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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

# METAL AM

## in this issue

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# METAL ADDITIVE MANUFACTURING

## Taking a more nuanced approach to the Gartner Hype Cycle

Until recently it was hard to avoid an AM conference presentation that mentioned the Gartner Hype Cycle and the infamous Slope of Enlightenment. Where were we on the cycle, and had we passed the Peak of Inflated Expectations? As it became clear that the industry was achieving sustained growth, discussions around this died down.

However, because Laser Powder Bed Fusion (L-PBF) has dominated the metal AM scene over the past decade, it could be argued that metal AM's current place on the Slope of Enlightenment is actually only L-PBF's place. After all, more than any other AM process, it has been through an intense period of industrialisation, driven by advances in quality monitoring systems, standards, simulation technologies and materials.

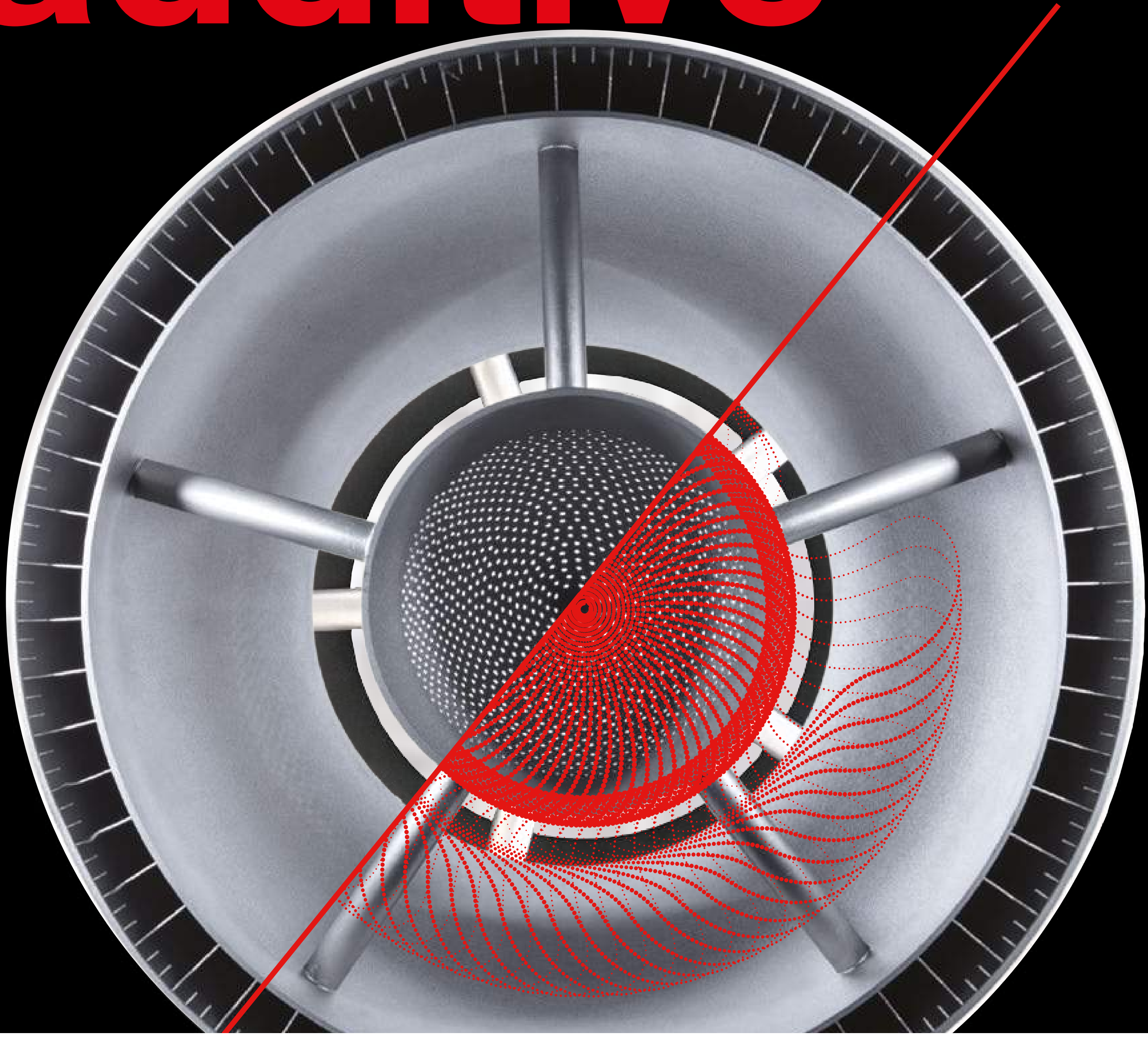
Whilst it is logical to bundle all metal AM processes together to describe an industry, in doing so there is a danger of misrepresenting the technological readiness of all the processes that fall within it.

The rise of metal Binder Jetting is a case in point. It is a hugely exciting technology, but with a unique supply chain. On one side, there are established players with proven technologies that have evolved out of low-volume production needs. On the other, there are new entrants with hundreds of millions of development dollars behind them aimed at high-volume production, but with yet to be proven technology. Logically, correctly placing this process on the Hype Cycle requires caution.

To help to moderate inflated expectations, avoid troughs of disillusionment and offer some enlightenment, this issue focuses on the elephant in the Binder Jetting room – the sintering process. As we reveal, it is not a dark art, but there is no 'easy button' either and, just as we have seen with L-PBF, a lot of factors will have to come together for this technology to reach the Slope of Enlightenment.

Nick Williams
Managing Director

**Cover image**
*EOS M400 systems installed at Sintavia LLC for the production of components for the aerospace and defence sector*



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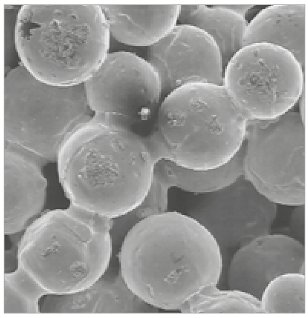


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# industry news

## Sandvik to begin production of titanium powder at new atomiser plant

Sandvik is adding titanium powder specifically developed for Additive Manufacturing to its range of Osprey™ metal powders. A new state-of-the-art atomising plant for the production of titanium powders, the result of an investment amounting to SEK 200 million, will be inaugurated in Sandviken, Sweden, on October 22, 2019.

With the recent additions of titanium and also nickel-based superalloys to its powder offering for AM, the company believes that it offers one of the widest product ranges in the industry. It is also capable of customising materials to suit customer specifications.

Kristian Egeberg, President of Sandvik Additive Manufacturing, stated, "With 157 years of leading materials expertise and more than forty years' experience in powder manufacturing, Sandvik is a true expert when it comes to gas-atomised AM-powders, as well as in matching or adapting the materials to the customer's specific print processes and applications."

Sandvik's new state-of-the-art titanium powder plant will produce titanium powders with low oxygen and nitrogen levels and will include a high level of automation, said to ensure even better reliability and consistency. It has a dedicated downstream sizing and large scale blending and packing facility. The plant will initially produce Osprey™ Ti-6Al-4V Grade 5 and Osprey™ Ti-6Al-4V Grade 23.

*The new titanium powder plant is located close to Sandvik's Additive Manufacturing Centre (pictured) in Sandviken, Sweden (Courtesy Sandvik)*

The new titanium powder plant is located close to Sandvik's Additive Manufacturing Center. With all relevant Additive Manufacturing processes for metals in-house, Sandvik stated that it can adapt the powder to any Additive Manufacturing process.

"Besides being a leading supplier of metal powder for Additive Manufacturing, we have since 2013 made sizeable investments into a wide range of AM process technologies for metal components, including Powder Bed Fusion (Laser and Electron Beam) and Binder Jetting," Egeberg added. "Adding seventy-five years in post-processing methods like metal cutting, sintering and heat treatment, Sandvik has well-established and leading expertise across the entire AM value chain."

In January 2019, Sandvik merged its Powder and Additive Manufacturing divisions. As a result, it now offers services covering the full metal AM process chain, from powder production to the supply of finished AM components. In July 2019, the company acquired a significant stake in BeamIT, Italy, an Additive Manufacturing service provider to the aerospace, automotive, energy and racing industries.

www.additive.sandvik

## Carpenter Technology sees strongest quarterly operating income since 2013

Carpenter Technology Corporation, Philadelphia, Pennsylvania, USA, has announced its financial results for its fiscal fourth quarter and year ended June 30, 2019. For the quarter, the company reported net income of $48.9 million, up from $42.8 million in the same quarter 2018, while net income for the full year 2019 was reported at $167 million, down slightly from $188.5 million in 2018.

Among the fourth quarter's highlights, it was reported that Specialty Alloys Operations (SAO) had delivered a 16.3% operating margin and 20.4% adjusted operating margin. Carpenter's SAO segment manufactures premium alloys and stainless steel, and saw net sales of $532 million for the quarter (2018: $518.3 million) and $1,967.3 million for the full year 2019 (2018: $1,803.8 million).

Carpenter's Performance Engineered Products segment, the segment of the company that includes its Dynamet titanium business and Carpenter Powder Products (CPP) business, achieved net sales for the fourth quarter of the fiscal year 2019 of $126.4 million, up from $116.3 million in the fourth quarter of fiscal year 2018. For the full year 2019, the segment reported net sales of $479.8 million, up from $429.7 million in 2018.

"The fourth quarter marked the end to a successful year as we generated our strongest quarterly operating income performance since fiscal year 2013," stated Tony Thene, Carpenter Technology's President and CEO. "Key highlights of the quarter include SAO delivering 20.4% adjusted operating margin, positive total company free cash flow of $115.8 million, and our twelfth consecutive quarter of year-over-year backlog growth."

"The fourth quarter's operating income results were driven by a continued strong product mix as we generated double digit sequential and year-over-year revenue growth in the aerospace and defence end-use market given our sub-market diversity and broad platform exposure," he continued. "Also, growth in the medical end-use market remained robust as we continued to benefit from our direct customer relationships with leading OEMs and increasing demand for our high-value titanium solutions."

"This past year we significantly advanced our Additive Manufacturing platform by adding powder lifecycle management solutions through the acquisition of LPW Technology Ltd," Thene added. "In addition, the expansion of our soft magnetics capabilities remains on track as we seek to capitalise on the disruptive impact of electrification across multiple end-use markets."

"Looking ahead, we are focused on advancing our solutions approach, capturing additional productivity and capacity gains through the Carpenter Operating Model, and investing in the future of our industry and our end-use markets," he concluded.

www.carpentertechnology.com

## GE Additive ships first Concept Laser M Line Factory system

GE Additive has shipped its first Concept Laser M Line Factory system from Germany to GE Aviation's Additive Technology Center (ATC), Cincinnati, Ohio, USA. The M Line Factory metal Additive Manufacturing machine has undergone significant changes since the acquisition of Concept Laser by GE Additive in December 2016, with its design architecture, system and software being extensively reviewed and redesigned in line with established GE processes and beta testing.

The M Line factory offers a modular machine architecture in which the units used for part production and for the set-up and dismantling process are physically decoupled. This enables these tasks to be carried out in parallel and separately from one another, with the system's architecture also said to offer a high degree of automation of both upstream and downstream stages.

The modular machine technology is said to be key to Concept Laser's smart factory concept of a fully expandable, automated and centrally controllable production system, enabling the economical AM series production.

www.ge.com/additive

## ASL commissions new gas atomiser for AM powders

Atomising Systems Ltd. (ASL), Sheffield, UK, has further expanded its capacity with the installation of a new 400 kg batch gas atomiser aimed specifically at the AM and Metal Injection Moulding (MIM) powder markets. ASL is a specialist in the production of stainless steel powders, and also produces low-alloy and Ni-based alloys.

The atomiser was designed in-house and is reported to be equipped with ASL's proprietary anti-satellite and hot gas system, resulting in powders that are low in satellites and high in flowability. The new atomiser can produce high yields of MIM and/or AM powders, enabling ASL to continue to serve its expanding customer base.

"The addition of another atomiser, along with the associated sieving and classification equipment, means that we are able to keep pace with the growth of our existing client base and the requirements of new clients, especially in the AM and MIM sectors," stated Paul Rose, Commercial Director. "In these sectors, the benefits of ASL's anti-satellite technology are clearly recognised through the excellent powder shape and flow properties."

www.atomising.co.uk



## US aerospace company adds six more MetalFAB1 systems

Additive Industries North America, Inc., based in Camarillo, California, USA, has reported that its largest aerospace customer, located in California, has purchased a further six MetalFAB1 systems from the company, to add to the four it has previously installed.

According to Additive Industries North America, the prestigious aerospace customer was able to consolidate approximately 700 kg of powder in June using the four MetalFAB1 systems currently in operation. The company stated that the application represents an inflection point in Laser Powder Bed Fusion (L-PBF) part production, where candidate parts were typically limited to fist-size volumes to meet ROI calculations.

Using MetalFAB1 systems, this customer is reportedly able to cost effectively serially produce a part which is 420 mm diameter x 400 mm tall and weighs 180 kg. The six new metal Additive Manufacturing systems are expected to be installed at the customer's facility later this year, bringing its total number of operational MetalFAB1 machines to ten, with further installations said to be possible in 2020.

"This part is likely the largest, most complex L-PBF part ever produced in series production. We are proud of our multi-disciplinary team that worked with this customer to make this production a reality as well as the capabilities of our MetalFAB1 systems to print for days back to back," stated Shane Collins, General Manager for Additive Industries North America, Inc.

"This order will bring the North America MetalFAB1 installed base to seventeen systems which has been achieved since the first machine was installed late in 2017. Considering each system has four 500 W lasers, the powder consolidation capabilities would equal roughly 68 single laser systems."

Daan Kersten, CEO of Additive Industries, commented, "The fast growth in North America is partly due to our focus on the aerospace sector and the aeronautics adoption curve for production Additive Manufacturing. We expect this growth to further accelerate when our customers publicly release their applications and more companies are able to visualise the large, complex parts that can be manufactured on the MetalFAB1 system in titanium, aluminium, steel and nickel-based alloys."

www.additiveindustries.com

*Additive Industries' largest aerospace customer will have ten MetalFAB1 AM systems (Courtesy Additive Industries)*

## ExOne reports record second quarter revenues

The ExOne Company, North Huntington, Pennsylvania, USA, has reported record financial results for its second quarter 2019, as well as record-setting trailing twelve month (TTM) revenue.

Consolidated revenue for the second quarter 2019 was reported to be $15.3 million, up 41% compared to the same quarter in 2018 and representing a record level for a second quarter. The company's gross profit for Q2 2019 was reported at $5.1 million, also said to be a record result for any second quarter in ExOne's history, and representing a gross margin of 33.7%, compared to a margin of 14.6% in Q2 2018.

"We are pleased with the significant progress we are making – from a technological, commercial and financial standpoint. We reached a milestone for ExOne this quarter, reporting record-setting second quarter revenue and gross profit levels, in spite of recent unfavourable macroeconomic factors," stated John Hartner, ExOne's Chief Executive Officer.

The second quarter 2019 was said to have benefited from improved operating leverage on higher volume, as well as a reduction in fixed costs resulting from the 2018 global cost realignment programme. The company's Additive Manufacturing machines product line achieved the best results in Q2 2019, reporting $9.3 million revenue, up 187% from $3.2 million in Q2 2018. The company's additively manufactured products, materials and services offering performed slightly less well, reporting Q2 2019 results of $6 million, down 21% from Q2 2018.

The company also reported that it had achieved a record-setting revenue of $66.7 million in the trailing twelve months to the end of Q2 2019, a significant improvement on the 2017–2018 result of $58.8 million.

Regarding its new X1 25PRO metal AM machine, Hartner added, "As we previously announced, Kennametal and Sandvik have agreed to beta test our new X1 25PRO™, our larger format, fine powder, high-resolution production machine that we displayed at the Rapid + TCT trade show in Detroit in May. This new platform is capable of printing standard industry powders utilised in MIM (Metal Injection Moulding) and other PM (Powder Metallurgy) processes. We secured our first order for a production machine that we expect to ship in the second half of this year."

www.exone.com

### Submitting news..

Submitting news to *Metal AM* is free of charge and reaches a global audience. For more information contact Paul Whittaker: paul@inovar-communications.com

## GKN Powder Metallurgy opens new customer centre in Bonn

GKN Powder Metallurgy has opened a new customer centre in Bonn, Germany, at which customers and partners can receive support and training in all aspects of Powder Metallurgy and metal Additive Manufacturing. The opening is the third in a year which has seen the company launch customer centres in Danyang, China, and Auburn Hills, Michigan, USA.

*The new customer centre in Bonn (Courtesy GKN Powder Metallurgy)*

The Bonn customer centre is expected to allow GKN Powder Metallurgy to host tailored visits for customers and business partners to meet their specific interests. Visitors to the site can also explore the integrated innovation showroom, with showcases featuring the full range of GKN Powder Metallurgy's technology strategy, and take advantage of its spacious conference and training rooms for hands-on workshops.

"Today, emerging countries can manufacture products of the highest quality. This means we have to further accelerate innovation in Germany," stated Guido Degen, President Additive Manufacturing at GKN Powder Metallurgy. "Our experience centres are an ideal platform for intensifying partnerships with our customers and strengthening collaboration. By discussing specific business challenges and evolving industry trends, we can identify areas of growth potential together."

"We have great confidence we're heading in the right direction because we are working with the world's most amazing companies," added Peter Oberparleiter, CEO at GKN Powder Metallurgy. "We're developing groundbreaking products with our customers, refining 3D printing processes with our partners like HP Inc. and EOS, and creating our own digital solutions driven by the collective ingenuity of our people. GKN Powder Metallurgy's focus on innovation will allow us to strengthen our position in the market even more in the future. "

GKN Powder Metallurgy employs more than five-hundred people at its IATF 16949-certified production site in Bonn, which was founded in 1934. The facility currently produces over seven million parts per week.

www.gknpm.com

## Digital Metal appoints Christian Lönne as its new CEO


*Christian Lönne has been appointed CEO of Höganäs subsidiary, Digital Metal (Courtesy Höganäs Group)*

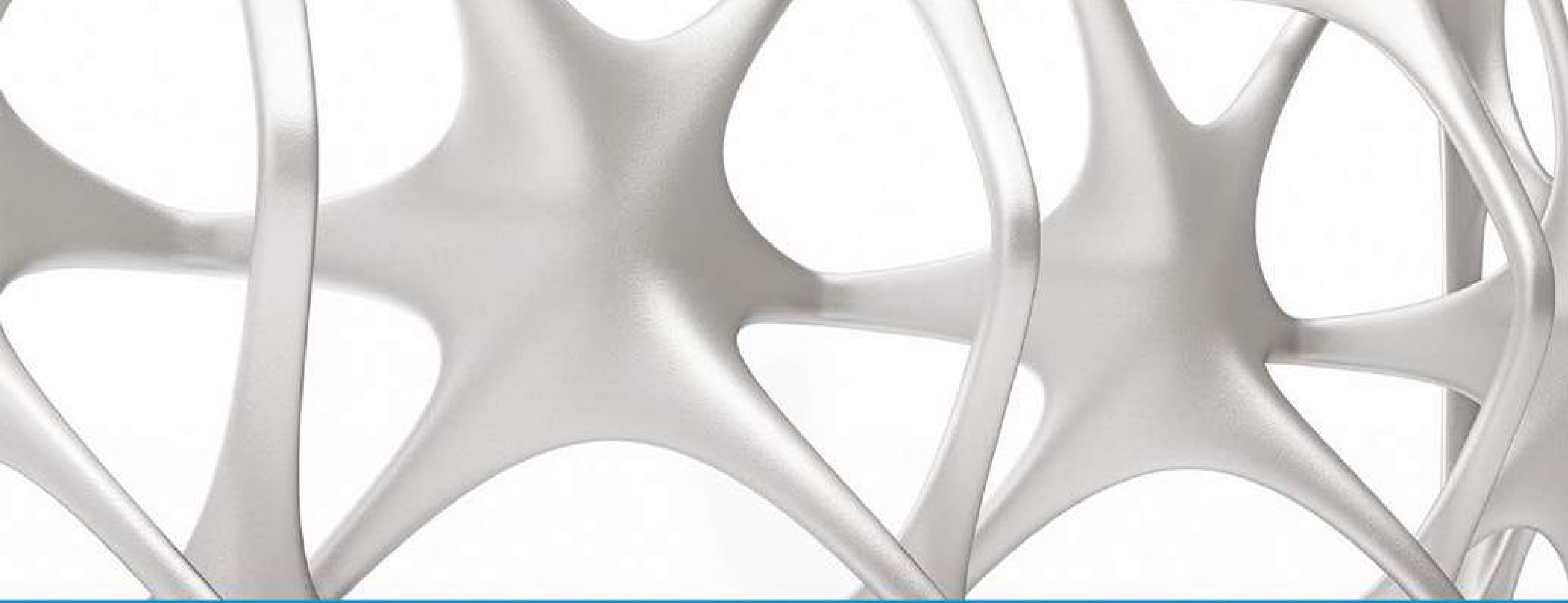
Digital Metal AB, a subsidiary of Sweden's Höganäs Group, has appointed Christian Lönne as its new CEO. Lönne is expected to take up his position on October 8, 2019, with former CEO Ralf Carlström to take a new managerial position as leader of Höganäs' investment in Metal Injection Moulding (MIM).

Lönne most recently worked for the accelerator Beyond in Lund, Sweden, where he held the position of head coach for large companies working with lean start-up methods and open innovation. He is said to offer many years of international experience from the corporate world, gained at companies including Sony Ericsson. Lönne has also held leading roles in the growth phase of companies in both digital technology and consumer products.

"Digital Metal is ready to take the next step in their development," stated Fredrik Emilson, CEO of Höganäs. "In the future, we will invite other partners to accelerate technological development and increase our global presence. Christian, with his background and experience, is a perfect pilot in developing the business and building a stable commercial platform for Digital Metal."

Lönne, commented, "I look forward to my assignment at Digital Metal. It is a very exciting company with a high level of innovation and cutting-edge technology that has a fantastic potential to change industries. The combination of a dynamic start-up company and a stable owner like Höganäs I see as a success factor."

www.digitalmetal.tech
www.hoganas.com



# YOUR AM TOOLBOX

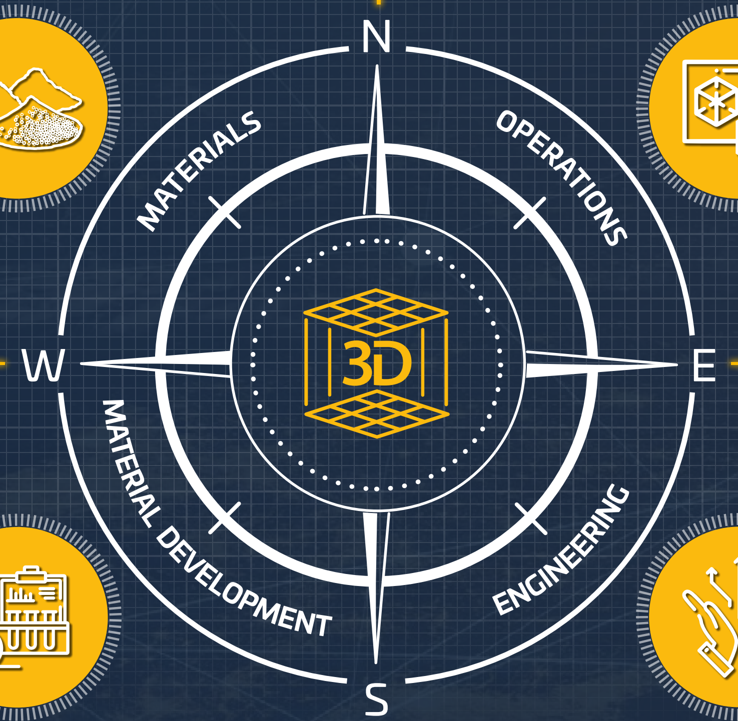
GKN ADDITIVE MATERIALS

GKN ADDITIVE COMPONENTS

- Low alloy water atomized steels, stainless steels and dual phase - structural steels
- Titanium-, Copper, Aluminium- and Nickel alloys, NiTi – Shape Memory alloys
- Magnetic alloys – Fe-Si

- High performance powder bed processes from 1 - 50.000 pcs
- Fully connected global print network
- MyAMQuality!

PRODUCT & PROCESS




- Inhouse testing capabilities for mechanical and physical properties
- Printing studies for Laser AM and Binder AM; Powder morphology
- ASTM standardized methods to certify chemical composition

- Design for AM
- Application know-how
- Simulation and validation

ENGINEERING SERVICES

## DESIGN CONCEPT

MATERIALS → PART

REGISTERED AS 9100 · ISO TS16949 · IATF 16949

GKN ADDITIVE


Metals Additive Manufacturing for Aerospace & Autosport
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• Nickel superalloys including: 247LC, In738, In718, In625, Haynes 282, Hastelloy X
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Growing fleet of 22 industrial printers, thereof
M400-x machines: EOS M400-1 • EOS M400-4
M300 machines: EOS M300-4
M2xx machines: EOS-M270 • EOS-M280 • EOS-M290
Renishaw: RenAM500Q

## H.C. Starck Tantalum and Niobium introduces AMtrinsic metal powders

H.C. Starck Tantalum and Niobium GmbH, Goslar, Germany has launched a new range of atomised tantalum and niobium powders and their alloys designed specifically for metal Additive Manufacturing processes. Under the brand name AMtrinsic®, the new powders are suitable for a wide range of demanding applications.

Tantalum and niobium, as well as alloys containing these elements, offer a unique set of properties including high melting point, high corrosion resistance, excellent chemical resistance and high thermal and electrical conductivity. This makes them ideal for high-tech applications in fields such as chemical processing, superconductors, energy and high-temperature environments.

In addition, parts additively manufactured from Ta/Nb containing alloys may offer an alternative for the optimisation of mechanical and biological performance parameters in medical implants. Multinary alloy compositions or high-entropy alloys containing Ta/Nb are said to be especially of interest for the design of completely new intrinsic material properties that can provide superior solutions in challenging applications, especially when combined with the freedom of geometric design available using AM.

"We see the introduction of our new Additive Manufacturing brand AMtrinsic as an important milestone in our new business development activities which should strengthen our position in the continuously growing AM market," stated Melanie Stenzel, Head of Marketing and New Business Development.

www.hcstarck-tantalum-niobium.com

## 3D Systems appoints Booth its new Executive VP and CFO

3D Systems, Rock Hill, South Carolina, USA, has appointed Todd A Booth as its new Executive Vice President and Chief Financial Officer. Booth will replace John McMullen, who announced his planned retirement earlier this year after three years at 3D Systems.

Booth has twenty-five years of financial leadership at large and mid-market growth companies as well as industry experience in automotive, healthcare, defence, energy, electronics and marine. His most recent role was as CFO for Teledyne Marine where he successfully led a complex, global transformation.

"I am excited to have a leader of Todd's experience join our team at such an important time for our company," stated, Vyomesh Joshi (VJ), President & CEO, 3D Systems. "Todd's experience leading complex transformations and large-scale efficiency improvements will be invaluable as we seize the opportunity ahead of us."

www.3dsystems.com

## Sandvik President and CEO to depart company in February

Björn Rosengren, President and CEO of Sandvik AB, Stockholm, Sweden, has informed the Chairman of the Sandvik Board that he intends to resign and will leave the company as of February 1, 2020. He will now join ABB, a multinational automation corporation headquartered in Zurich, Switzerland.

Johan Molin, Chairman of the Board for Sandvik, stated, "Björn Rosengren has, since he joined Sandvik in November 2015, established a solid decentralised business model for the company and made the organisation more flexible and efficient."

"The board is very grateful for his and all the employees' work during these years," he continued. "We will initiate the process to assign a very experienced and competent industrial leader that can succeed Björn in the role as President and CEO and continue to develop the company even further."

"This has not been an easy decision," commented Rosengren. "Sandvik is a great company with a lot of future potential and I will continue to lead the organisation with a strong commitment until the end of January."

www.home.sandvik

## Titomic and AP&C collaborate to develop titanium alloy powders

Titomic Limited, a metal Additive Manufacturing company based in Melbourne, Australia, has announced a supply agreement for Ti6Al4V powders with AP&C, a GE Additive company, headquartered in Saint-Eustache, Montreal, Canada. Under the supply agreement, the two companies have signed a Memorandum of Understanding (MoU) which will see them work together to develop titanium and titanium alloy powders.

According to Titomic, the agreement will provide a secure global supply of aerospace grade Ti6Al4V powders for use in its Titomic Kinetic Fusion (TKF) AM process. The MoU covers the following cooperation between the companies:

- Titomic and AP&C to co-develop industry standards of best practice for the storage and safe handling of titanium and titanium alloy powders
- Titomic and AP&C to develop custom-made homogenisation powder systems for titanium and titanium alloy powders for use in Titomic's TKF AM systems
- Titomic and AP&C to explore the optimisation of coarse (50–150 μm) titanium and titanium alloy powders for use in TKF AM systems with the aim of significantly reducing the cost of TKF manufactured products.

"AP&C, a GE Additive Company, is a global leader in the production of the aerospace grade titanium and titanium alloy powders using its plasma atomisation manufacturing process, which have the ideal characteristics for Titomic Kinetic Fusion process," stated Jeff Lang, Titomic's Managing Director.

"These agreements provide Titomic with not only a secure metal powders supply from AP&C, a reputable multinational company, but also allows for continuous improvement under a strong collaboration between the parties of their own unique capabilities for future digital manufacturing solutions for industries," he concluded.

Alain Dupont, President & CEO of AP&C, commented, "This agreement is a significant milestone in the supply of large volumes of titanium and titanium alloy powders, and we're delighted to be working with a recognised leader and manufacturing innovator, Titomic, to produce best practice standards for the future to lead the development of industry standards for titanium powders."

www.titomic.com
www.advancedpowders.com

## Wayland Additive raises £3 million in funding round

Wayland Additive Limited, Huddersfield, UK, has raised £3 million in its Series A funding round, led by Longwall Ventures with the Angel CoFund (ACF), among other investors. The Electron Beam Additive Manufacturing company is reportedly developing EB-based systems capable of building parts faster and with greater precision than laser-based technologies, and is thought to be targeting end-users in industries such as aerospace and medical.

Wayland Additive's technology is reported to be built on highly sophisticated developments in scanning electron microscopy (SEM) and electron beam lithography, and is expected to offer very high levels of productivity, material versatility, process monitoring and control. The company has acquired IP from Reliance Precision Limited, Huddersfield, which has developed AM technologies over the past three years.

The funds raised in this Series A funding round are expected to enable Wayland Additive to develop its advances in metal Additive Manufacturing from an advanced prototype to a launch product. The company plans to begin machine shipments in 2021.

www.waylandadditive.com

## Renishaw reports mixed 2019 results, considers AM business reorganisation

Renishaw, Wotton-under-Edge, Gloucestershire, UK, has reported challenging economic conditions resulted in a drop in fiscal year 2019 turnover, down 7% to £574 million (2018: £611.5 million). Adjusted profit before tax amounted to £103.9 million, down 28% from £145.1 million in 2018.

The company reported £532.9 million revenues from its Metrology business, down 7% from 2018 largely as a result of a slowdown in demand for its encoder and machine tool products in the APAC region. Renishaw added that the Metrology business had benefited from strong growth in its Additive Manufacturing product line. Renishaw's Healthcare business reported a 15% increase in revenue, reaching £41 million.

The strongest performing region for Renishaw in 2019 was still APAC, achieving full-year revenues of £240.1 million (2018: £289.2 million). EMEA followed with revenues of £167.2 million, up slightly from £165.1 million in 2018. In the Americas, the group achieved revenues of £132.6 million (2018: £126.6 million), and in the UK full-year revenues were reported of £34.1 million (2018: £30.6 million).

*Renishaw is planning to co-locate its AM technical and commercial teams in its Gloucestershire facilities (Courtesy Renishaw)*

**AM business reorganisation:**
In September, Renishaw reported that it was evaluating a potential reorganisation of its Additive Manufacturing business, with the proposed co-location of its AM engineering, marketing and commercial operations at its headquarters in Gloucestershire, UK. The co-location would see the closure of the company's site in Stone, Staffordshire, UK, at the end of 2019.

The company explained that, in the proposed move, its Gloucestershire headquarters would house an expanded demonstration facility, enabling customers to experience its range of industrial metrology and manufacturing technologies covering process development, Additive Manufacturing, finish machining and part verification.

"We have exciting plans for future systems that will further boost the adoption of AM for series production, but in a competitive global business we need to be agile and efficient in how we bring these new technologies to market," stated William Lee, Renishaw's Chief Executive. "Our current thinking is that the most effective way to achieve this would be for our AM technical and commercial teams to be co-located in our Gloucestershire facilities,"

www.renishaw.com

## Markforged files legal complaint against Desktop Metal

Markforged, Inc.,has filed a complaint in the U.S. District Court for the District of Massachusetts against Desktop Metal, reports *Boston Business Journal*. The company is said to have requested a trial by jury to address its claims that Desktop Metal has spread "falsehoods" about Markforged's products.

This latest legal complaint follows an earlier patent infringement lawsuit filed by Desktop Metal in March 2018, in which the company alleged that Markforged's Metal X Additive Manufacturing system violated two of its patents. In this lawsuit, the jury found in favour of Markforged, and the companies were reported to have reached an amicable resolution in October 2018.

At the time of the agreement, a mutual non-disparagement clause was agreed, prohibiting Desktop Metal from "misrepresenting the functionality of Markforged's products." The companies were in October reported to have agreed that $100,000 in liquidated damages would be paid for each violation of these terms.

When contacted for comment, Markforged stated, "Metal 3D printing is on pace to change manufacturing as we know it, and Markforged is leading the charge. We believe healthy competition is good for the industry, innovation, and – most importantly – customers. Unfortunately, as alleged in our complaint, Desktop Metal has chosen to compete by spreading false information. Markforged is taking this necessary step to ensure customers are making their buying decisions on facts, not lies."

A spokesman for Desktop Metal commented, "We are aware of the filing by Markforged and believe the claims are without merit. We will be addressing the allegations in the appropriate forum."

www.markforged.com
www.desktopmetal.com

## Stratasys reports strong performance in Americas

Stratasys Ltd., based in Minneapolis, USA, and Rehovot, Israel, has announced financial results for the second quarter 2019, reporting a slight fall in revenue to $163.2 million, compared to $170.2 million in Q2 2018. Gross profit was $81.2 million, compared to $83.6 million in the same period in 2018. However, with operating expenses of $80.4 million in Q2 2019, the company posted a $805,000 operating profit for the period, compared with a $1.9 million loss in Q2 2018.

"Our second quarter results reflect continued strong performance in the Americas, where we saw revenue growth across systems, consumables and services, which was offset mainly by significant economic weakness in Europe that we believe is impacting capital investments and general spending in the automotive and industrial machinery markets in that region, as well as by the adverse impact of foreign exchange rates in Europe and Asia-Pacific," stated Elchanan Jaglom, Interim CEO of Stratasys. "We believe that we are well-positioned to return to growth in Europe when macro conditions improve, and our new products and platforms are launched and adopted in the market."

www.stratasys.com



## Digital Metal launches two superalloy grades

Digital Metal AB has launched two superalloy grades for metal Additive Manufacturing, said to be suitable for use in extreme environments. The materials are DM 247, a nickel-based superalloy, and DM 625, a nickel-chromium superalloy.

The company states that, although the strength and corrosion resistance of superalloys makes them suitable for use in challenging applications such as aerospace, automotive and chemical, it has been difficult to use non-weldable materials such as MAR M247 in AM, where high solidification rates and thermal gradients are inherent.

According to Digital Metal, its unique Binder Jetting technology helps to avoid most of these problems by additively manufacturing in an ambient temperature without applying any heat, followed by a separate sintering step. Sintering densification takes place without melting and with minimal thermal gradients occuring during cooling from the sintering temperature.

The DM 247 grade is based on the non-weldable MAR M247, which is widely used as material for turbine blades and in other applications with elevated temperatures. DM 625 is an Inconel 625-grade material and its application areas range from chemical processing equipment to applications in the nuclear industry and aerospace sector.

"We have been receiving qualified requests for these materials from various large companies," stated Ralf Carlström, General Manager, Digital Metal. "Many producers within the aerospace and automotive business have long been anticipating high-quality superalloys that are suitable for 3D printing. Now we can offer them the perfect combination – our unique Binder Jetting technology and superalloys that are specially developed for our printers."

www.digitalmetal.tech

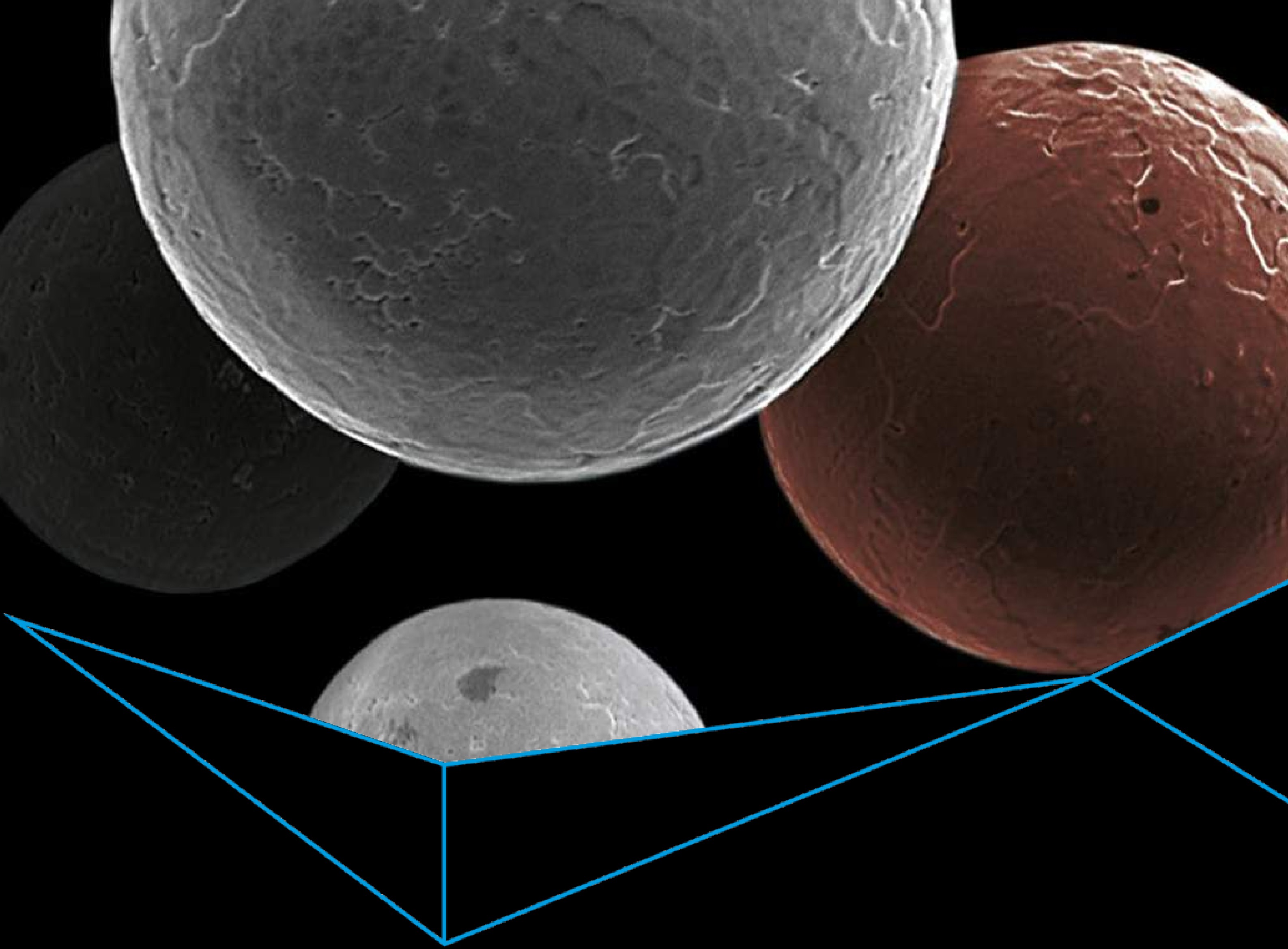
## NSERC's HI-AM network expands collaborations

The Natural Sciences and Engineering Research Council of Canada (NSERC)'s network for Holistic Innovation in Additive Manufacturing (HI-AM) has announced a number of international collaborators to enhance its AM research and create training opportunities for its students.

The HI-AM network brings together seven Canadian universities to investigate the fundamental scientific issues associated with pre-fabrication, fabrication and post-fabrication of components by a range of AM technologies, with a primary focus on structural metals.

Joining the network as international collaborators were Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), Fraunhofer Institute for Material and Beam Technology (IWS), University of Twente and RMIT University.

www.nserc-hi-am.ca



## MUT Advanced Heating celebrates its 25th anniversary

MUT Advanced Heating GmbH, headquartered in Jena, Germany, is celebrating its 25th anniversary. Founded by Heinz-Jürgen Blüm in September 1994, the company originally focused on environmental technology before moving into thermal processing. It was then rebranded as MUT Advanced Heating GmbH in 2003, and has since concentrated on the engineering and production of high-temperature furnace technology, both with defined atmospheres and under vacuum.

Increasing demands on the materials sector lead to increasingly complex manufacturing processes, the company states. Developments in materials science have fundamentally changed the required thermal processes. To meet these needs, MUT builds customised systems offering higher efficiency, as well as the associated degree of automation now required in many thermal installations. The company's certifications for manufacturing pressure vessels (HPO authorisation and welding fabricator certification) also enable it to define the optimal plant selection with its customers, and guarantee performance on the basis of certified processes.

*MUT founder, Heinz-Jürgen Blüm, with one of the company's debind and sinter furnaces (Courtesy MUT Advanced Heating GmbH)*

MUT has customers in the glass and ceramic, metalworking, Powder Metallurgy, carbon and chemical industries. The company designs systems for modern processes in sintering, debinding, joining techniques, heat treatment of aggressive substances as well as in the areas of high pressure and hot gas. A joint venture with Element 22 GmbH in 2006, creating TiGen (Titanium Generation GmbH), also provides solutions for the titanium sector that include heat treatment and sintering plant for titanium and other reactive metals that have been produced by MIM, AM or other forming processes.

A new range of heat treatment products, specifically developed to meet the demands of Additive Manufacturing processes, have also been introduced. These include suitable furnace technology for powder processing, debinding and sintering as well as for heat treatment. "Even after 25 years, we are still taking on new challenges that accompany advancing developments in the fields of materials, energy engineering, and production and process technology," the company stated.

"We would like to give a hearty thank you to all our customers, partners, suppliers and employees for the trust and loyalty they have shown to us over past years."

www.mut-jena.de

## Markforged unveils new 'Print Farms' for metal and carbon fibre AM

Markforged, Watertown, Massachusetts, USA, has unveiled its new 'Print Farms' – described as an economic way for customers to build their metal and carbon fibre Additive Manufacturing capacity with Markforged. The new Print Farm packages allow customers to purchase Metal X systems and carbon fibre X7 printers, priced together, to rapidly additively manufacture metal, composite, and hybrid parts that leverage both materials for high-throughput AM.

Markforged Print Farms are managed from a centralised, cloud-based software program, and are said to enable access to a full range of industrial materials on one platform and the opportunity to additively manufacture multiple materials in parallel. Jon Reilly, VP of Product at Markforged, commented, "We are introducing Print Farms to help customers maximise the efficiency of our Metal X systems. Three-to-five Metal X printers, one Wash and a Sinter-2 is the optimum package to maximise output. A properly balanced print farm helps companies accelerate their transition to digital manufacturing."

Markforged's metal AM systems can produce parts in 17-4PH Stainless Steel, H13 Tool Steel, and A2 Tool Steel. This month, Markforged is expected to add D2 Tool Steel, a high-carbon, high-chromium tool steel that can be heat treated to a very high hardness. This material offers high wear resistance and is widely used in cold work applications that require high compression strength and abrasion resistance.

www.markforged.com

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## Melrose announces 2019 half year results, GKN on track to achieve targets

Melrose Industries PLC has announced its interim financial results for the six months ended June 30, 2019. The company reported half year revenues of approx £6 billion, a significant rise from £2.97 billion in the first six months 2018. Operating profit was reported at £539 million, up from £284 million in the first six months 2018.

Melrose acquired GKN plc, including GKN Powder Metallurgy, the world's largest producer of Powder Metallurgy components, for £8.1 billion in April 2018. In its 2019 half year results, the company stated that the three main divisions of GKN are on track to achieve previously announced targets.

Of particular note was that Automotive and Powder Metallurgy divisions were maintaining profit well in an automotive industry downturn, due it was said to Melrose's decisive cost reductions. It was also stated that many operational improvement programmes and capital investment projects were underway to help improve performance further, while good progress is being made on resolving the GKN loss-making contracts.

Further, a new target to improve GKN's working capital efficiency is expected to release additional future free cash of £400 million within Melrose's ownership period. The company added that it has made record investments in aerospace technology so far in 2019, and announced plans to create the 'One GKN Aerospace' organisation with the aim of further improving performance in this sector.

Justin Dowley, Melrose Chairman, commented on the results, "These results show the initial fruits of the 'improve' stage of Melrose's ownership of GKN and, with the overall GKN margin increasing positively, we are excited about what is possible. The performance is in line with expectations and leverage is better than expected."

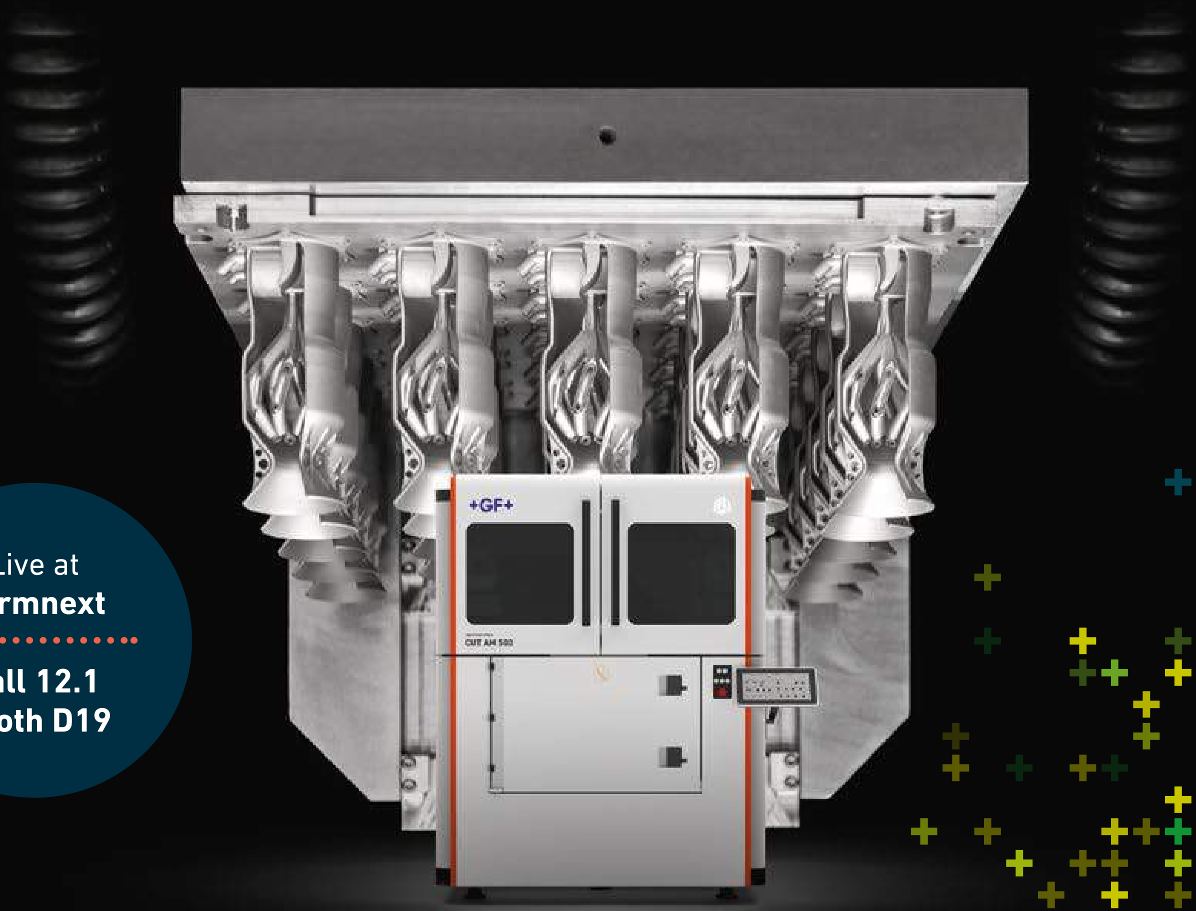
"At the same time, this has been a year of record investment in aerospace technology and substantial eDrive development," he continued. "The Melrose Board is confident that our businesses will deliver significant upside for shareholders."

www.melroseplc.net

www.gkn.com

## Submitting news..

Submitting news to *Metal AM* is free of charge and reaches a global audience. For more information contact Paul Whittaker:
paul@inovar-communications.com


+GF+

## GE's Arcam EBM and Concept Laser open new facilities

GE Additive has reported the opening of its Arcam EBM Center of Excellence in Gothenburg, Sweden, along with the inauguration of its Concept Laser campus in Lichtenfels, Germany.

Arcam EBM's new 15,000 $m^2$ facility is reported to have capacity for up to 500 employees, tripling the floor space of the company's Mölndal site. According to GE Additive, having production, R&D, training facilities and support functions housed under one roof allows it to put lean manufacturing at the heart of its operations to increase production capacity. As more industrial additive users begin to make the shift to serial production, the company stated that demand for its Arcam EBM systems is continuing to grow.

"The Arcam EBM team in Gothenburg is energised to be in its new home – a dynamic, sustainable workplace – in a great location. We will harness that energy and continue to research, innovate and drive EBM technology further," stated Karl Lindblom, General Manager GE Additive Arcam EBM.

During a ceremony in Lichtenfels, Germany, GE Additive officially opened its new 40,000 $m^2$ campus. Known as GE Additive Lichtenfels, the site will become the new home for GE Additive Concept Laser. The campus has capacity for up to 700 employees, and the transition of production from the current Concept Laser site to the new facility will continue throughout 2019. A planned office block is also currently under construction, and is scheduled for completion in 2020.

Jason Oliver, GE Additive's President & CEO, commented, "Today is a great milestone for GE Additive, for Frank and Kerstin Herzog and the entire Concept Laser family. There has been a lot of interest in the building over the past three years, both locally and from our customers. We want this modern, Lean manufac-turing production facility, here in Bavaria, to become a global focal point for the additive industry."

www.ge.com/additive

*GE Additive opens its Arcam EBM Center of Excellence in Sweden (Courtesy GE Additive)*

## Steady revenues at Sandvik despite drop in Q2 orders

Sandvik AB, headquartered in Stockholm, Sweden, has reported revenues for the group remained steady in the second quarter 2019 at SEK 26,467 million (apx $2,673 million), with adjusted operating profit for the period down 2% at SEK 4,968 million (apx $502 million). Order intake was reported to have declined by 5% and the adjusted operating margin declined to 18.8%.

Sandvik Materials Technology, which includes the groups metal powder division, saw a decline in organic orders of 20% year-on-year. Adjusted operating profit however (excluding the effects of metal prices) was up 9% at SEK 585 million ($59 million) and the adjusted operating margin improved to 14.6%. It was stated that the internal separation of Sandvik Materials Technology, announced in May, has now been initiated with the Board of Directors also exploring the possibility of a separate listing on the Nasdaq Stockholm Exchange.

"During the quarter, we announced new financial and sustainability targets. I am confident that Sandvik will deliver improved performance throughout the economic cycle," stated Björn Rosengren, President and CEO.

www.home.sandvik/en/

# PIM showcase to promote MIM and CIM technology at Formnext 2019

A major showcase of more than a hundred components manufactured by Metal Injection Moulding (MIM) and Ceramic Injection Moulding (CIM) will be held at Formnext 2019, taking place in Frankfurt, Germany, November 19-22. These processes, which come under the umbrella of Powder Injection Moulding (PIM), enable the high-volume production of net-shape, high-precision components from a diverse range of materials, including stainless steels, superalloys and titanium alloys.

Organised by *PIM International* in partnership with Mesago Messe Frankfurt GmbH, the showcase is designed to highlight the capabilities of PIM technology and its broad range of application areas. These include the automotive, aerospace, consumer electronics, medical and general engineering sectors.

Sascha F Wenzler, Vice President of Formnext at Mesago Messe Frankfurt, stated, "As the leading global exhibition and conference on Additive Manufacturing and the next generation of intelligent industrial production, Powder Injection Moulding fits perfectly into the scope of Formnext. We are delighted to be able to showcase the capabilities of MIM and CIM to our international visitors."

"Since its launch, Formnext has seen visitor numbers increase dramatically, from 9,000 visitors in 2015 to nearly 27,000 in 2018. Made up of product designers, management, engineers, technicians and entrepreneurs from an impressive range of end-user industries, this is an ideal audience to present with this group of dynamic technologies, to the benefit of both our visitors and the industries we represent," added Wenzler.

Nick Williams, Managing Director of Inovar Communications Ltd, stated, "The success of the metal Additive Manufacturing industry since the inaugural Formnext exhibition in 2015 reflects a growing acceptance of the use of metal powders for the production of high-performance end-use components for both general engineering and critical applications."

"As technologies that have much in common with metal AM, both in terms of the starting powders and also, in the case of metal Binder Jetting and Fused Filament Fabrication, the binders and the sintering equipment used, MIM and CIM are a natural fit. Through our publication *PIM International*, we are excited to be able to cooperate with the Formnext team to promote the technology on such an important stage."

The showcase, located in Hall 11.0, Stand A51, will feature parts from Europe, North America and Asia and includes award-winning parts from the European Powder Metallurgy Association and Metal Powder Industries Federation's Metal Injection Molding Association along with numerous application examples from Germany's MIM Expert Group and CIM Expert Group.

www.formnext.com

## Cytosurge announces spin-off of its micro-scale metal AM business unit

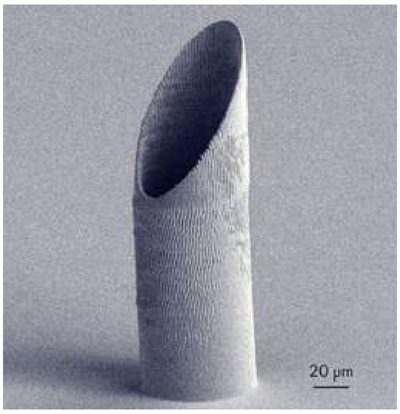
Cytosurge AG, Glattbrugg, Switzerland, has announced a spin-off of its Additive Manufacturing business unit, stating that the new company will focus on providing solutions for processes and instruments in the field of microscopically small metal components. The new independent entity will operate under the name Exaddon AG, and will be led by Edgar Hepp, who takes the role of CEO.

According to Cytosurge, the establishment of the spin-off company was initiated by exploring the applicability of its proprietary FluidFM® technology to the field of additive micro-manufacturing. Originally developed at ETH Zurich a decade ago, FluidFM has already resulted in several highly innovative solutions for customers in the pharmaceutical industry, as well as academic research in the field of cell- and bioscience.

Dr Pascal Behr, CEO of Cytosurge, stated, "Given the unique nature of the Additive Manufacturing business and specific requirements of our key target markets such as the semiconductor industry, we are convinced that an independent company can realise the high growth opportunities in this emerging market much better if it can focus entirely on this key goal. We are very proud to announce today the establishment of Exaddon AG for this purpose and I am convinced that Edgar and his team will thrive."

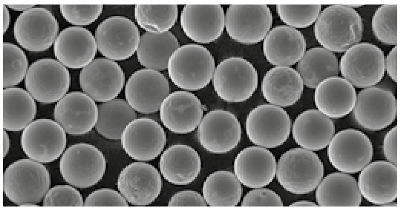
"We have developed a ground-breaking manufacturing technology and have brought it to market maturity. It enables our clients to additively manufacture high-end products at an unprecedented level," commented Hepp. "Exaddon AG is now responsible for all Cytosurge AG projects related to Additive Manufacturing and will continue to manage and develop them."

www.cytosurge.com
www.exaddon.com




*Copper microneedles can be customised to suite individual applications (Courtesy Exaddon)*

## Equispheres' success in sintering of aluminium alloys for binder jet AM



*Equispheres' aluminium alloy powders (Courtesy Equispheres)*

Equispheres, a materials science company based in Ottawa, Canada, in collaboration with McGill University, Montreal, Canada, has confirmed that after extensive testing, Equispheres' aluminium alloy powders are suitable for sintering following binder jet Additive Manufacturing.

According to the company, until now binder jet AM technology was unable to produce sinterable aluminium alloy parts, largely due to aluminium's oxide layer. Equispheres states that the powder it has developed will make sintering of aluminium alloy parts viable due to its thinner oxide layer and smoother surface. The specific findings of its testing include: compaction-free, sub-solidus sintering of the company's standard AlSi10Mg aluminium alloy powder, good densification (> 95%) and excellent microstructure.

Equispheres is reportedly working with McGill University, as well as other key partners, on the development of specialised binder agents for aluminium and specific automotive applications. The company is optimistic that the process and powder will offer a new high standard for many critical parts as the process is refined and testing continues.

"The unique and tailored attributes of Equispheres' powder have proven exceptional in compaction free sintering," stated Dr Mathieu Brochu, Associate Professor at McGill and Canada Research Chair in Pulse Processing of Nanostructured Materials. "We are excited to begin work with Equispheres' Binder Jet printing partners in the next phase to fully understand all aspects related to sintering of complex shape components and the fundamental relations with new specialised binder agents."

Kevin Nicholds, Equispheres' CEO, commented, "We are excited about the industry response to our unique aluminium sintering results. Although binder jet printer technology offers the speed and cost reductions necessary to enable Additive Manufacturing to meet the requirements of automotive mass production, the inability to print with aluminium alloys has been a major limitation to the technology – until now."

www.equispheres.com
www.mcgill.ca



# Xerion launches ultra-compact Fusion Factory debinding and sintering system

Xerion Berlin Laboratories GmbH, Berlin, Germany, has launched a new ultra-compact Fusion Factory debinding and sintering unit with external dimensions of 1,200 x 1,000 x 2,000 mm.

In contrast to its first Fusion Factory system, released 2018, which combines a Fused Filament Fabrication (FFF) system for metal and ceramic parts with a debinding and sintering system in one modular unit, this compact system does not include the FFF system, but enables the post-processing of FFF parts within twenty-four hours.

The main advantages of the FFF process include freedom from the tooling costs associated with MIM and CIM, cost-effectiveness when compared to other metal AM processes, short production times and more. However, one factor that has held back the industrial use of the process is that individual pieces of equipment for debinding and sintering had to be purchased from different manufacturers.

With Xerion's ultra-compact Fusion Factory debinding unit and the sintering furnace, both systems are available from the same manufacturer and take up limited space in the production environment. In accordance with the BASF CATAMOLD® principle, debinding is carried out by catalytic means, while the sintering furnace can reach temperatures of up to 1,450°C under protective gas conditions. Sintering under a 100% hydrogen atmosphere is also possible.

*Xerion's ultra-compact Fusion Factory debinding and sintering unit (Courtesy Xerion Berlin Laboratories GmbH)*

A number of research institutes are now said to be using the Fusion Factory to develop their own filaments and sintering strategies for FFF. To enable this research, the system supports an open architecture.

www.xerion.de

## Rapidia ships its first water-based bound metal paste AM system

Rapidia Inc, Vancouver, British Columbia, Canada, has begun commercial shipments of its solvent-free water-based metal Additive Manufacturing system. The first machine has been installed at the Hatch Accelerator, a start-up incubator based at the University of British Columbia, where the new Rapidia system will reportedly serve several start-ups located at the facility.

The Rapidia system builds parts using a novel water-based bound metal paste AM process, followed by a final sintering stage. The use of water, instead of a typical binding element, eliminates a solvent-based debinding step and is said to result in a fast, simple to use system that is environmentally friendly.

Complex internal structures are made possible using proprietary evaporative polymer supports. These supports are said to be unique to Rapidia, and are made possible by the water-based metal paste. By eliminating the debinding stage, polymer supports can be retained until the sintering stage, by which point the part is strong enough to support itself. These evaporative supports are used for almost all supports, substantially reducing post-processing time and cutting the amount of metal wasted on supports by up to 90%.

Currently, both 17-4PH stainless steel and Inconel 625 alloys are available for use in the Rapidia system. Under development are copper, 316L stainless steel, tungsten carbide, H13, titanium and alumina.

The system can build components from CAD file to finished metal part, including sintering, in around twenty-four hours. A number of further installations are said to be planned over the coming months.

www.rapidia.com

*Rapidia uses water-based metal paste supplied in ready to use cartridges system (Courtesy Rapidia)*

## MSC Software and MIG partner on microstructure simulation for AM

MSC Software, Newport Beach, California, USA, and the Materials Innovation Guild (MIG) at the University of Louisville, Kentucky, USA, have launched a new research collaboration focused on advancing Additive Manufacturing technologies through microstructure simulation. Through the MIG, the University of Louisville assists organisations such as NASA and Boeing in the development of Additive Manufacturing programmes, as well as training future engineers in new design and production techniques.

Under the partnership, MSC Software will support the university's on-site and distance learning by supplying software and training. Start-ups in the university's 3D Printing Business Incubator will also have access to MSC Software products in conjunction with education in the techno-economic aspects of AM to enhance its competitiveness in product and manufacturing design.

The consistency of material properties in new designs remains a barrier to the adoption of AM in high-performance and high-reliability applications. MIG research will use MSC Software's Simufact and Digimat modelling and simulation platforms to understand the fundamental materials properties and microstructure in metal powders, polymers and composites, and how to exploit the relationship between materials and design in AM.

Dr Sundar Atre, Endowed Chair of Manufacturing and Materials at the MIG commented, "By integrating MSC's Simufact and Digimat platforms into MIG's research and teaching initiatives, I believe we will provide the opportunity to introduce new material, design and product innovations in healthcare, defence and transportation."

The MIG is currently collaborating with NASA on a new metal Fused Filament Fabrication process which it calls MF3. MF3 will be simulated in the Digimat-AM product as part of the collaboration. Dr Kunal Kate, Assistant Professor at the University of Louisville, explained, "MF3 or similar powder-binder based 3D printing processes require post-processing steps of debinding and sintering, that are currently subject to trial-and-error experiments. Combining experimental research with the capabilities of MSC Software can develop new tools that predict 3D printed part material properties and effectively capture post debinding and sintering effects for powder-polymer based 3D printing,"

http://scipivision.scipitutors.com/
www.simufact.com

# High Pressure Heat Treatment. At the Heart of Lean Additive Manufacturing

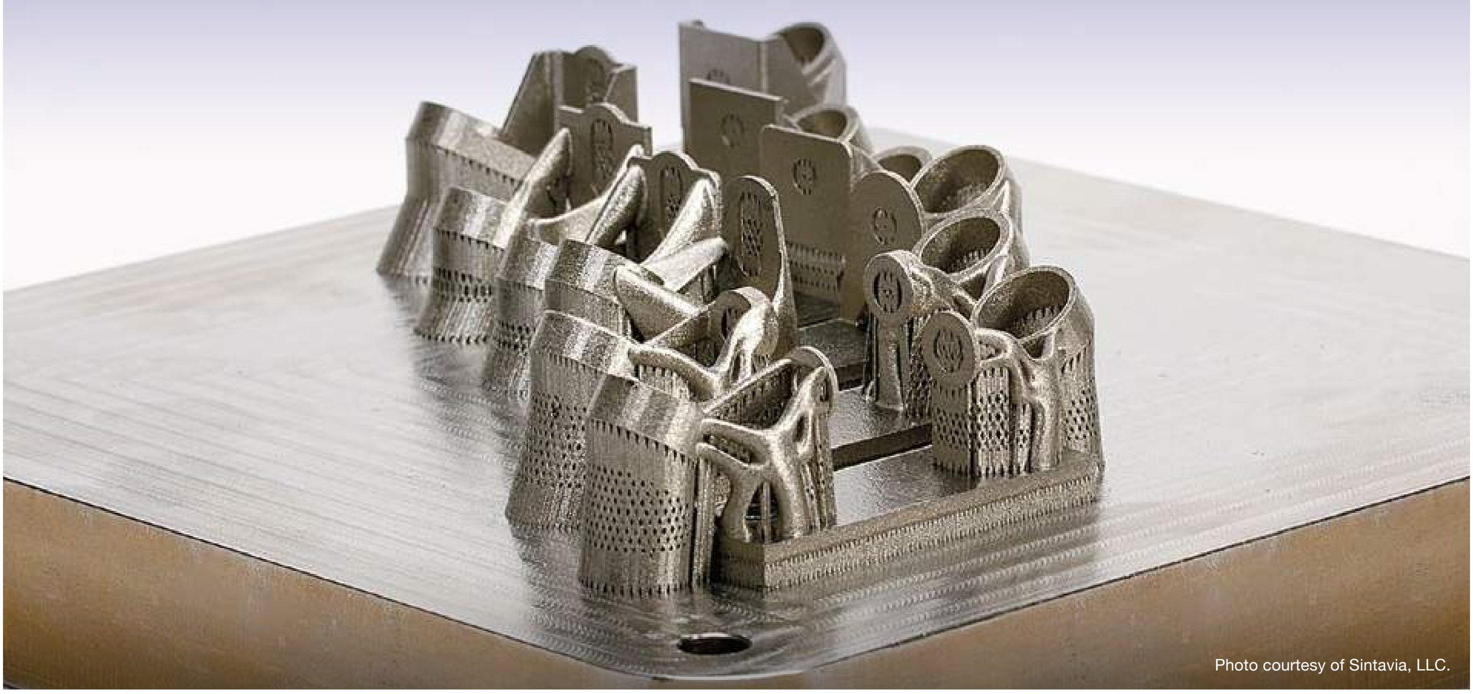


Photo courtesy of Sintavia, LLC.

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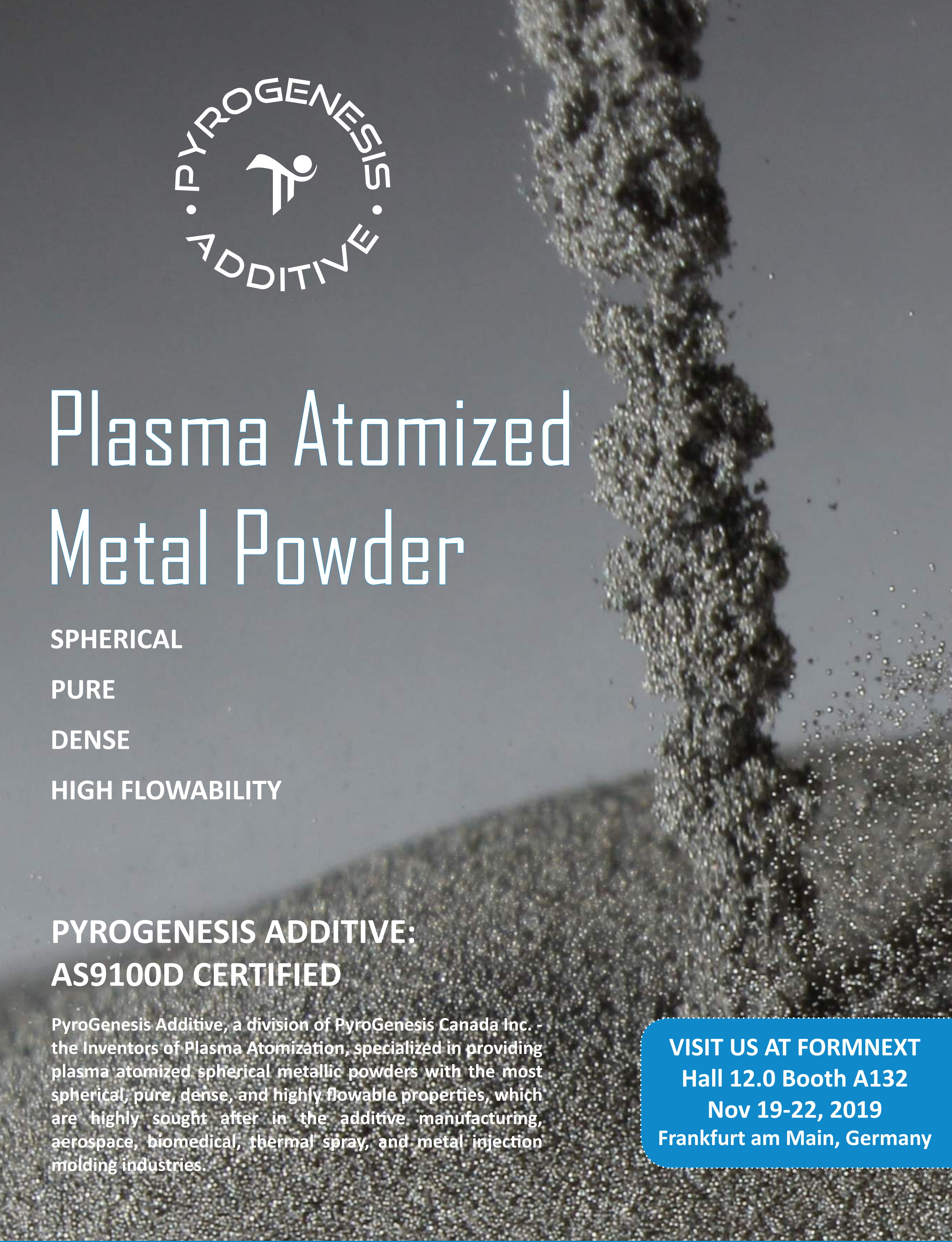
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## AddSteel project looks to develop new steels for AM

The federal state government of North Rhine-Westphalia, Germany, has launched the NRW Leitmarkt project AddSteel, aimed at digitalising the steel industry. Coordinated by SMS group GmbH, the three-year project aims to develop new function-adapted steel materials for Additive Manufacturing. In addition to SMS Group, the project's four participants include Fraunhofer ILT, Deutsche Edelstahlwerke Specialty Steel GmbH & Co. KG and Aconity GmbH.

One of the project's key areas of focus is the qualification of newly developed materials for Laser Powder Bed Fusion (L-PBF) at the Fraunhofer Institute for Laser Technology (ILT) in Aachen, Germany. One of the AddSteel project team's first reported successes was the development of case-hardening and heat-treatable steel powders designed specifically for L-PBF applications.

According to Fraunhofer ILT, steelmakers in Germany are facing a continuing decline in sales. Previously, efficiency was increased by modifying manufacturing processes and equipment. Now, however, developers and users are increasingly turning their focus to the alloys to be processed. Innovative materials are expected to offer new potential for competitive advantages.

The steel industry requires new materials to meet its customers' increasingly complex demands for products they can use, for instance, to manufacture lightweight and crash-resistant components for the automotive sector. AM processes such as L-PBF are extremely useful for lightweighting and part optimisation, and give users the opportunity to sustainably optimise the steel industry's value chain.

In recent years, scientists at Fraunhofer ILT have been working on developing L-PBF technology from a prototyping method to an industrial-scale method for the production of complex parts in small series. L-PBF is already being used by companies in the aerospace, turbomachinery, medical device and other industries to produce complex functional components.

The AddSteel project partners have reportedly chosen to develop alloys in an iterative process, combined with systematic adjustments to the L-PBF process and equipment. This will be followed by the construction of technology demonstrators for the fabrication of new components and spare parts that will be used to test and validate the materials' performance and cost-efficiency.

A plant has already been built at SMS group that can atomise suitable metal powders and Deutsche Edelstahlwerke Specialty Steel is now supplying the alloys that Fraunhofer ILT will soon be testing on its L-PBF system, after the alloys have been converted into powder form.

www.sms-group.com
www.ilt.fraunhofer.de

# DNV GL awards thyssenkrupp Additive Manufacturing Approval of Manufacturer certificate

DNV GL, a classification society headquartered in Oslo, Norway, has awarded thyssenkrupp AG, Essen, Germany, the first Additive Manufacturing Approval of Manufacturer certificate.

The society states that the certificate makes thyssenkrupp the world's first producer of additively manufactured parts for maritime applications to obtain manufacturer approval from DNV GL. Certification was important for thyssenkrupp Marine Systems, as the company reports that it is working with international customers on the integration of AM parts on ships and submarines.

According to DNV GL, the approval covers the Additive Manufacturing and processing of austenitic stainless steel parts. Certification was also awarded for the acceptance process in accordance with EN 10204 and the associated product information, particularly the chemical and physical material characteristics.

*An additively manufactured probehead produced by thyssenkrupp from austenitic heat resistant steel (Courtesy DNV GL/thyssenkrupp)*

"Additive Manufacturing will have a significant impact on the future maritime value chain," stated Geir Dugstad, Director of Ship Classification & Technical Director of DNV GL – Maritime. "Producing components that have the same level of quality as conventionally manufactured parts and fulfil class requirements is key."

Dugstad added, "At DNV GL, we are very pleased to certify that the thyssenkrupp TechCenter Additive Manufacturing has demonstrated its ability to reliably produce metallic materials using Additive Manufacturing. This is the first time DNV GL has awarded its Approval of Manufacturer certificate, and I would like to congratulate thyssenkrupp on this achievement."

Dr Luis Alejandro Orellano, Chief Operating Officer, thyssenkrupp Marine Systems, commented, "We are delighted that with thyssenkrupp TechCenter Additive Manufacturing we now have a certified partner who can supply thyssenkrupp Marine Systems with additively manufactured parts that meet both our own and our customers' high expectations. Together we are putting innovative solutions into our submarines and ships, setting new standards for the navy of the future."

"A team effort was particularly important here, as the certification required us to rethink traditional methods for quality evaluation and certification," explained Eva Junghans, Senior Principal Engineer, Materials & Welding at DNV GL – Maritime. "I would like to thank everybody involved for their support and collaboration."

www.dnvgl.com

www.thyssenkrupp.com



## Submitting news..

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paul@inovar-communications.com

## US Department of Defense awards contract to extend Flightware's in-situ inspection method

The Defense Logistics Agency (DLA), a combat support agency in the United States Department of Defense (DoD), has awarded a $1 million contract to a team led by Flightware Inc, headquartered in Guilford, Connecticut, USA, to extend its work in developing an in-situ inspection method for metal Additive Manufacturing.

"DLA is actively applying the benefits of AM to better perform our mission supplying spare parts to the warfighter," stated, Denise Price, DLA's Program Manager for the Small Business Innovation Program. "Flightware's in-situ inspection method can reduce scrap and improve yield, which reduces the cost and lead time of parts made by AM methods."

The two-year programme, which includes partners, the Edison Welding Institute (EWI) in Columbus, Ohio, and OpenAdditive, the research division of Universal Technology Corp. (UTC) in Dayton, Ohio, is using a Layer Topographic Mapping (LTM) method to determine melt quality, directly from as-formed layer surface measurements.

Under the initial effort, Flightware demonstrated that the LTM in-situ method can detect melt flaws, such as lack of fusion, in real time on a layer-by-layer basis with 98.2% detection rate and only 1% false detection. After detecting these flaw regions, appropriate repair procedures were automatically defined and then performed, as a demonstration of closed loop control.

Flyware states that this essentially eliminated the initial flaw porosity (up to 14%) and the repaired layer was restored to unflawed layer quality (less than 0.2% porosity). This reportedly salvaged the part, and allowed acceptance (based on CT scan results) of a part that otherwise would have been scrapped.

Under the programme, EWI is developing a large area profilometry sensor to measure the entire bed of the AM machine with high precision. The sensor will reportedly be installed in UTC's OpenAdditive PANDA printer, a commercial, open architecture, Laser Powder Bed Fusion (L-PBF) system. Flightware will then refine and improve in-situ inspection algorithms to reliably determine layer quality of both the as-formed melt and the powder bed

www.dla.mil
www.ewi.org
www.openadditive.com

## APWorks and Additive Industries look to series production of certified parts

*The MetalFAB1 system installed at APWorks, Taufkirchen facility (Courtesy Additive Industries)*

APWorks GmbH, a subsidiary of Premium Aerotec, located at Airbus' headquarters in Taufkirchen, Germany, and Additive Industries, Eindhoven, the Netherlands, are reported to be moving towards the next phase of industrial Additive Manufacturing, namely the series production of certified parts.

APWorks was Additive Industries' first customer, and has run extensive tests on its MetalFAB1 Beta system since its installation in March 2016, with its primary focus being on the development and production of complex and advanced applications in industries such as automotive, robotics and tooling, as well as new material and software development.

Together, the companies will collaborate on the series production of certified applications for the aerospace industry at a new Additive Industries Process & Application Development Centre in Filton, near Bristol, UK. Daan Kersten, CEO of Additive Industries, stated, "We are proud to continue our journey from prototyping to series production with APWorks, our first customer and one of the front-runners in our industry."

"We believe metal Additive Manufacturing will continue to evolve into a mature fabrication technology and prove to be able to compete with conventional processes like casting, machining and Powder Metallurgy," commented Joachim Zettler, CEO of APWorks. "In the next years we expect this market to continuously and rapidly grow, especially in the aerospace industry, new airplanes and aero-engines will contain a substantial number of parts that are additively manufactured."

Andreas Nick, CTO of APWorks, explained, "In the UK, our colleagues headed by our Chief Product Officer Jonathan Meyer will work closely with the Additive Industries Process & Application Development team led by Dr Mark Beard, their Global Director for Process & Application Development, on further qualification and certification of aerospace parts in nickel based alloys like Inconel 718."

www.apworks.de
www.additiveindustries.com

# Centorr Vacuum Industries launches two furnaces designed for sinter-based AM processes and heat treatment

Centorr Vacuum Industries, headquartered in Nashua, New Hampshire, USA, has announced the development of two new furnace lines designed specifically for Additive Manufacturing processes. The company, an established supplier of furnaces to the global Metal Injection Moulding (MIM)industry, has launched the Sintervac AM and Workhorse AM to meet the growing demand for metal Binder Jetting components.

The Sintervac AM furnace can debind in both partial pressures or positive pressures of Argon, Nitrogen, or Forming Gas depending on the customer's choice of binders. The all graphite furnace hot zone is said to offer a robust and inexpensive design for processing a variety of stainless steel, tool steel, mild steels and alloy materials. With a max temperature of 1600°C the Sintervac is reported to be able to process virtually all AM metals on the market today. The graphite insulation is fabricated from durable rigid graphite board secured to a stainless steel jail with CFC hardware in lieu of carbon felt, said to be more readily deteriorated in a binder-laden environment.

*Centorr's new furnace is designed for processing additively manufactured parts (Courtesy Centorr Vacuum Industries)*

The Workhorse AM is Centorr Vacuum Industries' production oriented offering specifically designed for the secondary heat treating, annealing, stress-relieving, de-gassing, and quench cooling of additivley manufactured parts. As laser-based AM processes may result in localised high-temperature melting of small spots within the overall part, micro-stresses can build up that need to be eliminated in order to achieve enhanced physical properties, such as fatigue strength, hardness, durability, and ductility. Annealing and stress-relieving in a vacuum or controlled atmosphere of inert gas provides that necessary furnace environment. The ultra-clean vacuum environment is also said to prevent oxidation, offering improved surface finish when compared to heat treatment in common atmosphere box furnaces.

The Workhorse AM design comprises of the standard hot zone rated for 1315°C with an optional upgrade to 1650°C for processing higher melting materials such as superalloys and Titanium. The furnace chamber is frontloading, said to offer better ergonomics and temperature uniformity compared with vertical top/bottom loaders or cylindrical hot zones.

www.vacuum-furnaces.com

# Midwest Prototyping announces AS9100 certification

Midwest Prototyping, LLC, a provider of Additive Manufacturing services headquartered in Blue Mounds, Wisconsin, USA, has achieved AS9100 Rev. D certification – the standard of operational excellence required for aviation and aerospace suppliers. The certification means that the company is now able to manufacture flight-ready components on all its AM technologies.

According to Midwest Prototyping, the AS9100 Rev. D certification builds onto its ISO 9001:2015 certified Quality Management System. In 2017, the company states that it became the first independent Additive Manufacturing service bureau to achieve the ISO 9001:2015 Standard, the most up-to-date version of the standard.

Steve Grundahl, president and founder of Midwest Prototyping, stated, "By achieving the AS9100 certification, we've opened up a new avenue for digital manufacturing – we can provide our technologies and expertise directly to aviation and aerospace companies of all sizes. We see this certification as a critical step forward to developing true digital manufacturing solutions for our customers."

Nate Schumacher, Director of Strategic Partnerships at Midwest Prototyping, who oversaw both the AS9100 Rev. D and ISO 9001:2015 implementations, commented, "The AS9100D certification process examines our entire operation. From the moment we quote a project or purchase raw material, to the finished product and the way we ship an order, our customers can have even more confidence in the quality of our work."

Schumacher continued, "I'm extremely proud of our team and their efforts to bring our organisation to the next level and the benefits this programme brings to both Midwest Prototyping and our customers."

www.midwestproto.com

## Nexxt Spine's additively manufactured spinal implant receives FDA clearance

Nexxt Spine LLC, a medical device manufacturer based in Noblesville, Indiana, USA, has reported that its Nexxt Matrixx® Stand Alone Cervical System, which was additively manufactured on a GE Additive Concept Laser Mlab system, has received FDA 510(k) clearance.

The stand-alone anterior cervical interbody fusion system is intended for use as an adjunct to fusion at one or two contiguous levels (C2-T1) in skeletally mature patients for the treatment of degenerative disc disease. It is intended to be used with the bone screw fixation provided and requires no additional fixation.

"This enhancement of the Nexxt Matrixx portfolio was the next natural progression for Nexxt Spine," stated Andy Elsbury, President, Nexxt Spine. "With patient care always top of mind, we strive to develop end products that surgeons prefer and hardware patients can count on. Our Stand Alone Cervical is no exception and will showcase the propensity of Nexxt Matrixx technology to facilitate the body's natural power of cellular healing for fortified fusion."

www.nexxtspine.com



## Cetim characterises new steel grade for Additive Manufacturing

France's Technical Centre for Mechanical Industry (Cetim) has released a new steel grade for the Laser Powder Bed Fusion (L-PBF) Additive Manufacturing of parts which can reportedly undergo nitriding treatment. According to Cetim, the new grade has been added to the list of steels used in AM and the organisation has characterised the 33CrMoV12 steel for the production of parts via L-PBF Additive Manufacturing as part of its R&D work carried out on behalf of French manufacturers.

The organisation stated that with its high carbon rate and nitriding capability, this steel offers attractive mechanical properties and opens up new application possibilities, especially in the power transmissions sector. It joins the three steels already commonly used for L-PBF manufacturing: X2CrNiMo17-12-2 (316L) and X5CrNiCuNb16-4 (17-4PH) stainless steels and the X2NiCoMo18-9-5 steel (maraging 300).

Cetim explained that although these three steels can be easily welded due to their low carbon levels (approximately 0.05%), the same is not true for the 33CrMoV12 grade, which can have a carbon percentage as high as 0.36%. Therefore, the powder for this type of material must be pre-heated before L-PBF, making the manufacturing process more troublesome.

Cetim believes that even though some AM systems have a pre-heating system, in most cases the pre-heating temperature is insufficient, being around 200°C and falling below the required 500°C. With a view to limiting and possibly eliminating this operation, one solution is to specifically determine the laser fusion parameters.

The organisation's study was carried out in conjunction with Volum-e, a polymer and metal prototyping and Additive Manufacturing specialist located in à Blangy-sur-Bresle (Seine-Maritime, France). By finely adjusting the parameters of the process, the two partners state that they were able to create test specimens and a demonstrator in the studied steel by L-PBF.

Cetim reportedly continued the work by minutely examining the parts including: chemical analysis of the material, porosity rates, residual stresses, influence of the heat treatment on the mechanical strength (tension and bending), capacity for nitriding, fatigue strength, etc. The organisation states that the assessment of this study reveals that the steel 33CrMoV12, can be worked by L-PBF exhibiting mechanical performance that is higher than that of the same steel when laminated, and due to its nitriding capability, its scope of use ranges to heavily surface loaded parts.

www.cetim.fr

## Maltese mining group PRG to buy Metalysis out of administration

Power Resources Group (PRG), a mining company headquartered in Valletta, Malta, has announced that it will buy Metalysis, Rotherham, UK, after the company announced that it had entered administration following financial difficulties in June 2019. Financial details of the transaction were not disclosed but, according to Reuters, PRG would be the sole owner of Metalysis.

One of the challenges said to have been faced by Metalysis was its reliance on externally sourced materials, the prices of which can be volatile, for the metal powders it produced for the Additive Manufacturing industry.

PRG mines tantalum and niobium in Rwanda, and has a refinery in North Macedonia and said that it is a good fit for Metalysis.

*Metalysis' Discovery Centre on the Advanced Manufacturing Park in Rotherham (Courtesy cloudinary.com)*

"The technology metals focus is a perfect complement to PRG's existing vertically-integrated mining and refining operations and customer base," PRG's CEO, Ray Power, told Reuters.

Metalysis grew out of research at Cambridge University and has spent more than a decade developing technology for applications in the aerospace and automotive industry. Set up in 2001, it employed sixty at two sites in Rotherham.

Power stated that Metalysis had reached industrial-scale production only in the last nine months and had been "just a whisper away from commerciality" when it went into administration.

The company has received a total of £92 million ($114 million) through numerous funding rounds, most recently in 2018. It was reported that Metalysis made an operating loss of £7.1 million ($9 million) in the year ended March 2018.

Eddie Williams of Grant Thornton, joint administrator of Metalysis, said the sale had been "a very challenging process."

www.metalysis.com

www.prgplc.eu

## voestalpine sees impact of economic slowdown and rising material costs

voestalpine Group, headquartered in Linz, Austria, has reported its results for the first quarter of its fiscal year 2019/2020. The group stated that the "macroeconomic environment has clouded over significantly since the start of the business year 2019/20," due to international trade conflicts and the associated, growing weakness of the global economy, which strongly affects Europe's export-oriented industries, and the automotive industry in particular.

The company reported €3.3 billion revenue for Q1 2019/20, down 3.8% from the previous year (€3.5 billion). Net profit was reported at €90 million, down from €226 million in 2018. In addition to the cooling economy and trade conflicts, a price increase in iron ore and $CO_2$ emission certificates were cited as the main factors.

However, the company stated that thanks to its broad product portfolio it had succeeded, despite these challenges, in generating positive demand throughout key customer segments such as rail technology, aerospace, warehouse and welding technology. In addition, it stated that it was already working on counteracting market pressures through cost and efficiency improvement programmes across the group.

All four of the group's divisions were said to have seen a slight decline in revenue, resulting mainly from declining delivery volumes. The start-up costs at the group's automotive plant in Cartersville, USA, were also said to have resulted in downward pressure on earnings in the reporting period.

Herbert Eibensteiner, Chairman of the Management Board of voestalpine AG, stated, "The Management Board of voestalpine AG continues to work in a difficult environment, particularly with respect to the development of ore and steel prices, on achieving EBITDA for the current business year that is comparable to that of the previous business year even though the uncertainties have mounted since the start of the current business year."

www.voestalpine.com

  


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## ExOne licenses method for AM of boron carbide from Oak Ridge National Laboratory

The ExOne Company, North Huntingdon, Pennsylvania, USA, has reported that it has licensed a patent-pending method of additively manufacturing aluminium-infiltrated boron carbide (B4C) collimators and other components used in neutron imaging from Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, USA.

Following the announcement of their collaboration project, researchers at ORNL developed the Additive Manufacturing method on the ExOne M-Flex®, a metal AM system that uses Binder Jetting technology to produce additively manufactured objects in stainless steel, bronze or tungsten, as well as sand, ceramics and composites.

The ORNL team, led by David C Anderson, Group Leader of Instrument Engineering, developed a process to additively manufacture objects in B4C, a neutron-absorbing material, and then infiltrate the objects with aluminium. The final aluminium-infiltrated B4C material is known as a metal-matrix composite (MMC), a type of cermet. ORNL's Amy Elliott and Bianca Haberl are co-inventors of the process.

According to ORNL, the development is significant because aluminium-infused B4C has strong but lightweight properties, as well as energy-absorbing characteristics that are useful in neutron scattering instruments, which enable researchers to capture data down to the atomic level.

ExOne states that it plans to use the licence to commercialise the AM production of aluminium-infiltrated B4C objects, such as shielding equipment and components used in neutron scattering instrumentation.

Dan Brunermer, Technical Fellow at the ExOne Company, commented, "It delivers results that X-rays can't. Neutrons can detect light elements, like hydrogen or water, but they also penetrate through heavy elements like lead, which enables analysis of complex processes in-situ."

The intellectual property covered in the licence agreement includes pending U.S. patent application no. 16/155,134, titled 'Collimators and Other Components from Neutron Absorbing Materials Using Additive Manufacturing,' as well as two additional provisional filings. Under the agreement, ExOne will also engage in ongoing AM production of a variety of B4C matrix components used in neutron scattering experiments at ORNL.

www.exone.com

www.ornl.gov ■■■

# Incus to reveal novel metal AM process based on photopolymerisation

Incus GmbH, a new metal Additive Manufacturing machine maker based in Vienna, Austria, will debut its novel metal AM system at Formnext 2019 this November. The company's Hammer Series machine uses a technology based on the principle of photopolymerisation for the Additive Manufacturing of intricate metal components.

This new metal AM technology is said to combine excellent surface aesthetics for fine structures with cost-efficiency, reproducibility and increased manufacturing speed. The process uses a feedstock which is said to increase working environment safety, eliminate the need to invest in protective gas atmosphere solutions, and offers reproducibility without elaborate process parameters.

The company evolved from ceramic AM specialist Lithoz GmbH. "Our goal is to become an integral part of production in the metal industry. To achieve this, we are focusing on absolute service orientation and our passion for bringing innovative metal printing solutions to market. Quality and partnership are cornerstones of our business model," stated Dr Gerald Mitteramskogler, CEO of Incus.

According to Incus, metal Additive Manufacturing technologies currently on the market offer the production of parts using relatively coarse metal powders in the range of around 40–100 µm. With the new Incus process, it is possible to use metal powders down to 20 µm at competitive build speeds.

Mitteramskogler further added, "With our new printer series, it is not only possible to produce very small complex components with the finest surface structure, it also allows us to use new metal powder mixtures, such as non-weldable powders. In material development projects with our customers, we have already shown that we can achieve similar material properties compared to Metal Injection Moulding, a mass production process for metal parts. We are always happy to take on challenges concerning new materials or geometries to benchmark our process."

Two beta machines are reported to have been in use for development for over a year, and feasibility studies have shown that the expectations for the technology are being met. Prof Carlo Burkhardt, Head of the Institute for Strategic Technology and Precious Metals at the University of Pforzheim and founder of local company MetShape, who has been involved in the development of applications for the new systems, stated, "We are always intrigued by cutting-edge technologies and are convinced that we are part of a new era in the metalworking industry. The components we produced in the beta phase with the printer exceeded our expectations."

AM Ventures, known for strategically sustainable investments in advanced manufacturing technologies, especially Additive Manufacturing, is backing the company. Johann Oberhofer, Chief Technology Officer of AM Ventures, commented, "When the project was presented to us, we saw immediately that this was not a small boost to innovation. We believe that this new technology will open up many opportunities in the metal industry and we want to help make this happen."

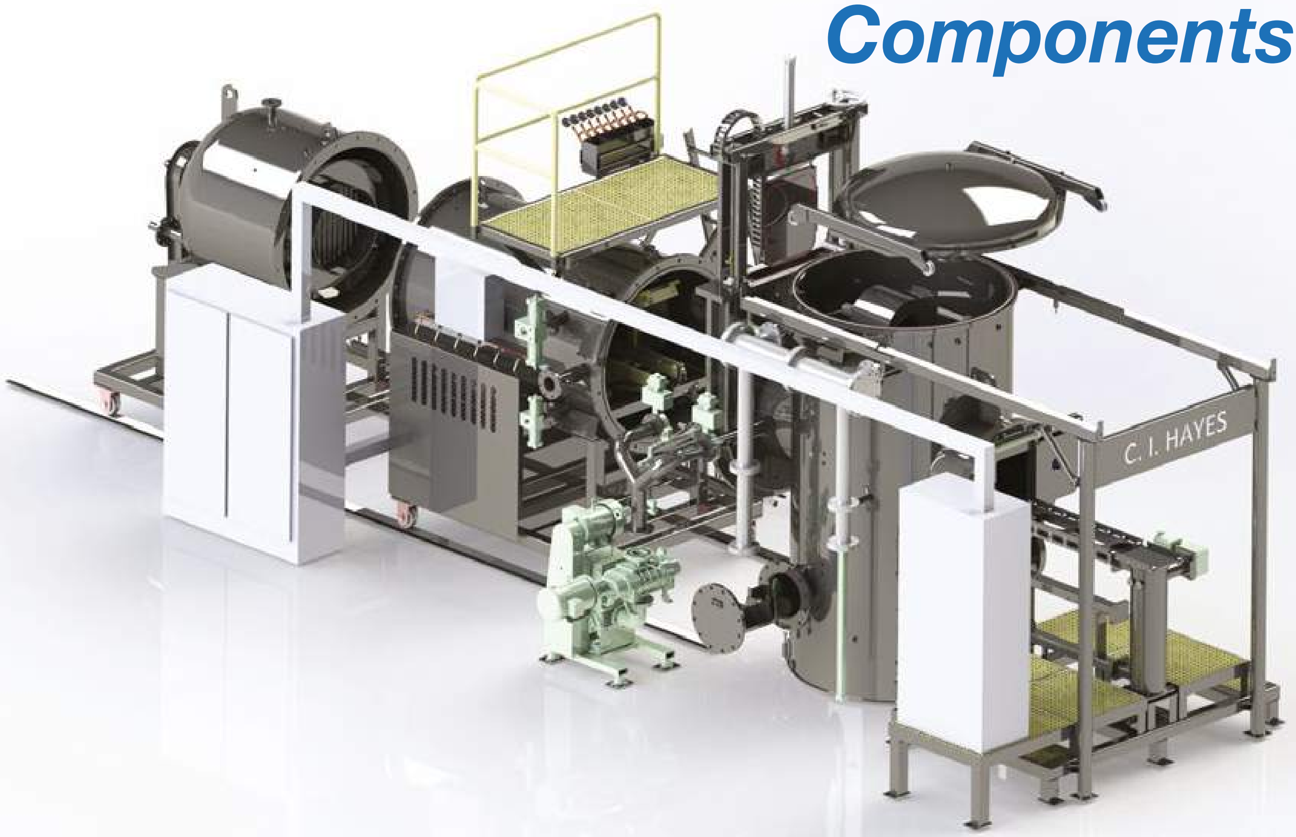
Incus will exhibit the Hammer Series at Stand D32 in Hall 11.1 at Formnext.

www.incus3d.com


*Gerald Mitteramskogler, CEO of Incus (left) hands over the first Hammer system to Professor Carlo Burkhardt, founder of MetShape (Courtesy Incus)*

*First components produced with the Incus Hammer series (Courtesy MetShape/Incus)*


C. I. HAYES



## Materialise invests in Engimplan to drive introduction of AM implants in Brazil

Materialise, the Additive Manufacturing solutions company headquartered in Leuven, Belgium, has invested in Engimplan Implants Engineering, a manufacturer of orthopaedic and cranio-maxillofacial (CMF) implants and instruments based in Rio Claro, Brazil, to accelerate the introduction of additively manufactured, personalised implants and instruments into the Brazilian market.

According to Materialise, it has signed an agreement to acquire a 75% stake in Engimplan through a combined acquisition of existing and new shares via its Brazilian subsidiary Engimplan Holding Ltda. As part of the transaction, Materialise will gain access to Engimplan's local production facility, expand the company's portfolio with its experience, and enter its existing partner and distribution network in Brazil. The closing of the transaction is expected to take place in August.

"Surgical planning and 3D printing are increasingly adopted by orthopaedic and CMF surgeons, as they understand the positive impact of personalised implants and patient-specific solutions on surgical outcomes," stated Brigitte de Vet, Vice President and General Manager of Materialise Medical. "With this investment, we will expand our medical product and service portfolio, confirming our commitment to strengthen our position and grow our global presence in the medical industry."

José Tadeu Leme, CEO of Engimplan, commented, "This investment by Materialise sends a strong signal to our customers and the industry that we remain committed to developing our innovative solutions that improve the lives of many people, and that we have the confidence and support of a pioneer and global leader in 3D printing. Together, we can introduce new levels of innovation in the development of personalised implants in Brazil."

www.materialise.com
www.engimplan.com.br

## Gefertec to open its first US manufacturing facility in Virginia

Gefertec, LLC, the US division of metal Additive Manufacturing company Gefertec GmbH, Berlin, Germany, is to open its first US facility in Danville, Virginia, USA. The new manufacturing facility will initially be based at Danville's Institute for Advanced Learning and Research (IALR), before moving to a permanent space in Virginia's Danville/Pittsylvania County area in future.

The establishment of the new facility will involve an investment of $1.9 million, and is receiving support from the Tobacco Region Revitalization Commission with a $45,000 Tobacco Region Opportunity Fund (TROF) grant, while the Danville Pittsylvania Regional Industrial Facility Authority (RIFA) will cover the cost of two years of temporary space at IALR.

"Gefertec is excited to announce the opening of our Danville – Pittsylvania County location as our first US location for our 3DMP Additive Manufacturing business," stated Andrea Clark, President of Gefertec, LLC.

Tobias Roehrich, CEO of Gefertec GmbH, added, "This is in alignment with our long-term commitment to Danville and the Institute for Advanced Learning and Research and we are excited to expand our business to the US. Danville has been chosen for its excellent business and community support and its involvement in the advanced manufacturing sector."

www.gefertec.de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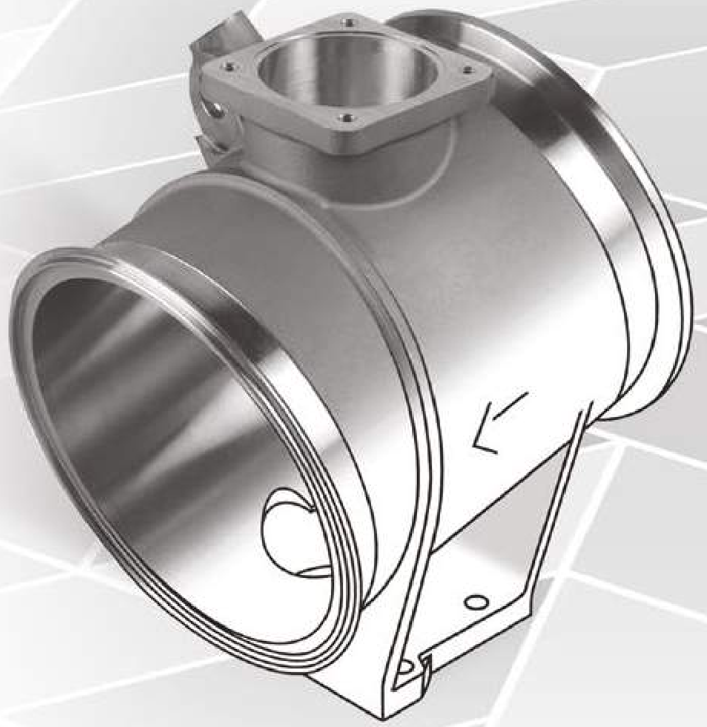


## Physna completes Series A funding round with investment by Drive Capital

Physna, a technology startup headquartered in Cincinnati, Ohio, USA, has completed a $6.9 million Series A round of financing led by venture capital firm Drive Capital, Columbus, Ohio, USA. Physna states that it will use the funding to continue its software product development, increase adoption of its technology, and expand its engineering and sales teams.

The company reports that it has built a geometric search engine that can increase efficiencies within CAD design and manufacturing by breaking down 3D files into a codified structure. Physna explains that this approach creates a 'DNA-like' structure representative of the 3D model, and that through machine learning, the search engine can recognise common traits.

According to Physna, results from its search engine are pulled from a user's own database of 3D files, and the results can include similarities and differences between 3D models returned by the search engine and the files used for the search, regardless of file types. The search is said to allow users to search millions of 3D models in seconds.

"The results are orders of magnitude more accurate and faster than was ever previously possible in 3D search," stated Paul Powers, Founder and CEO of Physna. "We are just scratching the surface. The uses for Physna's core technology are virtually limitless."

Mark Kvamme, Drive Capital Partner, commented, "We are very excited for the opportunity to invest in Physna. We believe what Paul and his team are doing in search has the potential to revolutionise the workflows of engineers around the world."

*Physna has built a geometric search engine that can increase efficiencies within CAD design and manufacturing (Courtesy Physna)*

"Drive Capital matches our passion for taking on major issues and fixing large, fundamental problems through groundbreaking technology," added Powers. "We are excited for Mark to join our board. We know the partnership with Drive will allow us to accelerate our development and growth."

www.physna.com

www.drivecapital.com

## Collaborative project to look at Additive Manufacturing of hardmetals

A new collaborative project on the Additive Manufacturing of hardmetals is now reported to be open for participation. The AddiHM Project is set to establish the benchmarking of three non-laser based AM processes for the production of homogeneous WC-12Co hardmetal blanks.

The AddiHM project is coordinated by OCSynergies along with Fraunhofer IKTS Dresden, the Katholieke Universiteit KU Leuven, TECNALIA Research & Innovation San Sebastian and the Technical University of Catalonia BarcelonaTech UPC. The aim is to establish a comparison of Fused Filament Fabrication (undertaken at IKTS), metal Binder Jetting (at Tecnalia) and direct ink writing (at KU Leuven). An evaluation of the final AM components will be also carried out at UPC.

It is stated that the AddiHM project will last twelve months and is now open for participation to all interested organisations. The total budget of the project is €69,900 to be shared by a minimum of six funding participants.The project will be conducted in memory of Dr Leo Prakash, who passed away in February 2019 aged sixty-nine, and who first conceived the idea for the project. Those interested in joining the AddiHM project or who wish to receive more information are invited to contact Dr Olivier Coube (olivier.coube@ocssynergies.com).

www.ocsynergies.com/projects

## Aeromet's A20X metal powder for AM surpasses 500 MPa UTS mark

Aeromet International Ltd, headquartered in Worcester, England, UK, reports that its patented A20X™ powder, an aluminium alloy for Additive Manufacturing, has surpassed the key 500 MPa Ultimate Tensile Strength (UTS) mark as part of its research project, HighSAP.

The HighSAP project is supported by the UK's National Aerospace Technology Exploitation Programme (NATEP), and led by Aeromet with collaboration from Rolls-Royce, Renishaw and Phoenix Scientific Industries (PSI). Aeromet states that the heat-treated parts produced using A20X achieved a UTS of 511 MPa, a yield strength of 440 MPa and elongation of 13%.

Mike Bond, Director of Advanced Material Technology at Aeromet, commented, "Since bringing the A20X alloy to market for Additive Manufacturing five years ago, we have seen significant adoption for high-strength, design-critical applications. By working with Rolls-Royce, Renishaw and PSI we have optimised processing parameters that led to record-breaking results, opening up new design possibilities for aerospace and advanced engineering applications."

www.aeromet.co.uk

## BASF expands reach of its Ultrafuse 316L metal filament

BASF 3D Printing Solutions GmbH, Heidelberg, Germany, has announced it is working with iGo3D (Germany), Ultimaker (the Netherlands) and MatterHackers (USA) to commercialise its Ultrafuse 316L filament, a metal-polymer composite designed for use in Fused Filament Fabrication (FFF) Additive Manufacturing systems.

Ultrafuse 316L is said to enable simple and cost-efficient production of fully metal parts for prototypes, metal tooling and functional metal parts. Once formed, parts are debound and sintered to achieve a final 316L stainless steel part.

"Ultrafuse 316L can, under certain conditions, be processed on any conventional, open-material FFF printer," explained François Minec, Managing Director, BASF 3D Printing Solutions. "Our goal was to develop a high-quality metal filament that makes the Additive Manufacturing of metal parts considerably easier, cheaper, faster and accessible to everyone."

Athanassios Kotrotsios, Managing Director of iGo3D added, "To reach the full potential of the metal filament and to ensure a solid start, it is necessary to understand that Ultrafuse 316L is not a conventional filament. Our goal is it to provide full service packages and support from the first request up to the finalised and sintered part, to implement metal 3D printing as a natural component in your manufacturing process."

Using metal powder within a binder matrix is said to dramatically reduce the potential hazards of handling the fine metal powders used in alternative powder based AM processes.

"The Ultimaker S5 raises the bar for professional 3D printing by offering a hassle free 3D printing experience with industrial-grade materials. We are proud to announce that print profiles for Ultrafuse 316L will be added to the Ultimaker Marketplace," added Paul Heiden, Senior Vice President Product Management, Ultimaker. "3D printing professionals worldwide can then use FFF technology to produce functional metal parts at significantly reduced time and costs."

The metal composite filament is highly flexible and strong, allowing it to be used with both Bowden and direct drive extruders, as well as being guided through complex filament transport systems.

"Ultrafuse 316L from BASF enables engineers and designers to produce true, pure, industrial grade metal parts easily and affordably using desktop 3D printers," stated Dave Gaylord, Head of Products, Matter-Hackers. "This material is a significant technological advancement and truly a shift in how we describe what is possible with desktop 3D printers."

www.basf-3dps.com

# Electric motor housing with integrated cooling for Formula Student racing team

JAMPT Corporation, Miyagi, Japan, has been working with the Technical University of Munich's TUfast Racing Team to develop an electric motor housing with integrated cooling for use on its Formula Student electric-powered racing car. Thanks to the use of metal Additive Manufacturing, JAMPT and the TUfast team optimised the design of the housing and inlet to produce a motor which allowed the vehicle to remain aerodynamic, which was lightweight, and which had sufficient power and torque.

The annual Formula SAE and Formula Student competitions challenge students to design and build race cars, which race and are also ranked based on their design, acceleration, efficiency, endurance and cost, among other factors. The 2019 competition required the TUfast team to produce two all-new Formula Student racing cars, one with an electric and one with a combustion powertrain.

In order to fit completely into the wheel rim of the vehicle to minimise drag, the electric motor housing developed in conjunction with JAMPT – which is also one of the team sponsors – had to be under 150 mm in length. The housing also required a sufficient cooling system to transfer heat induced by stator losses and to avoid overheating, which would lead to its automatic shut down.

To address this need, the team and JAMPT opted for an integrated water cooling system consisting of a 'pin' structure, incorporating 45° angled pins, enabling the surface to transfer more heat due to the increased surface area. The resulting turbulent flow of coolant also maximises heat transport, with the pin structure offering reduced flow separation and a lower pressure drop compared to a helix structure.

The only manufacturing method capable of producing a part with this type of inner structure in one piece is metal Additive Manufacturing. JAMPT produced the housing by Laser Powder Bed Fusion (L-PBF) on an EOS M 280 system, followed by milling and turning to achieve the final tolerances. The housing was built from AlSi10Mg due to the material's low density and weight, high heat conductivity and low cost.

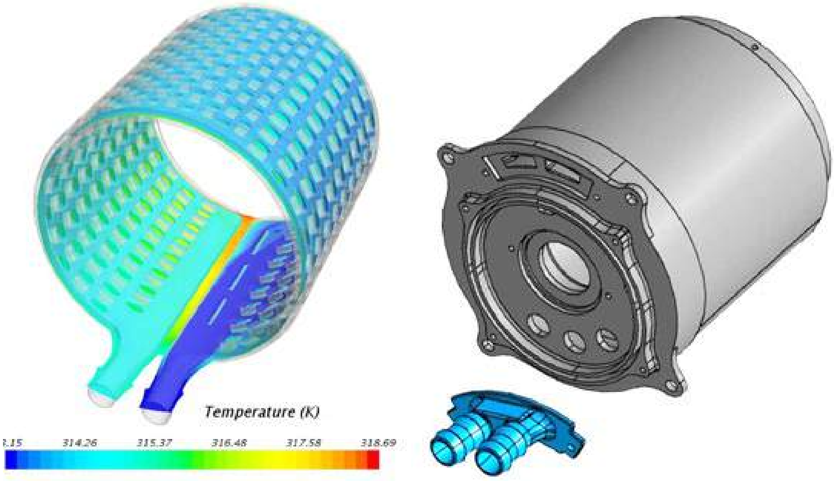
The optimised design of the internal structure made it possible to produce the part by L-PBF without the need for support structures within the cooling channel, and ensured that no metal powder was left inside the cooling channels after the build. To reduce the need for support structures at the front surface of the part, the inlet and outlet were also separated from the main body for the build process.

*The inlet and outlet were separated from the main body for the build process in order to reduce the need for support structures (Courtesy JAMPT Corporation, TUfast)*

To further save weight, a titanium hollow shaft was used in the motor design. A polygon connection was used between the rotor shaft and sun gear to reduce the length and lower weight. Axial length was kept as low as possible to fit the motor completely into the rim, and a carbon fibre-reinforced polymer (CFRP) cap was fitted for the HV-connection to avoid collisions with the tie-rod.

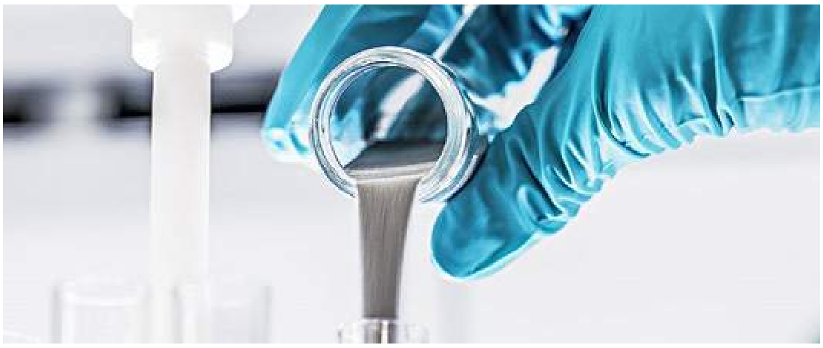
Since the launch of the Formula Student 2019 competition, the TUfast team has competed in two races in the electric race car in which the cooling shell and inlet are installed – Zala Zone, Hungary and Red Bull Ring, Austria – winning both. TUfast recently competed and took first place in the biggest event on the Formula Student circuit, at the Hockenheimring, Germany, which ran in August 2019.

www.jampt.jp/en
www.tufast.de




*CFD simulation (left) was used to optimise the cooling structure. The splitter at inlet offered better flow distribution (Courtesy JAMPT Corporation)*

# VDM Metals offers range of metal powders for Additive Manufacturing



*VDM Metals offers a range of metal powders for Additive Manufacturing (Courtesy VDM Metals GmbH)*

VDM Metals GmbH, headquartered in Werdohl, Germany, is a global supplier of metals offering a range of metal powders for Additive Manufacturing. Its product portfolio includes cobalt-chrome alloys, corrosion resistant alloys, superalloys and special stainless steels, as well as manufacturing custom alloys developed in collaboration with its customers.

VDM installed its metal powder manufacturing plant at its Unna, Germany, facility in 2017, following the construction of a new hall specifically for powder production. Earlier this year it announced a further investment of several million euros in its powder production plant, among other areas.

The company uses a vacuum inert gas atomisation (VIGA) process to manufacture its range of metal powder products. The standardised production method allows VDM Metals to offer a wide variety of particle sizes and particle size distributions particularly suited to metal Additive Manufacturing systems.

VDM Metals produces powders from proven alloys and also optimises conventional materials for the powder production process. The high-purity metal powder is produced by means of vacuum induction melting followed by inert gas atomisation, with the individual steps precisely coordinated to ensure the composition and purity of the powder.

www.vdm-metals.com

## AM Powder Plus network for efficient parts and powder handling

Assonic Dorstener Siebtechnik GmbH, Solukon Maschinenbau GmbH and ULT AG have announced the formation of a network, AM Powder Plus (AMP+), which will offer integrated solutions for highly automated parts and powder processing and handling in the Laser Powder Bed Fusion (L-PBF) Additive Manufacturing process.

This includes the collection, sifting, reprocessing and drying of surplus powder, with automated component removal and depowdering for clean transfer to post-processing. Unexposed powder can then be returned in a fully processable state, assuring occupational health and safety, dust explosion protection, and a clean working environment.

The AMP+ partners will reportedly pool their combined knowledge and experience in AM to offer these solutions to the industry. In practice, they stated that they have encountered blind spots in the L-PBF process chain that have so far prevented industrial users from making widespread use of this new technology. These shortcomings are concentrated on a comparatively short section of the process, between the completion of the build and the start of post-processing.

Currently, this blind spot results in a need for companies to conduct inefficient manual steps and consume unnecessarily high quantities of powder, the network stated. In addition, the challenge of avoiding explosion hazards and of airborne pollutants must be met for AM to truly succeed. AMP+ believes that its solutions can address each of these problems.

The AMP+ network will exhibit for the first time at this year's formnext, November 19-22, Frankfurt, Germany.

www.ampplus.de ■■■

## AddUp and IPC form Addilys for metal Additive Manufacturing in tooling

France's AddUp Group and Plastics and Composites Manufacturing Technical Centre (IPC), have formed Addilys, a joint platform focused on driving the adoption and deployment of metal Additive Manufacturing in the area of tooling and plastics processing. The new entity will be headquartered near to AddUp and IPC's headquarters.

The goal of the platform is to provide manufacturers with global solutions, from advice to maintenance, as well as tooling design, demonstrations and manufacturing services. The partnership is expected to make it easier for companies to deploy customised and optimised thermal solutions, particularly in industrial-level plastics processing, through the use of the conformal cooling solutions made possible by metal AM.

www.addilys.com | www.addupsolutions.com ■■■

# thyssenkrupp predicts $100 billion economic value for AM in ASEAN by 2030

thyssenkrupp AG, Essen, Germany, has published a white paper on the potential of Additive Manufacturing in the Association of Southeast Asian Nations (ASEAN) region, based on research undertaken by the company, with the support of partners in Singapore, as a prelude to the official launch of its AM TechCenter Hub in Singapore. Titled 'Additive Manufacturing: Adding Up Growth Opportunities for ASEAN', the white paper looks at the state of AM in the ten member countries.

AM penetration in ASEAN is currently quite small, accounting for only 5–7% of Asia's total AM spend (estimated at $3.8 billion) for 2019. However, thyssenkrupp's report states that there is huge potential for the ASEAN market given its contribution to the global manufacturing output. Manufacturing accounts for 20% of the region's GDP, employs nearly 50 million of its workforce and is expected to experience major growth in the near future.

The report predicted that Additive Manufacturing will generate around $100 billion of incremental value by 2025, impacting ASEAN's projected real GDP by 1.5 to 2%. Opportunities presented by AM are expected to enable a reduction of ASEAN's import dependence, with the potential to impact at least $30–50 billion by localising manufacturing closer to consumption and reducing overall import dependence by up to 2% for the region

AM can also contribute in sustainable development and improve ASEAN's competitiveness in already established global value chains across key sectors such as automotive, electronics, and chemicals, as well as accelerate the region's growth in industries like aerospace, medical devices, and healthcare. It is believed that Additive Manufacturing would enable the ASEAN region to further advance its Industry 4.0 and skills development focus, and promote local entrepreneurship with the potential to create 3–4 million additional AM jobs for the region by 2030.

"As our study shows, Additive Manufacturing delivers enormous potential to transform the ASEAN region and level up vital sectors," stated Jan Lueder, CEO of thyssenkrupp Regional Headquarters Asia-Pacific. "Additive Manufacturing will surely be an innovative solution to further drive growth in ASEAN, as long as stakeholders work together to continue building awareness as well as a supportive ecosystem for Additive Manufacturing adoption and development. We have found such an ecosystem in Singapore, and that is one of the key reasons in establishing our first Additive Manufacturing TechCenter Hub outside of Germany."

www.thyssenkrupp.com

# Farsoon and Next Chapter Manufacturing develop H13 components with conformal cooling


*The lifter design with a conformal cooling circuit (Courtesy Farsoon Technologies/Next Chapter Manufacturing)*

Farsoon Technologies, headquartered in Hunan, China, has collaborated with its partner Next Chapter Manufacturing (NXCMFG), Grand Rapids, Michigan, USA, to develop advanced process parameters for the production of robust H13 tool steel components using Laser Powder Bed Fusion (L-PBF) Additive Manufacturing. H13 tool steel is used for more hot work tooling applications than other grades of tool steel, as well as in a variety of cold work conditions, because of its high toughness and good stability.

H13 is suited to a range of applications, from die casting, extrusion dies and highly tough and polished (up to A1 grade) injection moulding components. However, its high carbon content makes it difficult to weld or process using standard L-PBF parameters, as the carbon content is easily vapourised and can contaminate the powder surface during the melting process – potentially leading to issues such as internal flaws, porosity and thermal cracks.

Farsoon and NXCMFG have partnered to find a solution for these challenges. A number of tests have reportedly been conducted by Farsoon's application team to develop processing parameters for the manufacture of parts in H13, considering factors such as the optimal laser power, scanning strategies, stress relief and heat treatment.

Farsoon reports that its optimised parameter set helps to eliminate the thermal cracks which may develop when welding H13 steel and delivers a high relative density of over 99%. The additively manufactured H13 parts achieved in the project are also said to exhibit excellent mechanical properties in comparison to wrought H13 material.

One successful H13 component which the partners have recently developed is a lifter used to cool and separate plastic parts from the core during the injection moulding process. A conformal water circuit design was added to the geometry of the lifter, and the component was additively Manufactured on a Farsoon FS271M system. Next Chapter Manufacturing stated that it was able to deliver four replacement lifters in eight days.

The company states that these lifters can be installed directly in the production line, with the new conformal water circuit helping to accelerate the cooling process and eliminate warpage in finished injection moulded parts. The optimised lifters are said to have improved production volume when using the original factory settings, reducing the cycle time from 48 seconds to 30 seconds and achieving a reported annual saving of over $100,000.

"We decided to partner with Farsoon Technologies because its system is open, which means we can develop specific processes that enable us to print H13 and other tool steels efficiently," stated Jason Murphy, President of Next Chapter Manufacturing.

"This open parameter system also enables us to do test builds and refine our process to improve robustness and speed further," he continued. "The technology of the Farsoon machine gives designers a significant amount of additional freedom to provide the most efficient designs for Additive Manufacturing, which other machines do not offer."

http://en.farsoon.com/
www.nxcmfg.com

# World's lightest cycle gear wheel additively manufactured and tested by Tour de France racers

CeramicSpeed, Holstebro, Denmark, and the Danish Technological Institute (DTI) in Taastrup, have collaborated to additively manufacture a lightweight titanium pulley wheel for a race-bike gearing system, aimed at professional cyclists. The radical new design, reported to be the world's lightest gear wheel, was race-condition tested by competitors from this year's Tour de France.

The pulleys, manufactured on SLM Solutions' SLM®500 metal AM system, are equipped with seventeen spokes with a diameter of 2 mm and a wall thickness of only 0.4 mm. Due to the hollow design, it has been possible to reduce the total weiaght of the sprocket to just 8.4 g.

"The hollow geometry of the objects cannot be produced with conventional methods, and the 3D printing in combination with subsequent specialised processes leads to a unique innovative product," stated Thor Bramsen, Industrialisation Manager at the Danish Technological Institute. Despite the complex geometry, DTI is able to reliably build the same quality parts in series production.

CeramicSpeed states that its R&D department have been testing the wear on the additively manufactured titanium parts, which proved to be more durable and suitable for corrosion resistance and strength at low density than conventional aluminium parts.

To offer serial production of a high-quality, additively manufactured product, it is stated that the entire process chain must be coordinated. The process begins with the component redesign for the additive process, in this case a delicate mix of not changing the customer's design, while adding material for surfaces that require CNC machining, optimising support, and minimising wall thickness and weight. After successful production, the equally challenging, yet important post-processing steps take place, where the Danish Technological Institute uses its entire range of manufacturing knowledge, ensuring that only assembly is required when the finished product is delivered.

"3D printing technology has given us a lot of leeway to experiment creatively with design, while at the same time being able to optimise a product's function," commented, Carsten Ebbesen, R&D Manager at CeramicSpeed. "The collaboration with DTI has led us to develop and produce gears in a radically new design form that is only possible with 3D printing."

The first ceramic bearings from CeramicSpeed were introduced to the Tour de France less than twenty years ago. Thanks to the design provided by Selective Laser Melting, and its partnership with the DTI, the company continues to develop cycling technology and is helping set new standards as riders test the latest innovations in their training to be the next to debut new advancements at future Tour de France races.

www.slm-solutions.com
www.ceramicspeed.com
www.dti.dk


*Only assembly is required when the finished product is delivered (Courtesy SLM Solutions)*


*The additively manufactured titanium pulley wheel produced by CeramicSpeed and DTI (Courtesy SLM Solutions)*

## Siemens to lead IDEA project for industrial AM in Germany

Siemens has taken over the role of project management for the German Ministry of Education and Research grant project IDEA (Industrial implementation of Digital Engineering and Additive Manufacturing). The goal of the IDEA project is to reduce development and production times in the powder-based Additive Manufacturing of complex metal components by approximately 50%.

Currently the individual work steps along the AM process chain often take place in isolation, from CAD design to component finishing. IDEA aims to bring together fourteen partners from business and science to drive ongoing efforts to industrialise and automate Additive Manufacturing.

The partners in the IDEA project include the hardware and software suppliers ALLMATIC, BCT, Jenoptik, ModuleWorks, and Siemens Digital Industries; machine makers EOS and Trumpf; and AM users Liebherr-Aerospace, MBFZ toolcraft GmbH, MTU Aero Engines, and Siemens Gas and Power. The project is supported by the Fraunhofer Institute for Laser Technology (ILT), the Fraunhofer Institute for Production Technology (IPT), and the RWTH Aachen University's Machine Tool Lab (WZL) and School of Digital Additive Production (DAP).

IDEA's priority is to further industrialise AM for Germany's industrial sector through the use of partnerships across the industrial spectrum, with a particular focus on linking hardware and software. Digital twins of products to be manufactured, the manufacturing process, and the entire production line are expected to significantly develop AM – which is still characterised by manual input – into a highly-efficient production line.

A development and implementation phase will be followed by a validation process in the second half of the project. This will involve measuring how well IDEA's targets have been achieved based on manufacturing demonstrator components in two pilot lines.

The prototypes for industrial production lines will be built in the Siemens gas turbine factory in Berlin and at MBFZ toolcraft GmbH in Georgensgmünd, and will take into account the requirements of small and medium-sized enterprises as well as those of large industry.

The project is part of the Line integration of Additive Manufacturing processes (LAF) funding initiative, which was created by the German Ministry of Education and Research under the Photonic Research Germany programme. The grant funds amount to just under €14 million. The project is scheduled for a three-year period.

www.siemens.com

## Materials Solutions becomes first Nadcap-accredited AM provider in UK

Materials Solutions Ltd – A Siemens Business (MSL), based in Worcester, UK, has become the first UK company to receive Nadcap accreditation for Additive Manufacturing for the aerospace industry. The company has been providing additively manufactured parts and components to the aerospace industry since its inception in 2006.

The business primarily uses Laser Powder Bed Fusion (L-PBF) for the production of high-performance metal parts, from high-temperature components for gas turbines and jet engines to tooling applications, as well as lightweight structural components and hydraulic applications.

The company has grown substantially in the past twelve months, moving into new facilities and increasing the number of AM machines and types of materials it processes as it looks towards serial production and the industrialisation of Additive Manufacturing. In addition to the aerospace industry, MSL supplies to a wide range of sectors including oil and gas, power generation, the tooling and process industries and motorsport.

Materials processed at its facility include nickel-based superalloys, titanium and aluminium, with the company offering a complete solution from software through automation, to engineering and manufacturing of final applications.

Phil Hatherley, General Manager, Materials Solutions Ltd, stated, "The team are specialists in using Additive Manufacturing technology to solve complex engineering challenges for our customers. We knew that in order to deliver the highest quality parts for the aerospace sector we needed to get the Nadcap accreditation to show we were serious about working in the sector. We want to be able to shift the perception of 3D printing from being a technology associated with prototyping to a viable option for the serial production of additively manufactured parts for a heavily regulated sector."

The National Aerospace and Defense Contractors Accreditation Program (Nadcap) recognises companies which have demonstrated an ongoing commitment to quality by satisfying customer and industry specifications. Nadcap accreditation has long been incorporated by the aerospace industry into its risk mitigation activity, as it validates compliance to industry standards, best practices and customer requirements.

www.materialssolutions.co.uk
www.siemens.com

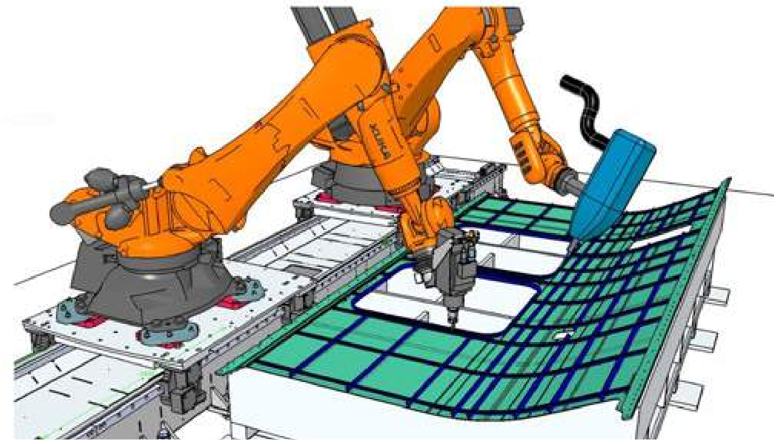
# Canadian Research Council partners with PolyControls on Cold Spray AM

The National Research Council of Canada (CNRC), headquartered in Ottawa, is partnering with PolyControls, a surface engineering solutions and equipment integration specialist based in Quebec, Canada, on the opening of a new research facility which will give manufacturers and researchers the opportunity to study, adopt and deploy metal Cold Spray Additive Manufacturing (CSAM) technology.

Expected to open in February 2020, the Poly/CSAM facility will be located at the NRC's Boucherville site in Quebec. Specifically, Poly/CSAM will focus on scaling-up the CSAM process by enabling the adaptation of laboratory-developed technology to meet factory and mass production requirements. The six year venture will also offer training for manufacturers to ensure the technology is implemented safely and securely.

"The National Research Council of Canada acknowledges the value and importance this collaboration can offer the industry and the Canadian advanced manufacturing ecosystem," stated François Cordeau, Vice President of Transportation and Manufacturing, National Research Council of Canada.

"We see great potential in bringing together different stakeholders to enable innovation and to build a network of industrial partners for a stronger Canadian supply and value chain," he continued. "Our renowned technological expertise and capabilities in Additive Manufacturing research and development will support Poly/CSAM and contribute to developing demonstration platforms targeted at end user-industries and cluster networks."



*The new Poly/CSAM facility is expected to open in February 2020 (Courtesy CNW Group/National Research Council Canada)*

The project is being supported by Investissement Québec, the Business Development Bank of Canada, and Bank of Montreal, with an initial investment estimated at CAD $4 million over the next six years. CNRC will also support technology development and provide strategic advice and technical services with a professional team of over forty experts.

Poly/CSAM is expected to offer a combination of unique technologies including surface preparation, coating and part manufacturing by CSAM; local, laser-based thermal treatment; in-situ robotic machining and surface finishing; new sensor technologies; extensive data logging and analytics; and machine learning.

Luc Pouliot, Vice-President Operations, PolyControls, commented, "PolyControls is eager to leverage its proven track record in thermal and cold spray implementation (aerospace and surface transportation industries) to showcase its capabilities as a large-scale manufacturing integrator offering custom equipment platforms with the objective of bringing disruptive technologies such as hybrid robotic manufacturing, data analytics and machine learning (supported by Artificial Intelligence) to the shop floor. We see Poly/CSAM as a way to strengthen Canada's industrial leadership in Cold Spray Additive Manufacturing and becoming more agile and competitive on the national and international scene."

www.nrc-cnrc.gc.ca
www.polycontrols.com

# Fraunhofer IWS to hold course on Hybrid Materials and AM Processes

The Fraunhofer Institute for Material and Beam Technology (IWS) will host the 2nd Hybrid Materials and Additive Manufacturing Processes (HyMaPro) Workshop on December 11–12, 2019, at the Fraunhofer Institute Center in Dresden, Germany. The workshop aims to provide information on AM technologies for metal and ceramic components by means of hybrid materials.

The course will look at CAE-based virtual design, and the structural and functional optimisation of AM parts, to AM devices for the production of multi-material components. Practical sessions and guided tours will offer attendees hands-on experience of multi-material AM, while a programme of plenary sessions and discussions will offer scientists and engineers a platform to discuss their latest R&D results in the field.

Further information and details of how to register for HyMaPro 2019 are available via the event website.

www.iws.fraunhofer.de


Scan Heads
Encoders, Motors, Drives, & Mechatronics
Laser Control & Software

## Renishaw enables increased fluid power capabilities with metal AM

Renishaw plc, headquartered in Wotton-under-Edge, Gloucestershire, UK, has collaborated with Domin Fluid Power Limited, Bristol, UK, to help the company maximise productivity when designing and manufacturing direct drive valves. Using metal Additive Manufacturing techniques, the company can reportedly now manufacture smaller, more efficient drives and reduce cycle times from five and a half hours to just one.

Domin collaborated with Renishaw to develop a new technology suite for the fluid power sector. The company visited Renishaw's AM Solutions Centre in Stone, Staffordshire, UK, to develop their understanding of AM and understand how the technology could help them produce highly-efficient drives for customers.

"Metal AM allows you to stretch the art of what is possible in the fluid power sector," explained Marcus Pont, General Manager of Domin Fluid Power. "After spending years on testing different prototypes and designs we have developed our knowledge in AM that will enable us to produce efficient parts for customers. For example, we have designed one of our drives that is 25% of the original size, 25% more powerful and produced at a third of the cost."

"At Renishaw we are always looking for opportunities to be involved with developing emerging technologies that make positive changes in the industrial world," added Martin McMahon, AM Lead Technical Consultant at Renishaw. "We've worked with Domin throughout the whole process, from investigating material properties, to exploring the advantages of using the latest technologies, such as the RenAM 500Q, in production."

"Additive Manufacturing is a key technology for Domin," he continued. "It gives the company the ability to build complex parts, free of tooling and with minimal operations and assembly. Trying to integrate such complex functionality into such a small design would not be possible using conventional manufacturing techniques."

www.renishaw.com
www.domin.co.uk

*A Domin Fluid direct drive servo valve manufactured using metal Additive Manufacturing (Courtesy Renishaw plc)*

## Sintavia acquires non-destructive testing company

Sintavia, LLC, Hollywood, Florida, USA, has announced its acquisition of QC Laboratories, Inc., a non-destructive testing (NDT) services company which is also based in Hollywood, Florida. The acquisition is expected to greatly enhance Sintavia's NDT capabilities for commercial aerospace applications, particularly with respect to surface finish conformance testing.

Doug Hedges, Sintavia's President and Chief Technology Officer, stated, "We have worked with QC Labs for a number of years to develop surface finish inspection metrics that are relevant for the Additive Manufacturing industry. Today's announcement is a natural extension of this same process, and we are looking forward to deepening the relationship with QC Labs as we continue to develop acceptable NDT metrics for production AM components."

"For more than fifty years, QC Labs has been trusted by critical industries, including aerospace and defence, to deliver high-quality NDT services," added John Ahow, QC Labs' General Manager. "It is very exciting to apply these same services to the developing field of Additive Manufacturing through Sintavia."

Founded in 1965, QC Labs operates from three locations in Hollywood, Florida; Orlando, Florida; and Cincinnati, Ohio. The company specialises in radiographic (X-ray & gamma), fluorescent penetrant, ultrasonic, magnetic particle, and eddy current inspections, and holds approvals for these processes from Honeywell Aerospace, Lockheed Martin, General Electric, Collins Aerospace, Pratt & Whitney, Cessna, Eaton, Aerojet Rocketdyne, and Rolls-Royce, among others. Post-closing, it is expected that QC Labs will operate as a stand-alone subsidiary of Sintavia.

www.sintavia.com

## 3YOURMIND receives €1.3 million to improve machine learning for AM

The investment bank of Berlin has awarded AM workflow software developer 3YOURMIND, Berlin, Germany, with €1.3 million in Pro FIT funding, co-financed by the European Regional Development Fund (ERDF). This funding will reportedly be used to extend machine learning applications throughout its software suite, designed to optimise the industrial Additive Manufacturing value chain.

3YOURMIND's software helps identify AM-suitable parts from existing inventories. For companies and AM services who are already actively using Additive Manufacturing technology, the software suite is designed to serve as their digital access point for accurate pricing, file management, automated order processing and transparent tracking of the production floor.

In addition to building out machine connectivity, 3YOURMIND will focus on interlinking its software suite with machine learning to improve depth of optimisation, lower processing costs and move Additive Manufacturing towards true automation. It will use the Pro FIT funding to add artificial neural networks (ANNs) into its software; an approach for programming challenges which have little or no explicit, systematic knowledge available.

As a relatively young industry, Additive Manufacturing is still developing process documentation and best practice techniques for industrial-scale production. This is especially true of serial AM. Stephan Kühr, CEO of 3YOURMIND, explained, "Our software makes it simple and cost effective for companies to enter and scale Additive Manufacturing. By adding more machine learning to our software, we will multiply the effectiveness of AM programme."

"AM is already a data-driven production method and we are the leading company to focus on connecting and optimising workflows using that data" he continued. "3YOURMIND is developing the software infrastructure for a level of automation we call agile manufacturing; the ability to quickly and accurately adapt production to customer needs and company resources."

Software is widely thought to be the key enabler for the industrialisation of AM, accelerating the rate of adoption by multiplying the effectiveness of individual design engineers, production engineers and division managers. The 3YOURMIND team will now analyse part information and platform usage from opt-in environments and evaluate non-sensitive data to identify and codify patterns.

Each development test will then be directly cycled into the software for further validation. The 3YOURMIND customer list, including AM companies in Europe and the USA, will be used to 'train' the software.

www.3yourmind.com

## SLV Halle adds Gefertec's arc405 metal AM system

SLV Halle GmbH, a research institute, located in Halle (Saale), Germany, has invested in the arc405 system from Gefertec GmbH, Berlin, Germany. The metal Additive Manufacturing system uses Gefertec's 3DMP® process and was installed at SLV Halle's site in June this year. The company states that the machine produces metal components measuring up to 0.06 $m^3$ with a maximum mass of 200 kg.

According to SLV Halle, by investing in the new machine, it aims to strengthen its position in Germany's growth market for generative manufacturing and to promote interest in the further development of this technology. The company states that it received subsidies from the state of Saxony-Anhalt to purchase the arc405 system.

The machine will reportedly be used for additively manufacturing large-volume metal components for industries including steel/metal, rail/commercial vehicles, machine/plant, and pressure equipment construction. SLV Halle reports that the results of this work will be presented for the first time when it hosts its first AM Symposium on November 12, 2019.

"We have no doubt that Additive Manufacturing processes can be implemented more frequently in today's industrial production operations," stated Prof Steffen Keitel, research institute director, SLV Halle. "The Gefertec arc405 enables us to drive the strategic expansion of our research infrastructure forward and make it easier for metalworking companies to integrate additive manufacturing processes."

www.gefertec.de/en
www.slv-halle.de/en

*Gefertec's 3DMP process is a wire-based Additive Manufacturing system (Courtesy Gefertec)*



3YOURMIND

# Agile Manufacturing Software Suite

The reality of additive manufacturing is that **successful scaling requires digital processes**: they facilitate manual work and streamline data flows. Our software suite meets this challenge head on by providing an infrastructure that automates the entire AM production workflow.

## Agile PLM

- Digital Inventory
- AM Part Identification
- Use Case Screening

## Agile ERP

- Technology Comparison
- Instant, Accurate Pricing
- Automated Order Management

## Agile MES

- Smart Part Prioritization
- Digital Production Planning
- Machine Connectivity


**3yourmind.com**

## GE Additive and Bralco Advanced Materials explore AM magnetic parts

GE Additive has signed a Memorandum of Understanding (MoU) with research, product development and commercialisation company Bralco Advanced Materials Pte. Ltd., Singapore, for the development of metal additively manufactured magnetic components for applications in the aerospace, medical, automotive, energy, industrial automation and robotics industries.

The MoU aims to progress the AM of magnetic components in the Asia-Pacific region in particular. It is expected that Bralco's strength in magnetic materials combined with GE Additive's expertise in powder manufacturing and AM technology will enable the companies to accelerate the development of soft and hard magnets and components in complex shapes, with differentiated magnetic fields and high mechanical strength. Such magnets could be capable of operating at elevated temperatures, high frequencies and high torque conditions, characteristics which would make them ideally suited for demanding applications such as in the traction motors.

According to the companies, the MoU contemplates giving Bralco access to GE Additive's AddWorks engineering consultancy team and its materials division, AP&C, potentially enabling Bralco to shorten its product development and commercialisation cycle. The MoU also contemplates the potential future appointment of Bralco as a service provider in the Asia-Pacific region for the production of parts and components using GE Additive machines and powders, based on Bralco's magnetic materials compositions.

Amit Nanavati, Founder & CEO, Bralco Advanced Materials, stated, "Bralco is honoured to be working with GE Additive in this very exciting space of digital industry 4.0. This collaboration is a major milestone for us, coming at a time when the demand for soft and hard magnets is growing rapidly due to their use in every aspect of modern life, be it healthcare, mobility, personal communication devices, renewable energy or robotics."

"We are very excited to set up our first R&D Lab and Product Innovation Centre in Singapore, fully equipped with a GE Additive machine and a state-of-the-art powder and built parts testing and characterisation lab," he added. "We hope these steps will add to the growing importance of Singapore as a global centre for the Additive Manufacturing industry and as one of the most attractive locations to set up a high tech R&D facility."

www.bralcoadvancedmaterials.com
www.ge.com/additive

# Rolls-Royce@NTU Corp Lab to include AM projects in Phase 2

The Rolls-Royce@NTU Corporate Laboratory in Singapore, jointly established by Nanyang Technological University (NTU), Rolls-Royce and Singapore's National Research Foundation (NRF) in 2013, has completed its first five years of research partnership and is now moving into its next phase with a joint investment of S$88 million (US$65 million).

The laboratory was the first corporate laboratory to be supported under the Singapore public-private research and development partnership between universities and companies. In Phase 1, it managed fifty-three research projects in areas such as power electronics, data analytics, and repair and manufacturing technologies. The research outcomes from these projects are now being used to help design and develop future power and propulsion systems and improve manufacturing operations in Singapore and other global Rolls-Royce sites.

Following the success of Phase 1, NTU and Rolls Royce are renewing their partnership to enter Phase 2 with twenty-nine projects focused on developing novel technologies that will power the future of aircraft propulsion. Among these will be projects addressing challenges involved in Additive Manufacturing technologies, such as finishing and polishing processes for internal AM components, and streamlining AM workflows.

Prof Subra Suresh, NTU President, stated, "The Rolls-Royce@NTU Corp Lab is a fine demonstration of NTU scientists working with the industry to develop relevant solutions to meet real-world issues. The first phase of research has achieved remarkable success with more than fifty research projects that can create significant impact in the aerospace industry."


*Phase 2 will look at the challenges involved in Additive Manufacturing technology (Courtesy NTU)*

"Building on that success, we are now moving into the second phase with renewed commitment and new projects that will elevate our collaboration to the next level," he continued.

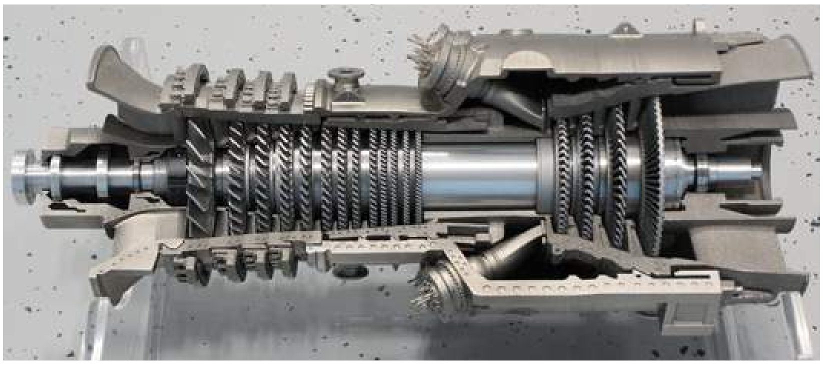
www.ntu.edu.sg
rrntucorplab.ntu.edu.sg
www.nrf.gov.sg

# Fraunhofer IFAM gas turbine development showcases potential of powder bed AM

Together with the H+E-Produktentwicklung GmbH in Moritzburg, Saxony, Germany, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) in Dresden, Germany, has developed a fully-functional, true-to-scale gas turbine which demonstrates the current potentials and limitations of powder bed-based Additive Manufacturing technologies.

The demonstrator 'Siemens SGT6-8000 H', a 1:25 scale model of a gas turbine for power generation, was completely manufactured with additive processes in all areas except for the shaft. The component assembly consists of sixty-eight parts made of aluminium, steel and titanium, which through component optimisation and the possibilities of Electron Beam and Laser Powder Bed Fusion (EB-PBF and L-PBF) technologies replace the almost 3000 individual parts that make up the original component.

Fraunhofer IFAM was involved in the manufacturing of the component as well as the data modification for the technology-adapted production. The housing components, with stator stages, were manufactured directly on site at the Innovation Center Additive Manufacturing ICAM® in Dresden using EB-PBF of Ti-6Al-4V in a GE Additive Arcam EBM Q20+ machine. The turbine stages and the other housing components were manufactured at H+E using L-PBF.


*The scaled model of a gas turbine for power generation, manufactured entirely using EB-PBF and L-PBF (Courtesy Fraunhofer IFAM)*

According to Fraunhofer IFAM, the production planning stage was particularly important and accordingly complex to determine the right technology for each component. The accuracy and roughness of the surfaces, for example, had to be taken into account, as well as the necessity and number of support structures and the component size had to be considered.

The functionality of the demonstrator was a prerequisite for all considerations. For example, the shaft and turbine stages had to be able to rotate freely between the stator stages and the individual components of the demonstrator had to be connected to each other with minimum effort – by screwing and plugging on.

The components were modified constructively in order to be able to manufacture the turbine 'first time right'. For example, it was made possible to manufacture the 316L housing segment by L-PBF without support structure.

The combination of different materials commercially available from the respective plant manufacturers is also demonstrated in the component. Not all processed materials correspond to the target materials for turbines; this is due to the fact that these materials cannot yet be processed in such a way as to be offered commercially.

www.ifam.fraunhofer.de
www.hedd.de

# SIMBA Chain to ensure security for US Air Force's Additive Manufacturing

Blockchain sepcialist SIMBA Chain, South Bend, Indiana, USA, has been selected to assist the U.S. Air Force as it seeks to ensure the security of its Additive Manufacturing efforts on the battlefield and domestically. The Air Force uses a complex supply chain to equip and repair forward-deployed forces.

According to SIMBA Chain, long value chains are among the biggest security issues in manufacturing for Industry 4.0. This is the case for all manufacturing but is especially critical in military applications, where hostile entities may attempt to obtain or modify critical data.

To coordinate distributed manufacturing in the field, the Blockchain Approach for Supply Chain Additive Manufacturing Parts (BASECAMP) project will use the SIMBA Chain platform to create a prototype demonstrating a blockchain approach for the registration and tracking of Additive Manufacturing components during their entire lifecycle.

The SIMBA Chain uses Microsoft Azure for trust and reliability, key factors when providing support on the battlefield. With SIMBA, the Air Force's BASECAMP project will be able to decentralise Additive Manufacturing in the field while maintaining the integrity of data. This means that repairs to vehicles cannot be tampered with by a third party, as top-secret build plans can be transmitted to forward forces without unwanted surveillance.

www.simbachain.com

## Aurora Labs increases its RMP1 Additive Manufacturing speed to 350 kg per day

Australia's Aurora Labs reports that it has substantially increased the speed of its Rapid Manufacturing Technology (RMT). Following tests carried out by the company on its RMP1, the first model in its series of RMT metal Additive Manufacturing systems, the company stated that it has achieved a build speed of 350 kg per day, an improvement of 2000% from its initial build rate twelve months ago.

The company stated that these results show that the RMP1 can manufacture metal parts at a price that is cost competitive with traditional manufacturing. David Budge, Managing Director, commented, "This is an outstanding result for Aurora Labs and one that underlines the potential of our metal 3D printing capability. Our RMP1 machine has the ability to produce high-quality parts, in a timeframe of hours – as opposed to traditional parts manufacturing that can have lead times of months."

"When you consider that we recorded print speeds of 15.8 kg per day on the Alpha Printer last September, this equates to a greater than 2000% speed improvement in twelve months," he continued. "The technical development of our Rapid Manufacturing Technology is occurring in parallel with some exciting progress in our market development activities."


*Aurora Labs' RMP1 can now process 350 kg per day (Courtesy Aurora Labs Ltd)*

Budge further stated that Aurora Labs is continuing to make progress with Gränges AB, with whom it signed a Memorandum of Understanding on aluminium Additive Manufacturing and the supply of aluminium metal powders in July, to convert the MoU into a formal agreement.

"We have held successful meetings with Gränges in both Stockholm and Perth to map out the relationship and we are now conducting further discussions around research projects and a pre-order for an RMP1 printer," he added. The company reported that it is also seeing interest from a number of other potential customers, including a US medical group, two major global industrial groups, a US aerospace company, a major global steel producer and global international car manufacturers.

"There is no doubt the global resources, industrial and manufacturing sectors are aware of the potential of Aurora's 3D metal printing to reduce costs and free up capital that is currently locked away in spare parts inventories, and today's news will add to that interest," Budge noted.

www.auroralabs3d.com

## Particle Testing Authority expands its pore analysis capabilities

Particle Testing Authority (PTA), a division of Micromeritics Instrument Corporation, headquartered in Norcross, Georgia, USA, reports that it has expanded its pore analysis capabilities by implementing Capillary Flow Porometery (CFP) and Liquid-Liquid Displacement Porometry (LLDP).

The company states that by using CFP, pore properties are calculated by measuring the fluid flow when an inert, pressurised gas is applied to displace an inert and nontoxic wetting fluid impregnated in the porous network of the samples with pore sizes of 500 to 0.015 microns. Parameters such as first bubble point (corresponding to the largest pores present) can be calculated with accuracy and repeatability according to ASTM F-316.

PTA explains that LLDP can measure nanopores (1,000 to 2 nm) at low pressures by displacing the wetting liquid with an immiscible liquid at increasing pressure. This reportedly eliminates error from collapse or mechanical damage caused by high pressure when measuring materials such as hollow fibres. With these recently implemented methods, the company can analyse materials such as textiles (woven and non-woven), paper, polymers, metals, ceramics, and porous rocks to understand how high a throughput can be achieved.

"We currently measure porosity and pore size using gas adsorption techniques and mercury porosimetry, so CFP and LLDP allow us to help more customers address their material characterisation questions and problems," stated Greg Thiele, PTA's General Manager. "We have performed various analyses for our customers in the energy storage industry, and CFP has allowed us to provide a more comprehensive characterisation for battery separators."

www.particletesting.com

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# Powder Solutions for Metal AM

## Main Powders

**Titanium:** Ti CP, Ti64 Gr5/Gr23, BT9, BT20, Ti6242, Ti4822, Ti2AlNb, 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:** AlSi10Mg, AlSi7Mg
**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

You Tube

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# Research project finds AM AF-9628 parts stronger than conventional AM alloys

The Air Force Institute of Technology (AFIT), located at Wright-Patterson Air Force Base, Ohio, USA, reports that Capt Erin Hager, a graduate of its Aerospace Engineering Program and an Air Force Research Laboratory (AFRL) employee, recently conducted a research project which found that additively manufactured AF-9628 parts are approximately 20% stronger than parts produced from conventional AM alloys.

AF-9628 is a steel alloy developed by AFRL's Dr Rachel Abrahams, which offers high strength and toughness. The formula to produce the alloy reportedly costs less than other high performance steel alloys, including Eglin Steel and HP-9-4-20, but is more expensive than common grades used in conventional munitions. It does not contain tungsten, like Eglin Steel, or cobalt, part of the formula for HP-9-4-20.

Sponsored by the Air Force Research Laboratory Munitions Directorate at Eglin AFB, Valparaiso, Florida, USA, Hager's research found that AF-9628 is an optimal material for Additive Manufacturing due to its high strength. AFIT explained that, while these findings are comparable to values reported in a similar U.S. Army Combat Capabilities Development Command Army Research Laboratory study, Hager's study yielded similar mechanical properties to conventionally forged and heat treated AF-9628.

Hager produced test parts from AF-9628 steel using Laser Powder Bed Fusion (L-PBF). "To determine if AF-9628 was printable, we characterised the shape and size of the powder and [identified] how it changed with melting and sieving," she stated.

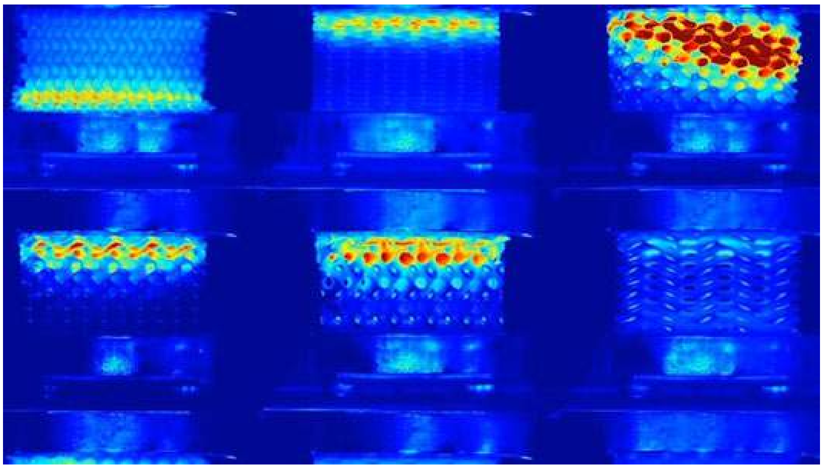
She then examined the steel under a scanning electron microscope (SEM) at AFIT and performed tests at the University of Dayton Research Institute using a size characterising light microscope. After producing various parts, she analysed the resulting porosity, strength and impact toughness.

Upon examination, Hager determined that the parts matched the required 10% elongation, indicating increased strength without becoming brittle. She went on to additively manufacture complex designs using two L-PBF machines at AFIT and produced appoximately 130 articles.

Currently, the AF-9628 powder is only available in small production quantities and companies can take months to formulate it. As such, while AF-9628 is a less expensive steel, Hager explained that the powder form is not currently cost-effective to acquire since the demand is low.

Hager stated that she hopes that the Air Force will "take this high strength steel and come up with some new applications that we haven't even thought of yet." She recently presented her research during an international Powder Metallurgy conference and at an ordnance and ballistics symposium.

www.afit.edu
https://www.wpafb.af.mil/



*Thermal imagery of parts additively manufactured with AF-9628 powder. (Courtesy photo/Air Force Institute of Technology)*

# Xiris Automation adds weld microphone system for WAAM process monitoring

Xiris Automation Inc., Burlington, Ontario, Canada, has launched Xiris Audio – a weld microphone system for integration into the Xiris weld camera system for process monitoring. The Audio is intended for use in arc and sub-arc welding, and is suitable for use in monitoring Wire Arc Additive Manufacturing (WAAM) processes.

According to Xiris, the combination of sight and sound monitoring while welding will improve operators' abilities to fine tune and monitor the process from a safe distance. This is especially important for critical welding applications where the process needs to be monitored remotely, such as from a control room.

The microphone system is designed specifically for the welding environment and includes the microphone, cables and a specialised signal processing card embedded in the Xiris HMI. Additional software features enable the recording and playback of audio in sync with the monitoring video, and equalise the audio to enhance or minimise surrounding noise.

www.xiris.com

# AM Solutions expands to add component manufacturing

AM Solutions S.r.l., Concorezzo, Italy, the Additive Manufacturing brand of Rösler Oberflächentechnik GmbH, Untermerzbach, Germany, has established a new division focused on the production of AM components. AM Solutions - 3D Printing Services will compliment the company's existing AM Solutions - 3D Post Processing division, enabling it to cover the entire process chain from engineering and design optimisation, to the production of components, mechanical post-processing, surface finishing and quality control.

AM Solutions is equipped with state-of-the-art software and supporting equipment to ensure its customers benefit from the design flexibilities and possibilities of Additive Manufacturing. This includes the complete engineering of components from scratch, the redesign of existing components for Additive Manufacturing, the validation of product designs and topology optimisation.

The company states that production of components will take place on state-of-the-art equipment, including an EOS M 290 Laser Powder Bed Fusion (L-PBF) system, which allows the manufacture of component sizes up to 250 x 250 x 325 mm. A number of materials can be processed, including stainless steels, aluminium and titanium.

For post-processing tasks, such as the removal of powder residues and support structures, as well as surface smoothing and polishing, the company reported that it uses a wide range of technologies and processes. Customers requiring a subsequent machining step will also have access to a range of machining equipment, including a DMG Mori 5-axis milling machine DMU 50.

www.solutions-for-am.com

*AM Solutions has established a new division focused on the production of AM components (Courtesy AM Solutions S.r.l)*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## 3D Systems to develop 'world's largest, fastest' metal AM system for U.S. Army

3D Systems, headquartered in Rock Hill, South Carolina, USA, has been awarded a $15 million contract by the Combat Capabilities Development Command Army Research Laboratory (ARL), to create what has been dubbed "the world's largest, fastest, most precise metal 3D printer." The system is expected to significantly impact key supply chains associated with long-range munitions, next-generation combat vehicles, helicopters, and air and missile defence capabilities.

According to the U.S. Army Additive Manufacturing Implementation Plan, the army has been using AM for two decades to refurbish worn parts and create custom tools. Once developed, it will place the new large-scale systems in its depots and labs. Subsequently, 3D Systems and its partners plan to make the new AM system's technology available to leading aerospace and defence suppliers for development of futuristic army platforms.

In each of these cases, the planned system's large scale and precision are expected to enable more efficient design and production of long-term durable parts with reduced material usage, as well as faster time-to-market for parts going into the field. The planned build envelope is 1000 mm x 1000 mm x 600 mm, with the ability to build to a minimum wall thickness of 100 µm and layer thickness of 30 µm.

"The army is increasing readiness by strengthening its relationships and interoperability with business partners, like 3D Systems, who advance warfighter requirements at the best value to the taxpayer," stated Dr Joseph South, ARL's Program Manager for Science of Additive Manufacturing for Next Generation Munitions. "Up until now, powder bed laser 3D printers have been too small, too slow, and too imprecise to produce major ground combat subsystems at scale."

3D Systems and the National Center for Manufacturing Sciences (NCMS) were awarded funding to create the new system and will partner with ARL and the Advanced Manufacturing, Materials, and Processes (AMMP) Program. In addition to bringing a new metal AM solution to the army, the company will also evaluate the feasibility of integrating the new technologies and processes into its existing portfolio of AM technologies.

"Through this project, we're looking forward to delivering a working manufacturing system like no other," commented Chuck Hull, co-founder and CTO, 3D Systems.

www.3dsystems.com

*The new metal AM technology is expected to significantly impact key supply chains associated with long-range munitions, next-generation combat vehicles, helicopters, and air and missile defence capabilities (Courtesy U.S. Army)*

## Boeing HorizonX Ventures investing in metal AM company Morf3D

Metal Additive Manufacturing company Morf3D Inc., El Segundo, California, USA, which specialises in precision manufacturing and engineering for aerospace, reports that it has secured a new round of funding from Boeing HorizonX Ventures following a significant increase in customer demand.

Since the company was established in 2015, Morf3D has helped clients develop, qualify and additively manufacture highly-complex structures for flight. It currently serves a number of the world's largest aerospace OEMs, including Boeing, Honeywell, Collins Aerospace and others.

"Our latest strategic investment in Morf3D extends our commitment to our Industry 4.0 efforts – technologies that can transform aerospace supply chains for future growth and competitiveness," stated Brian Schettler, Senior Managing Director, Boeing HorizonX Ventures. "We continue to work closely with Morf3D to help them bring innovation through Additive Manufacturing to more aerospace manufacturing partners."

Following the recent increase in demand, Morf3D has expanded its Additive Manufacturing footprint, increased its investment in precision machining technology and doubled its workforce with additional engineering, quality and support staff. "It is amazing to see our strategy come to life! Our vision to become a world-class leader in metals Additive Manufacturing for the aerospace industry is truly taking form," added Ivan Madera, Morf3D's founder and CEO.

www.morf3d.com

## Hydrogen embrittlement of AM nickel-718 in oil & gas industry conditions

Researchers from the The University of Texas at San Antonio (UTSA) and Southwest Research Institute (SwRI), also based in San Antonio, Texas, USA, will collaborate on a research project to examine how hydrogen embrittlement conditions develop on a nickel alloy used in the oil & gas industry, when fabricated through AM.

According to UTSA and SwRI, despite many industries quickly adopting AM there has so far been a lack of testing of the way hydrogen embrittlement impacts the material performance of metal AM parts made from nickel-718, an alloy used in critical conditions where high mechanical properties and corrosion resistance are desired. Without enough testing data to understand the effect of hydrogen embrittlement on the alloy when processed by AM, the safety of AM-fabricated systems remains unknown.

Prof Brendy Rincon Troconis, UTSA Department of Mechanical Engineering, and W Fassett Hickey, of SwRI's Mechanical Engineering Division, will work to understand the underlying mechanisms governing the susceptibility of additively manufactured nickel-718 to hydrogen embrittlement under oil and gas industry-related conditions. To do this, they will study hydrogen embrittlement on a molecular level to examine how the location of hydrogen atoms affects the integrity of the material under the high pressures and elevated temperatures typical of drilling environments. The team will also compare the results obtained from tests performed with additively manufactured nickel-718 with those for wrought nickel-718 under the same environmental conditions.

"The operational conditions in the oil & gas industry can lead to hydrogen embrittlement," stated Rincon Troconis. "This phenomenon causes the premature failure of structures as a result from hydrogen intake in the material. Hydrogen, once inside the material, interacts with the alloy microstructure, degrading its mechanical performance and resulting in brittle fracture without any warning sign."

"By understanding more about hydrogen embrittlement of Additive Manufacturing materials, we can provide crucial information, with more confidence, to optimise the AM and post-fabrication processes and prevent brittle fracture of future and current systems, while advancing the AM technology, which will all lead to better protection of the community, its assets, and the environment," she explained.

The hydrogen study is supported by the Connect Program, a collaborative initiative between UTSA and SwRI, and researchers are expected to have data available by Summer 2020.

www.utsa.edu
www.swri.org

## America Makes celebrates seventh anniversary as AM hub

America Makes, Youngstown, Ohio, USA, is commemorating its 7th anniversary. Since its founding in 2012, the organisation – which is managed and operated by the US's National Center for Defense Manufacturing and Machining (NCDMM) – has served as a national accelerator for Additive Manufacturing and the first of eight Manufacturing Innovation Institutes (MIIs) established and programme-managed by the U.S. Department of Defense (DoD) as public-private partnerships.

The institute now serves as a hub for advanced manufacturing innovation, having executed eighty-eight Additive Manufacturing R&D projects and evolved from a community of sixty-five to more than 225 member organisations. America Makes collaborated with the American National Standards Institute (ANSI) on the creation and publication of the first Standardization Roadmap for AM, and has three Satellite Centers across the USA.

John Wilczynski, America Makes' Executive Director, stated that he is inspired by the promise of the future not only for the institute but for the US manufacturing industry overall. "This is a really exciting time for the institute as we have a great deal of learnings and achievements from the last seven years," he commented. "We are acutely aware of the needs of our industry from commercial and defence sectors."

"We are grateful for all of the support from the DoD, Air Force Research Laboratory, and other government stakeholders," he continued. "As the pilot Institute, we have proved that the public-private collaborative model is effective and important to the ongoing economic success of US manufacturing industry. We transitioned from the initial start-up phase and then onto an incredibly driven project execution phase to where we are today – promoting and leading innovation."

www.americamakes.us

## Auburn University employs digital X-ray CT system for metal AM part inspection

The National Center for Additive Manufacturing Excellence (NCAME), based at Samuel Ginn College of Engineering, Auburn University, Alabama, USA, is set to employ X-ray CT technology and specialised in-house-designed Additive Manufacturing systems for the in-process inspection of additively manufactured parts. An X-ray CT system was acquired by the college with the assistance of a $1.5 million grant from the US's National Institute of Standards and Technology (NIST).

The new system incorporates a customised digital radiology vault from Pinnacle X-Ray Solutions, Inc., Suwanee, Georgia, USA, which accommodates Additive Manufacturing machines designed and built by the university's researchers to fit within it. This enables the engineers and partners to conduct three-dimensional, non-destructive interrogation of mission-critical metal parts, as well as providing real-time monitoring of the AM process. The system is also able to confirm internal dimensions of structures and assess the quality of finished parts.

The NCAME was established in 2015 and conducts research, trains and educates graduate and undergraduate students, and develops and promotes technological innovations with the aim of advancing the Additive Manufacturing industry. NASA recently awarded Auburn University $5.2 million to develop AM processes and techniques for improving the performance of liquid rocket engines.

"It's a real game-changer because while we're building a component with additive, it's difficult to monitor what's happening," stated Bart Prorok, Professor of Materials Engineering and Principal Investigator on the NIST grant. "With this new system, we can take two-dimensional X-ray pictures of a metal structure for real-time process monitoring or a series of 2D images in 360° of rotation that are then reconstructed into a 3D representation of the build."

www.eng.auburn.edu

*An Auburn University researcher examines a 3D rendering of scans produced by the new X-ray CT system (Courtesy Auburn University)*

# WPI receives $25 million from U.S. Army to develop cold spray AM technique

Worcester Polytechnic Institute (WPI), Worcester, Massachusetts, USA, has received a three-year, $25 million award from the U.S. Army Combat Capabilities Development Command Army Research Laboratory (CCDC-ARL) to develop cold spray Additive Manufacturing for use in the repair and production of metal parts.

WPI's cold spray Additive Manufacturing process uses a pressurised gas to accelerate metal powders to near supersonic speeds. The force of impact causes the powders to adhere to the metal build surface. The institute explained that the process can be adapted to work with a portable handheld applicator, making it suitable for use in the military field.

"The army is interested in cold spray 3D printing as a repair technique," stated Danielle Cote, assistant professor of materials science and engineering and director of WPI's Center for Materials Processing Data, and the principal investigator for the ARL project. "It's cheaper to repair a part than to replace it, and you get the equipment back in service faster."

"The army's primary interest is unit readiness," she continued. "If you're on a mission and need to move quickly to a safer place, and a critical part on your vehicle breaks, you're stuck unless you can repair it quickly. That's where cold spray comes in."

WPI states that its primary research focus will include developing, characterising, and testing new alloys optimised for use in cold spray. Cote explained that the characteristics of the metal powders used in cold spray are important since the metal is not melted before being sprayed onto a part that needs repair, nor heat treated after application.

Cote added, "With most manufacturing methods, metal alloys are alerted by first being melted, and then often heat treated to strengthen or otherwise improve their properties. With cold spray, what you end up with in the repair is exactly what you start with, so the characteristics of the powders are quite important."

As part of the research, the institute will reportedly use a variety of equipment, including instruments acquired as part of the new ARL award. These include tools to study the chemical and structural properties of the powders at the scale of nanometers, such as a SEM/EDS (Scanning Electron Microscope and Energy Dispersive Spectroscopy) unit, a synchronous laser diffraction and dynamic image particle analyser to determine powder morphologies, and nanoindenters to measure nano-scaled mechanical properties.

*Cold spray Additive Manufacturing can be used to perform surface repairs on damaged metal structures (Courtesy Worcester Polytechnic Institute)*

WPI's research team plans to work with several subcontractors, including the University of California Irvine, the University of Massachusetts Lowell, Penn State University, and Solvus Global. Among the modifications that are expected to be made to the powders are unique thermal processing treatments, a technique WPI states that it pioneered.

Unlike metals used in other metal manufacturing processing, including casting and forging, the alloys used in cold spray do not have to be capable of being heat treated, which gives the WPI researchers access to a wide range of potential materials. However, the properties of cold spray powders can be fine-tuned with the careful application of heat.

Cote further added, "This expertise is part of the reason the ARL continues to support WPI. We have discovered that the properties of metal powders can be significantly enhanced with thermal processing, and that is what we are looking to do with this new award."

As part of the research programme, a team of co-principal investigators from multiple disciplines at WPI will explore some new applications, including the use of cold spray to apply copper coatings to give equipment antibacterial properties. Researchers in WPI's robotics engineering programme will explore the use of multi-axis robots to automate the cold spray process.

Cote continued, "The army is especially interested in portable cold spray systems, but the technology can also be used on a larger scale in industry, for example and it will be exciting to see how robots can help expand the use of this and other Additive Manufacturing processes."

"I think there is much potential for this technique. With the work we will be doing with powder development, in robotics, and in a number of other areas, I think we are going to go a long way with cold spray. There really are endless possibilities," she concluded.

www.wpi.edu
www.arl.army.mil

## GE Additive optimises design for brewing equipment by AM

The team at GE Additive's Customer Experience Center (CEC) in Munich, Germany, has worked with brewing equipment manufacturer Kaspar Schulz GmbH, Bamberg, Germany, in the development of a racking blade used in a lauter tun during the production of beer.

On redesigning the racking blade, the goal of Kaspar Schulz was to improve the filtration effect of the spent grain bed in the vessel in order to rinse it more thoroughly, saving time and increasing efficiency. "We were very pleased that GE Additive approached us," stated Jörg Binkert, head of R&D at Kaspar Schulz. "We were already familiar with 3D modelling and making designs with CAD, but Additive Manufacturing was something new for us.

According to Dr Matthew Beaumont, GE Additive's CEC Munich site leader, "the design team was quickly able to come up with a design to efficiently loosen the spent grains and inject water, throughout the bed, during rotation. The design of a thin blade that has internal channels to distribute water evenly is only achievable using Additive Manufacturing."

Dr Benedikt Roidl, advanced lead engineer at GE Additive, added "Together with Mr Binkert and his team, our specialists CEC in Munich evaluated how to improve the lautering process and we came up with the idea of dynamically loosening the spent grain using an induced swirling flow field."

Beamont added that, "We set the goal of achieving a first design in time for this year's Oktoberfest, and we were able to do simulation analysis, complete the design and perform basic functional tests before now."

"What still lies ahead of us, though, is the final use verification in the complete brewing process. We want to verify the benefit via chemical analysis of an actual batch of wort – and of course a taste test by the project team!"

www.ge.com/additive
www.kaspar-schulz.de

*The racking blade incorporates internal channels to distribute water evenly (Courtesy GE Additive)*

# Senvol President elected chairman of SME's Additive Manufacturing Community Advisors

Zach Simkin, president of Senvol, New York, USA, has been elected to serve as Chairman of the Society of Manufacturing Engineers (SME)'s Additive Manufacturing Community. SME's AM Technical Community Advisors serves as the primary resource for guidance to SME and its members on Additive Manufacturing technologies, including materials, processes, industrial base and workforce.

The role of an AM Community Advisor is to "provide timely and expert guidance" to SME on AM activities, initiatives and content to best serve the Additive Manufacturing community. The AM Advisors also serve as 'faces of the industry' for SME. Community Advisors are reportedly chosen based on a combination of active industry contributions, reputation and personal commitment to expand the use of AM.

"AM continues to be a major strategic initiative for SME and a vital emerging sector for manufacturing as a whole," stated, Suzy Marzano, Product Development Manager at SME who oversees SME's Technical Communities. "We're thrilled at Zach's selection as Chairman for the upcoming year, we appreciate his vision and leadership, and we look forward to working with him and the rest of the AM Community Advisors to help further SME's leadership position in the industry."

Simkin is currently in the third year of a three-year term as an Advisor, and previously served as Vice Chair before being elected Chairman. Jennifer Fielding, the outgoing Chair of SME's Additive Manufacturing Community Advisors and Section Chief, Composite Performance and Applications Section at Air Force Research Laboratory, commented, "I've had the pleasure of working with Zach for several years. He is extremely committed to helping the AM industry advance and is a true thought leader in the industry. Under his stewardship, SME's AM Advisory Committee will continue to pave the way for the industry's advancement."

www.senvol.com

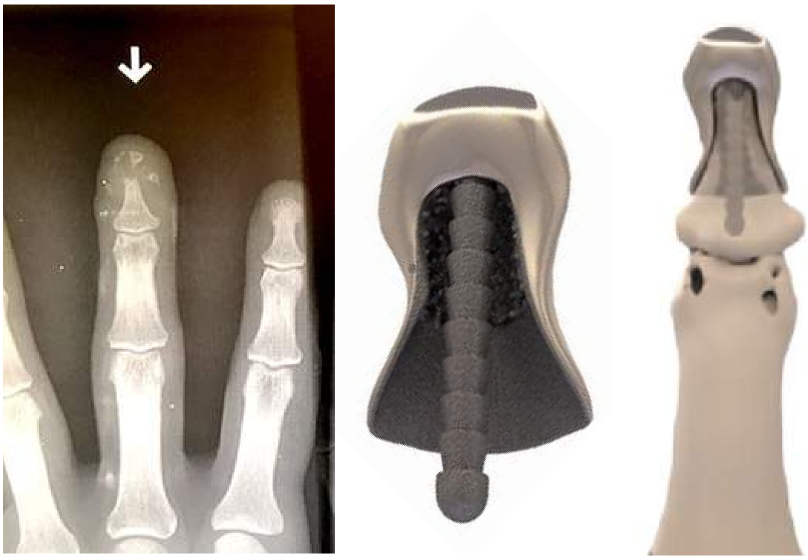
www.sme.org

*Zach Simkin with outgoing chair, Jennifer Fielding (Courtesy Senvol)*

## Florida doctor implants US-first metal additively manufactured finger bone replacement

Dr Daniel Penello, of Alexander Orthopaedic Associates, St. Petersburg, Florida, USA, has successfully implanted what is said to be the US's first metal additively manufactured finger bone implant, reports Fox 13 News.

The implant was designed for patient Robert Smith, whose middle distal phalanx was shattered in an ironworking accident in 2017, drastically hindering his hand's mobility.



*The shattered distal phalanx of Smith's middle finger (left) was replaced with a metal AM implant (centre and right)*

Smith was initially presented with the choice to live with the injury – which reportedly left him with no function and little feeling in the affected finger – or to opt for amputation of the digit. However, following further research and with the assistance of Additive Orthopaedics, Little Silver, New Jersey, USA, Dr Penello was instead able to develop a metal additively manufactured finger bone implant, custom-designed to fit Smith's measurements.

According to local news station WINK, the implant was produced on a GE Additive Arcam Q20plus system by FIT America. Following the surgery, Smith is reported to have regained full mobility in the affected finger and has been able to return to work.

"I'm fascinated because technology is really changing the way health care is being delivered," stated Dr Penello. "To be able to have full use and function of the finger, just like it never happened, is absolutely incredible."

www.alexanderorthopaedics.com
www.additiveorthopaedics.com

## Asiamold 2020 to take place in Guangzhou, China

Asiamold 2020, organised by Guangzhou Guangya Messe Frankfurt Co Ltd., will be held at the China Import and Export Fair Complex in Guangzhou, China, from February 26–28, 2020. The event will be held concurrently with SPS – Industrial Automation Fair Guangzhou (SIAF), and will bring together leading brands in the tool, die and moulding industries and cover a diverse range of metalworking technologies.

The 2019 edition of Asiamold, held together with SIAF, attracted over 98,000 visitors, and welcomed more than 988 exhibitors from twenty countries. A number of 'thematic zones' once again contributed to the 2019 show's success. In line with China's rapid development in the field of Additive Manufacturing, the 3D Printing Asia zone was said to have been a key highlight of the show, showcasing a series of cutting-edge AM technologies and solutions by prominent brands in the region.

Some of the exhibitors reported to have confirmed their attendance at Asiamold 2020 include: Beijing Tenyoun 3D Technology, Dongguan Chuangyi Metal Product, Dongguan Gunri Precision Mold, Dongguan U-Light Mould, Guangzhou Songxing Eletric, Hostar Hotrunner Technic and JK Mold. The organisers state that the event programme is still to be be announced.

Asiamold forms part of a series of international events including Formnext, Intermold Japan and Rosmould. Formnext 2019 will be held from November 19–22, at Messe Frankfurt, Frankfurt, Germany. Intermold Japan 2019 be held from April 17–20, in Tokyo, Japan, and June 19–22 in Nagoya, Japan. Rosmould 2019 will run from June 18-20 in Moscow, Russia. The first edition of Formnext + PM South China will be held from September 9–11, 2020, in Shenzhen, China.

Zhang Mingfu, General Manager of Hostar Hotrunner Technic Co Ltd, stated, "Asiamold is always a good platform for us to gain company exposure and to showcase our latest innovations in hot runner systems. We are able to meet a number of overseas visitors here, which is very crucial and beneficial for us to enter the international market, providing us the opportunities to export our products abroad."

www.asiamold-china.cn.messefrankfurt.com

## Paper submissions now open for WorldPM2020 and AMPM2020

In 2020, the World Congress on Powder Metallurgy & Particulate Materials (WorldPM2020) is heading to Montréal, Canada, from June 27–July 1, 2020. Taking place every two years, the series rotates between North America, Europe and Asia, bringing together the global Powder Metallurgy community for the largest event in the industry.

The Metal Powder Industries Federation (MPIF), organiser of the 2020 congress, has issued a call for papers and posters for the technical programme. The conference will cover the full range of Powder Metallurgy topics, ranging from metal powder production and technology, powder compaction, sintering and post-processing to Metal Injection Moulding, cemented carbides, porous materials, Additive Manufacturing and the design and simulation of PM parts.

In addition to the conference, there will be a major exhibition featuring a wide range of international exhibitors and providing an opportunity for networking with material and equipment suppliers, part producers and end-users.

**Co-located events to bring added value to the World Congress**

Co-located with WorldPM2020 will be the 2020 Additive Manufacturing with Powder Metallurgy conference (AMPM2020) and the 10th International Conference on Tungsten, Refractory & Hardmaterials (Tungsten2020), both taking place over the same days and allowing even greater interaction across the metal powder-based industries.

According to the MPIF, the AMPM conference has grown significantly since its debut in 2014 as the only conference focused solely on metal Additive Manufacturing, and in 2020 will feature an extra day of technical sessions. Topics will include process modelling, design of components, powder production, post-build operations, materials and testing.

The Tungsten2020 conference aims to address recent developments in the refractory and hardmetals field and will encompass refractory and hardmetal processing, microstructure, properties, and applications. Papers are requested on topics including powder production, processing, mechanical behaviour and modelling.

**Call for papers**

Those authors wishing to present at the WorldPM2020 congress, AMPM2020 or Tungsten2020 should submit their abstracts online no later than November 15, 2019. Full submission guidelines are available via the organiser's website.

www.ampm2020.org
www.worldpm2020.org

## Keselowski Advanced Manufacturing and Elementum 3D partner on metal AM

Keselowski Advanced Manufacturing (KAM), Statesville, North Carolina, USA, and Elementum 3D, Erie, Colorado, USA, will collaborate to create new opportunities for entry into the Additive Manufacturing industry. Under the collaboration, Elementum 3D will supply KAM with advanced materials for AM such as A6061- RAM2 powder, said to be the only Additive Manufacturing material comparable to wrought 6061-T6 properties.

According to the companies, aluminium 6061 is a commonly-used aerospace and automotive aluminium alloy which was previously impossible to additively manufacture. KAM states that it will be the first and only supplier in North America to use 6061 in an SLM 280 system. With the combination of the SLM 280 plus Elementum 3D's 6061 powder, KAM will reportedly be able to additively manufacture parts at an average of 65% faster. The companies report that they will also work together on different development projects in Additive Manufacturing, including the testing of new materials.

Jacob Nuechterlein, Elementum 3D's president and founder, stated, "Elementum 3D's commitment to the development of advanced materials aligns well with KAM's innovative growth plan based around hybrid manufacturing. We are proud to partner with their team and evolve our technologies together. There's increasing demand within our customer base for aluminiums like the 6061. It's taking off and this material is at the forefront of the trend."

Elementum 3D's IP technology, reactive Additive Manufacturing (RAM), is said to prohibit cracking that usually happens during solidification, while achieving or exceeding the same properties of the traditional alloys. Additionally, Elementum 3D's ability to develop customised materials to match wrought properties, such as the 6061, provide a solution to materials that are not printable in their current form.

"I love what they're doing at Elementum 3D," commented Brad Keselowski, founder and CEO of KAM. "Their materials enable KAM to engineer and manufacture metal 3D printed parts that are faster and higher in quality than anything that is currently out in the marketplace. I think we're going to continue to do a lot of innovative work together that'll lead to positive developments within the additive community. It's a really exciting time for both companies."

www.kamsolutions.com
www.elementum3d.com

# Aero engine cylinder design optimised by Cobra Aero and Renishaw


*The optimised engine included a lattice structure to increase airflow (Courtesy Renishaw)*

Cobra Aero, an engine manufacturing company based in Michigan, USA, has invested in a Renishaw AM 400 metal Additive Manufacturing system after working with Renishaw to improve the design of aircraft and motorcycle engines.

Cobra Aero worked with Renishaw engineers to gain expertise in Additive Manufacturing, visiting Renishaw's USA Additive Manufacturing Solutions Center. The companies collaborated to optimise an engine cylinder used in an unmanned aerial vehicle (UAV), where the use of AM allowed the design to incorporate a lattice structure to increase airflow, as well as being strong and lightweight.

"Staying at the cutting edge of manufacturing is important to Cobra Aero," explained Sean Hilbert, Cobra Aero President. "Investing in AM allows us to develop tools and new products for high-value, small-volume applications, speed up the manufacturing process and produce designs that would not be possible using conventional subtractive machining."

Hilbert added, "We decided to redesign the cylinder because of its importance in an engine. Design changes to this part of the engine must happen rapidly, and it is also a high value part, which is why we have chosen to additively manufacture this component. Improving the performance of the cylinder will also improve the overall performance of the engine."

Stephen Anderson, AM Business Development Manager, Renishaw – USA, stated, "By using metal Additive Manufacturing, Cobra Aero was able to design a part that was unique to the application. By using our Laser Powder Bed Fusion (L-PBF) technology, Cobra Aero was able to produce a single part with complex lattice structures that performs better than conventional component manufacturing techniques."

www.renishaw.com

www.cobra-aero.com

# Sintavia: New facility signals the move towards volume metal Additive Manufacturing for aerospace and defence

In May 2019, US-based Sintavia, LLC opened a state-of-the-art facility in Hollywood, Florida, dedicated to the volume production of metal additively manufactured components for the aerospace and defence sector, marking a significant expansion of the company's production capacity. Debbie Sniderman visited the new facility on behalf of *Metal Additive Manufacturing* magazine and reports on the company's ambitious plans and its management's views on the ongoing evolution of the industry.

Earlier this year, Sintavia, LLC, a leading independent metal AM service provider for the global aerospace and defence industries, formally opened its new 5,100 $m^2$ Additive Manufacturing facility in Hollywood, Florida, USA. With high-speed Additive Manufacturing systems co-located alongside a high-capacity precision post-processing operation and a full complement of quality control and testing services, this new facility is able to deliver along the entire AM process chain, from component development and parameter optimisation to serial production and inspection.

When fully commissioned, it is expected to be one of the most advanced Additive Manufacturing plants in the world, capable of producing thousands of precision metal components per month for the aerospace and defence OEMs worldwide who are recognising the economic, technical and strategic benefits of the technology. The facility is anticipated to generate revenue in excess of $100 million and now serves as the company's headquarters, originally located in the nearby town of Davie.

Sintavia's mission with this new facility has been to be amongst the first independent manufacturers to offer a vertically integrated, end-to-end metal Additive Manufacturing production process. It designs, pre-processes, builds, post-processes, and analyses all aspects of Additive Manufacturing in-house, from start to finish. With this business model, Sintavia believes that it is well positioned to supply serially manufactured aerospace and defence components with guaranteed quality and repeatability as part of an OEM supply chain.

*Fig. 1 Sintavia's new AM facility in Holywood, Florida, USA*

*Fig. 2 The entrance area to Sintavia's new facility, which is designed to house sixty large- and medium-sized metal AM machines*

## Vertical integration built around quality

In explaining what it means to be vertically integrated in the aerospace and defence sector, Doug Hedges, President of Sintavia, told *Metal AM*, "For aerospace and defence, quality is number one. We have to be good at these services and can do every core process involved in AM. Accreditations and certifications are a large part of the process and have been our goal from the beginning. While quality systems are baseline and standards such as ISO are rigorous, customer quality systems are even more rigorous. It has been our culture to abide by them and continually improve in a quality fashion," he stated.

"In many cases, the mechanical testing and laboratory services that Sintavia provides are acceptable to customers. There are, of course, a number of cases where customers want to test parts in their own approved facilities," he added. "We are continually improving and, as we grow, we add quality systems and special process approvals. The eventual goal is to have all customer quality systems in place here, so customers don't have to send parts to other testing laboratories all over the country. Our path is to have Nadcap credentials for all of our processes, not just AM, be it special metallurgical processes such as heat treating, Hot Isostatic Pressing, or X-ray CT scanning, etc. In modern advanced manufacturing, complete vertical integration is the path people are looking for."

*"Accreditations and certifications are a large part of the process and have been our goal from the beginning. While quality systems are baseline and standards such as ISO are rigorous, customer quality systems are even more rigorous."*

The company's metallurgical laboratory has been a key part of its operations from the beginning. Over time, it has complemented these capabilities with X-ray CT scanning for dimensional characterisation and internal inspection. It also has tensile, fatigue, creep and impact testing capabilities that support its ability to confirm heat and high-vacuum heat treatment with mechanical testing according to quality standards and specifications. This in-house capability is said to be critical for material and parameter development.

## Managing raw materials: Powder pre-processing and material development

Sintavia analyses raw powder material when it arrives to ensure that suppliers have done their due diligence. It also tests powder throughout a build, providing reports to the customer. Sintavia's accredited powder laboratory uses diffraction analysers, SEM, ICP-OES, gas analysis tools, flowmeter testing and true density testing equipment.

As well as processing established mainstream AM alloys, Sintavia also works closely with its customers to develop both new alloys and powder strategies for AM adoption. The company states that it was the first

*Fig. 3 EOS M400 systems installed at Sintavia for the production of components for the aerospace and defence sector*

AM company to develop a proprietary process for the Additive Manufacturing of F357 aluminium powder. Its customised parameters, processes and quality control procedures make it possible for Sintavia to serially manufacture parts and audit quality parts for critical industries.

Sintavia has three powder rooms dedicated by powder type, for storage and preparation of powder before use and to process recovered powder after use. Containers are filled with inert argon gas to displace oxygen and prevent contamination and oxidisation; this is particularly important for reactive powders such as titanium and aluminium.

Sintavia's powder recovery areas and powder removal stations have negative air pressure, so any accidentally released fine particles pass through filters instead of escaping into the wider area. Full face shields and respirators are worn while working in these finishing rooms to reduce the risk of inhalation and combat the possibility of contamination. Whilst during the build process most of the powder goes into the build chamber, some goes into the overflow and is recovered. The powder rooms' industrial sieving processes, with vibrating screens, support powder recovery and reprocessing.

Robust tracking processes for powders ensure that before powders are used or reused, they are sampled in the laboratory at Davie to check that element levels are within specification. Powders are reused a number of times, depending on customer requirements, until they fall out of specification. For clients which require virgin powders for their components, Sintavia keeps certain amounts of these materials in store.

Combining the physical tracking of materials through the facility with the requirement for recording high volumes of process data can be a significant challenge when moving to the series production of quality-critical metal AM parts. In addition to powder source and qualification data, ERP and PLM systems track every part, bin and lot of powder as it moves through the manufacturing process. Data from serial and lot numbers contain all machine and telemetry information, oxygen levels throughout the build process and tensile specimen test results. These can be compiled quickly into a customer report.

## AM production, post-processing and inspection

Having a variety of AM production systems installed, including some of the most widely used in the industry, gives Sintavia the flexibility to optimise production for its customers' needs. Component manufacturing currently takes place using eighteen AM machines from five different OEMs.

*Fig. 4 High speed machining centres*


*Fig. 5 Wire EDM machines*


*Fig. 6 A lathe and band saw for the post-processing of AM parts*

These comprise eleven EOS systems (two M400-1s, four M400-4s, and five M290s), three SLM Solutions 280s (two twin-laser, one single), one Concept Laser M2 dual-laser system and a Trumpf TruPrint3000. Two Arcam systems, an Q20+ EBM, and A2X EBM are also installed.

The new facility's lower production floor is divided into two equally sized halls, one with space for fifteen EOS M400s or the equivalent dedicated to nickel superalloys, Inconel 625 and 718, and heavier alloys, and one designed to handle large-scale builds using primarily titanium and aluminium. The upper production floor has space for twenty-five M290s or the equivalent for smaller builds.

All core post-processing operations are performed in a large finishing and machining area. A new, GM vacuum furnace that can fit six large 40 cm x 40 cm build plates at once, with a weight of more than 1000 kg each, is located in this area, as well as a Quintus Hot Isostatic Press, wire EDMs, CNC mills and lathes, band saws and wet and dry blasters.

Sintavia is one of few suppliers in the marketplace that has HIP in-house, an integral part of the manufacturing process for critical parts produced by metal AM. This minimises the need to send parts to external contractors for further processing, reducing cost and lead time and allowing full control to be kept in-house.

All final production quality and conformance inspections are performed in a new quality controlled inspection lab. This contains blue light scanning technology, which scans finished production parts on a rotating turntable, creating a 3D rendering of the part to make sure it conforms to requirements. SPC and CMM programmable fixtures ensure quality processes are the same.

First article inspections on qualification builds take place at Sintavia's Davie location using a CT scanner for dimensional metrology. "There are many radiography specifications for size inclusions, allowed voids and the distance between voids," explained Hedges. "Our CT

*Fig. 7 A post-build processing area at Sintavia*

scanner has high enough resolution that it allows us to go beyond most customers' radiography specifications to verify if there were problems. Every fifth part is scanned until qualification is complete, then every twenty-five or a statistical sampling after building a trust relationship. It's hard to do; we are disrupting the whole industry. This is the next industrial revolution."

Sintavia is AS9100 and ANAB certified, OASIS and ITAR registered, ISO 9001 and ISO/IEC 17025 accredited, and A2LA approved. Its laboratories are also both accredited, as required by customers. The company has Nadcap certification for Additive Manufacturing, and further plans to obtain this for heat treatment, post-processing later this year.

## Expanding the range of applications for AM in aerospace and defence

In April 2019, a major aerospace OEM accepted delivery of its first Sintavia metal AM part to be installed as commercial flight hardware. The piece that Sintavia built received approval and is now proven to go into one of the largest narrow body fleets. Every other part on the production chain was manufactured by the OEM itself, making this its first part made by an independent Additive Manufacturing firm.

*"We wanted to prove to OEMs and customers making precision cast parts that a simple non-rotating metal part could conform to specs and make internal engineering happy – and that we can do the job better than the traditional supply chain..."*

Brian Neff, Sintavia's CEO, stated, "We wanted to prove to OEMs and customers making precision cast parts that a simple non-rotating metal part could conform to specs and make internal engineering happy – and that we can do the job better than the traditional supply chain in the form of lower costs, shorter manufacturing times, and dramatic design improvements."

"Getting approval from our largest customer is a big deal," he continued. "It signals that it's the first time the technology is acceptable for commercial parts. This part, a simple filter cap, is only one part. The road stretches ahead over hundreds of thousands of parts over the next twenty


*Fig. 8 One of five EOS M290 systems installed at Sintavia's new facility*

years. We see the path forward to meet demand. We've done it for the first time and expect it to grow rapidly. There were no deviations; we met the drawings. There were no manufacturing review boards; the part was completely accepted. Now someone has proven a third-party can manufacture using AM so the promise is there. It's no longer hype."

Other aerospace and defence applications that the company has developed specific expertise in include valve bodies, ducts, chassis, and heat exchangers. AM has long been recognised as a natural production process for heat exchangers because of its ability to create internal passageways in geometries that cannot be manufactured by traditional methods. Sintavia manufactures heat exchangers for several industries and can manufacture wall thicknesses of 200 μm or less.

> *"The casting and forging industry that supplies aerospace products is huge and AM will replace precision casting over time because it is a competitive alternative. The technology itself is cheaper, faster, more efficient, and much less polluting."*

Sintavia also manufactures flow control valves for commercial aerospace and other critical industries, noting that the production of flow control valve assemblies is greatly simplified when using AM, with shorter lead times and fewer part assemblies.

## Heading towards displacement

"Sintavia is trying to become the largest independent metal AM supplier for the aerospace and defence markets," Neff stated. "OEMs typically rely on supply chains to manufacture a lot of their equipment for many reasons. They design, test, sell and assemble, but do not fabricate. The casting and forging industry that supplies aerospace products is huge and AM will replace precision casting over time because it is a competitive alternative. The technology itself is cheaper, faster, more efficient, and much less polluting. CEOs and aerospace leadership want to adopt a new supply chain that offers a technical and strategic advantage as well as having an alternative to the traditional chain. Sintavia has made good strides in filling this gap and is building itself as a leader for independent aerospace and defence projects."

He sees the metal AM industry growing as it displaces traditional casting houses – which is a $100+ billion industry globally – every year. "Whilst the smaller AM houses are to some extent competitors, the real challenge is to displace companies such as Precision Castparts Corp (PCC), Consolidated Precision Products (CPP) and Arconic," he explained. "Sintavia is committed to establishing an alternative and parallel supply chain for precision cast parts within the aerospace industry."

Demand, Neff believes, will come from middle management such as Program Managers for a specific engine or aircraft who trust the technology enough to take the risk and put it on their engines. "An under-capitalised family business with a machine or two cannot take this on - but Sintavia can. The Chief Engineers on an A350 or 787 are the decision makers we need to convince to adopt the technology."

*Fig. 9 An industrial scale GM vacuum furnace for the heat treatment of AM builds*

## The challenges of standards and AM

"We are bridging two worlds – the world of AM, science, technology and manufacturing in general, and the unique world of aerospace production, which is tough," Neff stated. "Quality requirements are the most stringent in the industrial world. A failure seven miles up is catastrophic. The challenge is not only to master the technology to manufacture to a precise and high-quality degree but conform it to a stringent quality management system, meeting what the customers want."

Peripheral services offer a challenge too; testing and post-processing means there are five or six divisions with different skill-sets at the company, in addition to its core competency in metal AM. "It's a challenge to learn them all quickly, because the industry is moving so fast. The technology is moving faster than the standards. We know a process is good but the standards for making aerospace parts are controlled by the SAE's Aerospace Materials Specifications [AMS], and there's no infrastructure for other manufacturing processes," Hedges added.

"Many standards are guarded or controlled as IP at different companies. We are just now starting to see documents flow out of government bodies to move the industry forward. Now that AMS has standards based around AM, others will come out. It needs to be done quicker to keep up with how fast the technology is moving. Documentation and standardisation are slightly behind. Instead of waiting for government bodies to release, we write the specifications internally or work with customers to write specifications to control the processes so they are fixed and repeatable. It is also challenging that many of these company specifications aren't transparent throughout the industry. But the industry could adopt all of them."


*Fig. 10 Arcam Q20+ and A2X EBM machines at Sintavia*

## A maturing supply chain

Neff believes that Sintavia's success in gaining acceptance for its first metal AM part in a commercial airliner is evidence that the supply chain has been developed to the scale and quality required to move the process from the fringes to the mainstream. "We're now at the point where our customers are accepting parts they didn't manufacture themselves for commercial air travel. At a high level, it's always been something our customers have wanted to do. We received our first production contract in the last half of 2018 and have proven it now in the first half of 2019."

*"In the next two-to-ten years we will start to see suppliers becoming more refined and narrowing their skill sets. Instead of doing it all, they will focus to be really good at certain components."*

"With any new technology in critical industries, at first, the adoption rate is always slower than everyone wants. But it then reaches the point where it rapidly accelerates. Sintavia is on that glide slope curve now, moving into the realm of producing tens of thousands of parts per year. Once we start with one, more will come," he stated.

Hedges agreed: "A few years ago the supply chain was small. It's still small today, but is getting bigger as more established companies, like Sintavia, make aerospace parts for real flying engines. The supply chain is further along, moving ahead and evolving to gain strength and experience."

"I don't think there will ever be a single supply chain. We are seeing that in this industry, one supplier can't do it all. The supply chain itself is specialised, with three or four companies that may specialise in making a certain component. In the next two-to-ten years we will start to see suppliers becoming more refined and narrowing their skill sets. Instead of doing it all, they will focus to be really good at certain components. For example, for us to produce high-pressure ducting, competing suppliers may need to specialise in steel and aluminium. There's a lot of room for growth in these supply chain-type companies," he concluded.

## Blueprint for growth

In the next three-to-five years, Sintavia plans to focus on ensuring that its new facility is able to reach capacity by employing 130 highly skilled workers and generating more than $100 million of annual revenues on the production of parts in the tens of thousands - a tremendous growth track. At the close of 2018, Sintavia had thirteen metal AM machines in operation. By the end of 2019 it will have twenty-two. Its new facility, with its capacity for sixty large and medium machines, is the prototype for future growth.

Looking ahead, Sintavia told *Metal AM* that it will replicate its vertically-aligned business model in locations across the US and Canada near its OEM customers. It is currently in the process of building a second production facility in Houston, Texas, USA, which will primarily service the oil and gas industry. Future locations are planned for Seattle, Washington, USA, and Phoenix, Arizona, USA, and later in Japan and Europe.

*Fig. 11 A view of the heat treatment area at Sintavia*

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# Thinking about metal Binder Jetting or FFF? Here is (almost) everything you need to know about sintering

With the arrival of high-volume metal Binder Jet systems and a growing interest in metal Fused Filament Fabrication, the AM industry is set for a new phase of growth. The ability to use this new generation of systems for the production of 'green' parts is, however, only half of the story. The sintering of these parts to create large quantities of finished product to a consistent quality requires both an investment in furnaces that can cost in excess of $1 million each, and a thorough understanding of sintering. In this article, Prof Randall German, the leading authority on the science of sintering, outlines the process and its core challenges.

Sintering is a heating process applied to shaped powders to provide strength by bonding the particles into a solid. Often, but not always, densification occurs during sintering. Surface diffusion forms the first sinter bonds without causing a dimensional change. When heated to a higher temperature, grain boundary diffusion induces densification, grain growth, pore rounding, and significant property changes. The optimal sintering conditions depend on the material and particle size, realising excessive heating leads to a loss of properties and even swelling of the component. Beyond classic textbook materials, sintered materials often rely on intentional grain boundary segregants, including liquids, to retard grain growth or accelerate sintering.

Within the confines of Additive Manufacturing, it is important to differentiate between the sintering process that is used to densify parts created by metal Binder Jetting and Fused Filament Fabrication, and the Laser Powder Bed Fusion of metal powders, often erroneously referred to as a variant of 'laser sintering', in which a very different melting process occurs.

The term 'sintering' arose from geology where 'cinder' was used to describe hardening of mineral phases around geothermal vents. Modern uses for sintering trace to the early 1800s and the fabrication of platinum crucibles for melting glass. By the early 1900s, sintering was used to fabricate tungsten ingots from which lamp filaments were drawn. Scientific understanding of how sintering occurred emerged as atomic diffusion became accepted in the late 1940s. Predictive models for the role of time, temperature, particle size, and green density emerged in a body of mathematical expressions by the 1980s [1,2]. Unfortunately, the

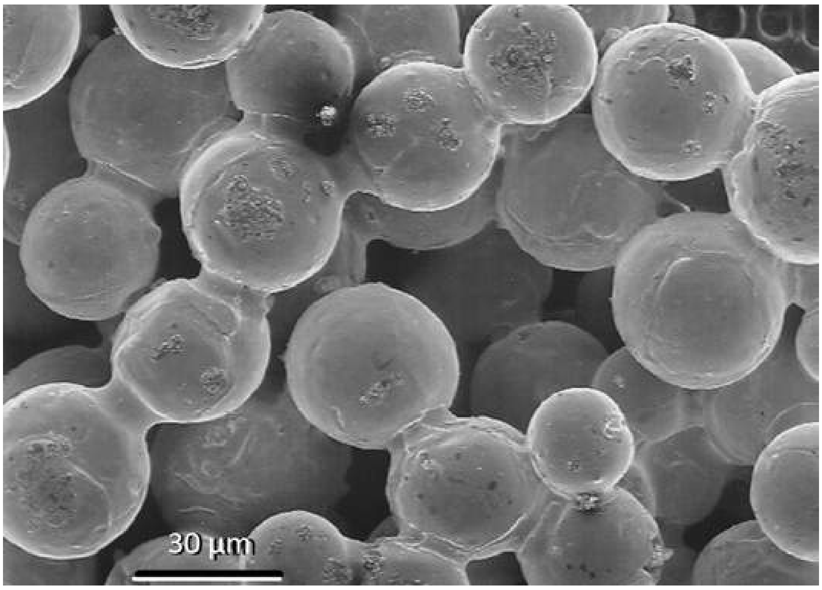


*Fig. 1 Scanning electron micrograph of spherical bronze particles to illustrate sinter neck formation between contacting particles prior to significant densification*

models assume ideal conditions and often ignore significant parameters such as heating rate and atmosphere reactions. With modern instrumentation it is clear that most sintering occurs during heating, not during the hold at the peak temperature.

The study of sintering spans a broad range of materials. In spite of its broad use, the sintering trajectory is essentially the same for most materials (polymers, ceramics, metals, composites, minerals and intermetallics). Thus, in teaching sintering behaviour, a broad range of examples and materials is available to help understand the general behaviour.

Industrial sintering cycles are defined by several parameters – green density, particle size, heating rate, peak temperature, hold time and process atmosphere. Pressure is applied in some cases, but pressureless sintering is predominantly favoured because of its significantly lower cost. Further variations arise in the design and operation of the sintering furnace. The peak temperature depends on factors such as the material melting temperature and particle size. The hold time at the peak temperature ranges from a few seconds to a few hours. Time at temperature can be adjusted to deliver equivalent thermal work; high temperatures require less time. Although the green body is weak prior to sintering, after firing it is strong, often competitive in properties with that attained via other manufacturing routes. Furthermore, the structure shows little evidence of the initial particles. Atmosphere selection is guided by the material chemistry and is a significant factor for proper sintering.

Binders are routinely added to powders to facilitate shaping. The binders are waxes or other common polymers that can be removed during heating to the sintering temperature – they decompose at temperatures far below the sintering temperature. Consequently, much of the sintering cycle is independent of the binder composition and component forming route, but it does depend on the powder chemistry and particle size. Thus, in spite of the availability of a diverse range of binders and shaping approaches, sintering cycles are often similar for seemingly different forming routes.

Formally, sintering is a thermal treatment applied to particles to increase strength by bonding particles to one another. The bonding occurs by atomic motion with a net reduction in surface energy as evident by surface area loss. It is possible to induce densification along with bonding, but a change in density is not always observed, especially for larger particle sizes. Filters and bearings are examples of sintered products where densification is intentionally avoided. Sintering is enhanced by smaller particles, higher temperatures and certain grain boundary phases. Although liquid formation is common during sintering, practically it is limited to less than about 15 vol.% liquid. Larger amounts correspond to semi-solid casting approaches such as rheocasting. Total particle melting with electron beams, lasers, or arcs is not sintering, but a variant of casting.

## The basics of sintering

Atomic motion during sintering results in a loss of surface area and surface energy. Temperature controls the process. During heating at low temperatures, bonding occurs at the contact points between particles, as pictured in Fig. 1. This image shows necks between spherical bronze particles during early sintering. As the necks grow, there is initially no densification. Later, with higher temperatures, smaller particles or longer times, the particles pull together to fuse into a dense structure that no longer shows evidence of the precursor particles. Indeed, coarsening during sintering results in grains several times larger than the initial particle size. Hundreds and even thousands of particles fuse to generate a single grain.

For loose powder, such as that used in sinter-based Additive Manufacturing, sintering follows a geometric progression consisting of four stages:

- Contact formation – Weak adhesive forces pull the particles together
- Neck growth – Initial bonding at particle contacts by surface diffusion
- Pore rounding – Growing necks merge to form tubular pores
- Pore closure – Final stage grain growth with closed pores

After initial bonding, the pulling together at particle contacts, due to capillary stress, results in shrinkage and densification. In turn, shrinkage induces formation of new particle contacts that further bond the structure. For sinter-based Additive Manufacturing, the initial structure corresponds to each particle having five to six touching particles, termed the coordination number. As shrinkage occurs the coordination number increases to an average of about thirteen to fourteen faces on each grain at full density. Thus, sintered properties dramatically improve with densification, due to an increase in the interparticle bond size and number of interparticle bonds. The coordination number $N_C$ relates to the fractional density *f* as follows:

$$N_C = 2 + 11\, f^2$$

Density is the most common measure of the degree of sintering. It is a good predictor of properties since most materials follow a power law relation between strength $\sigma$ and fractional density *f*:

$$\sigma = \sigma_O\, f^N$$

where $\sigma_O$ is the strength at full density. The exponent *N* is often from 4 to 6, depending on the material sensitivity to residual pores. For ferrous alloys, this means 15% porosity (0.85 fractional density) lowers strength to

50% of the full density level ($N \approx 4.3$). Besides density, other sintering monitors include shrinkage, conductivity and hardness. These parameters link to the neck size ratio; that is, the diameter of the sinter bond between particles $X$ divided by the particle diameter $D$, giving the dimensionless neck size ratio $X/D$.

Shrinkage is the decrease in dimension $\Delta L$ from the green body size prior to sintering $L_0$, giving $\Delta L/L_0$. It is often given as a percentage. Measures such as density and shrinkage are relatively easy to perform versus measuring neck size. A related parameter is densification, the change in porosity resulting from sintering normalised to the starting porosity. If all pore space is eliminated during sintering, then densification is 100%. These parameters are related and one can be used to calculate the others.

In most situations the sintered component volume is smaller than the green or initial volume, while mass remains essentially the same. The density increase associated with shrinkage (usually expressed as a positive value) is often assumed to be isotropic. If mass remains constant, the sintered fractional density $f$ depends on the initial unsintered fractional density $f_0$ and shrinkage $\Delta L/L_0$ as,

$$f = \frac{f_O}{\left[1 - \frac{\Delta L}{L_O}\right]^3}$$

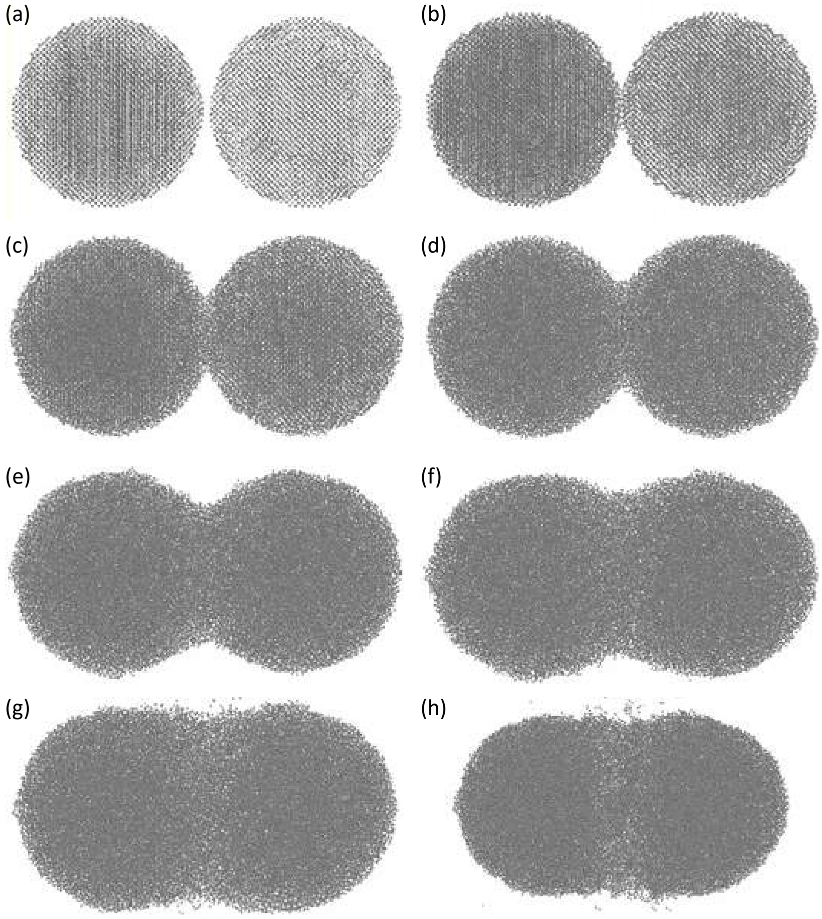


*Fig. 2 Molecular dynamics simulation of sintering for two body-centred cubic tungsten spherical particles. Initially the crystal planes are not aligned at the contact point, so a defective region arises in the neck that becomes a grain boundary. In this situation the images are taken during heating from a) room temperature, to b) 500 K, c) 1000 K, ... in 500 K increments to h) 3500 K. At the highest temperature, evaporation takes place as the particles coalesce to eventually form a single sphere. Initially the atomic motion is on the particle surface and later grain boundary diffusion is dominant.*

For a high green density, such as 85% of theoretical (possible using mixed particle sizes), a shrinkage of 3% gives 93% density and 5.3% shrinkage gives full density. On the other hand, at a green density of 45%, the required sintering shrinkage is 23.3% to reach full density. Generally the larger the shrinkage, the larger the distortion during sintering. A close look at sinter-based Additive Manufacturing approaches reveals density gradients in the green body, leading to anisotropic shrinkage. Other factors, including substrate friction and non-uniform heating, also contribute to sintered size variations.

Molecular dynamics computer simulations help visualise the atomic motion associated with neck growth. These simulations input atomic interaction potentials that govern atom motion during heating. Clusters of atoms are used to form particles. Each atom follows an interatomic attraction-repulsion potential that mimics melting, thermal expansion, and elastic properties. Atoms separated by more than the equilibrium spacing are attracted to one another, but atoms closer than the equilibrium spacing repel each other. Heat increases the atomic vibrational amplitude. During sintering the saturation vibrational frequency is near $10^{14}$ vibrations per second. As temperature increases, more atomic motion occurs, evidenced by increased vibrational amplitude. Initially, surface diffusion is active, where atoms move from convex surface sources to grow the concave neck. At the sintering temperature each atom changes position on average six times per second.

Sintering visualisation is possible as shown by the images in Fig. 2. These pictures correspond to tungsten particles heated to increasingly higher temperatures at a constant rate from room temperature

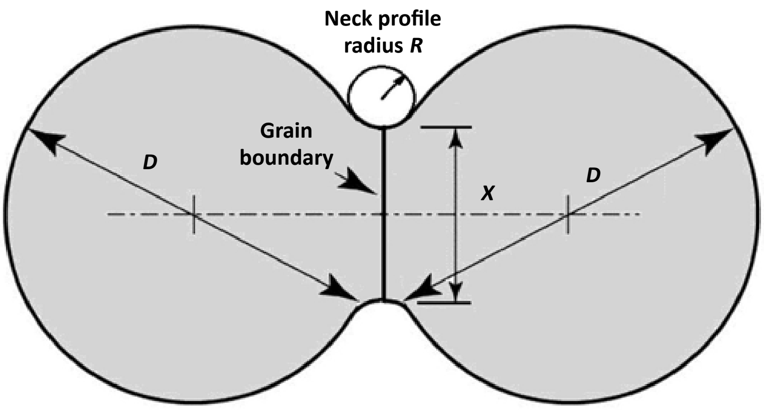


*Fig. 3 Outline of the neck size X and the particle size D (assumed spherical) and neck saddle point curvature R during two particle sintering. A grain boundary forms in the neck due to crystal misalignment of the contacting particles*

to melting. As temperature increases the particles grow a neck, then shrink together. A grain boundary forms in the neck due to random misalignment of neighbouring crystals. These grain boundaries are critical to subsequent shrinkage and densification. Evaporation is evident at high temperatures. For two particles, the lowest energy configuration corresponds to coalescence into a single particle 1.26 times the initial size.

Such simulations show several aspects of sintering – atoms move, randomly, but that motion is biased over time by a progressive reduction in interface energy. At first this is by atom motion over the particle surface, termed surface diffusion. The overall action is to eliminate surface area by neck growth. As grain boundaries form between particles, grain boundary diffusion emerges. It is grain boundary diffusion that gives densification, since atoms move into the pores from the contact plane between particles, allowing progressive particle approach or shrinkage and formation of new contacts.

It is possible to accelerate sintering by adjusting the grain boundary chemistry. One common step is to form a liquid phase, since atomic motion is hundreds of times faster in liquids versus solids. Solid diffusion involves the creation of a vacant site for atomic diffusion and a similar energy to 'jump' an atom into the vacancy. In liquids, the amorphous atomic structure circumvents the vacancy creation energy. Thus, liquid phase sintering is easier, faster and widely employed in industrial sintering – by nature, humans are impatient.

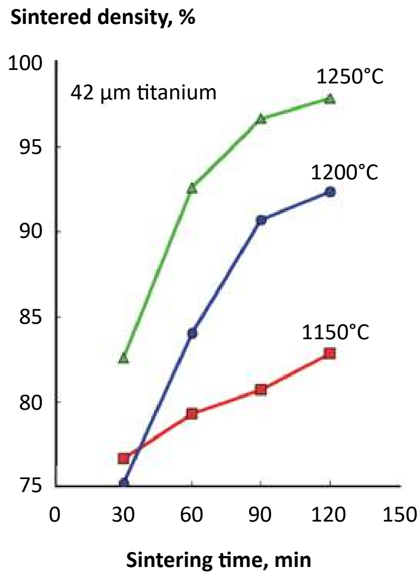


*Fig. 4 Sintered density versus hold time for 42 µm titanium powder vacuum sintered at three temperatures [3]. Faster rates of densification (steeper slopes) are associated with shorter times and higher temperatures*

## Atomic motion

Sintering combines surface energy and high-temperature atomic motion to bond (surface diffusion) and densify (grain boundary diffusion) particles. What happens at the contact between particles is replicated billions of times throughout a component. Thus, models for bonding of two contacting particles give a glimpse at the behaviour, realising the events are replicated throughout a component.

The idealised two-particle sintering profile is shown in Fig. 3. The spherical particles are *D* in diameter with a neck *X* in diameter. Initially, the neck contour forms a concave saddle approximated by opposing radii of *X* and the circle of radius *R*. Surface energy reflects broken atomic bonds, so the smaller radius is higher in energy, generating a capillary stress that pulls the particles together to enlarge the neck. This capillary stress is termed the sintering stress. It is roughly proportional to twice the surface energy (usually 1–2 J/$m^2$) divided by *R*. For a 10 µm powder, *R* is nominally about 1 µm so the sintering stress is about 2 MPa. That stress falls as the neck enlarges, but still it is sufficient to pull the contacting particles together up to about 95% density.

At room temperature, there is too little atomic motion to induce shrinkage or densification. However, at the sintering temperature there is considerable motion. For steel or stainless steel, sintering requires heating to a point where the material softens. This is termed thermal softening. Before significant bonding, a powder compact has a relatively low strength (in the 0.1 MPa range). Because of the low strength, fracture susceptibility is high during heating. Defects as small as 10 µm enlarge to become cracks; these form early prior to much necking. Differential shrinkage between thick and thin sections is a common difficulty, requiring slow heating rates to avoid cracks. Sinter bonding improves strength, but thermal softening at high temperatures reduces strength sufficiently to allow densification. That is, first the particles bond with no appreciable shrinkage (usually by surface diffusion), forming grain boundaries at the particle contacts. The neck growth increases the compact strength. Then, at higher temperatures grain boundary diffusion gives densification as the structure softens. Finally, remaining pores collapse into spherical voids that annihilate if they are not filled with an insoluble gas. This occurs late in the sintering cycle at high temperatures where the component is again weak due to thermal softening

Sintering is faster at higher temperatures since atomic motion increases amplitude on heating. A practical demonstration is given in Fig. 4, where sintered density is plotted versus hold time for 42 µm titanium powder sintered at three temperatures [3]. Prolonged time adds to the densification, but the role of temperature is dominant. Smaller particles are helpful, since they have a higher sintering stress and shorter diffusion distances. This is demonstrated in Fig. 5 for experiments using different particle sizes of ZnS sintered at 1000°C for 120 min. in nitrogen [2]. Indeed, with a stainless steel powder it is possible to reach 98% density after 120 min. at 1050°C with a 4 µm powder [4]. But 1300°C is required with a 9 µm powder, and 1385°C for 31 µm powder. Smaller particles respond to a lower sintering temperature.

Due to grain growth during sintering, the final grain size is larger than the starting particle size. However, pore size is complicated. Porosity decreases due to densification, but simultaneously pores coarsen to increase size by vacancy or gas exchange, reducing the number of pores and pore surface area. With too high a sintering temperature, or too long a sintering time, the combination of pore coarsening and grain coarsening results in loss of density and properties, termed over-sintering. Fig. 6 plots such behaviour for a tungsten alloy sintered at 1480°C. Optimal strength is attained with less than a two-hour hold. Sintered stainless steel exhibit a similar loss of strength with excess sintering [4].

The driving energy for sintering is small, typically less than 1 J/g, resulting in a slow process. For some materials, such as WC-Co

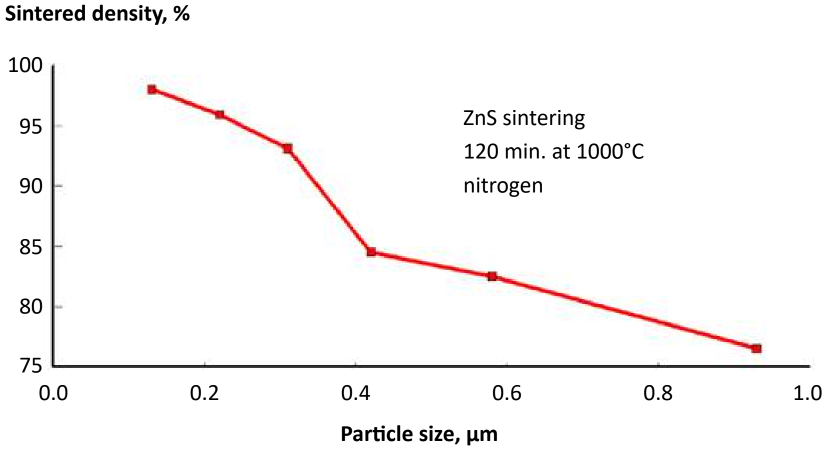


*Fig. 5 Sintered density versus particle size for zinc sulfide heated in nitrogen for 120 min. at 1000°C, illustrating the improved densification associated with small powders*

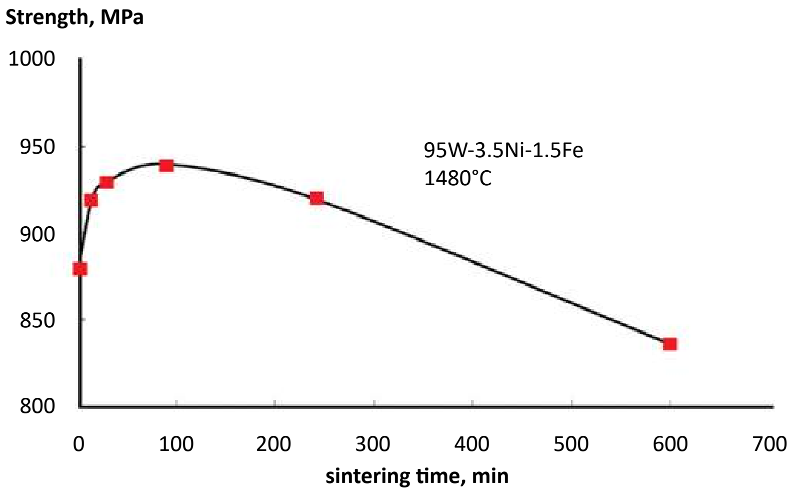


*Fig. 6 Over-sintering occurs as materials pass through the peak density and grain size combination. This plot gives tensile strength as a function of sintering time for a tungsten alloy heated to 1480°C in hydrogen for times up to 600 min*

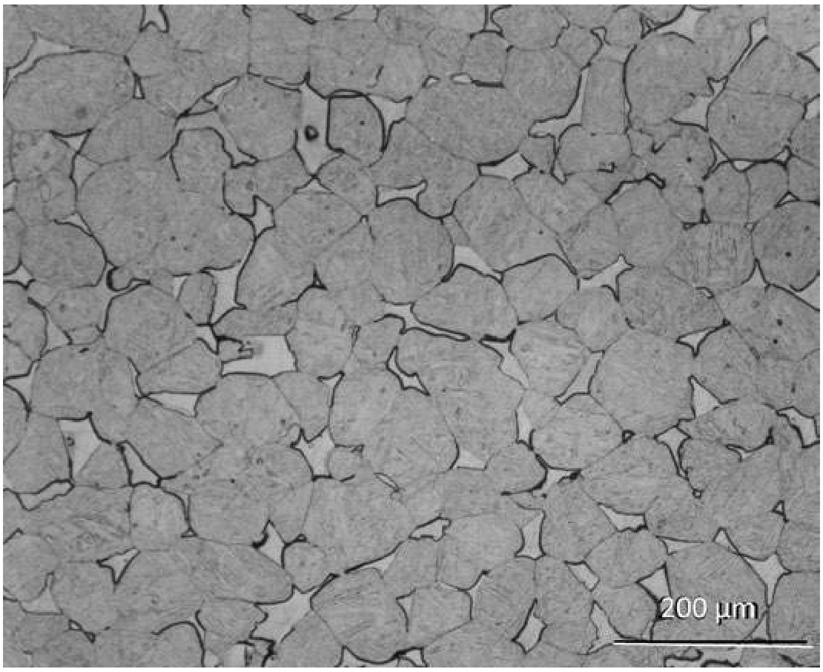


*Fig. 7 A 422 stainless steel doped with 200 ppm boron to enable full density when sintered for 60 min. at 1320°C in vacuum. On cooling the liquid phase solidified to form the second phase between the solid grains*

cemented carbides, this means heating to a temperature where liquid forms. Liquids that have solubility for the solid accelerate atomic motion and facilitate rapid sintering. Upon cooling, the liquid solidifies to give a composite microstructure consisting of solid grains bonded to one another with an interpenetrating second phase, as evident in the microstructure shown in Fig. 7. This stainless steel was doped with boron to form liquid on the grain boundaries during sintering. That liquid induced full density, without degrading properties. This is an alloy custom designed for sintering; boron reduces the sintering temperature by about 100 – 120°C. Table 1 shows a few examples of boron treatments [5-10]. Equivalent 12 µm powder without boron sintered at 1250°C gives a strength near 300 MPa and 18% elongation. The standard for sintered 316L stainless steel doped with boron is a strength of 520 MPa with 23% elongation [11]; for comparison, the industry standard for metal injection moulded 316L stainless steel is 450 MPa tensile strength and 40% elongation.

Liquid phase sintering relies on grain boundary wetting. Several examples are well known – TiC-tool steel, Fe-$Fe_3P$, WC-Co, W-Ni-Fe, Mo-Ni, Fe-Cu-C, stainless-boron, Cu-Sn, and most ceramics. For example, AlN is treated with $Y_2O_3$ to form a fast diffusion grain boundary phase. Indeed, covalent ceramics such as SiC and $Si_3N_4$ only densify when additives are employed to form an amorphous or glassy liquid phase on the grain boundaries.

Alloy powders liquid phase sinter when heated to the solidus temperature where liquid forms inside the particles. This liquid softens the structure sufficiently that the sintering stress quickly pulls the particle to full density. Temperature controls liquid formation, as evident by the plot of density versus temperature in Fig. 8 for 40 µm D7 tool steel powder [12]. Densification occurs near 1250°C. Hold time is a minor factor. This supersolidus sintering approach is applied to high alloy systems, such as tool steels, stainless steels, cobalt-chromium, and superalloys; generally alloys based on iron, nickel, cobalt, precious metals, or titanium. Fig. 9 shows the microstructure for a 0.8% carbon M2 tool steel sintered at 1280°C in 10 min. using a nitrogen-hydrogen

| Particle size (µm) | Additive (wt.%) | Sintering temperature (°C) | Sintering time (min) | Tensile strength (MPa) | Elongation (%) |
|---|---|---|---|---|---|
| 12 | none | 1250 | 60 | 300 | 18 |
| 12 | 0.4 B, 0.4 $Al_2O_3$ | 1252 | 60 | 575 | 55 |
| 12 | 1.5 NiB | 1250 | 60 | 491 | 36 |
| 45 | 0.5 NiB | 1245 | 45 | 575 | 18 |
| 45 | 0.5 NiB | 1280 | 90 | 480 | 38 |
| 79 | 0.5 NiB | 1250 | 30 | 480 | 23 |
| < 100 | 3.0 Ni-Mn-B | 1280 | 60 | 776 | 37 |

*Table 1 Comparison of 316L stainless steels and boron doping to induce liquid phase sintering*

  

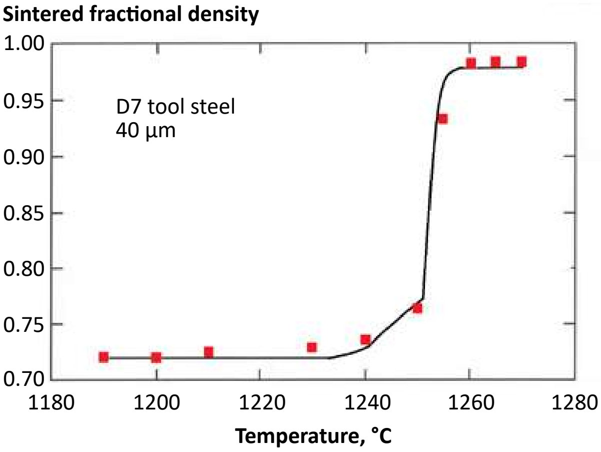


*Fig. 8 Sintered density for a 40 µm prealloyed D7 tool steel powder versus peak temperature, showing how supersolidus sintering densifies rapidly once the solidus temperature is reached [12]*

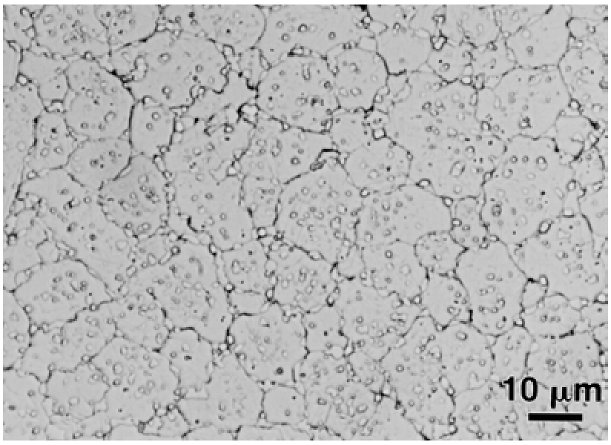


*Fig. 9 Microstructure after supersolidus liquid phase sintering a M2 tool steel containing 0.8% carbon. The powder densifies in 10 min. at 1280°C using a nitrogen-hydrogen atmosphere*

atmosphere. Supersolidus sintering requires precise temperature control because excess liquid causes component distortion.

There are two categories of atomic transport mechanisms – surface and bulk. Bulk transport along grain boundaries causes shrinkage, pore annihilation, and densification. Surface transport processes, mostly surface diffusion, reposition mass on the pore surface to smooth the pores and reduce surface area, but do not give densification. Such behaviour is useful in forming filters. In certain atmospheres (hydrogen doped with water or a halide such as chlorine), pore rounding without densification occurs by evaporation and condensation across pores. Otherwise, early sintering is predominantly by surface diffusion and later densification is by grain boundary transport. The exceptions are amorphous materials, such as glasses or plastics, that sinter by viscous flow.

In sintering science, the pores are assumed to be accumulations of vacancies. Pores emit vacancies, just like a helium balloon gives up gas. These vacancies are annihilated at free surfaces and grain boundaries. Atoms move in the opposite direction to fill the pores. Vacancies also migrate between pores, leading to the growth of larger pores while the smaller pores shrink. Fig. 10 plots such behaviour using log-log scaling for 4.5 µm iron powder sintering at 850°C [13]. Porosity decreases, grains grow, and after an initial transient the grain boundary area decreases while the number of pores decreases. The pore size enlarges progressively even though densification reduces the total porosity and number of pores.

As grain growth occurs, the grain boundary area declines, leading to slower sintering.

## Control parameters

Of the several parameters that control sintering, temperature is dominant. Fig. 4 previously illustrated this effect.

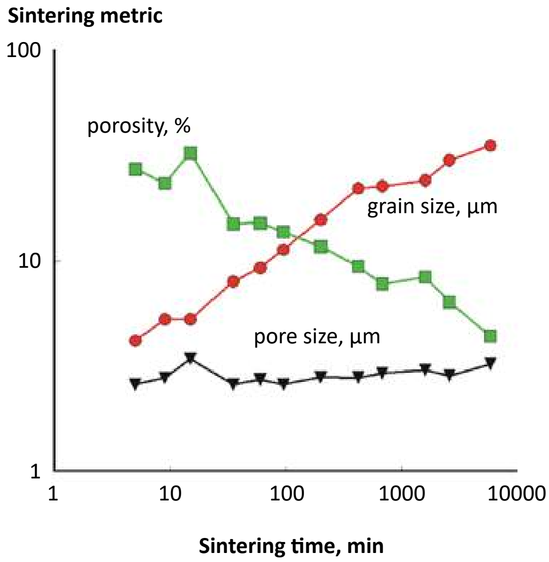


*Fig. 10 Log-log plots of sintering changes for a 4.5 µm iron powder sintered for a long time at a low temperature, capturing the loss of porosity, increases in average grain size, and slight increases in average pore size [13]. There is a large decline in the number of pores to accommodate the porosity decrease and pore size increase*

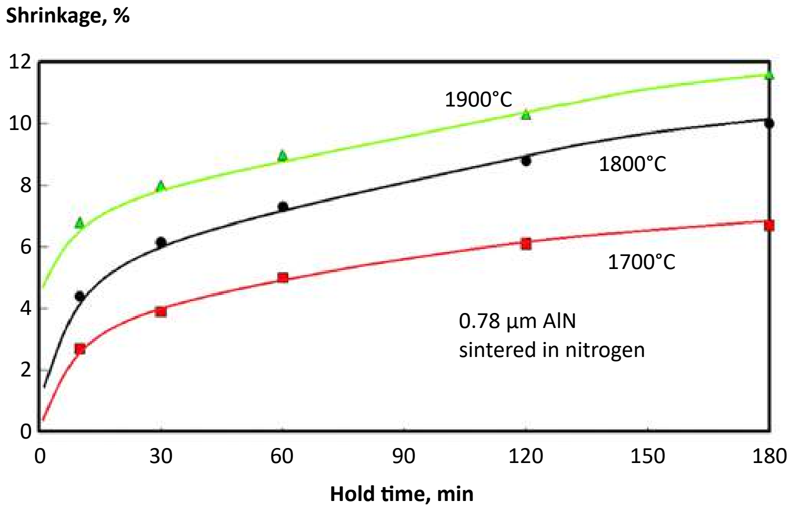


*Fig. 11 Sintering shrinkage for 0.78 μm aluminium nitride doped with yttria, sintered in nitrogen at various time-temperature combinations. Initial shrinkage is fast, but shrinkage rate declines during the isothermal hold*

Shrinkage increases with higher temperatures, but the shrinkage rate slows with time. Such behaviour is treated using models where the monitor *Y* (such as shrinkage, neck size ratio, surface area loss, or densification) depends on hold time *t* and absolute temperature *T* via the relation:

$$Y^N = \frac{C\,t}{T}\,exp\left[-\frac{Q}{R\,T}\right]$$

Here *T* is the absolute temperature, *Q* is an activation energy (proportional to the material's melting temperature), *R* is the gas constant, and *C* is a material-geometry constant. An example of the shrinkage relation to time and temperature is given in Fig. 11, where the shrinkage data correspond to an exponent *N* = 3.

The factor *C* depends on the material chemistry and particle size. If a phase transformation occurs, such as iron from body-centred cubic to face-centered cubic, then the rate of sintering changes due to shifts in diffusion rates, grain size and formation of new interfaces. This effect is seen in Fig. 12 for Fe-2Ni heated at 10°C/min. through the body-centred cubic to face-centered cubic phase transformation (alpha to gamma). The data were taken using dilatometry, where dimensions are measured directly during sintering. In this case, most of the shrinkage occurs in the lower-temperature body-centred cubic phase, slowing after the phase change. However, steels require sintering in the high-temperature face-centred cubic domain in order to adsorb carbon for strengthening. Thus, for many ferrous alloys the typical sintering temperature is 1150 – 1350°C.

Hold time at the peak temperature is not a strong factor. Sufficient time is required to ensure uniform heating,

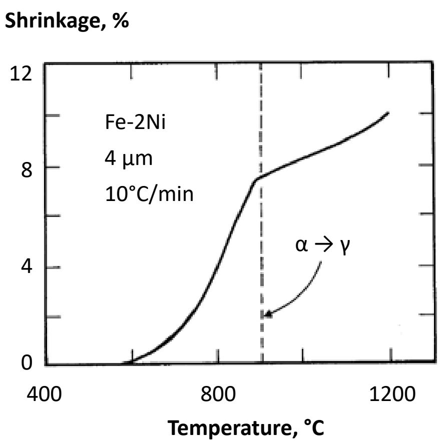


*Fig. 12 Shrinkage data taken during heating for mixed 4 μm Fe and Ni powders (2 wt.% Ni), showing significant slowing after the phase transformation from alpha (body-centered cubic) to gamma (face-centered cubic) crystal structure. The pure iron transformation is 910°C, but as nickel is dissolved into the iron, there is a progressive decrease in transformation temperature that is not shown*

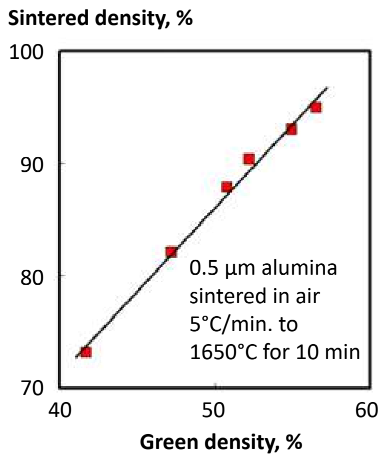


*Fig. 13 Demonstration of how green density impacts sintered density. These data are for 0.5 μm alumina heated at 5°C/min. to 1650°C for a 10 min. hold in air. The lowest green density corresponds a coordination number of less than 4 contacts per particle and the highest green density corresponds to a coordination number of 6 contacts per particle. The sintering shrinkage averages 16.6%*

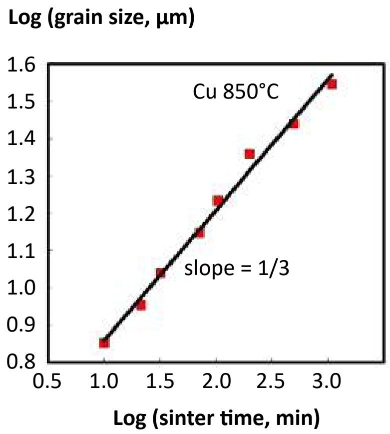


*Fig. 14 Logarithmic plot of grain size versus time to show grain growth behaviour for copper during isothermal sintering at 850°C. The slope of the graph shows the mean grain volume is a linear function of hold time*

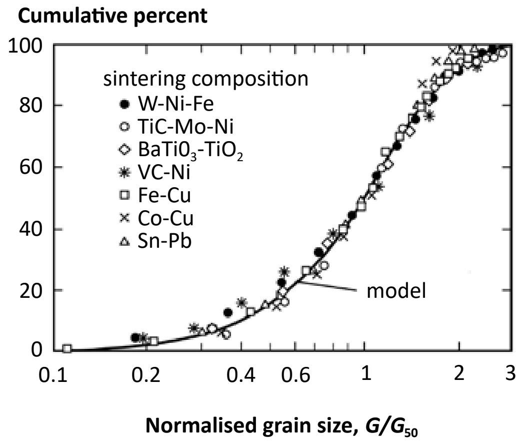


*Fig. 15 Cumulative grain size distribution for several sintered materials. The results are compared to a Weibull distribution model where the normalisation factor is the median grain size $G_{50}$ to collapse the results of various studies into a single curve*

but long times have diminished impact. Indeed, with respect to properties, long sintering times are counterproductive due to grain and pore growth. Some industrial sintering cycles are very short. For example, electronic films are sintered in a flash lasting only seconds. However, for bulk shapes, rapid heating induces thermal stresses that cause distortion. In metal injection moulded 316L stainless steel, the dimensional scatter increased with heating rate [14]. Thus, heating rates of 10°C/ min. or less are more typical.

Green density is another processing parameter. Smooth particles improve green density. A lower green density makes sintering more difficult since there are fewer particle contacts. It takes less net atomic motion to densify a well-packed, high-coordination number compact. Loose packing only reaches about six to seven contacts per particle. For spheres an idealised packing reaches a coordination number of twelve, resulting in improved sintering [15]. An example with 316L stainless steel powder contrasts sintered density versus initial packing (1360°C for 60 min. in hydrogen):

- 66.4 vol.% packing sinters to 99.1% density,
- 63.1 vol.% packing sinters to 98.2% density,
- 61.5 vol.% packing sinters to 94.6% density.

A high packing density helps sintering as illustrated in Fig. 13. The sintered density is plotted versus the green density for alumina powder subjected to the same sintering cycle. From a practical standpoint, if the green density falls below about 45%, then it is very difficult to reach full density.

## Microstructure trajectory

Several microstructure parameters change during sintering. Besides neck growth and surface area loss, pores round and coalesce while grains grow. Grain growth involves atomic exchange across grain boundaries and accelerates on approaching full density. Pores slow growth since they reduce the grain boundary area. Hence, the slowest rate of grain growth is during initial heating, when there is little grain-grain contact. As necks emerge and pores round, the higher grain boundary area allows for more grain growth.

During isothermal sintering, grain growth occurs with the median grain volume ($G^3$) increasing as follows:

$$G^3 = G_O^3 + K\,t$$

This says the median grain volume depends on the initial grain volume $G_O^3$, hold time t, and a temperature dependent parameter *K*. As a demonstration of this behaviour, 850°C sintering data for copper are plotted on a log-log basis in Fig. 14. The slope of one-third corresponds to $G^3$ varying with *t*. Grain size is important to several properties.

The sintered grain size distribution is self-similar, meaning the distribution shape is the same no matter the median grain size. Example sintered gain size distributions are plotted in Fig. 15 for a wide range of materials. The size scale is normalised to the median grain size. The symbols are experimental measures from a variety of sintered materials, while the solid line corresponds to a fit; *F(G)* is the cumulative fraction of grains with size of *G*, where $G_{50}$ is the median size (half the grains are larger and half are smaller),

$$F(G) = 1 - \exp\left[\beta\left(\frac{G}{G_{50}}\right)^M\right]$$

This is a Weibull distribution with $\beta = -ln2$ (or -0.6931), ensuring *F(G)* = 0.5 at the median grain size when $G = G_{50}$. The exponent *M* reflects the distribution dispersion and is usually near 3.

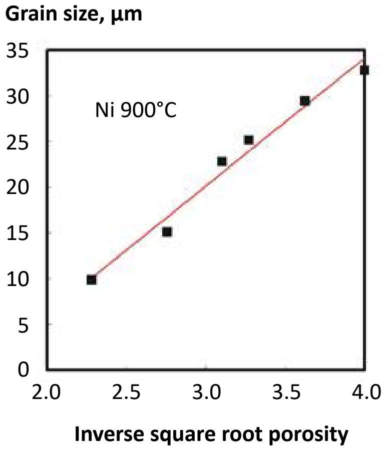


*Fig. 16 Data for sintered nickel showing mean grain size versus the inverse square-root of the fractional porosity. Such behaviour is characteristic of sintering, implying that if the starting grain size and porosity are known, then the grain size evolution is simply a function of the sintered porosity (density)*

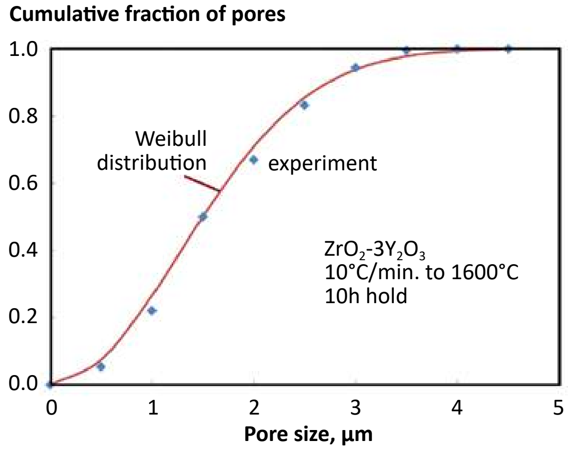


*Fig. 17 A demonstration of how the cumulative pore size distribution conforms to a Weibull distribution using data from yttria doped zirconia sintered at 1600°C*

Initially, grain growth is slowed by pores since vapour transport is relatively slow (evaporation and condensation) so grain boundaries encounter a drag force from the pores. As a result, a relation emerges between sintered median grain size $G_{50}$ and fractional density *f*,

$$G_{50} = \frac{G_O\, \theta}{\sqrt{1-f}}$$

Again $G_O$ is the initial grain size (effectively the particle size) and $\theta$ is typically near 0.6. This relation is invalid when the sintered material reaches full density because grain growth continues without a change in porosity. Fig. 16 plots data from 4.3 µm nickel powder sintered at 900°C to reach a final density of 93% to show agreement with this equation.

Because sintering results in a self-similar microstructure we find the pore size *d* is a function of fractional porosity $\varepsilon$ and grain size *G* as follows:

$$d = G\left[\frac{\varepsilon}{6}\right]^{1/3}$$

Grain growth leads to a pore size increase while porosity and the number of pores decline.

Pores and grains are coupled to one another during sintering; thus, the pore size also conforms to a Weibull distribution. The cumulative fraction of pores *F(d)* larger than size *d* depends on the median pore size $d_{50}$ and an exponent *M*. The corresponding distribution is expressed as,

$$F(d) = 1 - exp\left(\beta\left(\frac{d}{d_{50}}\right)^M\right)$$

Again $\beta$ equals -0.6931. Fig. 17 plots cumulative pore size distribution data for sintered zirconia according to this relation. The solid line is the fit to the pore size data using *M* = 2. The coupling of pores to grain boundaries causes the pore size distribution to follow the same trajectory as the grain size distribution.

Thus, during sintering the microstructure evolves, where the median grain size enlarges, the number of grains decreases, porosity declines, but pores coalesce and enlarge. The microstructure is self-similar, meaning the distributions in grain size, grain shape, and pore size generally track the same characteristics independent of the time-temperature, material, and processing factors.

## Effects of key sintering parameters

Most applications for sintered metals are structural components requiring attention to mechanical properties. Sintered surgical stainless steel illustrates the key parameters and their impact on properties. The common alloy is 17-4 PH, formally designated AISI 630. It is a precipitation hardened martensitic stainless steel that gives a good combination of strength and corrosion resistance [16-19].

Pre-alloyed 17-4 PH powders are available from 0.2 to 100 µm sizes, with 10 to 20 µm being most popular. Usually the particles are rounded or spherical to enable good packing to about 60% green density. For a typical 15 µm powder, a hold near 600°C during heating ensures binder removal. Sintering shrinkage starts about 900°C, so another hold near that temperature is appropriate to remove oxides while pores are open for evaporation. Hydrogen is able to penetrate pores from the surface, forming steam that egresses out of the body. Long hold times at the peak sintering temperature are not productive, since most densification occurs during heating. For example, at 1320°C the peak density is achieved within 10 min. Higher sintering temperatures

  

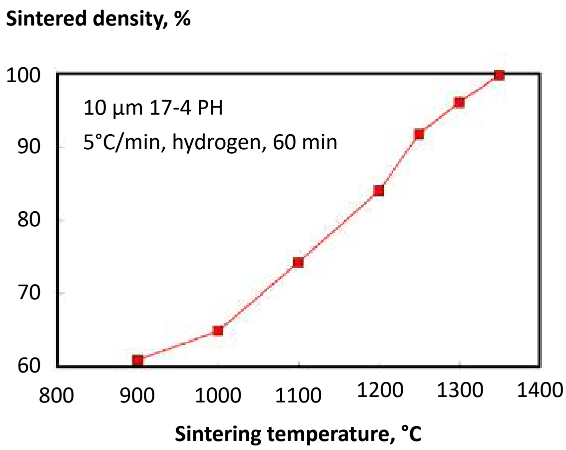


*Fig. 18 Plot of sintered density versus peak temperature for 10 µm 17-4 PH stainless steel*

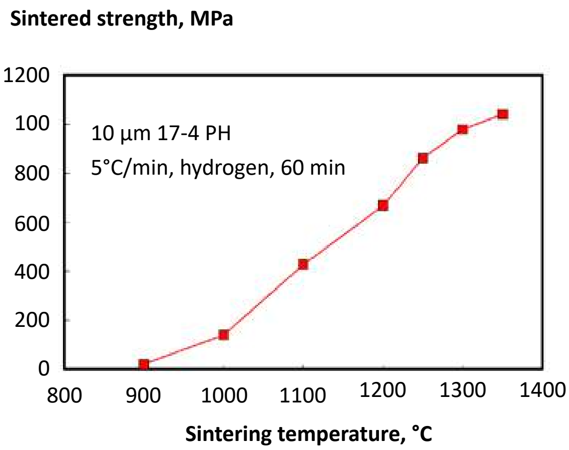


*Fig. 19 Sintered tensile strength for 17-4 PH stainless steel heated at 5°C/min. with a 60 min. hold at various peak temperatures*

induce grain growth and evaporative loss of chromium and copper, compromising corrosion resistance and strength. However, heat transfer in the sintering furnace takes several minutes, so a hold is needed to obtain uniform shrinkage throughout the furnace load. The high thermal conductivity of hydrogen helps ensure uniform heating.

Strength increases with sintered density, so understanding the conditions for reaching at least 95% density is a key concern. Typical data for sintered density versus temperature are shown in Fig. 18 for a 10 µm powder (heated at 5°C/min. to temperature with 60 min. soak) [18]. In turn, sintered strength increases, as shown in Fig. 19. These results rely on hydrogen sintering; however, production atmospheres vary between operations and include vacuum, hydrogen, partial pressure hydrogen, argon, partial pressure argon, argon-hydrogen, and nitrogen-hydrogen. Argon is insoluble, so it inhibits densification once pores close, resulting in lower sintered density and properties. Nitrogen forms chromium nitrides, resulting in loss of corrosion resistance. Thus, high mechanical properties come from hydrogen or vacuum sintering, giving 99% density and heat treated hardness of 42 HRC, with 1317 MPa tensile strength and 10% elongation (1172 MPa yield strength) [16].

Graphite vacuum furnaces are successful for sintering 17-4 PH. Graphite reacts with residual oxygen to create a low partial pressure of carbon monoxide. Chromium oxide is reduced by carbon monoxide when the CO partial pressure is maintained at a low level, below about 100 ppm at temperatures over 1100°C. A similar principle operates in argon sintering in a graphite furnace, but the argon remains in the pores to inhibit final densification. For this reason, a low partial pressure of argon is an option to suppress evaporation with only a minor impediment to final densification [4].

As with other ferrous alloys, additives are effective in reducing the sintering temperature. Boron added as nickel boride allows sintering to full density at 1260–1280°C. After heat treatment to 52 HRC the tensile strength is 1400 MPa with 7% fracture elongation [17].

Sintered dimension uniformity is a concern, especially with large shrinkages. Dimensional variation arises from: anisotropic pore shapes in the green body, powder segregation in the forming process, thermal gradients in the furnace, gravity (especially for larger components), sticking or friction with the substrate, and mass variations between components. As an example, consider rapid heating.

*"Dimensional variation arises from: anisotropic pore shapes in the green body, powder segregation in the forming process, thermal gradients in the furnace, gravity (especially for larger components), sticking or friction with the substrate, and mass variations between components."*

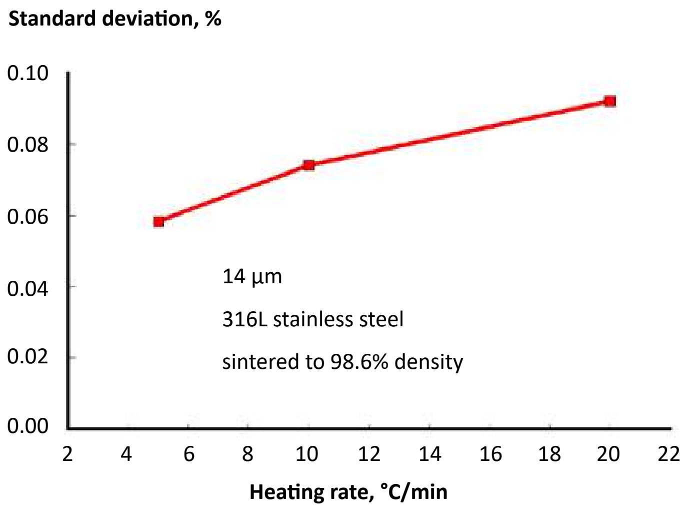


*Fig. 20 The standard deviation in component length (100 mm green size) for 14 µm stainless steel powder sintered to 98.6% density by heating to 1385°C at various heating rates [14]*

Heat transfer leads to temperature gradients in the furnace and in the component. The furnace centre is cooler than the edge, resulting in gradients that induce different dimensions depending on position in the furnace. Further, dimensional variation increased with heating rate as illustrated in Fig. 20 [14]. These data are for a 100 mm starting dimension formed using 14 µm 316L powder, sintered at 1385°C. Likewise, component mass variation, as often occurs in the forming step, is a precursor to differences in sintered dimensions between components [2,18].

Dimensional uniformity requires uniform green bodies and repeatable sintering cycles. Slow heating, uniform temperature, and sufficient hold time to thoroughly reach temperature are key to reduced dimensional variation. However, those measures cannot correct for variations introduced in the forming step.

This article hints at the underlying science explanation for sintering. At the atom scale the atomic motion events are random, but the slight bias provided by interface energy results in a progressive elimination of first surface area and later grain boundary area. Component densification is a by-product of this energy reduction. At the component level, shrinkage occurs. Non-uniform shrinkage and dimensional variation is the by-product of nonuniform green body and gradients introduced during sintering. Improved dimensional control requires attention to several factors besides the time-temperature cycle. Indeed, sintering is often just the messenger about variations occurring prior to sintering.

*"Improved dimensional control requires attention to several factors besides the time-temperature cycle. Indeed, sintering is often just the messenger about variations occurring prior to sintering."*

## Conclusions

Sintering is a thermal process applied to solid particles to bond, strengthen, and possibly densify the particles. The events responsible for sintering take place at the atomic scale. Some liquid is often formed during a sintering cycle, but liquid phase contents are kept to a minimum, under 15 vol.%. Thus, sintering is different from melting such as occurs with Electron Beam or Laser Powder Bed Fusion-based Additive Manufacturing. Liquid phase sintering is similar to brazing the particles together, where the solidified liquid glues the solid grains together into a coherent and strong composite.

Sintering occurs at high temperatures where atomic motion is active and the material is soft. At high temperatures, surface energies are sufficient to induce bonding by surface diffusion. Subsequently, densification occurs by grain boundary diffusion. A high green density increases the number of bonds per particle to increase the attractive force for better sintering. Smaller particles have a higher curvature that determines the capillary force known as the sintering stress. The sintering stress acts to pull the particles together. With small particles the diffusion distances are shorter, so they naturally sinter faster. Temperature is an important control parameter, and for most materials, active sintering is observed close to the melting range. Long hold times at the sintering temperature are not useful and extended holds result in over-sintering. While densification ends when porosity is eliminated, grain growth continues and even accelerates as porosity is eliminated. Thus, peak sintered properties are often found at less than full density while grain size is small. Note that additives are common in sintered materials, to either impede grain growth or improve densification.

Pore behaviour is an anomalous part of sintering. As porosity declines, the average pore size increases, but the number of pores decreases. Both pore size and grain size take on self-similar Weibull distributions. The role of atmosphere in sintering is involved;

  

active atmospheres accelerate sintering and help attain high final densities. On the other hand, inert gases become trapped in the pores to retard final stage densification. Often, vacuum sintering with a partial pressure (hydrogen or argon) provides a good balance between the several factors of heat transfer, suppression of evaporation and oxide reduction.

Structural components dominate the applications for sintered metals and electronic components dominate the applications for sintered ceramics. Both mechanical and electrical properties are quite sensitive to residual porosity, so high sintered densities are mandatory. Dimensional control, reflecting an ability to replicate final size with a small variation, is a major challenge in sintering. Although dimensional scatter is often assigned to the sintering step, in reality the source of scatter arises from poor control of the incoming powder or loose control of the shaping step – effectively sintering is the messenger, but not the cause.

## Author

Professor Rand German is the most highly-cited researcher in sintering. He consults with firms in both Additive Manufacturing and Powder Injection Moulding, and serves as consulting editor for *Powder Injection Moulding International*. At San Diego State University, his current experiments are literally out of this world, involving microgravity liquid phase sintering on the International Space Station.

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# Metal Binder Jetting and FFF: Considerations when planning a debinding and sintering facility for volume production

A new generation of Binder Jetting machines now promises to deliver high volumes of parts at previously unimaginable speeds. *Metal AM*'s Nick Williams interviews Stefan Joens and the team at Elnik Systems LLC, a leading provider of industrial debinding and sintering furnaces, about the reality of entering this field and the technologies and equipment that are needed for the often underestimated processes of debinding and sintering.

Batch debinding and sintering furnaces manufactured by Elnik Systems, based in Cedar Grove, New Jersey, USA, have over a period of nearly twenty-five years become a common sight in Metal Injection Moulding (MIM) facilities around the world. The company's leading position in the MIM industry will, it hopes, also put it in a strong position to deliver the industrial scale debinding and sintering equipment that is needed to process parts produced using metal Binder Jetting (BJT) and Fused Filament Fabrication (FFF). These technologies are rapidly gaining traction as a 'second wave' in the development of metal AM for industrial applications.

Elnik's involvement in MIM dates back to the early 1990s, when BASF launched its Catamold® feedstock system. It was shortly after this that the company commenced the development of a 'one-step' debind and sinter partial pressure furnace specifically to meet the needs of the growing MIM industry. The company's MIM 3000 furnace, launched in 1994, provided a cost-effective alternative to the two-furnace technology commonly used at that time.

Elnik states that its system was the first all refractory metal furnace with partial pressure operation from 10 mbar to 800 mbar for hydrogen, nitrogen or argon, with laminar gas flow via an internal retort to remove the second stage binder. This shortened processing time from the thirty plus hours which was typical at the time, to around twenty hours.

Over the years there has been a process of continuous improvement in the company's products, focusing in particular on laminar gas flow, temperature uniformity and accuracy through its proprietary Accu-Temp system, process control automation, hot zone and retort strength, and durability. An automatic cleaning process for the binder traps and the

*Fig. 1 Elnik Systems furnaces installed at DSH Technologies, the wholly owned subsidiary of Elnik Systems that offers process development, consulting and toll debinding and sintering services*

  

Fig. 2 The Elnik/DSH team, from left to right: Bruce Dionne (Vice President of Operations, Elnik Systems), Claus Joens (Founder and Chairman of the Board, Elnik Systems), Bryan Sherman (Project Manager and Chief Metallurgist, DSH Technologies) and Stefan Joens (President, Elnik Systems)

vacuum pump, which are the areas that see the heaviest flow of binder, have enhanced ease of use and enable the recording of all process parameters for quality and auditing requirements.

Today, more than 350 of the company's MIM-grade furnaces are installed worldwide, with the majority in North America and Europe. They range from 1 ft$^3$ (27 litres) up to 9 ft$^3$ (234 litres) in useable volume, meaning they can accommodate a wide range of production capacity.

The company has recently gone through some significant changes. In March this year, Stefan Joens took over at the helm as President as part of a strategic transition, ten years after he returned to the business that his father, Claus Joens, founded in 1969. Claus, as Chairman of the Board, continues to be involved in the business. At the same time, MIM industry veteran Bruce Dionne joined Elnik as Vice President of Operations. Dionne formerly served as Vice President & General Manager of US MIM producer Megamet Solid Metals – later Ruger Precision Metals, LLC – where he served as Director of Operations.

DSH Technologies, a wholly-owned subsidiary of Elnik Systems that offers process development, consulting and toll debinding and sintering services, also saw management changes with the appointment of Bryan Sherman, another experienced MIM professional, as Project Manager and Chief Metallurgist.

## There's no 'easy button' when sintering AM parts

Outside of the Metal Injection Moulding industry there is currently limited awareness of the complex realities of debinding and sintering metal components. Stefan Joens told *Metal AM* magazine, "We see a wide range of knowledge levels through our work with AM-related customers at DSH Technologies. Companies that are developing AM machines are generally more versed, as they have built teams that include metallurgists and material science personnel, and have access to furnaces, but even here there are still gaps. We make a strong effort to help from ground level and discuss the process steps related to debinding and sintering."

"Companies that want to adopt sinter-based metal AM technologies in-house and are completely new to the technology need to make sure they do their homework, or develop strong working relationships with leaders in this field. Debinding and sintering aren't black magic, but one needs to be open minded to learn a new technology and not assume there is an 'easy button'. This is where DSH Technologies has an impact, with its ability to provide support and education to customers looking to learn about the technology."

Even the largest of industrial companies can be surprised when they discover that, in order to debind and sinter parts created on high-volume commercial binder jet AM machines that might retail for around $400,000, they may have to spend double that on a full-size sintering furnace that meets their needs.

Commenting on how potential customers respond to this, Joens stated, "Whilst polymer AM has become hugely popular and widespread thanks to its accessibility and ease of use, with sinter-based metal AM there is certainly a misunderstanding of total equipment needs and upfront costs. Debinding and sintering equipment is as vital to the process as the AM machine itself and needs to be included in the evaluations for capital equipment costs. While we produce a wide range of furnace sizes at varying costs to meet any production need, often at much less than double the cost of a printer, additional facility expenses such as process gas supply, air, power, water cooling systems, etc., often go unrealised in an analysis. The path to helping a customer understand the total equipment cost for Binder Jetting and FFF starts with education."

*Fig. 3 This view of the DSH facility illustrates how additional facilities required to run a furnace, such as process gas supply, air, power, water cooling systems, etc., involve expenses that can often go unrealised in an analysis*

## Understanding furnace capacity requirements

Key to efficient metal binder jet and FFF production is understanding production volumes, given the need to fill an expensive furnace. Commenting on how many 'production-scale' binder jet AM machines might be required in order to fully utilise an industrial MIM/AM furnace, Joens stated, "To understand the size of furnace that you require, a number of factors need to be considered – the build box size of the AM machine, the size of the parts you are making, and the number of parts that you are looking to produce. One cannot just look at the build box volume and assume a furnace needs the exact same process volume. The type of parts one plans to fabricate, the intended positioning of these parts on process trays and the total part size and mass all have an impact on furnace volume requirements. Ideally, to optimise equipment utilisation, the furnace should be planned to operate once per day. From here, one can calculate the output of an AM system and match it to the stacked volume in the furnace. In some cases, depending upon the parameters, it may take more than one AM system to achieve this optimisation."

One often unspoken factor that increases turnaround time from the AM machine to the furnace is the post-processing stage after a build has completed. Depowdering and then staging the green parts on sinter trays are all aspects of the process that are not yet particularly efficient. The time needed to complete these steps needs to be analysed when understanding throughput of an AM system into a furnace.

## The furnace supply chain: A bottleneck ahead?

Metal AM technology development and adoption is happening at remarkable speed. Currently, this is especially true of sinter-based AM technologies. The promise of the imminent availability of new high-volume binder jet systems from HP and Desktop Metal is driving technology awareness and lifting the fortunes of longer established suppliers, such as ExOne and Digital Metal, who are themselves making strides towards the full 'industrialisation' of their binder jet technologies.

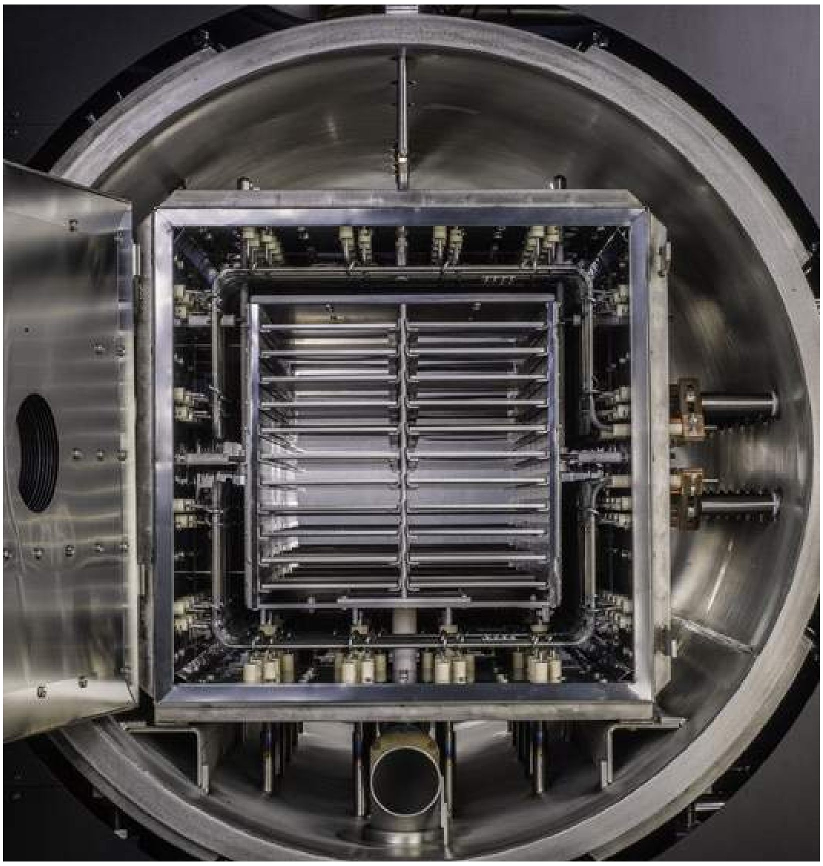

*Fig. 4 A view of the molybdenum hot zone in a MIM 3045 series furnace manufactured by Elnik Systems*

Given the formidable combined sales and marketing capacity of the above companies, one can anticipate that a significant number of binder jet AM machine sales will soon happen, in a relatively short space of time. Can the MIM furnace supply chain keep up? After all, this is an industry made up in large part of small- to medium-sized businesses who are more used to dealing with a predictable pattern of orders, booked with 'reasonable' lead times. So, could you buy a large, industrial-grade vacuum debind and sintering furnace or two 'off the shelf' for delivery next month? Probably not.

Joens stated, "There is a lot of speculation as to what the market will demand in terms of production capacity, in particular from the metal binder jet industry. There is still volatility and manoeuvring among the leading players and it is hard to tell how things will evolve. Since the successful growth of the binder jet industry is dependent on both the availability of Binder Jetting machines and debinding/sintering equipment, it will take communication and collaboration to successfully meet upcoming market demands."

"With collaborative strategies and a lean manufacturing approach to standardised equipment packages, there is no reason that the demands of the industry cannot be met in a timely fashion. Without this collaborative approach, and without visibility of volume potential, customers will be left to source AM systems and furnaces independently, ultimately leading to longer lead times and potential bottlenecks in production. This same philosophy needs to be applied in relation to ancillary equipment manufacturers such as gas generators, water cooling systems, powder suppliers, etc."

Commenting on whether the anticipated rise in sinter-based AM will lead to a reduction in the cost of such sintering furnaces, Joens stated, "A higher demand for equipment has the potential to drive equipment pricing down due to efficiencies in the build process, but this in itself is not the path to price reduction. For true efficiency gains, there needs to be standardisation and collaboration with AM equipment manufacturers on delivery schedules and expectations. Efficiencies can be gained in times of high demand and we are working toward being able to offer these efficiencies and gains to our customers via many ways, including lean manufacturing and leveraging volume purchases of products and fabricated parts."

## Planning a metal Binder Jetting production line

A prospective investor in a production line for high-volume metal Binder Jetting needs to fully understand the facility infrastructure required when installing an industrial vacuum debinding and sintering furnace. In many ways such a facility is the mirror of a MIM operation, except that the moulding machines are replaced by the Binder Jetting machines. Of course, you don't need the tool shop, but instead you do need post-processing facilities. As a guide, in order to start up a MIM manufacturing facility, the rule of thumb is a bare minimum of $2 million investment capital for all the required equipment, plus at least a year's worth of working capital of another $1 to $1.5 million.

Joens suggests that any start-up company needs to consider the following facility shopping list, in addition to a furnace, when thinking of venturing down the path of beginning to make metal binder jet parts:

- AM machine/curing oven/ depowdering equipment
- Powder storage and management
- Primary debinding system (where applicable)
- Secondary stage debinding/ sintering furnace
- Water cooling system
- Gas generators, or bottle supply
- Extraction system

  

*Fig. 5 An Elnik 3045 series furnace ready for shipping to a customer*

- $H_2$ sensors (where applicable)
- Facility cooling and heating
- Power supply (200–800 amp service depending on equipment size)
- Mobile staging carts/worktables
- Quality control equipment
- Secondary processing equipment (where applicable)
- Relationships with heat treatment service providers

**Furnace uptime**

An industrial debinding and sintering furnace is subject to extreme and demanding daily production cycles, whilst at the same time needing to offer a high level of availability to avoid production delays. Commenting on the reality of furnace uptime, Joens explained, "Furnace uptime depends on the quality of what is being produced and how the end user runs and maintains the furnace. When reliable components, good manufacturing practice and a strong team come together it typically results in long lasting equipment. Of the many hundreds of furnaces that we have made for the MIM market, 97% are still in service today. The majority are running with 85–90% uptime, if not better."

**Power consumption**

Power consumption and cost, stated Joens, is related to equipment capability; a hydrogen all metal partial pressure furnace uses a lot more power than a graphite furnace running under nitrogen.

**Process trays**

Furnace process trays – the trays on which green parts are placed for loading into the furnace – have a varying lifetime depending on customer use. Extending the life of these items can be down to simple working practices – as an example, Elnik flips its trays after each process run to ensure they stay straight for a longer time. "Most customers get five to seven years of life out of molybdenum process trays, if not more, depending on the total load being processed repeatedly," stated Joens.

**Hot zones and retorts**

How often hot zones and retorts need to be replaced is again down to total production volumes, a company's maintenance regime, and sintering temperature. "The majority of our customers see five-to-seven years of life on these units. Some users find ways to need replacements after two years of processing. This is typically a result of not removing parts that have fallen onto the refractory metal, not performing burn out runs regularly, overloading furnace trays, consistently running loads that have a very high level of binder, and using parameters outside of the recommended limits. Conversely, some customers have had retorts and hot zones in their furnaces for more than ten years."

*Fig. 6 A selection of MIM parts showing the range of shapes and sizes that can be manufactured by the technology, typically to net shape. The smallest part here is a 316L stainless steel locking device for a spectacle frame hinge, weighing 0.028 g and produced in volumes of more than 4 million parts a year. The largest part is a 316L tripod base which weighs 260 g and is 65 mm high*

## Learning from the MIM industry

At the most basic level, metal Binder Jetting and FFF are simply MIM without the tooling. This means that anyone looking to get into this area of metal AM can relatively easily educate themselves on best practice, markets, materials and more from a very similar but far more mature industry.

A number of MIM companies are currently openly partnering with binder jet AM machine producers, bringing their crucial understanding of sintering to the table. Initially, it is logical that MIM companies will lead the adoption of metal Binder Jetting and FFF thanks to their existing debinding and sintering capacity. Joens commented, "As an AM equipment manufacturer, the MIM industry is a great place to start as the players know the debinding and sintering processes very well. They are proficient at equipment use and extremely knowledgeable about part staging, secondary operations, heat treatment and finishing processes. These technologies are also a great complement to the MIM industry as they expand the niche that the MIM industry already fills, but with the benefit of potentially thicker cross sections, larger parts and higher part complexity. Time will tell how these technologies will compete, but for now, they are great companions."

Joens believes that there are a number of critical lessons any AM part maker can learn from the MIM industry:

- Effective plant layout to ensure maximum efficiency of workflow and use of personnel
- Understanding the proper production flow of how parts will move throughout the production floor to ensure maximum uptime
- Setting up ancillary equipment needs for future expansion
- Proper facilities and equipment for secondary operations
- Building strong vendor relationships both pre- and post-part fabrication.
- Part handling techniques and strategies throughout the facility

"In addition to *PIM International*, the industry magazine, there are also some well-known books available on MIM process-related topics. The science of binder removal and sintering has been developed for many years – there is no reason to try and reinvent the wheel".

## AM design freedom versus gravity

Metal Binder Jetting and FFF come with the promise of great design freedom but, as with MIM, gravity can get in the way when it comes to sintering. As such, the design restrictions imposed by the sintering stage of the process need to be fully understood. Joens explained, "Design freedom is for sure the most exciting aspect of metal AM. We are seeing designs, sizes and cross sections that MIM could only dream of. With that, however, comes some of the challenges. What is the ultimate cross-sectional thickness possible? What is the largest mass possible? What ultimately are the repeatable expectations for shrinkage in the X, Y and Z dimensions? Are mechanical properties going to be repeatable? The list really goes on and on. Green density plays a big part in the achievable density of any part, be it metal or ceramic. Keeping this density above 60% by volume will assist with good sintered densities. Gravity is an additional factor. Unlike MIM and conventional 'press and sinter' Powder Metallurgy, there is no compression step in the Binder Jetting or FFF processes. This makes for inherent challenges when designing a part if the effects of shrinkage and distortion are not well understood. While these are a few of the topics that many of the equipment manufacturers are working to resolve, we are far from really understanding sinter-based AM's full potential and full limitations."

Joens added, "There are ways to provide structural supports or setters for sintering, but these can be expensive in high volume production. Some companies also offer an anti-sinter layer, but there are other viable ways to achieve similar results. These are all issues that we have helped companies understand through discussions with our team."

## Consulting on process and application development

When it comes to the sintering of metal powder parts, a specific debinding and sintering cycle is required in order to reach the required densities and properties. This cycle is influenced by a number of factors that include part size, the alloy used, wall thickness, the volume of parts loaded into the furnace, and the position and spacing of these parts on the furnace trays, etc. Variations in this cycle will impact on both dimensional repeatability and mechanical performance.

Commenting on how DSH works with clients to develop an application or a debinding and sintering cycle, Bryan Sherman stated, "We start by assessing a company's readiness and understanding of the technology. Our desire is not to just provide access to state-of-the-art equipment but to educate: we want to see our customers succeed! We then move to the science, evaluating the part the customer is looking to process and what materials they are using – both in terms of metal and binder. Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) curves give detailed insight into what is happening during each stage of the process. This, combined with previous processing experience and real-world production techniques, leads to robust processes that our customers can employ for the lifetime of a part's production. This, of course, also gives our customers more tools and experience to rely on in the future, making them better, more efficient parts producers."

It is important to understand the significant differences between AM production methods. Laser Powder Bed Fusion, for example, involves melting rather than sintering the powder. "When working with customers versed in other AM processes and production methods, it is critical to review the science behind sintering. Such an approach lays a solid foundation from which to understand a part's metallurgy and properties. This sets realistic expectations and leaves the customer better informed as to when and how to employ MIM and binder jet technology to get the most out of what the processes can provide."

Sherman also stressed that it is important to know if an application requires maximum mechanical properties or if it is non-stressed, allowing a more strategic approach to processing in order to maximise the cost/benefits for the end customer. "Understanding the differences in process and methodology to get to the end part allows for customers and clients to more readily find profitable opportunities".

*"It is important to know if an application requires maximum mechanical properties or if it is non-stressed, allowing a more strategic approach to processing in order to maximise the cost/benefits for the end customer..."*

## Metal FFF for prototyping and low-volume part production

Back in 2013, when Bruce Dionne was running Megamet Solid Metals, I visited his operation in my capacity as editor of *PIM International*. One evening the conversation led to a discussion of the viability of extruding MIM feedstock to make AM parts. Whilst it was more of a 'blue sky' conversation than a serious proposition, the technology is now very much a reality with Desktop Metal's Studio System and Markforged's Metal X system, among others, and the arrival of BASF's Ultrafuse filament.

Commenting on how MIM feedstock-based AM technologies have taken off, Dionne stated, "Nick, I really love that you remember that discussion! I always knew that the metal FFF technology would evolve and eventually become a reality.

When I served as President of the Metal Injection Molding Association [MIMA] I challenged the industry to come up with ways to print MIM feedstocks. At the time my motivation was to reduce time to market by minimising the design cycle and using the printed parts for prototype assemblies, and also to figure out sintering cycles, furnace layouts and setter designs all in advance of the injection moulding tool being delivered. What has evolved is way more exciting and put the same ability in the hands of anyone with an FFF machine."

Dionne stated that one of the drawbacks of current FFF technology is that, for the most part, we are seeing single-head builds, meaning only one stream of material is being extruded at a time. "In this case, it is a great process for one off or very low volumes of parts, prototypes and experimentation. However, even this technology is evolving as we are starting to see multi-station machines. Additionally, the technology allows for a truly 100% enclosed internal honeycomb structure, something that is impossible with Binder Jetting without trapping loose powder. As the technology evolves, we will continue to see new and exciting applications."

**Comparing compact 'workshop' furnaces with their industrial counterparts**

Whilst office friendly FFF-based metal AM systems are growing in popularity, thanks in part to their cost and limited demand on infrastructure, there are, significant differences in the performance of an industrial vacuum furnace, which can work with various atmospheres and different levels of vacuum, compared to a compact office or workshop-based furnace. Dionne stated, "Office-based metal FFF systems are proving to be an attractive proposition for those making a first step into metal AM, or for those with limited volume demands. The purchaser wants something similar to the FFF plastic process that can be easily set up and operated in an office, light industrial area or even a garage at home. This can, however, be problematic from the sintering standpoint. The infrastructure needed to support a partial pressure atmosphere of hydrogen in a vacuum furnace – the accepted process for the sintering of MIM stainless steels – is simply unviable for office or at home use."

"So, while some AM machine producers are offering an office-friendly sintering solution, it must be recognised that they are limited in their ability to provide results similar to or approaching industrial equipment. A part may look good, but there will inevitably be a world of difference when it comes to mechanical properties. For the production of fixtures, fittings and non-functioning samples, this may be fine, but for stressed end-use components, careful consideration is needed," Dionne concluded.

## Looking ahead

For manufacturers of specialist MIM-grade furnaces such as Elnik Systems, the growth of 'MIM-like' AM processes presents a range of exciting opportunities. Beyond the goal of selling furnaces to this new sector, by sharing their experience of debinding and sintering, and thereby avoiding the need to 'reinvent the wheel', they are in a strong position to positively impact the industrialisation of Binder Jetting and FFF processes.

For companies such as Elnik, which through its DSH operation can also offer toll debind and sintering services, further opportunities exist in supporting companies whose projects do not justify the investment in a furnace, or whose facilities do not have the necessary infrastructure. In 2018, Elnik opened a second toll debinding and sintering facility in Waldachtal, Germany, that expanded its capabilities in this area. A further expansion of these services is, states Stefan Joens, a distinct possibility.

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# Velo3D: How a 'support-free' Laser Powder Bed Fusion process could remove roadblocks to serial Additive Manufacturing

With its Sapphire machine and Flow build preparation software capable of highly-controlled, virtually support-free Additive Manufacturing, Velo3D is pushing the limits of what is possible with Laser Powder Bed Fusion (L-PBF). Since launching its first machine in 2018, the California-based company has seen success with a range of highly complex parts which would challenge even the most experienced AM engineer. In this article, Zach Murphree, Velo3D's Vice President of Technical Partnerships, explains the key factors which set the company's process apart from the wider AM market.

There is a misconception in the Additive Manufacturing world that Zach Murphree, Vice President of Technical Partnerships at Velo3D, is on a mission to clear up. The scaffold-like structures that everyone in the industry refers to as 'supports' are in reality, he says, anchors. They are used to keep the layers of fused metal powder from peeling up and away from the previously-built layers or build plate below, rather than to support the layers above and prevent their collapse.

"The term 'support' is really a holdover from plastic printing," he told *Metal AM* magazine. "Here, you need support structures because you're fighting gravity, and the part would distort or even collapse without them. With L-PBF, however, you're fighting the metal's tendency to curl upwards, especially at angles of 45° or less. If you don't anchor these surfaces down, your recoater blade will eventually smash into them, damaging the workpiece, the blade, and possibly even the machine."

This 'taco shell effect' is not unlike what happens when two sheets of unrestrained metal are butt-welded together. In AM, however, any unrestrained metal can lead to build failures, hence the need for temporary structures that later require costly, labour-intensive machining and grinding to remove. And it is this secondary post-processing – more than any other manufacturing constraint


*Fig. 1 Velo3D's Sapphire Additive Manufacturing system*

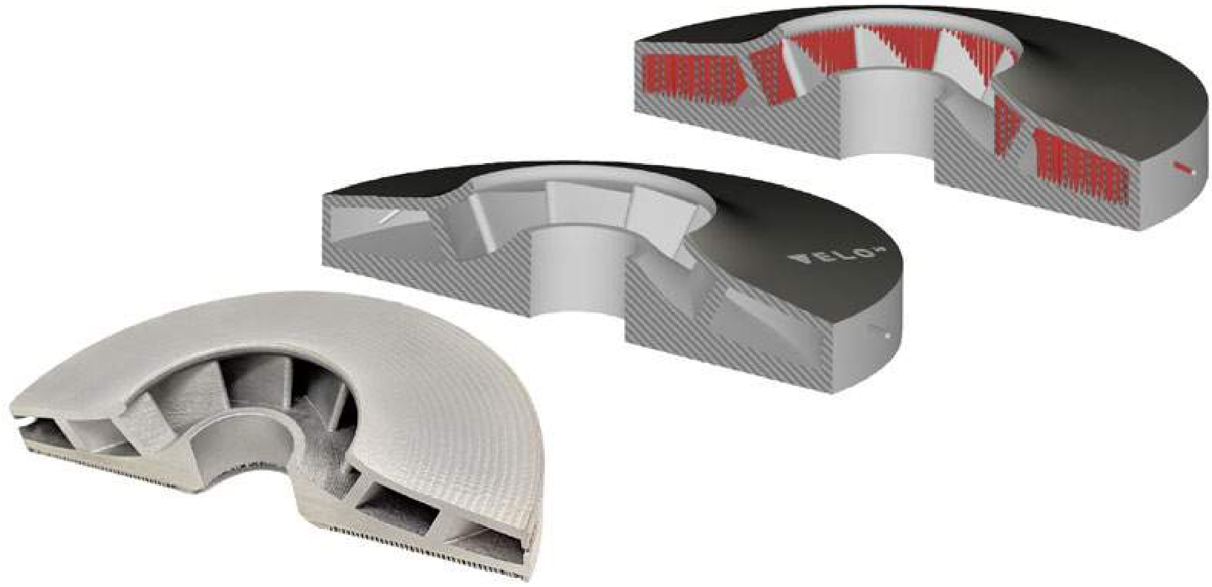


*Fig. 2 An impeller designed with standard supports (top left) and reduced supports (middle) for production on Velo3D's Sapphire Additive Manufacturing system*

– that has been the thorn in metal powder bed AM's side since its very inception.

Whether they are supports or anchors, Murphree and his colleagues at Velo3D aim to reduce the reliance on them in metal AM. Doing so will, it is expected, allow manufacturers to skip the lion's share of post-processing; they will no longer need to use valuable time 'taking down the scaffolding' post-build. Build plates could also, the company believes, become a thing of the past, if parts were to be made free to 'float' within a fully-utilised build chamber. Most importantly, reducing support structures could allow the realisation of the much-vaunted design freedom associated with AM, which has until now come with many caveats. Geometric constraints might be largely eliminated, as well as worries over warping, part orientation, and wasted support material.

*"... reducing support structures could allow the realisation of the much-vaunted design freedom associated with AM, which has until now come with many caveats."*

## Reaching the goal of support-free AM

Velo3D isn't quite there yet, stated Murphree, but it is close. The company's Sapphire AM system can currently build support-free surfaces at angles lower than 10° (often horizontally), as well as structures with large inner diameters that would normally need to be tear-drop shaped to maintain their structural integrity using conventional L-PBF systems (Fig. 2). In addition, Velo3D states that it is often able to build even very complex workpieces 'right first time', something that few in the Additive Manufacturing industry can claim.

While Velo3D's process has some unique features, it, like almost all powder bed AM processes, relies on a bed of finely-atomised metal powder; a pair of lasers; and a gas-filled, oxygen-free chamber. As in the majority of AM processes, parts are built layer by layer, from the bottom up, with a recoater spreading fresh material across the burgeoning workpiece at every step.

Explaining what is different about Velo3D, Murphree stated, "For the most part, our technology is based on a much higher level of process control. Our company founder and several others here have extensive experience in the semiconductor industry, and they have leveraged that experience to develop a far more capable AM machine, one that no others can currently match in terms of beam management, integrated metrology, machine construction, our non-contact recoater design and, especially, the build software. That's key."

## Infinite control over finite elements

The processing algorithms within Velo3D's Flow software, Murphree noted, are an order of magnitude more advanced than those used by most AM systems. This software is able to accurately simulate the build in advance; analysing, predicting, and then compensating for potential deformation long before manufacturing begins (Fig. 3). In addition, rather than processing one layer at a time, Flow looks at 'several tens of layers' both above and below the current one, detecting part geometry on-the-fly and applying feature-specific routines wherever needed to further optimise the build strategy.

This is somewhat similar to Finite Element Analysis (FEA) software, Murphree stated, which uses implicit modelling to analyse an entire workpiece at once. "If you're going to build the correct geometry, you need to consider the complete geometry, and focus your efforts on applying the right processes in this larger context," he says. "This is a big chunk of our 'first part, good part' success ratio."

The computing power needed to achieve this FEA-like functionality would likely have been cost-prohibitive as little as five years ago, but thanks to parallel computing and the use of very efficient software code, Velo3D can solve 'huge slabs' of the model simultaneously. This means analysing thermal boundaries all around the melt pool, then applying an optimised mix of laser power, beam positioning, and spot size to fuse the metal without negatively impacting the surrounding area.

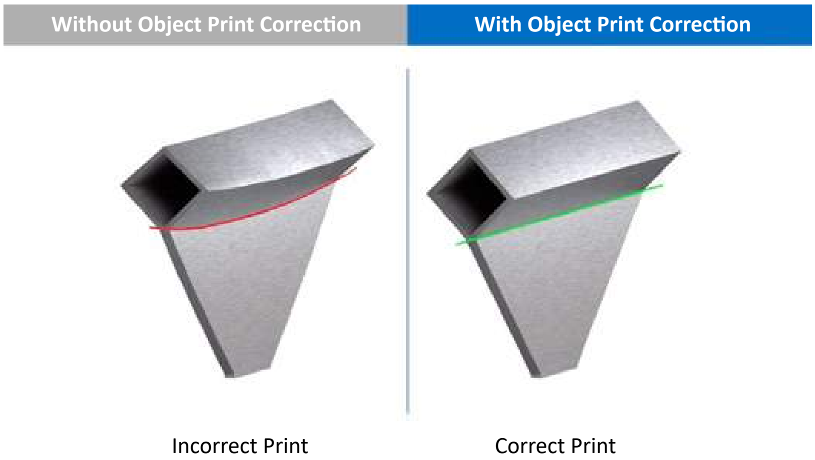


*Fig. 3 Object Print Correction (OPC) within Velo3D's Flow software corrects build deformation issues before the build begins. The simulation engine applies counter-deformation to the part to ensure that the first build is a good build*

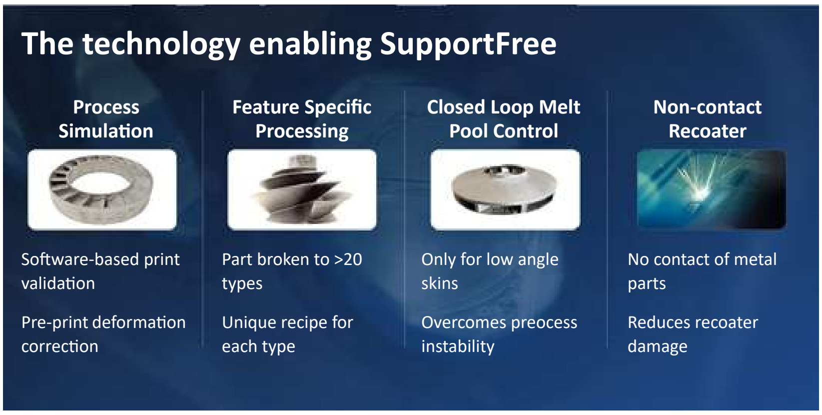


*Fig. 4 This is the foundation to Velo3D's SupportFree technology, which is a combination of simulation from Flow, in-process metrology, and its non-contact recoater*

## Greater accuracy through the elimination of process variables

Even the best build software doesn't guarantee that the laser will go where you tell it to. Build accuracy may be affected by alignment issues, beam quality and atmospheric conditions within the build chamber. Murphree states that Velo3D has addressed each of these factors in its technology. Using the same attention to detail found in semiconductor fabrication, his team believes that it has reduced or eliminated the process variables common to L-PBF systems (Fig. 4).

This last factor highlights another important difference between Velo3D's system and others, he says. "For example, we have the ability to align our lasers to within 50 µm or less of one another at every single layer. The result is far greater part quality, with no visible overlap or witness marks where the lasers have traded-off duties. We have a non-contact recoater and enhanced gas flow, both of which serve to improve process stability. We also control the oxygen levels to less than 10 ppm, and often fall below 1 ppm – roughly 1000 times better than the industry's standard. We've found that an oxygen level of even 50 ppm affects the surface tension on the melt pool, and has a dramatic impact on its behaviour."

## Monitoring and control of spot size

Murphree explained that control of spot size in laser powder bed systems is crucial, explaining that even a 10% increase in the diameter of the spot can decrease the amount of applied power at the melt pool exponentially.

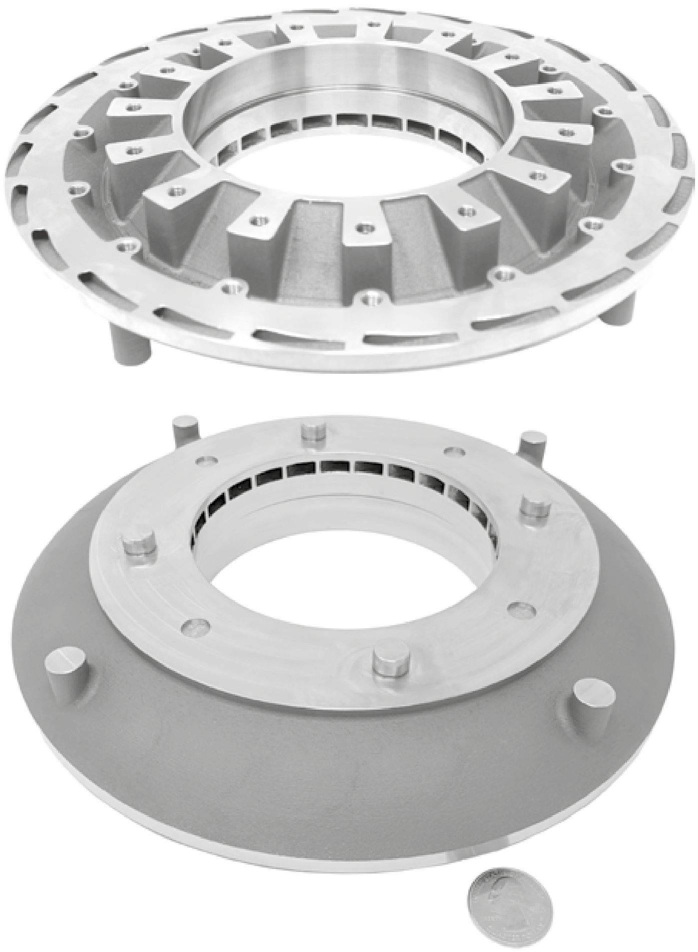

Fig. 5 The as-printed KW Micropower diffuser housing, top and bottom views

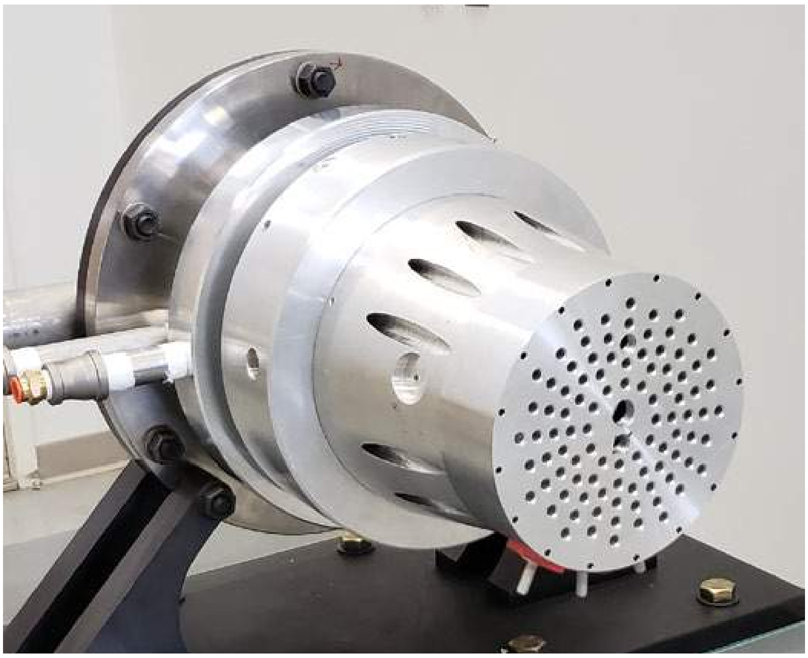

Fig. 6 KW Micropower's generator is small enough to fit in a suitcase but promises to generate 30 kW of electrical power

"Left uncompensated, this can mean 98% material density instead of the 99.9%, fully-dense metals expected by the industry. This might not sound like much, but it's actually a huge difference, especially for those producing aerospace and power generation components. The metal's mechanical properties can deteriorate markedly as well, with unacceptable levels of porosity as well as lack of fusion between layers, a failure mode that's quite difficult to detect."

Velo3D manages these variables and more, he says, through gas-tight, thermally-stable machine architecture and continuous process monitoring via a host of onboard sensors. Aside from the basics such as chamber temperatures and oxygen levels, data on thermal lensing, scan-field distortion, and other indicators of optical health – what he calls the heart of any AM system – are also collected, providing complete in-process history of all part builds as well as an opportunity to further refine system performance. "That's been an important goal for us from the very beginning and to learn from all this data," stated Murphree.

## Case study: KW Micropower Inc.

Recently, Velo3D collaborated with Florida's KW Micropower Inc. to develop a unique diffuser housing for production by metal Additive Manufacturing (Figs. 5, 6). Enrique Enriquez, founder and President of the business, stated, "I'd talked to every AM company I could find and they all told me the same thing: we can't build your part. Fortunately, at the last IMTS show, a friend suggested I stop by the Velo3D booth – and that changed everything."

Enrique's diffuser housing is a Ti6Al4V disk measuring approximately 25 cm in diameter by 10 cm high, and contains a complex series of internal, low-angle passageways for gas flow. It is a critical component in a miniature power generator that he's been working on for the past four years, and he will soon be exploring serial production of the device.

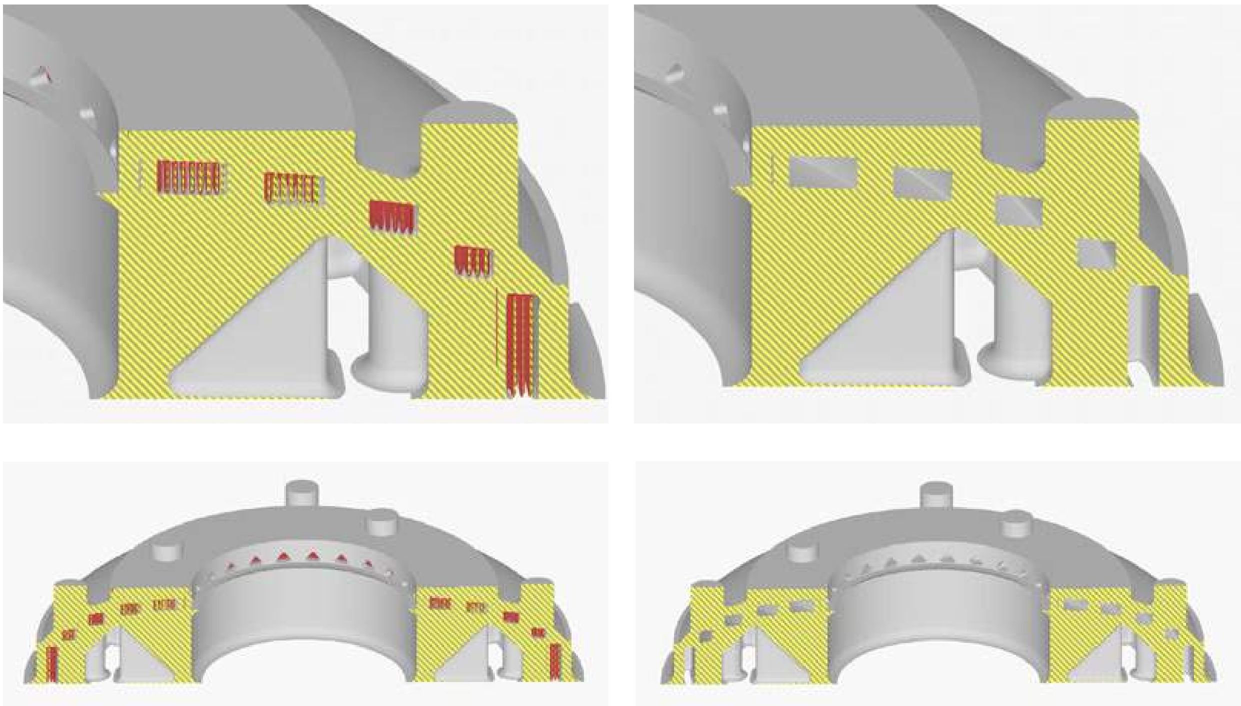

*Fig. 7 Cross section overview and details showing support structures within the channels (left) if the diffuser housing were to be printed by existing L-PBF platforms, versus how the Velo3D Sapphire system can print the channels support-free. Machining the support structures in this specific part design would be incredibly complex.*

When finding a manufacturer who could produce the part, the hurdle was the internal channels and the fact that there was no way to remove the hundreds of tiny supports required by other metal powder bed printers (Fig. 7). As stated earlier, Velo3D's process is nearly support-free. In addition, due to the Sapphire's high level of process control, Murphree had few concerns over building the part in titanium, a difficult-to-process and reactive alloy. He was also able to use the company's Flow software to improve Enriquez's original design, reducing its weight by 37% while improving its flow characteristics. According to Murphree, the part was built correctly on the first attempt.

As with almost all additively manufactured parts, the component still required some post-processing following the build process. Murphree contacted Jim Thompson, Director of Operations for Keselowski Advanced Manufacturing (KAM) in Statesville, North Carolina, USA, to inquire about finish machining several of the diffuser housing's close-tolerance features. KAM has extensive experience in the fields of both additive and subtractive manufacturing and is quite familiar with Ti6Al4V.

The diffuser housing was machined on the KAM shop's Mazak I300S 7-axis machining centre, allowing Thompson to complete the part in one operation. KAM also built an aluminium replica of the part on one of its existing metal powder bed AM systems to test the impact of Velo3D's support-free process on its post-processing requirements (Fig. 8). Following testing, Thompson stated, "With the Velo3D part, the internal channels were clean – no supports, just like Zach told me. In contrast, the part printed on our legacy equipment, as we anticipated, required us to spend approximately forty hours on support removal and clean-up of the surfaces afterwards. There was none of that with the Velo3D part, nor were there any of

*"When finding a manufacturer who could produce the part, the hurdle was the internal channels and the fact that there was no way to remove the hundreds of tiny supports required by other metal powder bed printers."*


*Fig. 8 Top left, Brad Keselowski, Founder & CEO of KAM, and Michael Mullen, KAM Engineering Manager, discuss the differences between two builds of the KW MicroPower diffuser before machining. Bottom left, qualifying the diffuser's datum surface on MAZAK i300 Integrex Mill/Turn machining centre. Right: CNC machinist Colby Burgin checks the diffuser dimensions for best fit of machining to built part, ensuring proper alignment of the part envelope with the machine work coordinate system*

the usual problems with supports breaking loose and getting caught between the cutter and workpiece, possibly damaging both."

KAM's President, John Murray, added another key point: "Because the Sapphire is inherently more accurate than competing technologies, parts come out of the machine closer to net shape. This means you'll need less machining time to finish them. And as anyone who owns a metal printer knows, the raw material itself is not inexpensive. Comparing the Velo3D part with the one that we printed, I figure you could save an additional 10–30% on material costs, plus the additional build time necessary to lay down all that metal, only to machine it away later."

## Conclusion

Following the successful build and finishing of his part, a pleased Enrique Enriquez stated, "The results have been totally amazing. We've logged thousands of test hours with the generator, and hope to start sending prototypes out next year for evaluation. A device this small is very sensitive to what they call parasitic losses due to friction and imbalance; in order to compensate for that, you need to find ways of making everything more efficient. That's what Velo3D brought to the table. Because of their capabilities, we're now able to do some amazing things that were never expected out of a generator this small. Their technology has opened up a world of opportunities for me."

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# New horizons for Additive Manufacturing in the oil, gas and maritime industries

The wide potential of Additive Manufacturing in the oil and gas and maritime sector has come to be widely accepted, with the technology offering significant advantages in terms of lead time, part weight, part count, higher levels of geometric complexity and new material properties. However, in these safety-critical industries, there remain some concerns regarding the quality of AM parts. A Joint Industry Project (JIP), begun in January 2018 and consisting of twenty partners, aims to deliver a new JIP Guideline on Additive Manufacturing for this sector. Here, DNV-GL's Harsharn Singh Tathgar and Berenschot's Onno Ponfoort report on the guideline's development.

In January 2018, eleven companies began two seamlessly-aligned Joint Industry Projects (JIPs) aimed at delivering a JIP Guideline on Additive Manufacturing (guideline) for the production of quality-assured metal additively manufactured spare parts in the oil, gas and maritime industries. By July 2019 this group had grown to include twenty partners, with the goal of developing the requirements necessary (technical, documentation, roles, etc.) to introduce spare parts produced by AM into these industries, and an accompanying economic model. The consortium aims to have a practical guideline available by the end of 2019.

The guideline will provide a framework to ensure that metal components produced by Wire Arc Additive Manufacturing (WAAM) and Laser Powder Bed Fusion (L-PBF) are manufactured according to specifications, in a safe and repeatable manner, addressing the unique challenges related to AM.

From the beginning, the partners argued that AM should not only deliver parts that meet specifications, but that it must also present a practical and economically viable alternative to existing production methods. Therefore, the project has focused on delivering a guideline that is in line with realistic business and manufacturing processes. To assess the economic benefits of AM over current manufacturing practices, a highly detailed Business Impact Model (BIM) has also been developed alongside the guideline.

In this article, we will give an overview of the most relevant aspects of the project and of the initial outcomes, and share the set-up of the guideline and of the Business Impact Model. We will also introduce aspects for further development in new Joint Industry Projects.

## Participation of the full value chain

An important prerequisite for the success of this project was the participation of partners representing the complete value chain (Fig. 1). In Additive Manufacturing, the collaboration of multiple partners with expertise

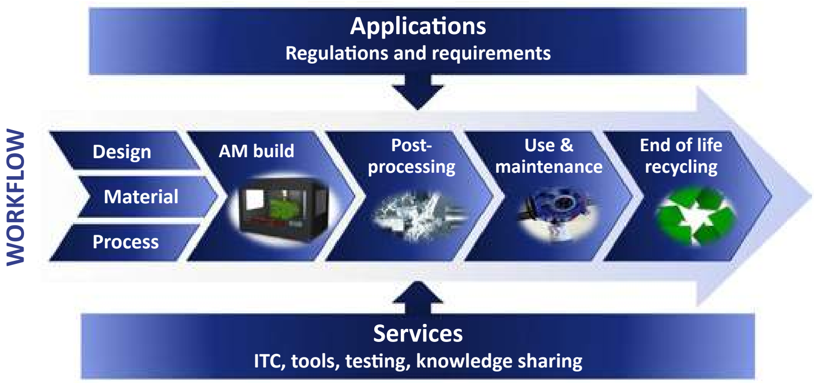


*Fig. 1 The Additive Manufacturing value chain*

| Operators | Contractors | Fabricators |
|---|---|---|
| BP | SLM Solutions | ArcelorMittal |
| Equinor | TechnipFMC | Voestalpine |
| Shell | IMI CCI | Additive Industries |
| TOTAL | Kongsberg | University of Strathclyde |
| | Siemens | HIPtec |
| | | Sandvik |
| | | Aidro |
| | | Immensa Technology Labs |
| | | Vallourec |
| | | Ivaldi |
| | | Quintus Technologies |

*Table 1 The twenty consortium partners involved in the project*

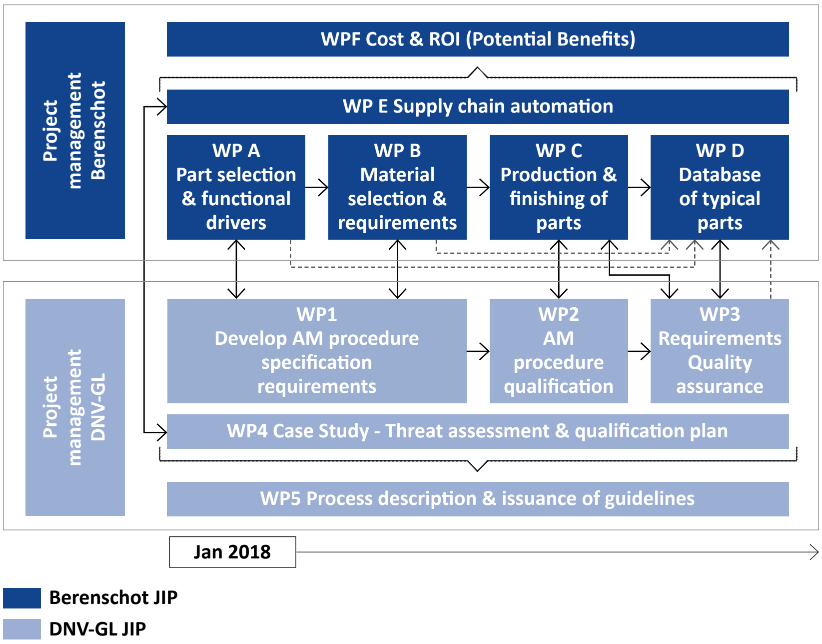


*Fig. 2 The aligned JIPs: Toolbox Program (top) and Guideline Program (bottom)*

in specific processes and activities, is essential. We use the value chain model as a framework; this framework indicates a workflow which is designed with three major Additive Manufacturing constraints in mind:

- The interdependence of design, material and process when engineering a part
- The framework and industry requirements the part must conform to
- The availability of tools, testing and industry expertise to ensure technical and economic feasibility.

The consortium partners are shown in Table 1. Together, they represent the entire value chain, from part design to end-use, and from material and process development to post-processing and testing. To each of these partners, ensuring quality is of utmost importance, with one stating that, "We will not use parts subsea that are not qualified or certified." In the oil and gas industry, therefore, having a framework for quality assurance is a prerequisite for the adoption of Additive Manufacturing. This explains why some consortium partners which might otherwise be seen as competitors are willing to cooperate for the sake of developing an industry practice for the qualification of AM components.

The project is organised via two aligned JIPs as shown in Fig. 2. The objective of the Guideline Program, managed by DNV GL, Norway, is to develop requirements necessary to introduce components made by Additive Manufacturing for the oil, gas and maritime industries and related applications. The Toolbox Program, managed by Berenschot, the Netherlands, is dedicated to part and material selection, and the assessment of the economic impact of adopting AM. Another core focus of this programme is the management of part production for case studies selected by the end-users.

Aligning these two JIPs creates an iterative process. The drafts of the guideline are used to standardise the production processes of various parts. The in-use experiences with the draft guideline are fed back into the development process to revise and verify the practicality and quality enhancement of the guideline. In addition, insights from part production are used to further improve the business impact model by benchmarking its performance against real production costs.

## Production of real world parts

Via actual part production, the consortium partners hope to ensure the development of a high-quality guideline that is in tune with realistic manufacturing practices. A first round of part production enabled the consortium to assess all activities that need to be monitored and qualified to ensure a complete guideline. A second round of production was used to assess the completeness, but also the contents of the guideline in terms of requirements, quality-level indications and testing requirements.

Nine different parts have been produced and assessed during this project using two different Additive Manufacturing technologies. Four parts were produced using Laser Powder Bed Fusion:

- An Equinor impeller in Inconel 625 (Figs. 3-4)
- The same impeller in Ti-6Al-4V (Fig. 5)
- A Kongsberg propeller blade in titanium
- A Kongsberg crank pin in 316L Stainless steel

Five parts were produced using Wire Arc Additive Manufacturing:

- A Vallourec circulating head using X90 low-alloy construction steel (Fig. 6)
- A BP cross-over in Inconel wire, in two versions: limited scale and full scale (Fig. 7)
- A Kongsberg crank pin, using S700 low-alloyed wire
- A Technip FMC/Total-designed crossover, using F22 alloy steel

Using real world parts is essential in a project like this. Both the guideline and the business impact model need to be tested under conditions that resemble real life situations. By using real world parts, it is possible to assess the variations between traditional manufacturing processes and the Additive Manufacturing process. These variations are found along the entire value chain, not only in the discrete production phase.

Even when using a standard and known part, redesign, material selection and process selection come into play when moving to Additive Manufacturing. Often, the material used for the additively manufactured part is not the same as the material that was used when milling or forging the traditional part. Powder bed-based AM will also require support structures to be designed and built along with the part, to ensure its correct orientation and robustness. And more importantly, the decision to use AM is often driven

*Fig. 3 Impeller for Equinor, designed by Eureka Pumps and built using an SLM280 in Inconel 625*

*Fig. 4 The test set-up at Eureka Pumps (Courtesy Eureka)*

*Fig. 5 The impeller for Equinor, designed by Eureka Pumps, this time built on an Additive Industries MetalFab1 in Ti-6Al-4V*

*Fig. 6 Circulating head for Vallourec. Designed by Vallourec, shown as welded, during machining process using Böhler X90-IG*

by the possible functional benefits that AM can offer, requiring a redesign of the part. These examples again indicate the interdependence of design, material and process.

Correct and precise information will, in such a situation, only be obtained when the AM process can be referenced against a traditional process that aims at delivering a similar part to meet industry standards. In addition, the mindset of part owners and production partners is completely different when producing a real part that can be put to use in practice, compared to conducting a 'design exercise'. Of course, parts produced as design exercises can be tested, but only case studies conducted using real parts ensure full attention is given to all relevant aspects.

## Developing a practical guideline

The safety and reliability of operations depends on having equipment, devices, facilities and personnel that perform as per the requirements in the designated service context. A framework is therefore needed in order to assess and document that relevant requirements are adhered to. The goal of this guideline is to provide such a framework for additively manufactured components. By combining it with other service designated standards, a framework is made available which ensures that the component performs as intended, as well as that the unique challenges involved in AM are assessed.

The guideline will provide purchasers of additively manufactured components with guidance on what needs to be communicated and what documentation and quality to expect, and will also provide manufacturers with requirements on what documentation they need to produce and how to demonstrate integrity. This standardised approach will create trust between purchasers and providers of additively manufactured components.

The development of the guideline began by identifying all possible failure modes, where over 300 failure modes were identified and discussed based on industry knowledge and AM expertise. The Failure Mode, Effects and Criticality Analysis (FMECA) worksheet was modelled after the value chain set-up, and has proved to be a living document and a practical tool to ensure that all aspects deemed critical have found their way into the guideline.

## Part classification

The guideline offers a quality assurance methodology for the selected Additive Manufacturing processes and parts. Specific requirements for each activity, as indicated in the value chain, are outlined. Parts are divided into three categories depending on the consequence of failure: AM Class 1 (AMC 1) is intended for non-critical components, AM Class 2 (AMC 2) is intended for less critical components and AM Class 3 (AMC 3) is intended for critical components.

Depending on the AM Class, different assurance steps are involved based on the AM technology used, such as build process qualification testing, production testing and part qualification testing:

- All parts shall be manufactured using a qualified build process. A build process is qualified through a defined Build Process Qualification Testing (BPQT) procedure. The purpose of the BPQT is to prove and provide a baseline that, when using a certain set of essential parameters, a certain quality is achieved
- Production testing is intended as a control to ensure that the manufacturing process produces parts according to the qualified build process not just once, but also on, for example, the second, tenth or twentieth build. The extent of production testing and type of tests carried out are different for the different AM technologies
- Depending on the criticality of the part to be manufactured, the part itself or a representative geometry may need to be tested. This is due to the unique possibility AM brings to produce the material and geometry simultaneously. The methodology and extent of part qualification testing depends on both AM Class and AM technology.


*Fix. 7 A cross-over for BP in production at the AFRC Strathclyde University. Produced via WAAM in Inconel 718 in shielded environment based on a BP design*

DNV GL has a long history of developing and issuing guidelines for a wide variety of manufacturing technologies. For Additive Manufacturing technologies to meet existing standards is not an easy task, as often specific production or testing regimen as given in norms or standards do not apply when using AM. The bridge that DNV GL's new AM guideline will offer towards meeting these norms and standards is practical and legitimate.

The activities indicated in the AM value chain cannot often be carried out by one company alone. Handovers apply, but what can the next actor in the value chain expect when taking over the design for production, the part produced for post-processing, or the post-processed part for testing? The guideline offers value chain partners a common language and an overview of topics, including minimum requirements, to support the handover of these activities.

AM is a prime example of a digital manufacturing method, relying on multiple design iterations to get to high-quality parts. It is not a pure stage-gate process. Another aspect to bear in mind is that AM is often used for its capacity to quickly and economically produce slight variations of similar parts, allowing manufacturers and users to meet precise demands. For instance, a cross-over to connect two pipes with different diameters might perform the same function and be made of the same material with the same manufacturing process, but vary in appearance based on the diameters given. DNV GL set out to produce a guideline that makes it possible to obtain these benefits through slight variations where the risk allows.

## Focus on benefits for business

As mentioned, the partners in the consortium also want to ensure that AM presents a practical and economically viable alternative to

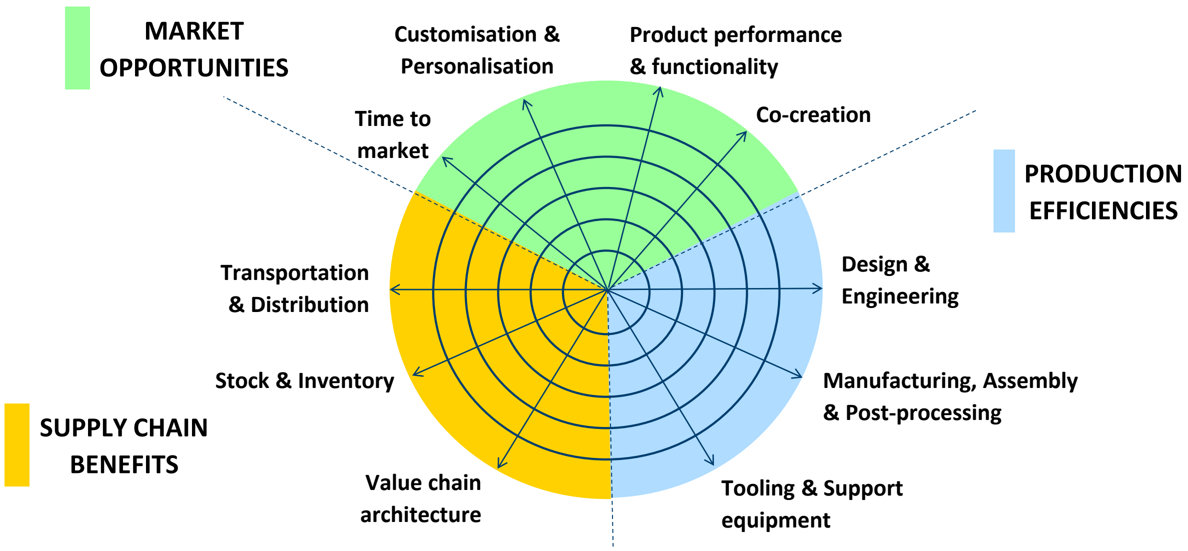


*Fig. 8 The benefits AM can deliver to a business are commonly indicated by three categories, as shown above, using the Business Impact Model (BIM)*

current practices. The benefits AM can deliver are commonly indicated via three categories:

- Market opportunities that can be obtained
- Production efficiencies that can be achieved
- Supply chain benefits that can be realised

The Business Impact Model helps to determine which benefits to focus on and what economic impact AM can be expected to have. The model can be used to different levels of detail, ranging from a quick cost assessment to get an indication of the unit cost price of one part, up to a full business case including estimations and investment assessments (Fig. 8).

In line with the value chain set up of the guideline, the BIM model ensures awareness of all aspects regarding the demand, design, production, testing, use and maintenance of the AM part. The model allows the user to get an indication of the economic variance between AM and traditional manufacturing and quantify the impact on the bottom line with a lifetime perspective.

The parts produced in the JIP demonstrate clearly the economic benefits that AM can deliver in the oil and gas industry. The production times for the cross-overs, for example, were a fraction of the production time currently observed. Further, though many spare parts are kept in stock, sometimes even in multiple locations globally, a replacement for a broken part is often not readily available or carries a long lead time. The shorter production times offered by the AM of spare parts can reduce downtime and loss of efficiency in production facilities. The thruster blade and circulating head in this project are further examples of parts offering these benefits.

In addition, spare parts kept in stock often become obsolete, but the building up and storing of stock represents a major capital investment. By reducing inventory levels through the use of AM to produce spares on demand, funds may be freed up and used for more profitable activities. Producing parts on demand with short lead times also makes it possible to avoid producing parts which become unnecessary in the end; one of the project partners indicated that its investment in the production of tooling for oil well exploitation often begins before the final decision for exploitation has been made. Parts are produced to begin exploitation as soon as the go ahead is received, but final analysis often leads to a decision not to exploit the well. AM could enable tooling to be produced much closer to the date of the final decision, thus avoiding production of parts that are destroyed without ever being used.

Amongst the parts produced while developing the guideline, other benefits of AM spare parts were highlighted, such as lightweighting and improved functionality. The BIM is expected to help companies make well-founded decisions on whether to adopt AM to produce a part.

## Status of the guideline

Aligned practices are essential to optimise the use of AM. The possibilities offered by the on-demand, on-location production of quality assured parts will have a huge impact on the cost and efficiency of operations in the oil and gas industry. The alignment proposed in the guideline covers elements of quality control that go far beyond the part production alone; the guideline stipulates the organisation of a quality management system for the entire part production process, ranging from purchasing information, manufacturing procedure specification and personnel

  

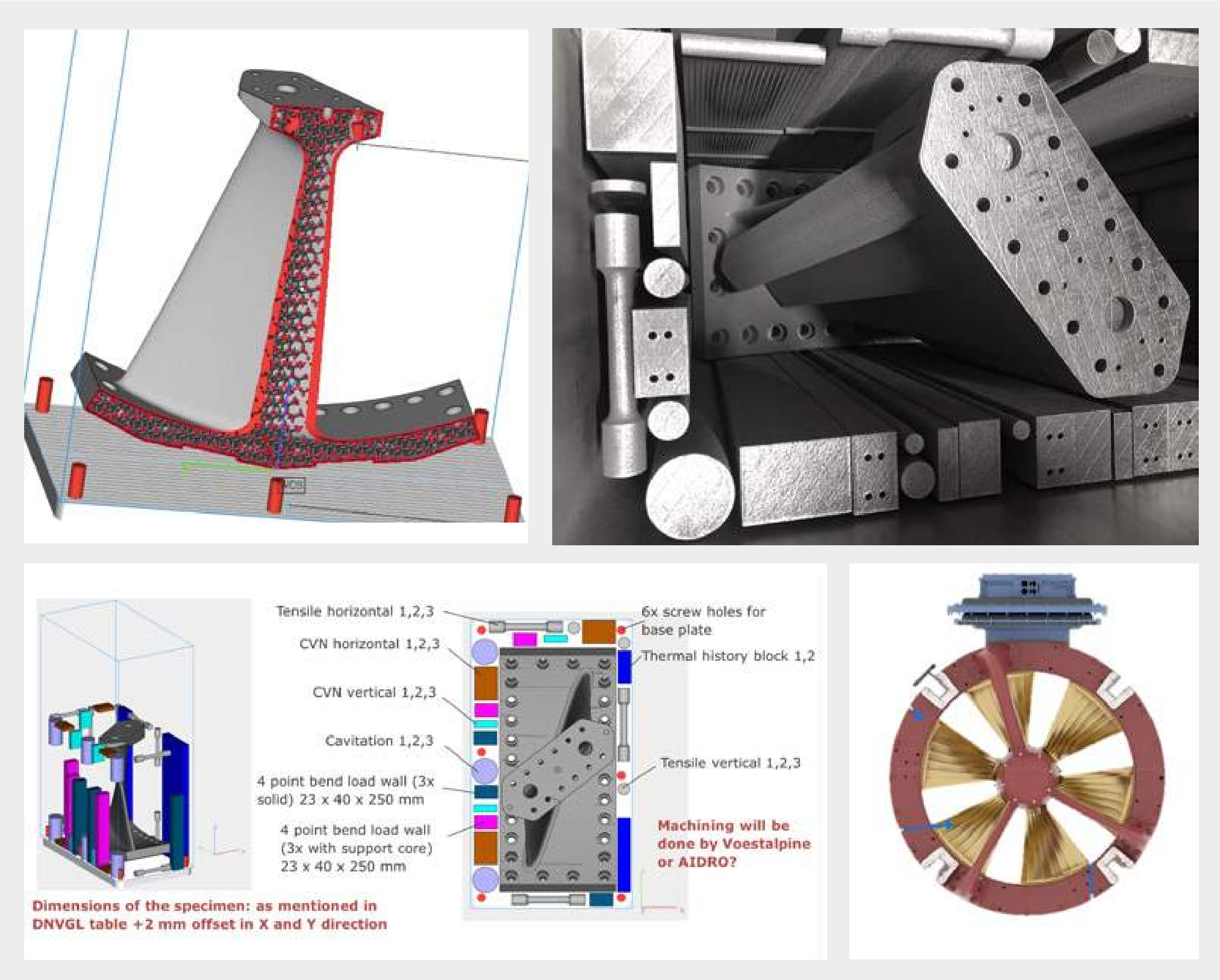


*Fig. 9 A titanium propeller blade built for Kongsberg, based on a Kongsberg design, using an SLM Solutions L-PBF system. Top left: the redesigned blade; top right: the build box with propeller and witness parts; bottom left: the nesting plan; and bottom right: the end-use application*

requirements, to HSE requirements and quality control procedures for feedstock, equipment and operator qualification. Rules for administering delivery, traceability and operational limitations are also included.

The technical requirements in the guideline cover pre-build requirements, build requirements, post-processing requirements and testing requirements. For testing, both destructive and non-destructive testing regimen are described.

The guideline brings AM closer into line with codes and standards that are agreed upon in the industry. Full reference to ISO and ASTM standards is made, with the latest editions applying unless dated references are given. The guideline does leave room to use other recognised codes and standards, provided it can be demonstrated that they meet or exceed the requirements of the referenced codes and standards, and the deviations are duly documented and agreed upon between manufacturer and purchaser.

To initiate a common language while using a new and still developing manufacturing technology, the guideline enforces the use of the terminology defined by the ISO/ ASTM, such as in the 52900 standard (Additive manufacturing – General principles – Terminology). The issuance of the guideline requires the full acceptance of all partners in the consortium, assuring that all relevant stakeholders in the industry underwrite the contents and the practical usefulness of the document. The fact that multiple operators and supply chain partners from three continents will be an advocate for the standards guideline offers the industry a basis for aligned practices and common use of AM in the oil and gas industry.

## Conclusions

The JIPs has created a thorough understanding of the benefits and the essential technical requirements which must be met to make use of AM in the oil, gas and maritime industries. With a focus on two manufacturing processes (L-PBF and WAAM), industry leaders experienced the importance of describing the demands of the industry in detail to ensure the quality output of the production process. They were also inspired by the design freedom AM offers, triggering new functionality and part assemblies not possible to produce with conventional manufacturing practices.

On the other hand, the AM industry leaders in the consortium gained a full understanding of the importance of part quality and risk consciousness in the oil, gas and maritime industries. Material properties requirements were shown to be especially demanding. Collaboration between industry and AM experts opened the door to unique designs for both end-parts and witness samples for testing, as shown in Fig. 9.

The partners in the consortium also concluded that additional Joint Industry Projects would be beneficial to further the adoption of AM in the oil and gas industry. These JIPs might cover other AM process technologies and other materials; focus on getting to standardised processes on specific activities like non-destructive testing; or delve into the supply chain developments associated with digital manufacturing processes. They are developing two new JIPs to begin in 2020 with a number of partners, focusing on hybrid material production and digital warehouse concepts.

The oil and gas industry is in the midst of a transformation in which alternative energy sources are sought for and sustainable business practices are demanded. Climate change and public opinion are forcing companies in this arena to review and adjust their business practices. Additive Manufacturing offers many opportunities to respond to that call; for example, better designs can improve the efficiency of operations, while on-demand production can decrease the number of obsolete parts and thus minimise material usage and waste.

Digital manufacturing processes can also support the emergence of completely new business models, allowing for new collaborations to be undertaken and industry-wide solutions to be developed to limit the impact on our planet and its natural resources. As such, JIPs like these are not only a means to develop a common framework, but also a driver of sustainable business practices.

## Acknowledgements

The authors are grateful for the support of the JIP Program partners and the contributions to the article from Fabian Nullmeier (Berenschot) and Ole-Bjørn Ellingsen Moe (DNV-GL). Readers of this article are invited to contact the authors to discuss essential aspects of accelerating the acceptance of Additive Manufacturing as a valid alternative for producing quality assured spare parts.

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# Redesigned for Additive Manufacturing: Serial production of a new fuel swirler for Siemens gas turbine

Whilst the principles of Design for Additive Manufacturing (DfAM) may suggest 'clean-sheet' components are the best way to reap the benefits of AM technology, many examples of redesigns have brought significant performance and economic benefits. In this article, Ray Huff and Terry Wohlers report on further success at Siemens in the use of AM for gas turbine fuel swirlers, highlighting both the development process and the evolving role of digital data in manufacturing.

Since purchasing Materials Solutions, Worcester, UK, in 2016, Siemens has been vigorously evaluating conventionally-made parts as candidates for Additive Manufacturing and driving new component design with AM in mind. As early as 2012, Siemens showed work it had done to repair gas turbine burner tips using AM technology. In 2017, the company subsequently redesigned its entire burner for manufacture by AM, yielding a more functional part with fewer manufacturing steps. This application was extensively covered in the article, 'Siemens: Digitalisation enables the industrialisation of metal Additive Manufacturing at Finspång', published in the Autumn/Fall 2018 issue of *Metal AM* magazine.

Most recently, Siemens has redesigned another burner component, bringing additive serial production to its large flagship gas turbine product line. The new part, a fuel swirler, fits into the company's SGT5/6-8000H gas turbine engine. The part followed the now-familiar workflow of redesign for AM, which takes advantage of the benefits of AM quickly, while making a strong business case for the new manufacturing method. Siemens credits AM for enabling higher firing temperatures in its combustion chambers. The swirler is responsible for mixing air and fuel prior to combustion by the burner.

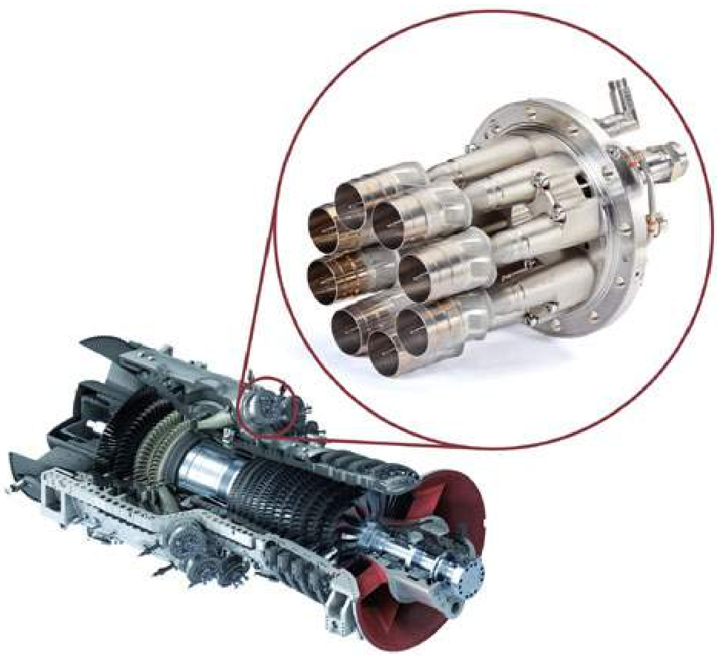

*Fig. 1 Swirlers and burner assembly and their location in the gas turbine (Courtesy Siemens)*

  

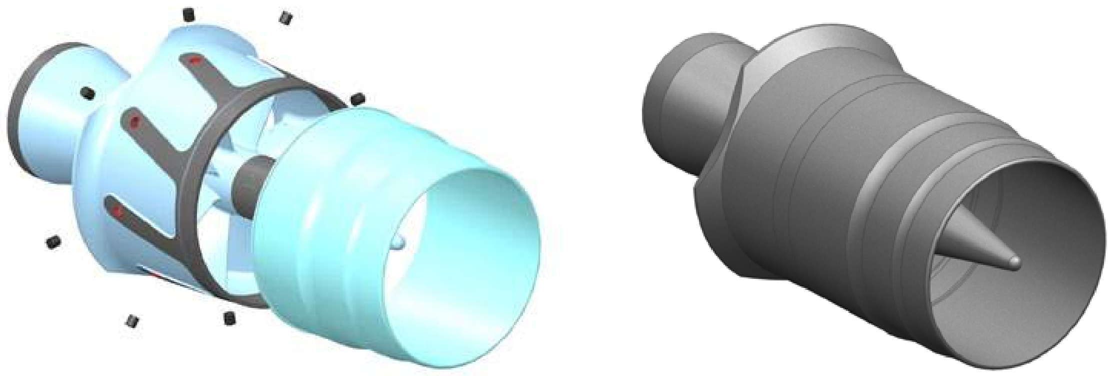

*Fig. 2 Conventional design of ten parts (left) consolidated into a single AM part (right) (Courtesy Siemens)*

Conventionally, the swirler is made up of ten cast and machined parts welded together. The part is an active service component with production demand of more than 1,000 units per year.

## Considerations behind the redesign

Siemens redesigned the swirler assembly by integrating vanes, a shroud, and mounts into a single AM design, which is about 250 mm (9.8 in) in length. To meet the high-temperature demands of the application, the swirlers are made in a proprietary, solution-strengthened Inconel alloy. The core IP related to the AM redesign is in the integrated control over the entire process chain. Everything from the powder and machine parameters, to the post-processing and heat treatment, has been developed specifically for this engine component.

The conventional swirler design required many machining and welding steps to produce and assemble. This accounted for about six hours of processing time per swirler for the conventional design, not including the time for casting. The AM version, on the other hand, requires only one hour in post-processing. This consists of depowdering, part removal by wire EDM, removal of support structures, and bead blasting. It also requires CNC machining at the base of the part where it is later welded to the larger burner assembly. After printing, each swirler is individually measured and uniquely marked for serialisation.

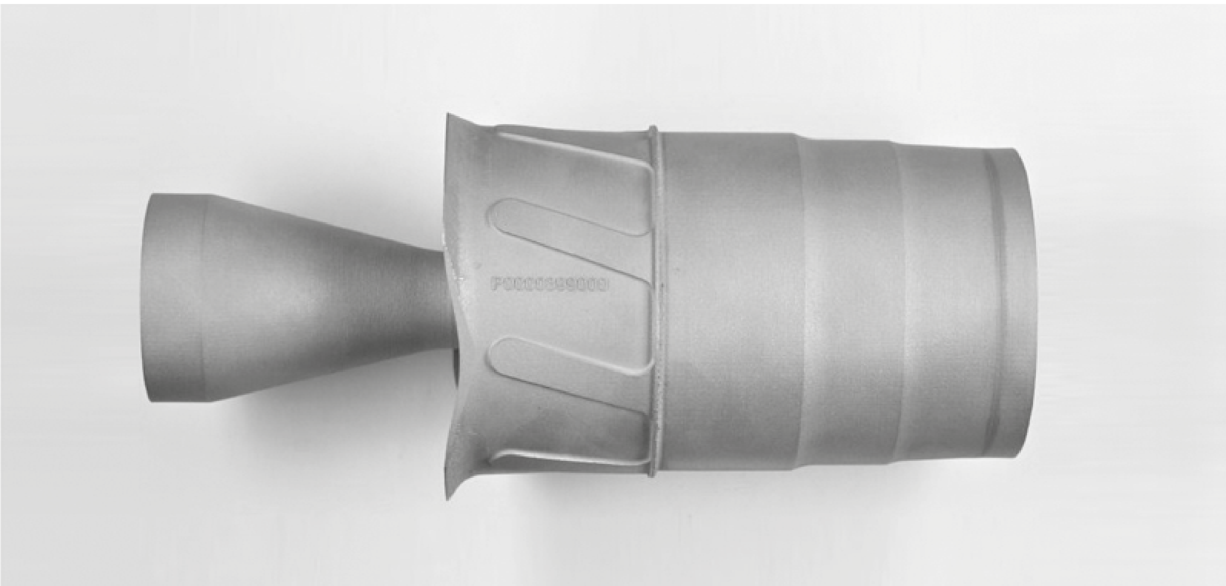

*Fig. 3 Swirler redesigned for production by metal AM (Courtesy of Siemens)*

  


*Fig. 4 Burners printed in an array of sixteen parts on a Laser Powder Bed Fusion machine (Courtesy of Siemens)*

## A focus on key value drivers

Siemens uses time, cost and performance as the value drivers when choosing which parts might be produced by AM. In the case of the swirler, the principle driver was the time savings offered by AM and the fact that the entire manufacturing process could now be done in-house. Time savings were a consideration in each step of production. For example, Materials Solutions has invested in automated depowdering systems from Solukon to shorten hands-on post-processing time. The AM-produced swirler is functionally identical and cost-competitive to its conventionally produced counterpart.

To meet production demand, sixteen swirlers are printed at one time on EOS M 400-4 quad-laser Powder Bed Fusion systems. By adapting build parameters at individual regions of the part, the team reduced the print time by 33% over standard settings. With optimised build settings, a full build takes up to a hundred hours. Siemens is currently running more than forty metal AM machines – all Laser Powder Bed Fusion – across its locations, with twenty-two in operation at Materials Solutions.

## The power of software: Enterprise Resource Planning and the digital twin

The company uses an Enterprise Resource Planning (ERP) system in combination with its Real Time Locating System (RTLS) to track parts through the various production steps. The system is connected to a production scheduling system, which is expected to include the facility's industrial powder management workflow in the future. The Materials Solutions team collaborated with Siemens Digital Industries to capture digital data along the entire process chain, from concept development to serial production. A digital twin of the swirler is available at every stage of development, and continually updates as new data informs design and process changes.

The digital twin, which begins with the CAD model, provides several benefits. For example, it is the basis for the printing process. After printing, parts are scanned, resulting in a second digital twin, which is compared against the original CAD model. If any significant deviations are found between the digital and additively manufactured models, the process has the potential to update the model for a more accurate part if necessary. Each version of the digital twin is stored and later used to generate machining toolpaths for accurate post-build machining.

## Part certification

Materials Solutions has also invested in its part certification process. For Siemens industrial gas turbines, parts require ISO certification at minimum. Aerospace customers are served by similar certifications from Materials Solutions. The facility is certified by the National Aerospace and Defense Contractors Accreditation Program (NADCAP). It also has AS9100 and ISO 9001 quality management certifications. The entire process chain, including AM build parameters, is locked down and 'frozen', which is required by the certification process. This ensures repeatability over the part's production life, with the possibility of building spare parts in the future.

The company required about six months to qualify its first two AM machines for swirler production. As of July 2019, these two machines were qualified, with two more in the queue. Gas turbine parts with a less critical function can be certified in as little as ten weeks.

## Conclusion

While parts fully designed for AM are often touted as the harbingers of change in manufacturing, parts at many OEMs can benefit from this 'adapt for AM' approach. Such production parts will not only save customers money, but also help build confidence in AM. Wohlers Associates expects that in more heavily regulated sectors, such as aerospace, mainstream use of AM for series production is still some years away. Even so, Michael Gorelik of the Federal Aviation Administration (FAA), has expressed his belief that the transition to safety-critical parts will occur sooner than initially expected.

In the meantime, Siemens and its energy business are leveraging design for AM more heavily to turn the rudder of manufacturing with innovative AM production parts. Siemens already has more than thirty parts qualified for AM serial production, with plans to industrialise two hundred parts in the future.

## Acknowledgements

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# Understanding metal powder requirements for Additive Manufacturing: Views from the industry

At the 2019 Additive Manufacturing Users Group (AMUG) Conference in Chicago, Illinois, a panel was held to discuss requirements for Additive Manufacturing systems. Despite the late hour of the panel and depth in the week at which it was held, a formidable crowd organised themselves to hear Ryan Dehoff of ORNL, Filip Francqui of Granutools and John Barnes of The Barnes Group Advisors discuss the topic of powder in AM. In this article, the panellists explore in more detail the differences in powder requirements between AM systems.

During the 2019 AMUG conference in Chicago, held from March 31–April 4, a panel discussion was organised on the topic of powders for Additive Manufacturing. As panellists, our motivation was to generate some discussion on powder requirements. Requirements for parts flow down from the environment or system they operate in and typically help us to decide which manufacturing process and material we will use to meet those requirements; they are liberating for our industry because they simplify how many actual choices we have to make in producing a part and focus the mind on what is truly important, versus a rule of thumb.

We contributed data from our experience in AM to test some of the industry's views on powder, with the ultimate hope of improving quality and reducing costs. In recent years, the industry has clearly begun to question some firmly-held beliefs about powders, as indicated by the questions we received from the audience.

## Powder origins and characteristics

Understanding how metal powders are made can inform an understanding of how they behave. Metal powders are typically produced using an atomisation process, whereby the metal is heated until molten and either gas or water is jetted at the stream to break up the liquid into smaller particles. Physics then drives the droplets towards a spherical shape, seeking a lower energy state, as the particles cool and solidify. Characteristically, the powders produced via atomisation have a Gaussian distribution for size.

*Fig. 1 The 2019 Additive Manufacturing Users Group (AMUG) conference attracted more than 2000 international participants (Courtesy AMUG)*

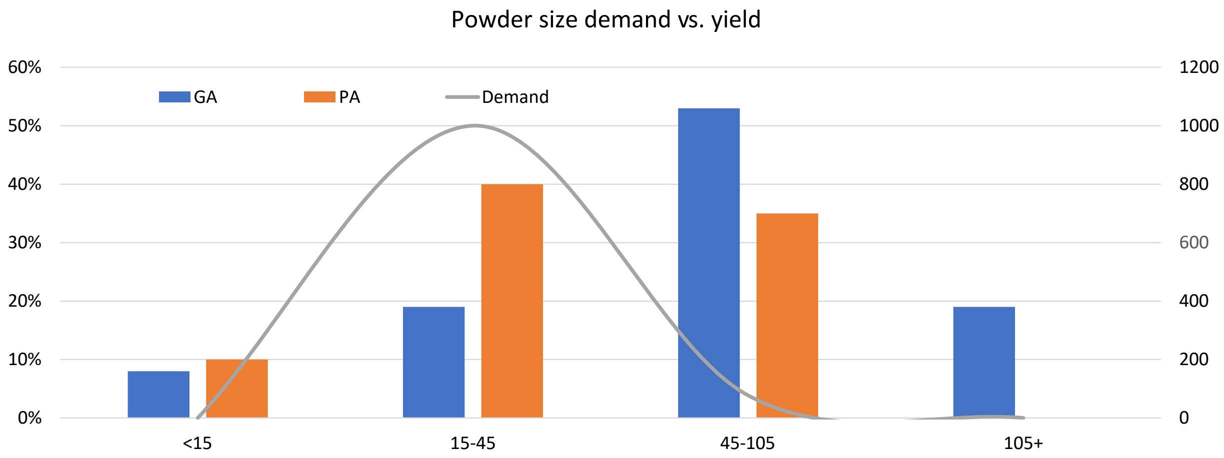


*Fig. 2 Ti6Al4V representative PSD for gas (GA) and plasma atomisation (PA) (in percent) vs industry demand [1]*

Depending on what kind of atomisation is used, the morphology can be very spherical (gas or plasma) to very granular (water), with a structure that is almost like coral.

Once the powders have been produced, they can be sieved and classified to separate them into their respective bins or markets. This is when the next set of powder characteristics begins to evolve, including the powder's flow, spreadability and apparent and/or tapped density.

Due to the different atomisation methods and derivations within the field, powder characteristics differ by process and alloy. Some of the more important characteristics are:

- Particle Size Distribution (PSD)
- Morphology
- Spread and flowability
- Densities
- Defects
- Chemical/phase composition

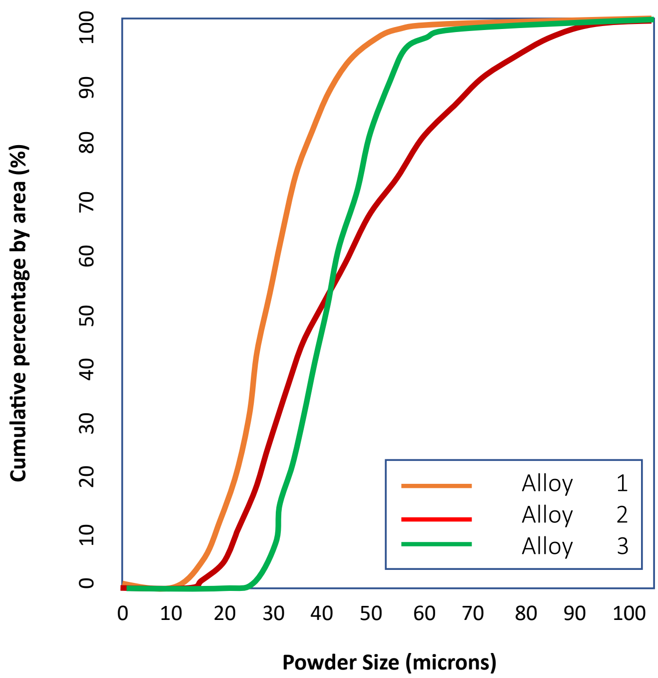


*Fig. 3 The effect of alloy on powder production efficiency or PSD [2]*

**Particle Size Distribution**

Fig. 2 shows a representative PSD for a titanium alloy for two different atomisation techniques. It also shows the conceptual demand from the AM market emanating mostly from Laser Powder Bed Fusion (L-PBF) systems. You will note that the highest demand does not correlate to peak production yield for powder. The demand curve highlights the large numbers of L-PBF machines and the perceived PSD requirements on powder, i.e. the desire for the 15–45 µm range. The imbalance in production capacity and demand creates excess supply for Electron Beam Powder Bed Fusion (EB-PBF) and Directed Energy Deposition (DED) powders, while trying to match supply and demand for the more commonplace L-PBF systems.

The choice of the alloy system to be atomised will also strongly affect the yield of usable powders. Fig. 3 shows the particle size distribution for several different metal alloys. Through understanding the process of how metal powders are made, we can begin to appreciate the commercial influences through supply and demand that affect price. By unintentionally overspecifying powders, the price can be inflated without sound technical reasons.

Due to the wide range of solidification behaviours in metal systems, sphericity and size distributions can vary widely from one atomisation technique to the next. Water

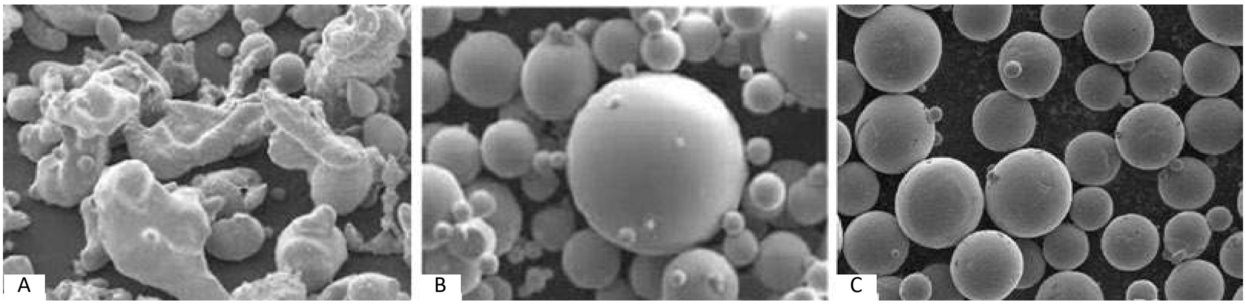


*Fig. 4 Representative morphologies obtained from water atomisation (A), gas atomisation (B) and plasma atomisation (C) [3]*

atomisation (WA) produces very non-spherical particles, whereas gas and plasma atomisation (GA and PA) techniques produce more spherical powders (Fig. 4). There are other powder production methods, but we will discuss the most common.

**Morphology**

Sphericity is often discussed, but rarely defined. Fig. 5 shows the range in sphericity attainable for a metal alloy, where sphericity is calculated using Sphericity=Ideal Surface Area/Actual Surface Area. In Fig. 5, micro CT was used to measure particles and the sphericity was calculated and shown for values from 0.73 to 0.96, where 1 is perfectly spherical. In practical terms, particles with a sphericity calculation of > 0.91 are typically considered to be 'spherical'. While it can be calculated, the idea of what is 'spherical' still involves some subjectivity.

Circularity and aspect ratio can also be used to describe the sphericity or roundness of the particle. Fig. 6 shows the relative fraction of 'circular' and uniform aspect ratio particles as a function of production from atomisation. Not all of the production has the same circularity or aspect ratio; this issue can reduce the saleable yield.

**Spread and flowability**

Spreading, flow and density characteristics are affected by the sphericity, size and size distribution of the powder. Our ability to understand what we need with regard to these parameters can be influenced by conventional wisdom and not purely by physics or melt characteristics, which affect spread, flow and density requirements. Generally speaking, large particles flow better than small ones; more circular/spherical particles flow better than less circular/spherical particles; and PSD also has an effect. PSD can change over the useful life of a powder lot once atomised, after each run in an

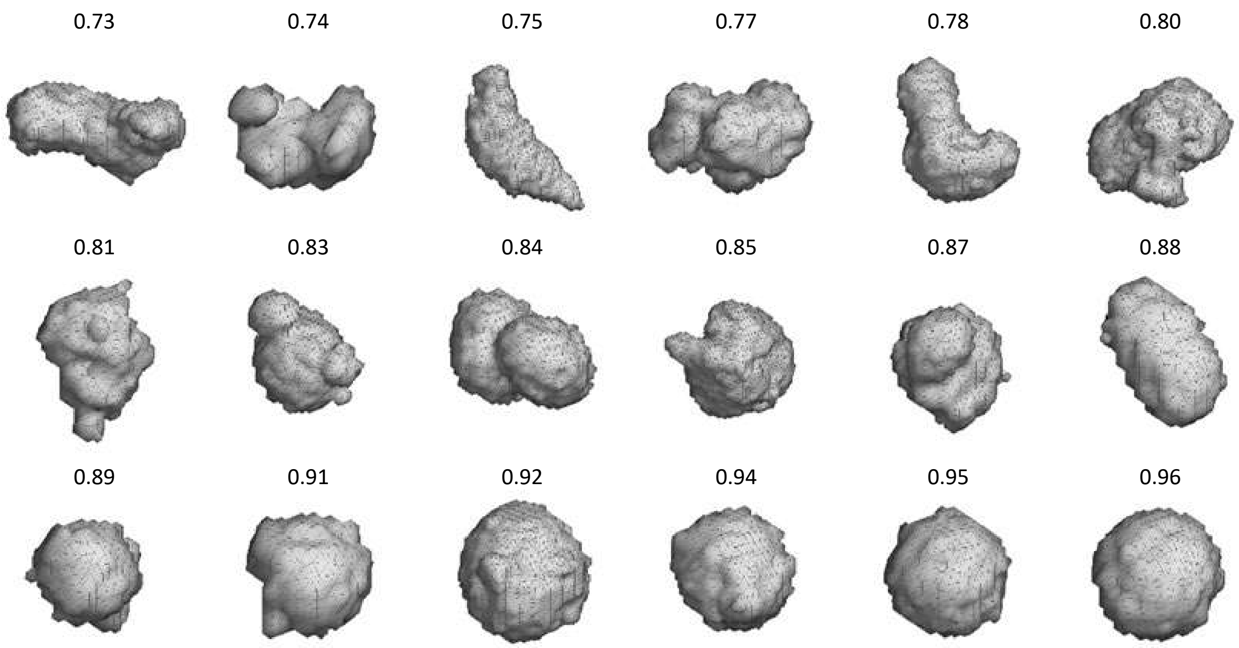


*Fig. 5 Measurements of sphericity by CT [4]*

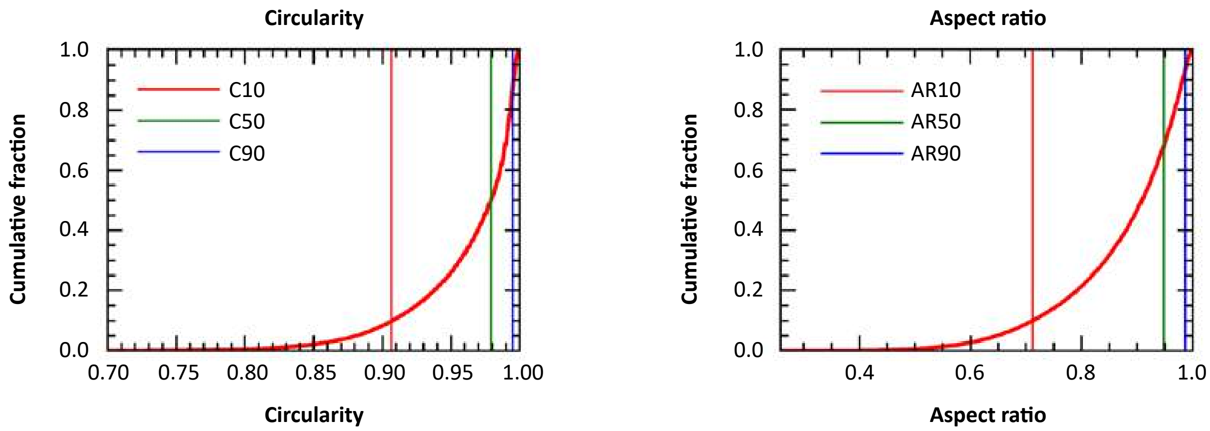


*Fig. 6 Circularity and aspect ratio as a function of production [5]*

AM system; the population of fines (< 15 µm) decreases, which improves the flow characteristics. In addition, environmental factors like humidity are relevant.

Flow is typically defined by the Hall Flow method (ASTM B213), where 50 g of powder is placed in a funnel-shaped cone and the time it takes for the powder to vacate the funnel is measured. Lower values of the required time indicate higher flow.

Spreading on the other hand, can be measured by different means, such as cohesive index, angle of repose, etc. [2]. It is perhaps more important to AM than Hall Flow, because there are only rare instances where a circular orifice, like that used to measure Hall Flow, exists in an AM machine.

In some machines, forced gas is used to help move the powder. Whether or not a powder spreads is mostly due to the interactions between the particles: the stronger those interactions, the worse the spreading. The strength of those interactions can be expressed by the cohesive index. The cohesive index is influenced by powder population, but also by the energy imparted on the population. As seen in Fig. 7, a range of cohesion can be measured through different powder population characteristics, but, as more energy is applied to that population, the cohesive index becomes the same. This phenomenon is possible due to aeration of powders.

Other methods are also employed to address how easily a powder spreads. The industry needs a test that reliably measures this spreading ability, taking into account factors such as humidity or moisture. Coupled with the environmental factors, it is already observed that higher fractions of fines oppose spreading and can create higher avalanche angles. What is acceptable? This would then depend on the AM process and machine being used.

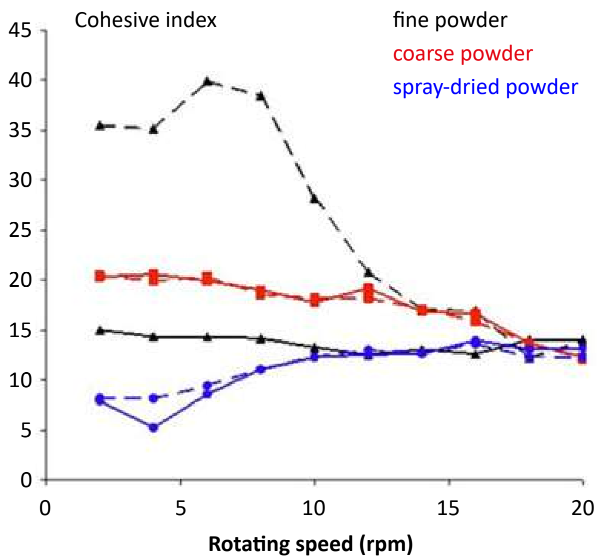


*Fig. 7 Cohesive index for fine and coarse powder versus rotating speed [6]*

### Density

Density, in this context, is the packing density of the powder, not of the individual particles. It can be described by the Apparent Density or Tapped Density (ASTM B212 or B527) and it is a proxy for the bed in a Powder Bed Fusion or Binder Jet (BJ) AM system. Skeletal density gives the true density of the powder and can therefore be used to evaluate the existence of entrapped gas in the powder.

  

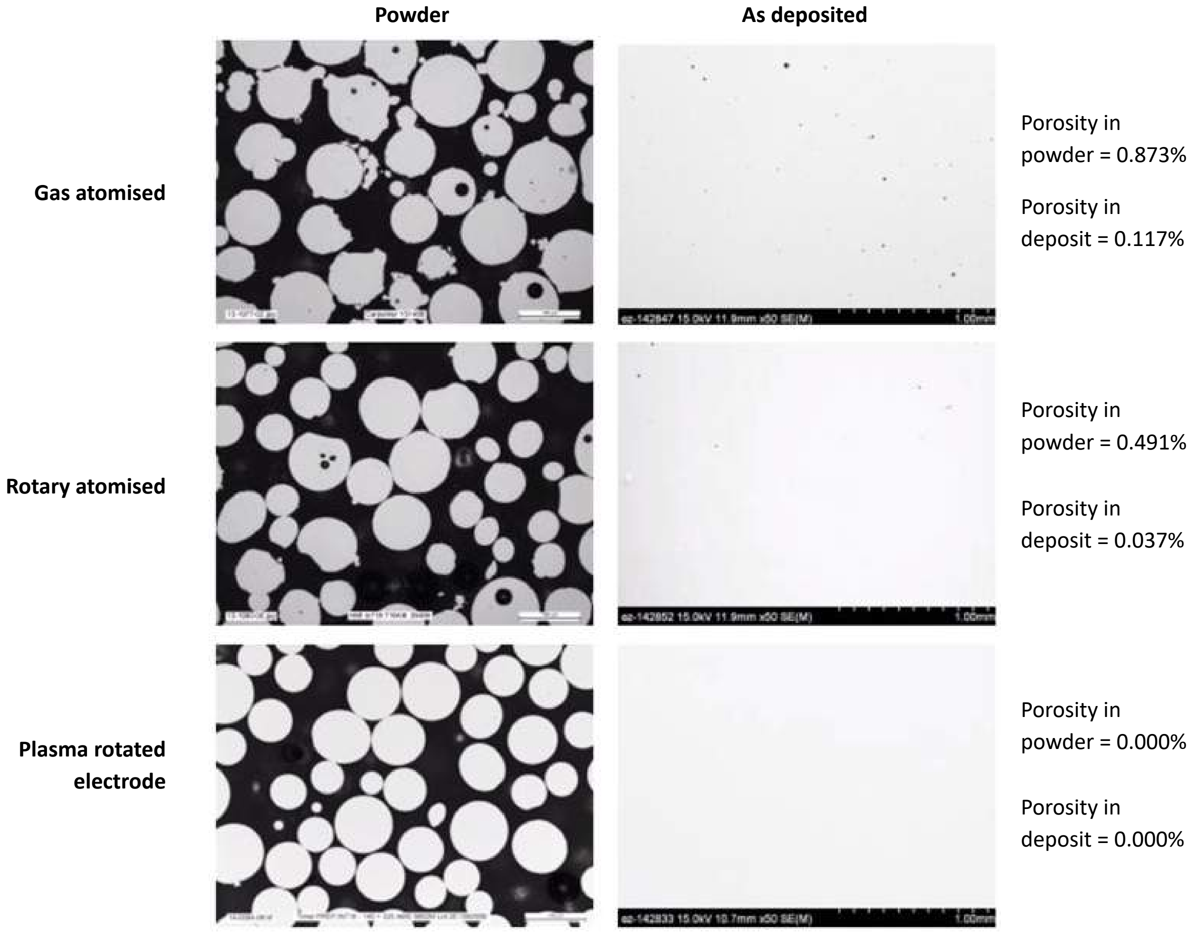


*Fig. 8 Atomised powder porosity and subsequent printed density [2]*

Of the many factors that influence density or packing, principal among them are sphericity and PSD. By narrowing the PSD, the packing efficiency begins to drop. In fact, a study conducted by Princeton University [7] filled a 5-litre flask randomly with ellipsoids (M&Ms) and spheres (gumballs). Ellipsoids filled 74% of the space on their own versus spheres at 64%. While it is true that hand packing the spheres will give you about the same results, this will result in very slow recoating speeds.

**Defects**

Inherent in powder production via atomisation is the presence of entrapped gas during the solidification process. Work carried out by Oak Ridge National Laboratory identified the presence of porosity in powder particles from different atomisation methods [2]. This entrapped gas survived the AM process and remained in the printed samples (Fig. 8); the solidification rates involved are too fast to allow the gas to escape from the particles 100% of the time. For fatigue-limited applications, this most likely means that a Hot Isostatic Pressure (HIP) cycle will have to be performed to minimise residual pores or defects.

Further to this line of thinking, Carnegie Mellon University has demonstrated that the HIP only compresses the gas bubbles, which regrow upon the addition of heat [8].

**Chemical and phase composition**

The chemistry and phase composition of atomised powders can be highly relevant and this explains why not all alloys are available as powders. PBF generally favours metals that are weldable; the same principle that governs the build process also has merit when atomising. Atomising is a kinetic process allowing metastable phases to form. For alloys which are heat treatable, the powder chemistry may be correct, but the phase content will be different. While this is unimportant in fusion-based processes like PBF, it is crucial in other AM processes which do not melt powders to achieve density, such as Binder Jetting or Directed Energy Deposition derivatives like Cold Spray Additive Manufacturing.

The development of other powder manufacturing techniques that do not rely on melting would open up new material solutions for the ever-expanding technology space of AM.

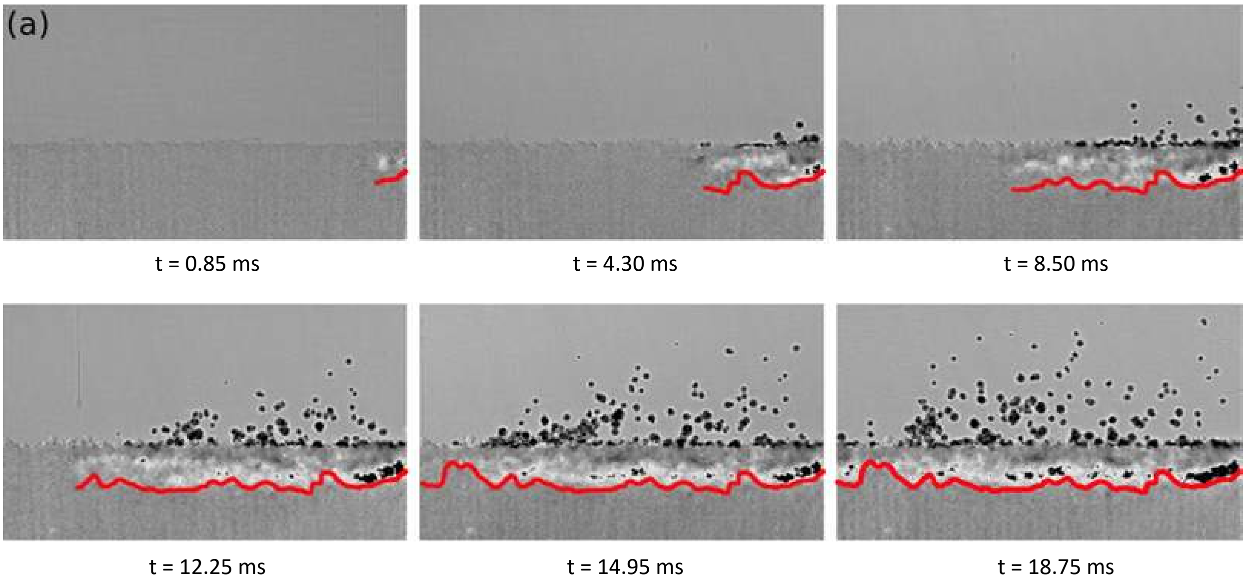


*Fig. 9 The effect of binder ejection on highly flowing, spherical powder [9]*

## Process requirements

There are a diverse range of Additive Manufacturing technologies that create dense parts via different means and therefore also have different requirements for powders, if used. Seven AM methods are defined by ASTM F42:

- Powder Bed Fusion (PBF)
- Directed Energy Deposition (DED)
- Binder Jetting (BJ)
- Material Extrusion (ME)
- Material Jetting (MJ)
- Sheet Lamination (SHL), and
- Vat Photopolymerisation (VP).

Of these seven forms, PBF, DED, BJ and ME can use metallic particles.

Even within a category, powder needs can be different (for example, DED can use blown powder melt or a cold spray solid state process). Both PBF and Binder Jetting require powders to be moved from a hopper storage unit and spread across a build plate. It is preferable to create a consistently dense bed. Binder Jetting and ME achieve part density via sintering, which puts additional requirements on powders, where smaller particles with a higher surface area to volume ratio and lower activation energy sinter earlier than larger particles.

Within PBF, Electron Beam systems traditionally use a 45–105 µm PSD, whereas most laser-based systems desire 15–45 µm PSD. DED systems can tolerate an even wider range PSD because of the forced gas delivery. In addition, the PSD and powder size can have a strong influence on the as-built surface finish of the final part. Within powder bed technologies, many different methods of distributing metal powders are used – rollers, rakes, dosing wheels, recoaters coupled with gravity feed or cartridge charge – all of which come with different requirements whilst aiming for similar end results. It is not possible to describe the powder requirements as being identical for each of these mechanical propositions.

Ultimately, it makes rational sense that, in a system that employs a bed of powder, a consistent bed with some minimum density requirement is a good thing; and yet we take a lot of different approaches to creating that bed, without seeing huge differences in the resulting part. This is partly fed by the recent movement toward 'highly flowing' powders. Highly flowing powder, by definition, requires little energy to induce it to move.

*"Ultimately, it makes rational sense that, in a system that employs a bed of powder, a consistent bed with some minimum density requirement is a good thing; and yet we take a lot of different approaches to creating that bed, without seeing huge differences in the resulting part."*

  

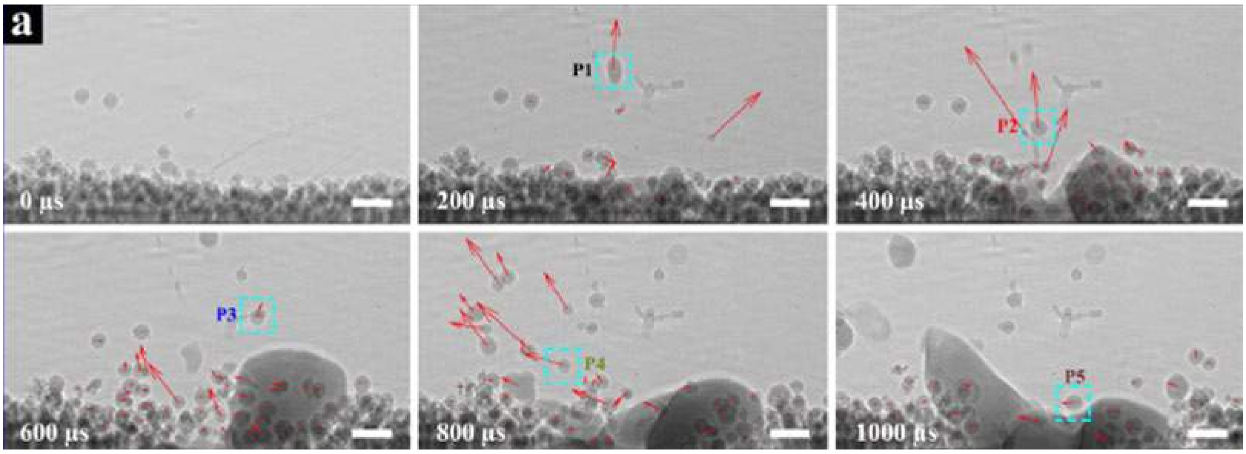


*Fig. 10 Powder motion during PBF of flowing metal powder [10]*

This also means that it requires little energy to force the powder particles to move out of the desired position; in both PBF and Binder Jetting, the energy applied by a laser or a binder jet print head may cause the powder bed to be disrupted before it has been consolidated (Fig. 9).

In PBF, similar phenomena are seen. Fig. 10 closely mimics what was seen by ND Parab *et al* [9] in Fig. 9. In this study, powder particles from the bed were tracked as they were ejected from the melt area. The velocities at which they are ejected can also be quite high; the authors cited ejection speeds in excess of 10 m/s from the melt area.

Within powder bed systems like PBF and Binder Jetting machines, the systems themselves have a need to move powders from a storage system and spread them onto as wide an area as possible. This area is then the limit of the size of the part that can be built in one session. In Binder Jetting, the physics and mechanics are slightly at odds with each other. Ultimately, small, non-spherical particles are required for sintering; however, these characteristics oppose the mechanics of flowability.

In PBF, the Electron Beam process already uses larger particles, but also employs a pre-sinter to connect the particles together, thus minimising ejection by melt dynamics. In laser-based processes, once the powder bed is created, gas flows across the surface and local temperatures rise rapidly to thousands of degrees as the laser couples with the metal. Immediately, the gas in the bed, which comprises at least 30% of the volume, is instantly heated and, as the metal melts, metal vapours are produced, which also promote subtle chemistry changes as higher vapour pressure elements evaporate preferentially. The combination of these events can eject the powder upward.

Despite these dynamics, the process works. However, there exist opportunities for defects stemming from lack of fusion or keyholing, but also from the atomisation process leaving entrapped gas in the powder particles. Each of these could create additional costs to remedy.

## Technical summary

In this article, we have covered a range of technical issues and pointed out some inconsistencies in what might be desired versus what is actually required. End-part requirements should be paramount; how these requirements are met is a combination of process and materials, as it has been with every other manufacturing technology. It is important to understand the difference between a requirement and a rule of thumb:

- Particle Size Distribution is widely recognised as an important parameter affecting how well powder spreads (the smallest 20% of powder particles strongly affects powder 'cohesiveness')
- Smaller particles allow finer resolution of part dimensions & surface finish, but may preclude the ability to spread
- Powder 'spreadability' can determine whether a powder can be successfully used in a particular machine, but acceptable 'spreadability' varies between machines
- Particle morphology (i.e., circularity, aspect-ratio, surface roughness) also affects flow and spreading behaviour, but usually to a lesser degree for AM powders than the size of the smallest 20% of the powder
- The addition of a machine- and alloy-specific bulk powder 'index' test, as a surrogate for spreadability, may allow a wider range of powders to be 'accepted'/'qualified' for specific AM machines
- High flowability and spreadability can adversely affect the ability to create a consistent, maximum-density powder bed
- Ellipsoidal particles would have better and more consistent natural or random packing
- Atomisation is a way to make metal powder, but not the only way

- The choice of powder should be matched with the AM process – it is not a case of 'one size fits all'

Of course, we are not implying that atomisation is not the most effective way to make metal powders, as most of the industry is facilitated to do so. What we are asking is whether further cost-effectiveness can be achieved by truly understanding the requirements to make a part via AM, keeping in mind there are currently seven AM technologies. Simply using more of the PSD, for example, could improve the cost-effectiveness of atomisation. There are a wide variety of methods to produce powders and particles.

Having dense, defect-free particles of the right chemistry, both in terms of elements but also phase content, would seem highly desirable. The ability to pack well randomly should be positive, but some AM technologies will still see the bed disturbed. Beyond that, the particles need to be able to flow or spread well enough to get into position, and that should really be matched to the AM technology used. Ultimately, matching the requirements for the process to the powder feed opens the door to lower costs and more material choices. This is complicated, but as the adage goes, "the journey of a thousand miles begins with a single step."

## Final thoughts from the panel discussions

A key takeaway from the panel was that powders, specifically metal powders, are still not well understood in the AM industry. From the production methods, to the production cost, to the requirements or characteristics relevant to different processes, there is still much to learn. There is a strong thirst to resolve these open queries and there is an interest in more education and information. Balancing powder requirements and the nature of production helps to understand the costs. Taking it a step further into the process, understanding what is ultimately driving powder behaviour, then what is driving needs, goes to influencing cost. Over-specifying can be just as bad as under-specifying.

The process and powder relationship is clearly key. Further characterisation so that we, as an industry, can better understand those interactions, was a common theme of panel discussions.

We can borrow from what other industries have learned. The field of Powder Metallurgy has certainly gained a lot of knowledge, as has have pharmaceuticals. However, AM processes are different than prior press and sinter techniques, and metal powders have significant differences from polymers; these sound like simple statements, but it can be confusing to know what information and data from other industries is relevant and what is not. For example, while we can learn a lot from pharma, metal powders have much higher densities and lower hygroscopy than the powders used in this industry.

Perhaps the main takeaway from the panel discussions was simply this: that everyone is interested and concerned with maintaining AM part integrity, and that the interest in understanding powder mechanisms and control processes is real and genuine. What that means is that this is a great time to be involved in Additive Manufacturing.

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# Towards a true digital twin for the metal Additive Manufacturing process

On July 4, 2019, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) sponsored and co-organised a one-day symposium in Melbourne entitled 'Towards a True Digital Twin'. The event, which followed APICAM 2019, the 2nd Asia-Pacific International Conference on Additive Manufacturing, brought together experts in a range of relevant fields including metal Additive Manufacturing, computational modelling, multi-scale techniques, structure-property relations, machine learning and artificial intelligence, and digital twins of industrial processes. Here, CSIRO Manufacturing's Dr Dayalan Gunasegaram and Dr Tony Murphy consider the importance of the digital twin in AM and report on some of the event's key findings.

For metal Additive Manufacturing to reach its full potential, a realistic virtual representation of the complete process is required. A 'digital twin' that describes the process in the simulated domain will accelerate process design, optimisation and control, and form a crucial part of process certification and component qualification. It is expected that such technologies will be increasingly embraced in the connected economies of the Industry 4.0 era and even become commonplace.

This article draws on presentations and discussions from the Melbourne symposium to explore the requirements of digital twins for metal AM processes, and consider the hurdles that must be overcome in developing them. Ideas exchanged during a road-mapping session are also presented. While the focus of the symposium was on powder bed-based AM processes, most ideas that were exchanged are applicable across a broad spectrum of metal AM technologies.

## How predictive modelling will transform AM

Having the ability to control and optimise a process is critical to the successful operation of any manufacturing business. A reliable process ensures quality products that consistently satisfy specifications.

This assumes even greater significance in Additive Manufacturing, for which the ability to produce customised parts contributes substantially to the value proposition. This, however, results in products that are unique and relatively expensive. The slowness of the process adds to the part cost through increased overhead per part.

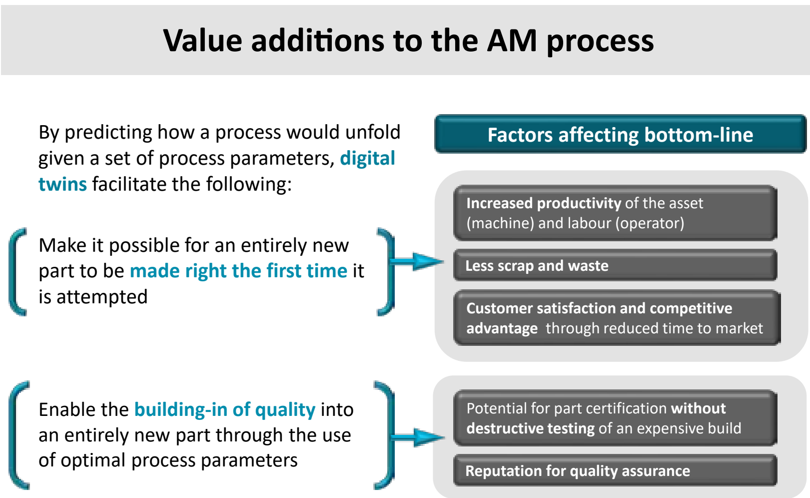



*Fig. 1 How digital twins add value to a business*

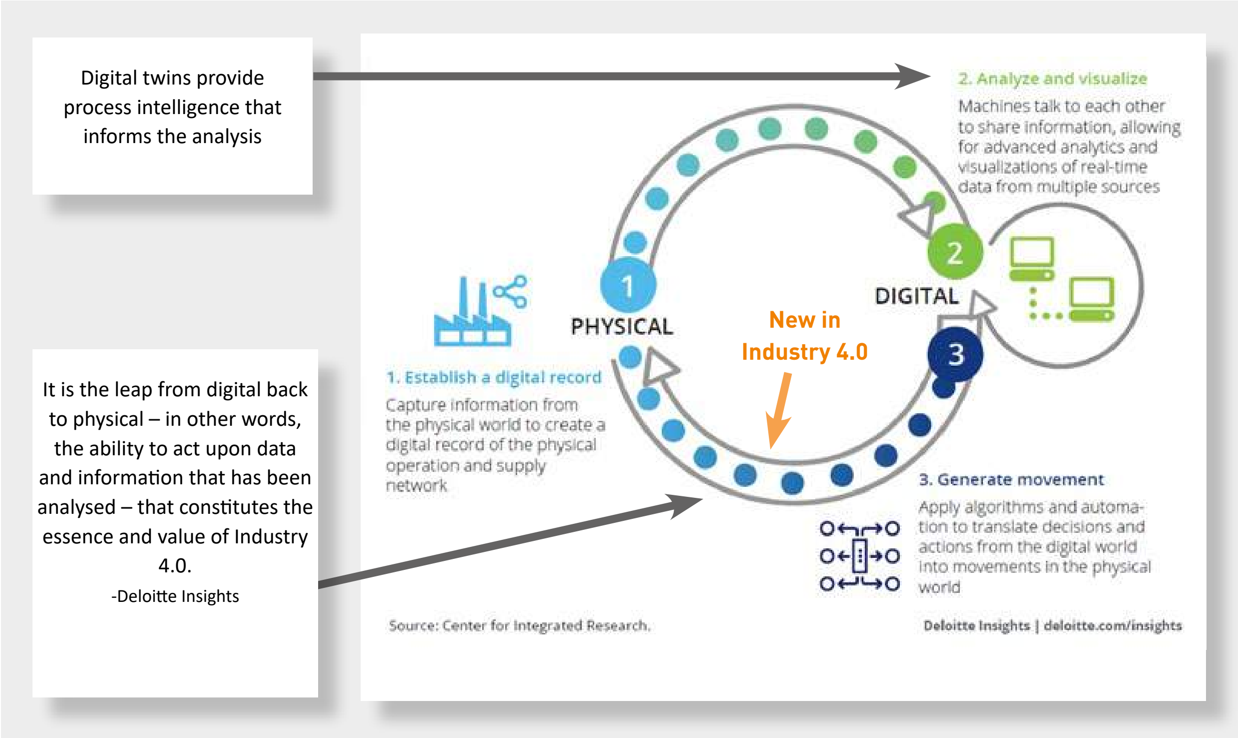
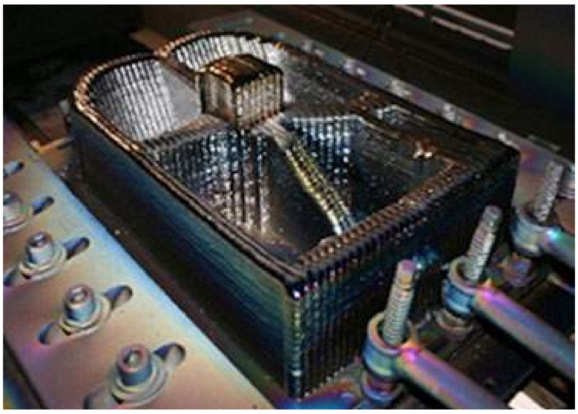



*Fig. 2 How digital twins facilitate closed loop control, which is a cornerstone of Industry 4.0*

Given this scenario, any business that possesses the capability to produce an AM part right first time has a competitive advantage through reduced rejects, which has the flow-on effects of decreased material consumption, increased productivity and shortened delivery periods.

In addition, if quality can be assured in AM products, the confidence that accompanies the production of each such part can lead to the certification of this part without the need for the destructive testing of an expensive item (Fig. 1).

The challenge is therefore to understand how can such a capability be acquired. Robust predictive modelling capabilities that realistically simulate the AM process and its behaviour can provide the foreknowledge that is required to plan the building of a new part and get it right on the first attempt. That is because the models, or 'digital twins', will be able to provide information on how the process is going to unfold for a given set of process parameters. This allows changes to be made to the inputs if it is found that desired outcomes, such as specified part quality, are not going to be achieved. The digital twins can also assist in keeping a process within set boundaries, since any deviations from the optimum path recommended by the models can be corrected through closed-loop control.



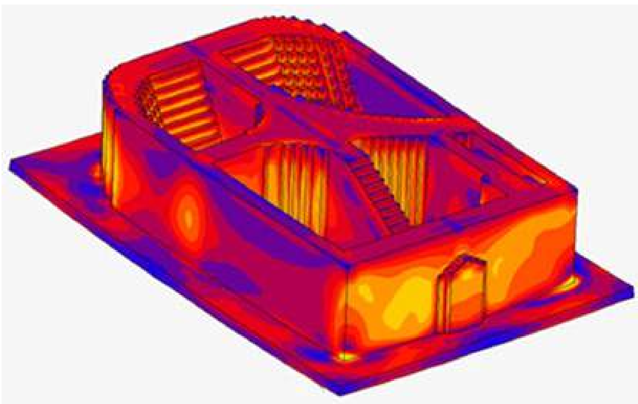


*Fig. 3 A photo of a complex AM part (left) and a simulation showing the predicted residual stress (Courtesy of Vu Nguyen)*

Such control is a foundation of Industry 4.0, which differs from the status quo in that it espouses corrective action based on an intelligent analysis of data received from sensors monitoring a process. The process intelligence required for the analysis is provided by physics-based digital twins of the AM process. It should, therefore, come as no surprise that, in the metal AM industry where trial-and-error methods are still widely prevalent, the introduction of digital twins in process planning and control can cause step changes in process productivity and part cost.

## About digital twins

A digital twin is a digital model of a real-life object, process or system. Importantly, it is not a virtual model in isolation; it is constructed in such a way as to conduct a two-way information exchange with its physical counterpart, informing and receiving data, for instance from sensors that monitor performance indicators. The aim is to improve the digital twin over time until it becomes a true reflection of its counterpart so that the virtual model can be used in the optimisation and control of the performance of its physical twin (Fig. 2).

It is worth highlighting that digital twins of processes are a relatively new concept, although twins for products (e.g. GE aircraft engines) and systems (e.g. Tesla automobiles, the city of Singapore) have existed for some time. Even when referring to process twins, most allude to logistical process flow in factories whereas, in our case, we expressly limit ourselves to physics-based models for metal AM processes.

### Physics-based digital twins of AM processes

The metal AM process comprises several stages involving complex physical and metallurgical phenomena. For instance, in powder bed systems, these include powder bed raking, heat transfer and flow in the molten pool, microstructure formation and residual stress development (Fig. 3). A complete, end-to-end capture of these various stages in computational sub-models is necessary for a realistic representation of AM in the virtual domain.

These models need to be underpinned by science so that any deviations in inputs from the experimentally validated sets can still be accommodated in predictions. They should not only be accurate and fast, but they have to be tightly integrated with one another. For instance, the output from the powder bed raking sub-model should be available as input to the laser melting sub-model, although the two sub-models simulate completely different physics and thus use entirely different computational methods (Fig. 4).

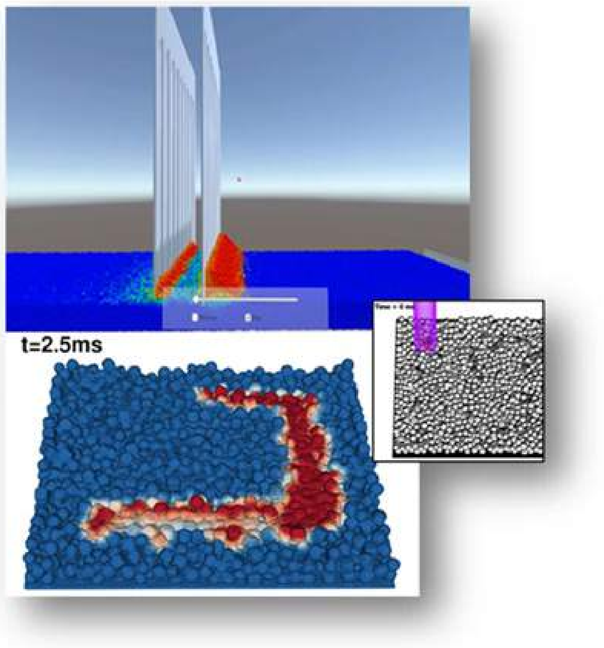



*Fig. 4 CSIRO Data61 developed digital models of raking of the powder bed and laser melting of powders (Courtesy of Gary Delaney and Paul Cleary)*

This is a critical obstacle since there are usually incompatibility issues between the mathematical approaches. This is exacerbated by the fact that the sub-models often treat phenomena occurring at vastly different time and length scales, from microstructures (nanometres) to powder (micrometres) to part (up to metres). Thus, considerable collaborative thought and effort are required for the successful development of linking strategies for sub-models that retain much of the solution fidelity when crossing physics as well as scales.

## Observations from keynote lectures

Recognising the significance of digital twins to the metal AM industry, CSIRO organised this symposium to bring together international researchers and managers from AM industry players, government bodies and universities. A total of eighty-six delegates attended from Siemens, Boeing, Thales, CSIRO, Defence Science and Technology (DST), Australia's Nuclear Science and Technology Organisation (ANSTO), Lawrence Livermore National Laboratories (LLNL), RMIT University, University of Melbourne, Swinburne University, Flinders University, Pennsylvania State University, Nanjing University of Aeronautics and Astronautics and University of Texas at Arlington, to name just a few. The event was sponsored by software vendors for ThingWorx, Solvia, Simufact, Materialise and Flow-3D, emphasising the interest from the commercial software community.

The specific aims of the symposium were to define the requirements for a true digital twin of AM, identify the main barriers to developing such software models, discuss potential solutions to overcome those barriers and plan a roadmap that can provide general guidance for the development of digital twins. These aims were achieved through a combination of keynote lectures, poster presentations and facilitated discussion sessions. Keynotes were spread between modelling, experimental validation and machine learning/artificial intelligence for model speed-up purposes.

Some of the main messages from the symposium's keynote speakers are outlined below. These were the opinions of the speakers, and some may not necessarily be incorporated in the creation of the roadmap.

**The use of digital twins in tailoring metal AM processes**

The overarching theme of the presentation by Dr Ibo Matthews, Lawrence Livermore National Laboratory (LLNL), USA, was the potential that exists for the use of digital twins in tailoring metal AM processes. A sound understanding of the physics involved, as well as the availability of suitable experimental data for validation purposes, were emphasised as prerequisites for accurate modelling.

The following phenomena were among those listed as needing further in-depth understanding:

- Liquid spatter due to unstable local laser/melt-pool/powder bed interactions
- Depressions in the powder bed due to vapour pressure and pore formation as a result of the highly dynamic interactions and the resulting flow profiles and subsequent solidification
- The effect of all of the above and cooling rates on microstructure evolution.

LLNL is presently studying the use of machine learning (ML) to predict process fidelity (via track width) based on in-situ high-speed video monitoring, but these methods will be later augmented by sophisticated algorithms that can accelerate part certification.

**Fundamental physics relating to powder-bed technology and complexity in materials**

The main discussion points from the presentation by Prof Leila Ladani, University of Texas at Arlington, USA, focused on the fundamental physics relating to powder bed technology and complexity in materials. The essential take-aways from this presentation were as follows:

- The physics associated with the various phenomena and materials are too complex to be modelled in a computationally efficient way, hence it is advisable to identify a few parameters that have the most influence and concentrate on modelling those influences using suitable simplifications and assumptions, at least for a start (for instance, consider modelling the powder bed as a block rather than as a collection of particles using 'effective powder thermal conductivity')
- It is critical to have accurate thermophysical properties, which may be temperature- and/or laser wavelength-dependent
- The research community needs more innovative approaches to be able to model the processes with the lowest computational costs.

**Modelling should go hand-in-glove with experimental efforts**

In the presentation by Prof Tarasankar DebRoy, Pennsylvania State University, USA, compelling justification was provided for using modelling hand-in-glove with experimental efforts for expanding the knowledge base associated with metal AM processes. DebRoy mentioned that it took the welding community close to a century to develop the knowhow that they currently possess. If we extrapolated that to the AM process, where the number of permutations and combinations in terms of process parameters easily surpasses that of welding, and which is slower and more expensive, it would take much longer to reach that level of knowledge – unless it is done differently.

Difficulties in optimising microstructures, part properties, and control of distortion after a build were listed as key challenges that can be tackled using digital twins. The speaker mentioned that other benefits of using digital twins included:

- A shortened time for bringing a product to market
- Increased chances for introducing process and product design innovations in the industry
- Improved agility to successfully follow market trends and the creation of a process-savvy workforce.

Some of the sub-models that can become the building blocks of a digital twin for metal AM processes were considered, and some hurdles in their development were outlined. These include the lack of a coordinated global approach between the stakeholders who are driven by their own agendas, the unwillingness of large multinational corporations to share knowledge and the difficulty in synthesising the huge amount of data being generated in the field.

**Enabling weight reductions in parts**

The main thrust of the presentation by Prof Dongdong Gu, Nanjing University of Aeronautics and Astronautics, China, was to bring to the attention of the delegates the importance of the metal AM industry to aeronautics and space in terms of enabling weight reductions in parts (through the design freedom it affords) and the acute need to develop more suitable materials and novel process innovations to achieve this purpose.

Again, the requirement for an in-depth understanding of the science underlying various processes was emphasised, with particular references to particle flow, laser energy

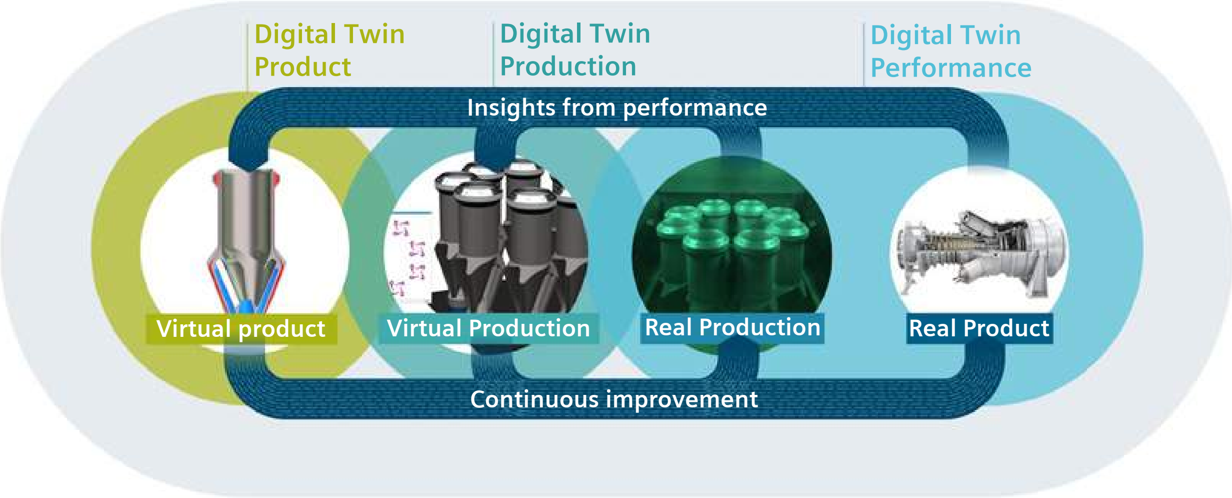



*Fig. 5 Linkages between digital twins of a product, its production and its performance (Courtesy Siemens)*

absorption, powder melting thermodynamics and surface morphology evolution.

**Training machine learning models**
Dr Amanda Barnard, CSIRO Data61, Australia, considered the intricacies of training machine learning models based on experimental results and solutions from validated physics-based models. These 'surrogate' machine learning models typically provide solutions faster than computationally prohibitive physics-based models, and so are prime candidates for use in real-time closed-loop control as artificial intelligence for data analysis in an Industry 4.0 setting.

Barnard mentioned the requirements for selecting an appropriate, interpretable machine learning model and highlighted the need for combining simulations (predictions) with informatics (inference). She cautioned against the likely traps of biases in data and learning as well as data recording errors, emphasising that surrogate models can inherit (and often amplify) the influences from these.

Possible challenges to creating machine learning models were identified as: insufficient data sets, missing data, outliers and difficulties with feature label extraction (a statistical procedure that deals with potentially correlated variables). One of the most sought-after outputs from machine learning is the ranking of features (structure) by how influential they are in predicting (controlling) labels (properties). It was suggested that one must pay as much attention as possible to the available data, 'clean' the data and standardise, as well as attempt to extract as many features (relationships) as possible from it. Models should be cross-validated and optimised to ensure that they make sense in relation to domain knowledge.

**The industrial applications of digital twins**
Chris Vains, Siemens, Australia, focused on examples from industry sectors that have already embraced digital twins in non-AM applications. This helped delegates imagine how they might expect the metal AM industry to react to the application of a well-performing digital twin in their own realm. The speaker emphasised the need to create a 'holistic' digital twin that encompasses product (design), process (production) and performance in order to facilitate continuous improvements in the delivery of solutions to customers (Fig. 5).

## Discussion on roadmap development

In the second half of the symposium, delegates took part in a collaborative workshop overseen by professional facilitators from ThinkPlace, a design and systems transformation consultancy. The aim was to collectively explore the vision, benefits and features of digital twins, the hurdles faced and their solutions within six domain topics suggested by CSIRO. Additionally, the priority of solutions for achieving the vision and the critical path to achieve these solutions – the roadmap forward – was considered. The outcomes of the workshop are summarised below.

**Vision**
The participants concluded that a digital twin for the metal AM industry should ideally:

- Accurately predict the process and include a multi-disciplinary approach
- Comprise multi-scale models that are robust
- Be validated and reliable
- Be accessible to everyone
- Have links to an open-access database that is updated by scientists globally

| | Domain | Hurdles identified | Potential solutions proposed |
|---|---|---|---|
| 1 | **AI and speed of computing for timely solutions** | • Access to data<br>• Technology limitations | • Training and skilled personnel in various domains<br>• Open data access to create more specific, simple and informed models<br>• Increased computational power through global AI and neural networks |
| 2 | **Experimental data for model validation** | • Quality of data and lack of protocols for experimentation<br>• Unwillingness to share data and results with different groups | • International collaboration on data management, framework and standards<br>• Incentives for increased collaboration, sharing of data and experiments (e.g. Git Award)<br>• Creation of protocols for data experiments |
| 3 | **Shortcomings in existing computational approaches** | • Gaps in models needing domain expertise to fill and address<br>• Technology limitations in multi-scale processing, time and 4D visual results<br>• Lack of validation standards and test cases | • Research and development for better technology at lower costs<br>• A connected network to share computational needs |
| 4 | **Lack of material property data** | • Lack of data in materials and properties relevant to AM<br>• Lack of consistent formatting standards<br>• Lack of commercial interest in sharing data | • Creation of an open database of AM materials with funding for international public research<br>• Development of standards for methods, materials and data informatics for AM |
| 5 | **Difficulties in linking codes (different scales and physics)** | • Lack of standards for data and metadata which propagates uncertainties, with missing links and parameter information<br>• Bridging multi-disciplinary teams and experts<br>• IP and legal issues | • Provide verification and validation measures and standards<br>• Use open source software or current software to its full potential |
| 6 | **Industry and research partnership** | • Lack of trust and shared vision<br>• Misalignment between researchers (publication-driven) and industry (dollar-driven) on successful outcomes, expectations and acceptance of failures | • Embedding researchers within industry and vice versa to build understanding on both sides<br>• Communication and upskilling to reduce mismatches on perspectives<br>• Consider rewards for common goals |

*Table 1 Hurdles and solutions in the implementations of digital twins for AM, as based on the roadmap discussions*

- Be able to accommodate a range of materials
- Be able to assist in product design by providing feedback to designers
- Be able to assist in virtual testing by predicting localised part properties
- Be able to assist with closed-loop-control of AM machines

**Benefits**

The participants saw the potential benefits of digital twins as:

- Enabling the virtual testing and use of new materials sooner
- Enabling the development of new materials for AM
- Enabling the extension of AM products into new applications (e.g. by improving properties through a deeper understanding of influencing factors)
- Allowing the testing of 'crazy' ideas in the virtual world, sparking innovation
- Allowing a deeper awareness of production costs

**Features**

The participants listed the required features of digital twins as:

- Able to predict defects in products or faults in processes
- Capable of arriving at an optimised process
- Able to provide data for surrogate ML models
- Able to deliver solutions for real-time decision-making
- User-friendly so that they can be used by anybody in the product design and production environments

**Hurdles and solutions**

The participants discussed the hurdles and solutions for the six pre-selected domains as:

1. AI and speed of computing for timely solutions
2. Experimental data for model validation
3. Shortcomings in existing computational approaches
4. Lack of material property data
5. Difficulties in linking codes (different scales and physics)
6. Industry and research partnership

*Fig. 6 A section of the delegates during the discussion session for roadmap development*

In three round-robin sessions, the participants moved between domains they themselves selected in order to explore the hurdles and potential solutions in those domains. Ideas were recorded onto poster templates, which were subsequently used for the prioritisation of potential solutions.

The ideas that were put forward are summarised in Table 1. Priority Solutions and Roadmap are being developed and will be reported on shortly in a separate publication.

## Final remarks

This one-day symposium brought together international stakeholders in the metal AM industry to deliberate on the creation of a true digital twin for AM processes and to exchange ideas towards creating a roadmap. It was abundantly clear from these discussions that the metal AM industry needs computational assistance for several reasons. An overarching requirement is to expand the scientific knowledge base within a reasonable period. An example of a more specific requirement is to support the development of novel AM alloys and associated processes to satisfy strong demand for lightweight and heat-resistant AM structures from sectors such as aerospace.

The participants agreed that a digital twin would significantly help the AM industry, especially as it transitions into the connected economies of Industry 4.0, where the focus will be on productivity improvements in the production process. In a future publication, prioritised solutions, as well as a suggested roadmap, will be dealt with in some depth.

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www.pmexchina.com

**Manufacturing World Nagoya 2020**
April 15–17, Nagoya, Japan
www.japan-mfg-nagoya.jp/en-gb.html

**Rapid + TCT 2020**
April 21–23, Anaheim, USA
www.rapid3devent.com

**Space Tech Expo USA**
May 18–20, Long Beach, USA
www.spacetechexpo.com

**WORLDPM2020**
June 27–July 1, Montréal, Canada
www.worldpm2020.org

**Formnext + PM South China**
September 9–11, Shenzhen Shi, China
https://formnext-pm.hk.messefrankfurt.com/shenzhen/en.html

**Euro PM2020**
October 4–7, Lisbon, Portugal
www.europm2020.com

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