shows only weak to medium correlation (0.2–0.65) in all cases. This points either towards negligible effects for the given RLs in the range of 0-5 or to the fact that other parameters have to be included in order to reliably judge the recycling effect on powders, e.g. humidity in the powder.

As the volume of data in the database increases, further tasks will be addressed in future:

- Modelling the relationship between particle properties and powder behaviour (regression analysis) to allow for the prediction of particle size distributions from given rheometer data
- Pattern recognition: Are powder morphology variations reproduced by a combination of parameters? How are batch-to-batch variations condensed in the database?
- Including process and part characteristics to allow for a prediction of part properties based on process and powder properties

Static and dynamic characterisations of IN625 powder for Powder-Bed Fusion application

The final paper, from Kewei Li, Amy Nommeots-Nomm, Jose Muniz-Lerma and Mathieu Brochu (McGill University, Canada), also addressed static and dynamic characterisations, in this case for IN625 powder for Powder-Bed Fusion AM [4].

All powder-bed fusion processes rely upon the distribution of thin layers of powder feedstock with a thickness typically ranging between 20 and 60 µm. An ideal powder would easily spread across the powder bed, resulting in a uniformly distributed layer with a high particle packing density. Research has shown that the particle size distribution and inhomogeneities within the powder layer can influence the melt pool dynamics during processing and can result in defects in the parts being built.

To obtain thin powder layers with high packing density, there is a tendency to use as fine powders as possible. The utilisation of fine powders is beneficial to the printing resolution and the reduction of incomplete melting of previous layers. This can minimise thermal distortion and pore defects and thus result in products with low surface roughness and high dimensional accuracy. However, fine powders tend to agglomerate due to the occurrence of inter-particle forces such as Van der Waals attractive force, gravitational force, cohesive force and liquid bridges. The resulting effect of such inter-particle forces is the reduction of powder flowability due to the formation of large aggregates.

It is known that powder flowability decreases with reducing particle size. This is not only due to the agglomeration behaviour, but it is also postulated that both moisture and surface chemistry affect both static and dynamic behaviour.

A knowledge gap exists in the relationship between moisture and finer superalloy powders. Thus, quantitative studies and comprehensive theoretical insights into the particle surface chemistry, surface energy and surface roughness effects are still lacking.

To gain an insight into these issues, a newly developed semi-automatic experimental set-up was employed to understand the dynamic behaviour of IN625 superalloy powder. This tool mimics the powder flow during a powder raking step by subjecting the powder to dynamic flow via a rotating drum. In the current paper, special attention was paid to the investigation of the effects of moisture and surface chemistry on the flowability of IN625 nickel-based superalloy powder.

Argon atomised IN625 powder left in an AM system's powder storage container for 90 days and named 'as-received powder' was used as the starting material in the current study. Its particle size distribution was measured by laser diffraction. The spherical particles had a size distribution between 22 µm (D_{10}) and 45 µm (D90) with mean volume diameter around 30 µm (D50). Although most of the particles were spherical in geometry, a small content of non-spherical particles could be visually identified. The majority of these were caused by fine spherical particles attaching to the large spherical particles during production to form satellites.

Two batches of the as-received powder were dried at 200°C for 1 h in a vacuum (termed vacuum dried powder). One batch of the dried powder was then spread in a large pan with thickness of ~0.5 mm and left in air with humidity of 23% for 6 days (termed 23% RH powder). The other batch of dried powder was kept in a glass container settled in a 0% humidity incubator (termed 0% RH).

The dynamic flowability of the powder presented in this work was determined using the GranuDrum™ from the company Granutools. The testing device is composed of a horizontal aluminium cylinder of diameter D=84 mm and length L=20 mm with coated glass side walls. The drum is half-filled with 50 ml of powder. The cylinder rotates around its axis at a dictated angular velocity ranging from 2 to 20 RPM. To perform the measurements, a CCD camera was used to capture images of the surface of the powder at different times, as shown in Fig. 7. For each angular velocity, 50 images of the rotating drum are recorded at 0.5 second intervals. The positions of the air/powder interface are measured by inbuilt image processing software and analysed. The average air/powder interface position and the fluctuations around this average position are computed. With the fluctuations of the interface, the standard deviation σf can be calculated and this is denominated as cohesive index. The avalanche angle (αP) is the angle of a linear regression of the free powder surface as shown in Fig. 7. The cohesive index and avalanche angle are directly related to the flowability of the powder inside the drum. The flowability measurements were repeated three times and the average values are presented.

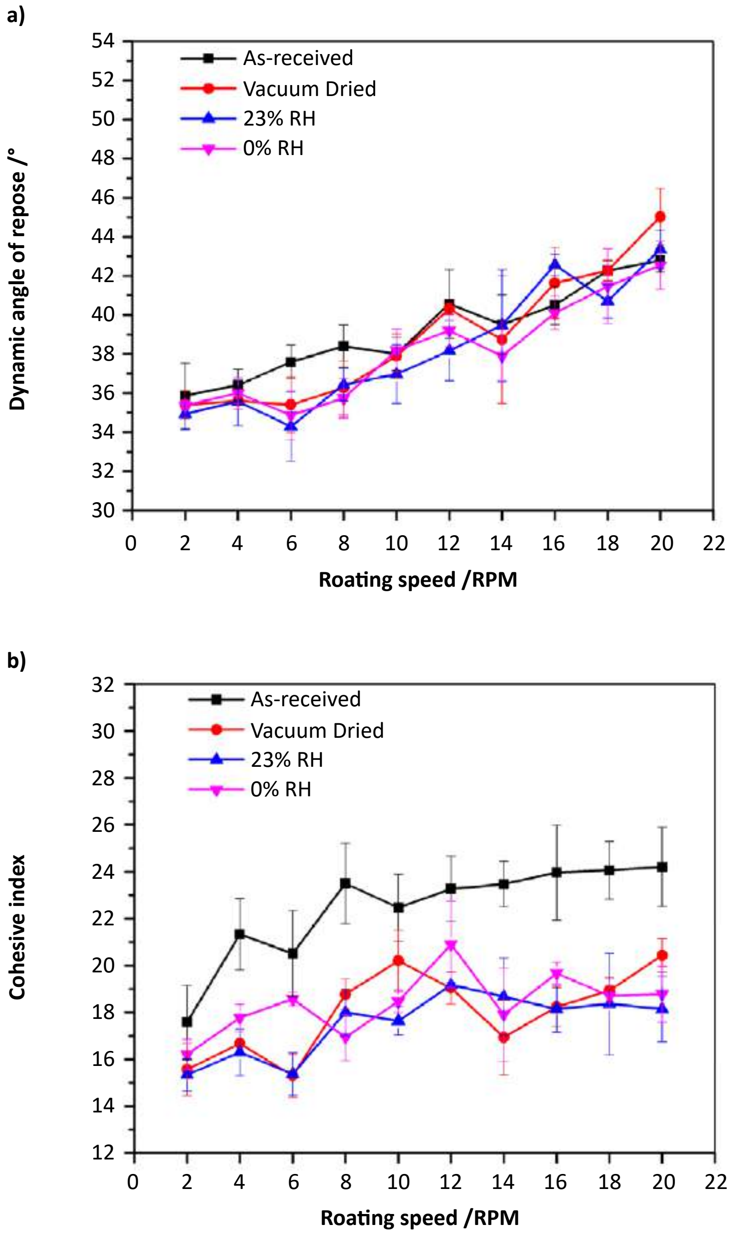

Fig. 8 The evolution of the dynamic angle of repose (a) and cohesive index (b) as a function of the rotating speed for IN625 in different states: the initial powder as-received, after exposure in a container for 90 days, vacuum dried at 200°C for 1 h, the dried powder exposed in relative humidity of 23% and the dried powder stored in a container at 0%RH [4]

Fig. 8 shows the dynamic angle of repose (a) and cohesive index (b), obtained using the GranuDrum™ method, as a function of rotation speed. The results indicate that the dynamic angle of repose of the IN625 powders did not change significantly between powder storage conditions, whereas the cohesive index of the as-received powder was slightly higher than the other three samples, suggesting that drying the powder at 200°C for 1 h can improve the powder flowability by eliminating moisture-related cohesion formed

Sample	Ni	Cr	Nb	Fe	Mo	Mn	O	C	Si
As-received	6.56	5.19	3.27	2.23	1.89	5.69	41.63	31.78	1.77
Dried	5.82	5.78	3.23	3.01	1.69	6.07	42.13	30.34	1.93

Table 8 Atomic percentage concentrations in an XPS survey scan for IN625 particles [4]

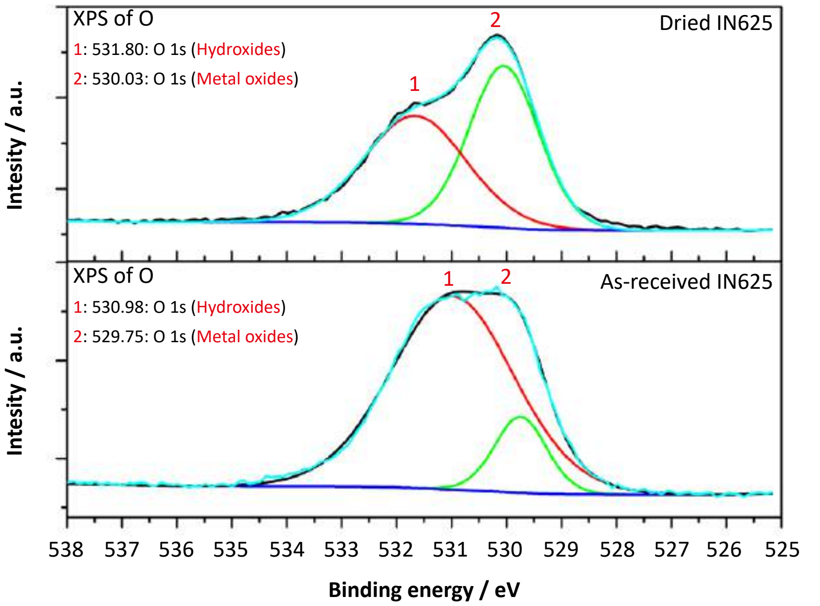

Fig. 9 XPS results of the oxygen binding energies for as received and dried IN625 [4]

between the particles themselves. Interestingly, the cohesive index remained unchanged even after being exposed in humid air for 6 days or in a sealed glass container for 2 months, suggesting that humidity-related cohesion effects in a 23% RH environment take longer than 6 days to develop.

To further understand the improvements seen in flowability with drying, XPS was conducted on the dried and as-received IN625 powder to determine if the surface chemistry was altered by the drying process; the results are summarised in Table 8. These results show the presence of nickel, chromium, niobium, iron, molybdenum, silicon and oxygen at the particle surface, suggesting that changes within the surface oxide layer occur with drying. This implies that drying the powders not only enhances flowability by the elimination of liquid bridges, but that it may also alter the oxide formation upon the particle surface. Oxygen binding energy analysis via XPS (Fig. 9) showed a shift in the relative ratios of hydroxide to metal oxide species with drying. However, further analysis to understand the localised metallic bonding is needed. Changes in surface oxide state could have potential downstream effects on laser absorption during the build process. Further analysis would need to be conducted to gain a full understanding of these relationships.

The overall conclusion was that the results of the investigation of the flowability of IN625 powder, using the newly developed rotating drum instrument, indicate that the flowability of the as-received IN625 powder can be improved by drying at 200°C for 1 h. Preliminary XPS analysis suggests that the surface elemental chemical composition changes with drying. Further work to understand the particle surface oxidation behaviour and topological features may be key to understanding the flowability of IN625 powders in this context.

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