

THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

# METAL AM

Vol. 5 No. 1 SPRING 2019



**in this issue**

**3D ADDITIVE MANUFACTURING  
AM IN AUSTRALIA  
SCALMALLOY CASE STUDY**



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# METAL ADDITIVE MANUFACTURING

## Taking the long view

Just how far Additive Manufacturing technology has come over the last thirty years was put into perspective during a recent visit by two of the *Metal AM* magazine team to UK-based 3T Additive Manufacturing. The company's outgoing CEO, Ian Halliday, first embraced the commercial potential of rapid prototyping in 1989, and has witnessed at first hand its evolution into the disruptive force that it is today. A key observation featured in our discussion was how, whilst current realities do mirror past expectations, the speed of adoption of the technology by end-users was commonly over-optimistic.

Looking further from home, few can be unaware of the growing presence of Australian firms on the international AM scene. The 'lucky country', rich in natural resources, has long harboured ambitions to develop the technologies that could add value to domestically-sourced raw materials by processing them into end-products at home, rather than importing end-products at a higher price. As Alex Kingsbury explains, this has resulted in the development of world-class research and education facilities, and a dynamic and outward-looking business environment in which Additive Manufacturing is thriving.

If you are viewing this issue of *Metal AM* in digital format and are interested in reading the print edition, look out for the complimentary copies offered at a host of events this spring, including AMUG, Rapid + TCT, AMPM2019, and other national and regional conferences and seminars throughout the world.

Nick Williams  
Managing Director  
*Metal Additive Manufacturing*

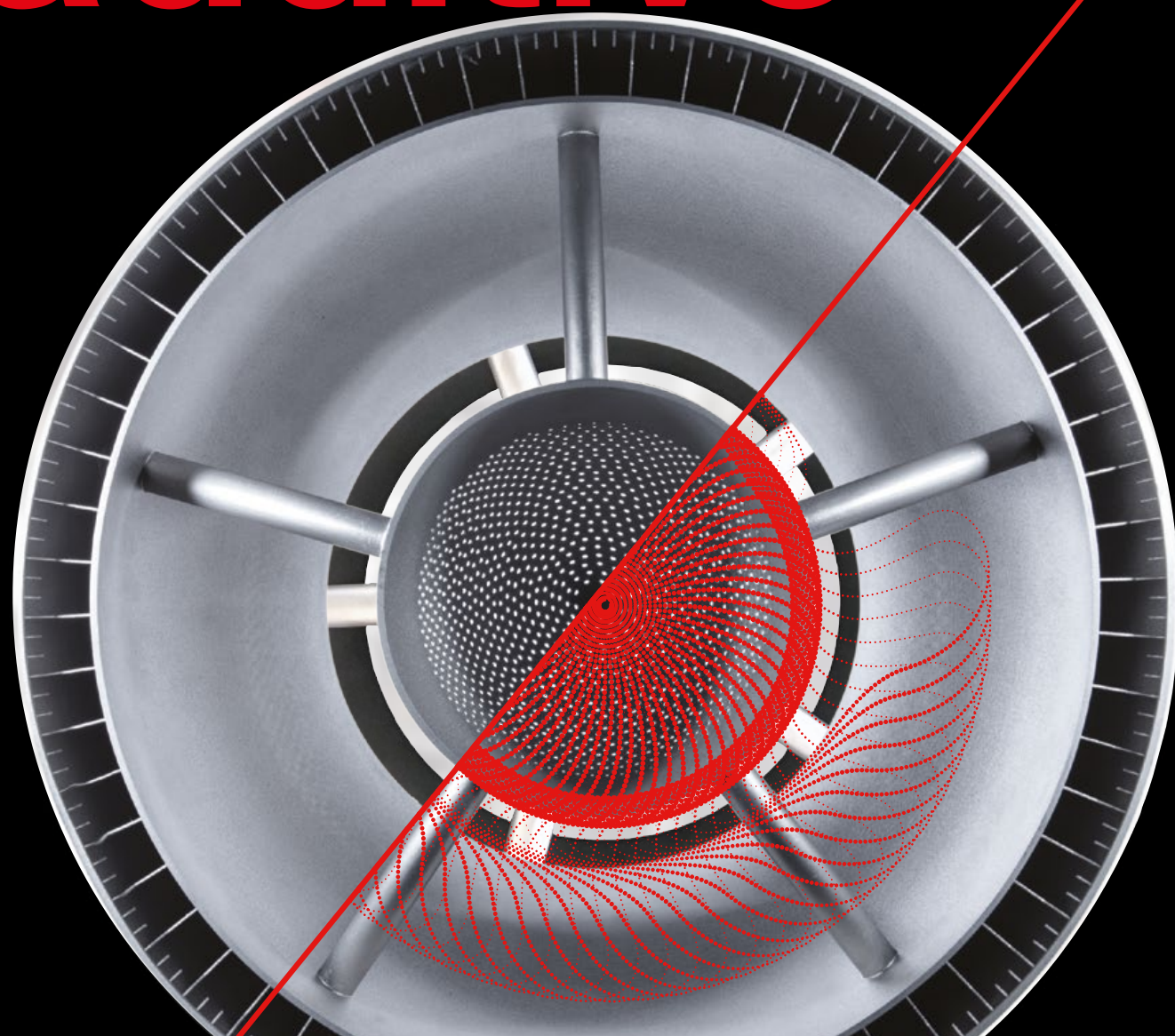


#### Cover image

A high-performance additively manufactured heat exchanger from Australia's Conflux Technology



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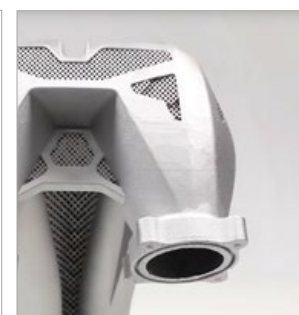
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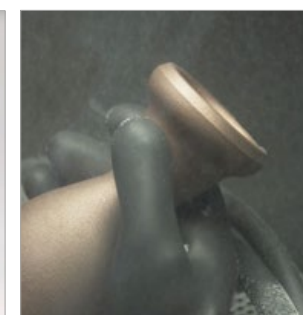
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With two decades of experience in part production using AM technologies, 3T Additive Manufacturing Ltd, based in Newbury, UK, today enjoys a strong position as an international developer and supplier of cutting edge components. At a time of transition for the company, we met with outgoing CEO Ian Halliday and his successor, Nigel Robinson, to discuss the evolution of the metal AM industry to date and the business's plans for further expansion.

### 115 Natural resources and national strategies: How metal Additive Manufacturing is taking off in Australia

Australian expertise is today becoming much more commonplace on the international AM scene. From technology and materials suppliers to application developers, companies are growing on the back of world-class research and education facilities, and a business environment where innovation and international trade are rewarded. Combine this with an abundance of AM-relevant natural resources and, as Alex Kingsbury explains, an environment has been created where AM is thriving.

### 127 Scalmalloy® is too expensive and design optimisation only makes sense in aerospace. True or false?

AM is not a cheap production process. The software, machine time, materials and expertise required to make the most of the technology all come at a significant cost. The resulting financial pressures may give rise to the temptation to select a

material on its price and view advanced topology optimisation as a luxury. As Jon Meyer and John Barnes demonstrate, the unique capabilities of AM mean that basing material choice on cost without considering the impact of material performance on the mass of the part is a false economy, limiting the competitiveness of AM and the potential of an application.

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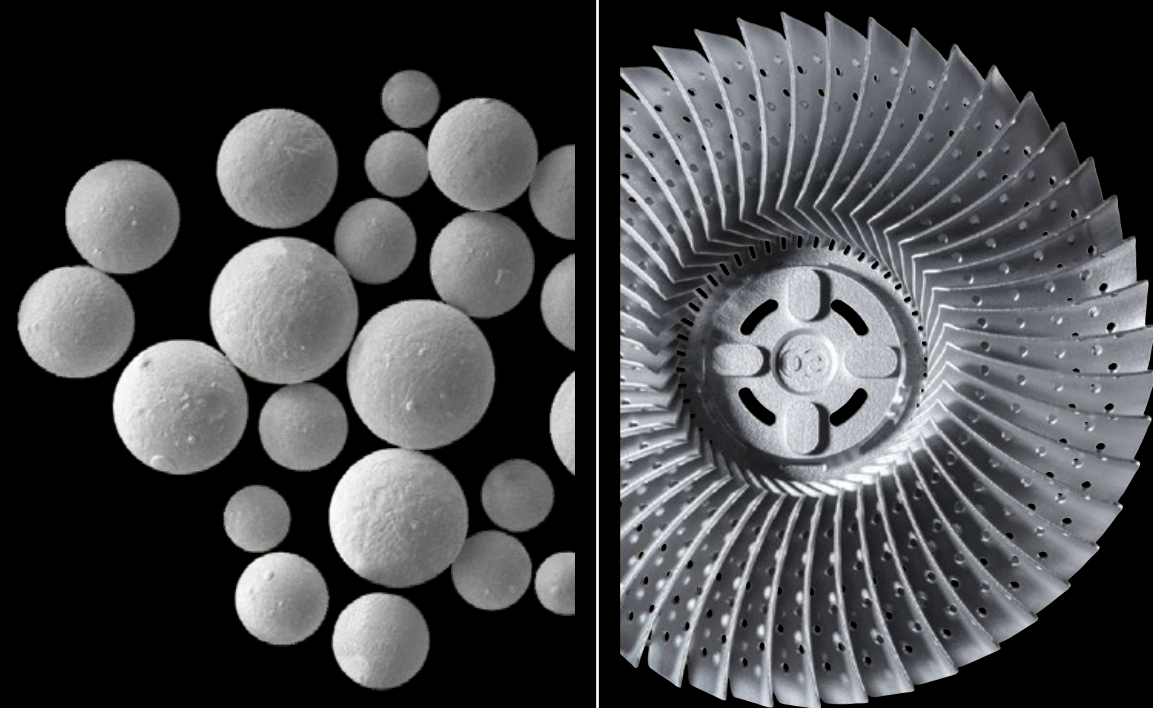
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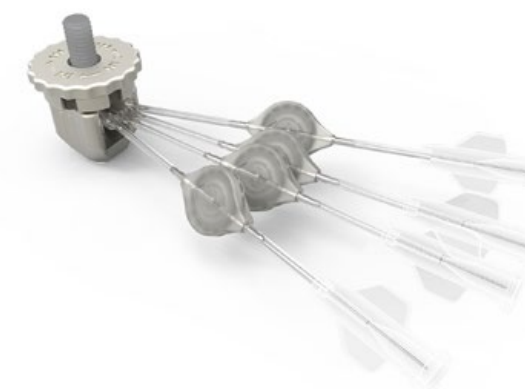
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## industry news

### Metal Additive Manufacturing enables device with potential to cure Parkinson's disease

Renishaw plc, Gloucestershire, UK, has produced a titanium port by metal Additive Manufacturing for use in a groundbreaking clinical trial. Manufactured on behalf of the North Bristol NHS Trust, the device enables the precise delivery of a new drug candidate, Glial Cell Line Derived Neurotrophic Factor (GDNF), directly into the brain of individuals with Parkinson's disease, with the aim to regenerate dying dopamine brain cells and thereby improve symptoms.

Renishaw worked with Prof Steven Gill, Consultant Neurosurgeon, to manufacture the new drug delivery system, which reportedly offers a practical method to bypass the blood-brain barrier. During the trial, forty-two patients had the AM titanium port embedded into their skull, through which GDNF was delivered via micro-catheters to the putamen, a critical region of the brain for motor function. The device was implanted using the Renishaw Neuromate™ surgical robot, which positioned four catheters into the brain.



*A four-needle application set is designed to kinematically locate and lock onto a transcutaneous port implanted on the patient's skull (Courtesy Renishaw plc)*

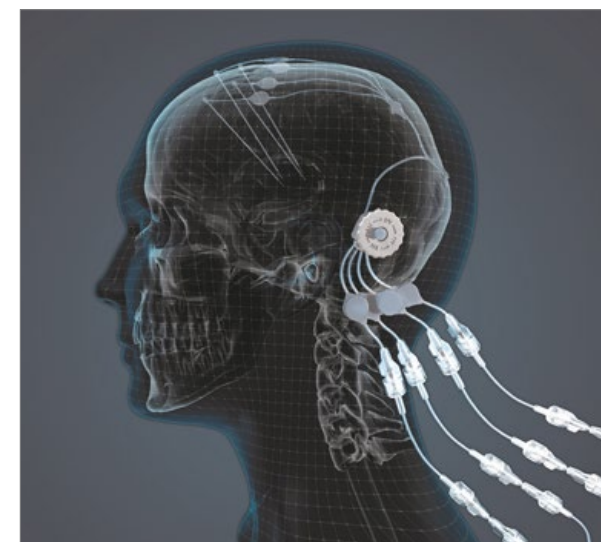
The trial was funded by Parkinson's UK with support from the Cure Parkinson's Trust, in association with the North Bristol NHS Trust. Results announced in February 2019 were said to show that the drug delivery system performed effectively and reliably, and a similar device developed by Renishaw called Neuroinfuse™ is now being used in other clinical trials.

The results of the trial were aired on television in the UK as part of a documentary, *The Parkinson's Drug Trial: A Miracle Cure?*, on BBC Two. Paul Skinner, General Manager for Neurological Products at Renishaw, stated, "It has been a privilege to work alongside the study team and with the participants in this ambitious trial. We are very encouraged that there were changes in the brain scans, demonstrating that GDNF is having an effect, and that the delivery system achieved precision administration of drugs into the brain."

"This provides great potential for using the drug delivery system, being developed by Renishaw, for future Parkinson's studies and experimental treatments for other neurodegenerative diseases and brain tumours," he concluded.

Prof Gill commented on the results, "This is a significant breakthrough in our ability to treat neurological conditions such as Parkinson's, because most drugs that might work cannot cross from the bloodstream into the brain due to a natural protective barrier. Even at a low dose we have seen evidence of patient improvement, which is incredibly encouraging."

[www.renishaw.com](http://www.renishaw.com) ■■■



*The new drug delivery system, manufactured by Renishaw for the North Bristol NHS Trust, offers promising results for the treatment of Parkinson's disease (Courtesy Renishaw plc)*



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### Digital Metal DM P2500 becomes first Binder Jetting system to achieve UL certification

Digital Metal has announced that its DM P2500 has become the first metal Binder Jet Additive Manufacturing system to receive UL certification. Founded in 1894 and headquartered in the USA, UL (Underwriters Laboratories) is the world's largest not-for-profit product safety testing and certification organisation. The new UL certification proves that the DM P2500 printer meets all expected standards for the US and Canadian markets.

Digital Metal stated it has received notice of completion of product testing and authorisation to apply the UL Mark to its DM P2500. The company's proprietary Binder Jetting technology enables the production of high-quality complex objects with superior surface finish.

The technical team at Digital Metal stated that during the concept phase of its DM P2500 system, the requirements for both UL and CE certification were addressed. Preparation for meeting these standards involves all steps of developing and designing a new machine. Each

single component and system in the machine must be taken into account. Not only does this ensure machine safety, it also contributes to good working environment.

"Employee and customers safety should be the number one priority for every business owner. It is crucial that the equipment you use on a regular basis is working

properly and more importantly, that it is manufactured and installed correctly. The UL certification is an important way to ensure that and we are very happy to receive it," stated Ralf Carlström, General Manager at Digital Metal.

Digital Metal was founded in 2012 and has its headquarters in Höganäs, Sweden. The company is part of Höganäs Group, the world's largest producer of metal powders. In addition to machine sales, Digital Metal also manufactures metal components for its customers.

[www.digitalmetal.tech](http://www.digitalmetal.tech) ■■■



*Digital Metal's DM P2500 is the first Binder Jetting system to achieve UL certification*

### Tekna to begin powder production in Europe

Tekna, a subsidiary of Arendals Fossekompagni ASA with its headquarters located in Sherbrooke, Canada, has announced a €5 million investment for the production of spherical powders intended for Additive Manufacturing at its new industrial site in Mâcon, France. The site can accommodate various specialised plasma atomisers, enabling the manufacturing of a variety of strategic materials and alloys.

The production volume on site will be capable of achieving 400 to 500 tons, increasing Tekna's annual global capacity to over 1000 tons. The company stated that replicating

its production means and processes in Europe will ensure that Tekna perfectly duplicates its powder production activities and provides a continuous supply to its clients. In addition to the start-up of powder production, the new site hosts its European Customer Service Centre and a laboratory dedicated to quality assurance and the development of new powders.

"In line with the rapid growth of our activities, this major investment enables us to provide our clients with closer support while accounting for the safeguarding of their supply chain and volume expansion, in addition to

controlling costs and logistical risks," stated Rémy Pontone, VP, Sales and Marketing, and Managing Director of Tekna Plasma Europe SAS.

"At Tekna, we guarantee our clients high-quality products that are always delivered on schedule at the best costs. I would like to acknowledge the technical and manufacturing teams on site who have contributed to successfully completing this strategic project. As a result, it is our clients who are the big winners," added Tekna's CEO, Luc Dionne.

Tekna uses a plasma spheroidisation process to manufacture a wide range of metal powders. It also produces a range of turnkey plasma systems for the production of metal powders.

[www.tekna.com](http://www.tekna.com) ■■■



## Xerox eyes metal Additive Manufacturing with acquisition of Vader Systems

Iconic printer and photocopier manufacturer Xerox, headquartered in Norwalk, Connecticut, USA, announced during its 2019 Investor Day that it has acquired metal Additive Manufacturing company Vader Systems. The company stated that this acquisition will enable it to offer its customers access to low-cost AM with more metals.

"Manufacturing customers want to use 3D printing, but the current offerings only serve the prototyping market well, not broad manufacturing," the company stated. "Xerox-developed, acquired and partnered printing, software and material technologies are expected to deliver the productivity, materials range and cost and design tools to enable part manufacturing."



The Polaris metal Additive Manufacturing system (left) uses Vader's patented liquid metal process. The Ares Microsphere Production System (right) is reported to produce highly uniform and consistent metal 'microspheres' for on-demand usage (Courtesy Vader Systems)

The company also stated that it has received strong customer feedback from major manufacturers, and that it expects its metal and plastic AM solutions to move into product commercialisation this year.

Based in Buffalo, New York, USA, Vader Systems is a developer of liquid metal Additive Manufacturing technology which primarily uses affordable metal wire feedstock. Its offerings include the Vader Polaris™ liquid metal AM system, the Magnet-o-Jet™ Subsystem for hybrid manufacturing equipment integration, and the Ares™ Microsphere Production System for the production of spherical metal powders.

No further comment on the acquisition has been given at this time, but notably, Vader Systems' home page has been replaced with Xerox's page on Additive Manufacturing via redirect. On this page, Xerox states: "Xerox is constantly looking for new ways to deliver more value to our customers. We are leveraging our experience and expertise in digital printing to polymer and metal 3D printing technologies and will introduce new equipment, materials, services and design tools to the market."

[www.xerox.com](http://www.xerox.com) ■ ■ ■

## USPTO approves Authentise secure streaming and monitoring patent for digital manufacturing

Authentise, a developer of data-driven workflow tools for Additive Manufacturing, has announced that the United States Patent and Trademark Office (USPTO) has approved its patent: 'System, Method and Program Product for Digital Production Management.' The patent shows how streaming designs or machine code directly into manufacturing devices (down the PLCs that control the individual movements within the machine, eventually) can help not

only protect the intellectual property of the part but enable remote integrity control (by monitoring the feedback remotely) and close the loop completely by making remote in-process amendments, such as integrating watermarks in the object once we've verified that the part was produced correctly.

"We are happy to have our leadership in advanced security and integrity tools for digital manufacturing, and additive in

particular, recognised by the US Patent Office," stated Andre Wegner, CEO of Authentise. "The patent was a foundational piece of our early days, and while the distributed manufacturing future it predicted is further away than we hoped it still sends important messages. First is that data-enabled manufacturing processes such as Additive Manufacturing can deliver entirely new functionality such as digital quality assurance and seamless intellectual property protection. Secondly, that the resulting new business models such as distributed manufacturing are an inevitability that we must invest in, today."

[www.authentise.com](http://www.authentise.com) ■ ■ ■

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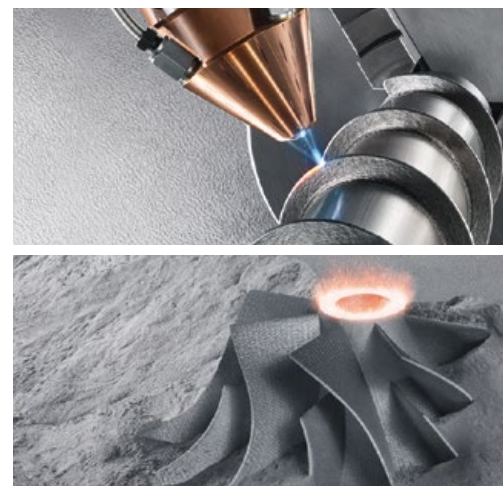

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## Prodways reports revenue up 75% in 2018

Prodways Group has reported that its revenue was €60.9 million in 2018, up 75% from €34.8 million in 2017, exceeding the Group's objective for the year, which had already been upgraded to €58 million. The surge reflects growth in all of the group's activities, bolstered by the contributions of Solidscape and Varia 3D.

The Systems division, comprising 3D software, Additive Manufacturing systems and related materials, generated revenue of €13.6 million in the fourth quarter of 2018, a significant rise of 85.5% compared with the fourth quarter of 2017. Year-on-year, the Systems division posted impressive growth of 120.8%, to €38.4 million. In the fourth quarter, the Systems division benefitted from the integration of the US 3D printer maker Solidscape, which contributed approximately €2 million to quarterly revenue, as well as from strengthened marketing and sales efforts and the release of new machines (ProMaker LD-20 and ProMaker V10). Prodways Group saw an increase in the number of customers with more than one Prodways machine and shortened decision-making processes. In the medium term, the increase in sales of machines dedicated to manufacturing applications is expected to benefit materials sales.

Revenue from the Products division, including on-demand parts manufacturing and medical applications, was €5.9 million in the fourth quarter of 2018, up 2.9% compared to a strong fourth quarter in 2017. The on-demand parts production business remained buoyant, with more than 1 million parts manufactured this year, and higher demand for mass production, particularly in the optics and aeronautics sectors, for which production capacities were expanded during the financial year.

In January 2019, Prodways Group completed the acquisition of Surdifuse-L'Embout Français, a major French player in audiology. Following the merger between Surdifuse-L'Embout Français and Interson-Protac, acquired in 2017, the Group aims to create the French leader and one of the European leaders in customised hearing aid eartips. This acquisition is expected to generate more than €3 million in revenue in 2019 and to have a positive impact on the group's income.

In the current scope and excluding new acquisitions, the Group expects for 2019 full-year revenue growth above 15%. This increase will be especially pronounced in the Systems division, driven by the launch of new machines: ProMaker V10, ProMaker LD-20 and Solidscape DL. In the Products division, the group continues to implement the digital transition of its medical activities, which should bear fruit in the medium term.

www.prodways-group.com ■■■

## AP&C plans growth with expansion of Saint-Eustache

AP&C, a GE Additive company, has purchased a 40,000 m² plot in Innoparc Albatros, Saint-Eustache, Montreal, Canada, where it has been based since 2016, to support its future growth plans. The firm currently employs around one hundred at its Allée du golf facility Innoparc Albatros.

Alain Dupont, AP&C's President and CEO, stated, "We are thrilled to work with the dynamic Ville de Saint-Eustache team! Our firm is currently enjoying rapid growth and we need more space for our projects, along with a good location for drawing fresh talent. Innoparc Albatros meets both of these urgent needs. It is clear that AP&C's future is right here in Québec and, in particular, Saint-Eustache!"

Pierre Charron, Mayor of Saint-Eustache, commented, "We are extremely proud that AP&C, the flagship of its industry, has decided to multiply its activities in Innoparc Albatros, thereby making big contributions to Saint-Eustache's economy. Innovation breeds more innovation and we are confident that AP&C's increased presence will bring new businesses to our techno-park and encourage other high-tech firms to come here."

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## Norsk and SAE collaborate on world's first DED specification

Norsk Titanium and SAE International have released the first specifications for Directed Energy Deposition (DED) Additive Manufacturing. Developed within the SAE Additive Manufacturing Committee, the specifications utilise Norsk's Rapid Plasma Deposition (RPD) process and material requirements. With the release of the SAE Aerospace Materials Specifications (AMS) documents, the process will now be available to a broader base of users across the world.

"Our engineers have thoroughly enjoyed working with the SAE team to validate our proprietary process with the engineering community," stated Michael Canario, Norsk's President and CEO. "RPD is truly a disruptive process to the current subtractive manufacturing industry with wide benefits supporting not only the supplier, but the end-user."

The release of AMS7004, *Titanium Alloy Preforms from Plasma Arc Directed Energy Deposition Additive Manufacturing on Substrate Ti-6Al-4V Stress Relieved* and AMS7005 *Wire Fed Plasma Arc Directed Energy Deposition Additive Manufacturing Process*, establishes the minimum basis required for the procurement of RPD

Preforms from Norsk by an aerospace or non-aerospace customer. In addition, the specifications are said to support the regulatory certification process by ensuring consistent process and quality control.

"Given that advanced materials and advanced manufacturing are strategic focus areas for SAE International, we continue to support the aerospace industry's advances and adoption of Additive Manufacturing technologies," stated David Alexander, Director, Aerospace Standards at SAE International. "As well as contributing vital technical expertise, Norsk Titanium played a leadership role as document sponsor in the development of the groundbreaking new specifications and along with the other AMS-AM output, these new material and process specifications help address the regulatory authorities' request for guidance material for this critical emerging technology."

SAE's AMS-AM Committee continues to develop aerospace material specifications for metal and polymer AM to support the needs of the aerospace industry. Over 500 global participants from more than twenty countries representing aircraft, spacecraft, and engine OEMs, material suppliers, operators, equipment/system suppliers, service providers, regulatory authorities, and defence agencies are involved in the committee.

[www.norsktitanium.com](http://www.norsktitanium.com) | [www.sae.org](http://www.sae.org) ■■■

## Elnik Systems to provide MIM expertise to Triditive's Scaladd Consortium

Triditive, Spain, has announced that US-based Metal Injection Moulding (MIM) equipment specialist Elnik Systems is to provide comprehensive metallurgical assistance and production services, at its German and US facilities, to the Scaladd Consortium.

The Scaladd Consortium was established by Triditive to grant industrial companies access to Additive Manufacturing production in metals and polymers, as well as the technology and services provided by consortium members. Through the cooperation, Elnik will draw on its expertise in the MIM debind and sinter industry, giving access to its wide range of advanced furnaces suited to the processing of metal components, such as those manufactured on Triditive's AMCell machines. Elnik builds furnaces that can process any metal with any binder, including one-step systems and catalytic and solvent debind options.

Triditive expressed its hope that the equipment provided will help to make metal Additive Manufacturing a 'final solution' for the industry. "We have a clear objective working with Elnik Systems: to demonstrate that AM is ready for mass manufacturing in metals using AMCell® automated machines," stated Mariel Díaz Castro, Triditive CEO.

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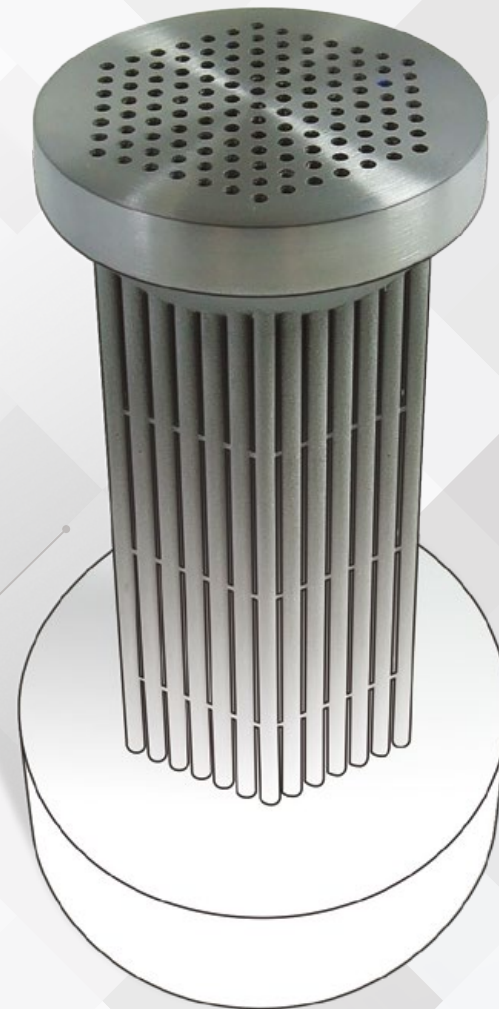
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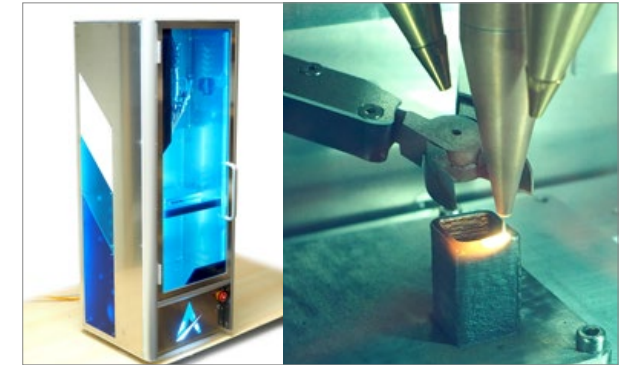


## Additec launches desktop-size metal AM system

Additec, located in Las Vegas, USA and Bremen, Germany, has launched a new desktop-size metal AM system named the  $\mu$ Printer. The  $\mu$ Printer can process both wire and powder feedstock using the company's unique Laser Metal Deposition-Wire Powder (LMD-WP) process, with the complete system being offered at a price point starting at \$90,000 USD.

Producing parts from wire has the advantage of low material cost and high availability of stock, being safe and clean to handle. Combining the ability to process powder is said to close the gap to conventional LMD, whilst also allowing users to mix alloys in-situ. Switching between wire and powder on the  $\mu$ Printer does not require a nozzle change and can be done automatically on the same part.

Additec's LMD-WP process works by having multiple high-power diode laser sources arranged around the central axis of the deposition head. Wire is fed through a central wire guide, while powder is fed through an annular gap nozzle around the wire guide. Closed loop process control is a standard feature on the  $\mu$ Printer, with the system being controlled either via a locally hosted web interface, or through USB.



Additec's desktop size  $\mu$ Printer can processes both wire and powder feedstock (Courtesy Additec)

Process stability was said to be the most important aspect for the development of the  $\mu$ Printer. The company developed its own process control structure to adjust the processing parameters and measure the height of the individual layers, allowing nozzle to part distance to be adjusted automatically.

Additec's LMD-WP process is also suitable for cladding and repair work. It is also offered as a retrofit package that could be used to turn existing CNC platforms into metal AM or hybrid manufacturing systems.

[www.additec.net/ \$\mu\$ Printer](http://www.additec.net/<math>\mu</math>Printer) ■■■

## Protolabs adds Inconel 718 for metal AM

Protolabs, headquartered in Maple Plain, Minnesota, USA, has added Inconel 718 to its materials offering for Laser Powder Bed Fusion (L-PBF) metal Additive Manufacturing. Due to the high strength and corrosion-resistant properties of the material, along with its ability to be used at extreme temperatures, Inconel 718 is a proven superalloy in the development of turbojet engines for aircraft, among a variety of other applications.

Daniel Cohn, General Manager of 3D Printing Services at Protolabs, stated, "Other manufacturing methods sacrifice some of the material properties of Inconel, therefore I am delighted that Protolabs is now able to offer this material through 3D printing. Combining the exceptional properties of the material with Protolabs' expertise in DMLS means we are able to rapidly produce complex geometries for parts which are exposed to the harsh environments typical of the aerospace sector."

As a nickel-based heat-resistant alloy, Inconel 718 can be used at temperatures between -252°C and 704°C. Its high-temperature strength is derived from its ability to create a thick, stable passivating oxide layer at high temperatures, protecting the material from further attack. Inconel also has good tensile, fatigue, creep and rupture strength.

[www.protolabs.com](http://www.protolabs.com) ■■■

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## Ansys to acquire materials information technology provider Granta Design

Ansys, Pittsburgh, Pennsylvania, USA, a provider of engineering simulation software, has entered into a definitive agreement to acquire Granta Design, Cambridge, UK, a provider of materials information technology. The transaction was expected to close in the first quarter of 2019.

With advances in the performance of metals and other materials, as well as innovations in areas such as Additive Manufacturing, manufacturers have a large range of material choices when developing products. At the same time, they require accurate, traceable and reliable materials information to make smart choices and to ensure simulation accuracy.

Ansyes' customers will benefit from access to Granta's software for managing corporate material intelligence and the market-leading solution for materials sources, selection and management. Granta stated that its customers can now expect easier access to Ansys simulation technology. The company will also continue its open ecosystem, integrating with a range of product lifecycle management, CAD and computer-aided engineering solutions.

Granta's products include Granta MI, a system for enterprise materials information management, and CES Selector, which enables users to explore the impact that different materials have on the behaviour of their products. Granta also develops CES EduPack, a teaching resource for materials topics in engineering, science, processing and design, which is used by more than 1,000 universities worldwide. Its customers include Airbus, General Motors, Emerson Electric, Lockheed Martin, NASA, Saudi Aramco and Rolls-Royce.

"Granta Design has pioneered the field of materials information technology," stated Shane Emswiler, Ansys Vice President and General Manager. "With materials engineering becoming an increasingly important aspect of product development, our customers require high-quality and comprehensive materials information for accurate simulation results. Integrating Granta's solutions into the Ansys portfolio will provide a seamless user experience – and enable our customers to innovate like never before."

"For nearly fifty years, Ansys has been the leader in engineering simulation," added David Cebon, Co-founder and Managing Director of Granta Design. "Combining that expertise with Granta's decades of experience in material intelligence will help our customers make smarter decisions when developing their next-generation products."

www.ansys.com

www.grantadesign.com ■■■

## Desktop Metal receives further \$160 million funding

Desktop Metal, Burlington, Massachusetts, has announced the closing of a \$160 million funding round, led by Koch Disruptive Technologies (KDT). Since its inception in 2015, Desktop Metal has now received a total of \$438 million in funding, reported to be the largest total funding of any private AM company to date. KDT, a subsidiary of Koch Industries, is an investment firm focused on finding and funding innovative and emerging technologies and in the last six years has invested more than \$17 billion into technology companies.

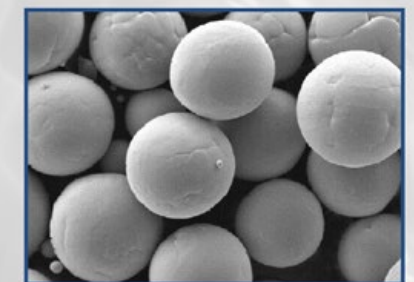
Chase Koch, President of KDT, stated, "Desktop Metal's 3D printing solutions can redefine prototyping and mass production of metal products, which has profound disruptive implications for manufacturers like Koch Industries. We are very bullish about the prospects of Desktop Metal, not just as an investor, but also as a customer and partner."

Additional investors in this Series E funding round include GV (formerly Google Ventures), Panasonic, and Techtronic Industries, as well as previous venture capital investors in the company, including Lux Capital, New Enterprise Associates (NEA) and Kleiner Perkins.

www.desktopmetal.com ■■■

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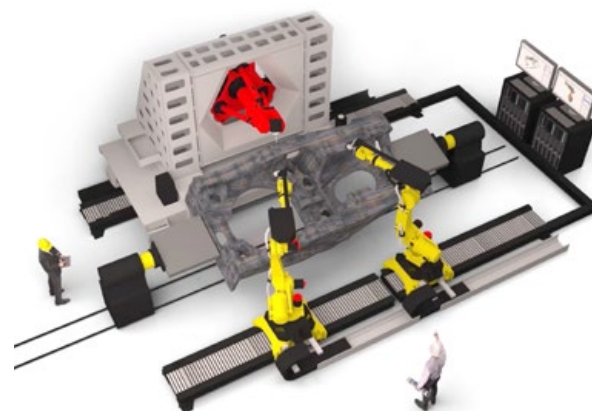


## Large Additive Subtractive Integrated Modular Machine ready to build

The Large Additive Subtractive Integrated Modular Machine (LASIMM) project has announced that the hybrid machine, which offers metal Additive Manufacturing and subtractive manufacturing capabilities, is now ready to build demonstrator parts.

The new system, said to be one of the world's largest hybrid manufacturing machines, is expected to be capable of manufacturing large pieces of metal and large parts and structures for construction. It was developed by ten partners with funding from the European Union's Horizon 2020 research innovation programme, in the hope of reducing costs and improving efficiency by producing a machine with the capability to manufacture components for the most demanding industries, directly from CAD models.

The machine will now be tested to manufacture a demonstrator part designed by industrial end-users. It offers capabilities for Additive Manufacturing, machining, cold-work, metrology and inspection, said to deliver a 20% reduction in time and cost expenditure, as well as



*LASIMM was developed through a EU Horizon 2020 research innovation programme. The system will be capable of manufacturing large pieces of metal for numerous applications (Courtesy EWF)*

a 15% increase in productivity for high-volume Additive Manufacturing.

It also includes a modular configuration of industrial robot arms for the Additive Manufacturing of aluminium and steel, and a specialised milling robot for machining away surplus material to provide the final finish. This process will enable entire large-scale industries to move away from standardised components and towards bespoke solutions for industries such as aerospace, renewables, energy, transport, construction and more.

In the field of software, the LASIMM project is also endeavouring to move from a single machine process CAM towards a multi-machine multi-process CAM, driving hybrid machines where multiple processes are combined to manufacture the end component.

Eurico Assuncao, Deputy Director at the European Federation for Welding, Joining and Cutting (EWF) and LASIMM Project Coordinator, stated, "While 3D printing for consumers and makers has received a great deal of publicity, it is within the industrial manufacturing and construction industries that this technology could have its most significant and lasting impact."

"Its use has now reached a tipping point and this technological achievement will pave the way to enable entire construction infrastructures to be 3D printed in the future," he continued. "At EWF, we are hard at work to ensure these advanced equipments are handled by adequately trained and qualified professionals. We are thrilled to be part of this unique project."

LASIMM's project partners include the European Federation for Welding, Joining and Cutting, BAE Systems (Operations) Ltd., Foster + Partners Limited, Vestas Wind Systems A/S, Cranfield University, Global Robots Ltd., Loxin2002, S.L., Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung GmbH, Autodesk Limited, and Instituto Superior Técnico.

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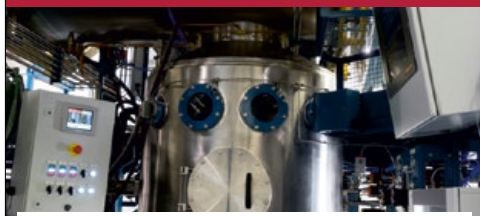
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## Additive Industries receives €10 million for international expansion

Additive Industries, Eindhoven, the Netherlands, has secured a loan of €10 Million from BOM Brabant Ventures and existing shareholder Highlands. BOM Brabant Ventures is a regional investment fund in the Dutch province of North-Brabant, an area home to many high tech OEMs in and around Eindhoven, where Additive Industries was founded in 2012.

"Additive Industries plays an important role in 'smart industry' developments in Brabant, one of the cornerstones in our investment policy," commented Miriam Dragstra, CCO of Brabant Development Agency (BOM). "The company has everything in place to become a leading global player in its market. Both employment and innovation of Brabant manufacturing industries benefit from this. Therefore, we are proud to be financing Additive Industries' growth plans and assist the ambitious management team to expand their global footprint."

"From the start, we have worked hard to build a stable and solid financial basis for the long term plans of Additive Industries," added Jonas Wintermans, Co-founder of Additive Industries and Board Member of Highlands, together with his brother Boris Wintermans. "We have great confidence in the ambitions of the team. This loan is both a proof-point in the company history that underlines the trust we have in the team, as well as an essential fuel for further development of the business."

Ilko Bosman, CFO of Additive Industries, stated, "We are grateful for the continuous support we have received from Highlands since our inception as well as for the new partnership and trust of BOM Brabant Ventures. We will invest the funds in advancing our process & application development activities, increasing R&D and expanding our support infrastructure. Customer satisfaction is our number one priority."

www.additiveindustries.com ■■■

## Furnace and heat treat specialist Ipsen appoints Somary as group CEO

Ipsen International Holding GmbH, Kleve, Germany, has announced the appointment of Geoffrey Somary as CEO of Ipsen Group worldwide. Somary succeeds former Thorsten Krüger, who served as CEO from 2013-2019 and who has now moved to the company's Advisory Board.

Since 2005, Somary has held various senior positions within Ipsen and was said to have been closely involved with customers and with team members of the company. He has reportedly demonstrated the ability to bring together employees of different cultures in a way that delivers the best possible solutions to Ipsen customers.

The Advisory Board expressed its thanks to Krüger for his contribu-

tions to the company since his appointment in 2013. It was stated that, in shifting his role from operational to advisory, he will continue to support the further development of the company.

Ipsen designs and manufactures industrial vacuum and atmosphere heat-treating systems, supervisory control systems and predictive maintenance platforms for a wide variety of industries, including aerospace, automotive, commercial heat treating, energy and medical. The group has production locations in Europe, North America and Asia, along with representation in thirty-four countries.

www.ipsenUSA.com ■■■

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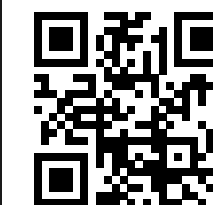
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## Liebherr begins serial metal Additive Manufacturing of aerospace components

Following approval by Airbus, Liebherr-Aerospace & Transportation SAS, headquartered in Lindenberg, Germany, has begun the serial metal Additive Manufacturing of components for the company, beginning with nose landing gear brackets for the Airbus A350 XWB. These brackets will be the first Airbus parts to be qualified for Additive Manufacturing in titanium.

Josef Gropper, Managing Director and COO of Liebherr-Aerospace & Transportation SAS, stated, "This milestone shows that we are a recognised pioneer and trusted partner in the aerospace world. We are planning to produce more complex components in the future in order to fully utilise the potential of Additive Manufacturing."

Liebherr launched its Additive Manufacturing / Research & Technology project, headed by Alexander Altmann, more than six years ago from its Lindenberg facility. On March 30, 2017, Airbus successfully flew Liebherr-Aerospace's additively manufactured spoiler actuator valve block on a flight test A380. This marked the first additively manufactured primary flight control hydraulic component flown on an Airbus aircraft.

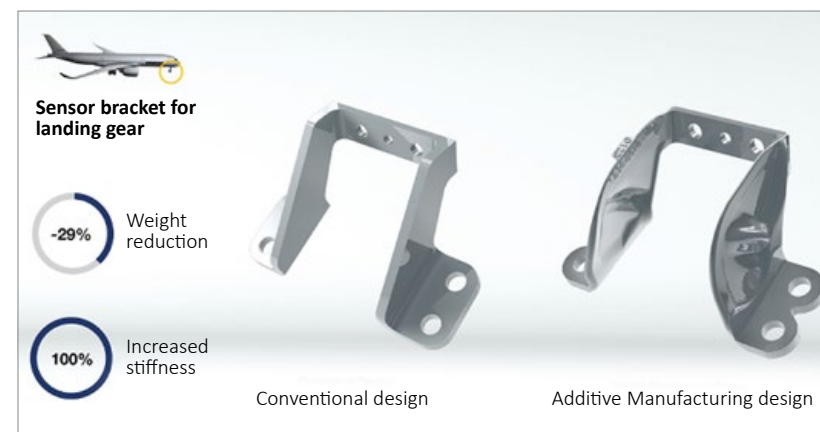
In Autumn 2017, Liebherr-Aerospace Lindenberg GmbH, Liebherr's centre of excellence for flight control systems, landing gears, gears and gearboxes, achieved authorisation by the German Federal Aviation Office (Luftfahrtbundesamt, LBA) to produce components using metal Additive Manufacturing. It has since been producing class 2 and 3 titanium serial parts by AM, delivering them under EASA Form 1.

Liebherr-Aerospace & Transportation is one of eleven divisional control companies within the Liebherr Group and coordinates all activities in the aerospace and transportation systems sectors. The company has more than five decades of experience supplying systems for the civil and military aviation industry, with the range of aviation equipment it produces including flight control and actuation systems, landing gear and air management systems, gears, gearboxes and electronics.

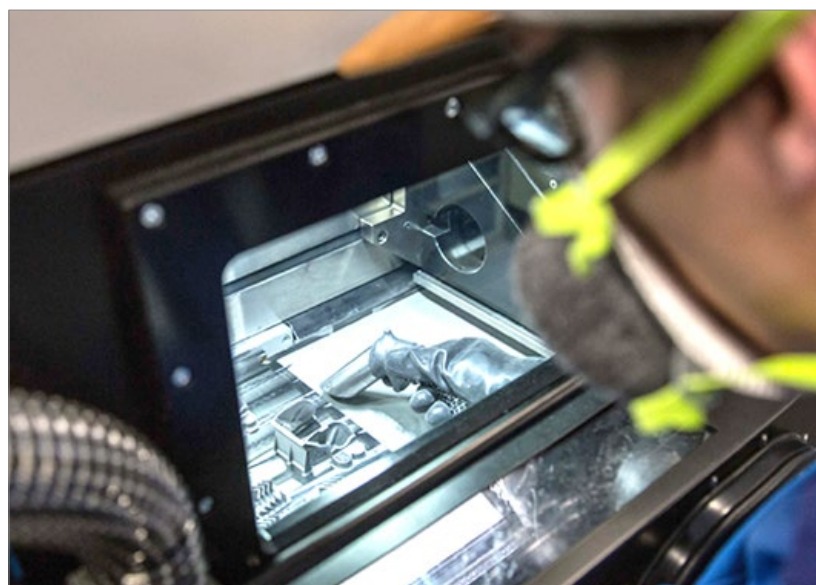
These systems are deployed in wide-bodied aircraft, single aisle and regional aircraft, business jets, combat aircraft, military transporters, military training aircraft, civil helicopters and combat helicopters. The aerospace and transportation systems division employs around 5,400 people and has four aviation equipment production plants at Lindenberg, Germany; Toulouse, France; Guaratinguetá, Brazil; and Nizhny Novgorod, Russia.

[www.liebherr.com](http://www.liebherr.com)

[www.airbus.com](http://www.airbus.com) ■ ■ ■



Additively manufactured nose landing gear bracket produced by Liebherr-Aerospace for the Airbus A350 XWB (Courtesy Liebherr-Aerospace)



Powder removal from the build chamber at Liebherr-Aerospace's metal Additive Manufacturing facilities (Courtesy Liebherr-Aerospace)



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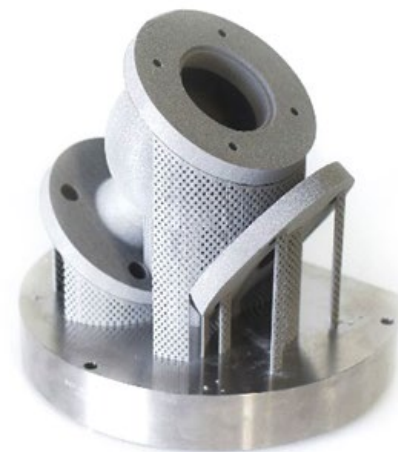


## Aurora Labs proves Rapid Manufacturing Technology's scalability at high build speeds

Aurora Labs, Bibra Lake, Australia, has completed the current phase of testing for its Rapid Manufacturing Technology (RMT) for metal Additive Manufacturing and reports that it has demonstrated the scalable nature of the technology while achieving high build speeds of 113 kg/day. According to Aurora, this makes RMT approximately fifty-five times faster than the nearest comparable machine speed (estimated to be 1.96 kg/day).

In conventional Additive Manufacturing processes, a digital part design is run through software which 'slices' it into a series of thin layers. The machine then deposits a very thin layer of powder on the print bed and builds the first 'slice' of the part using a laser or electron beam to scan the surface of the powder bed, melting and fusing the powder in the shape and dimensions of the slice. This process is repeated until every slice has been built.

By comparison, Aurora's Multilevel Concurrent Printing (MCPTM) process deposits multiple layers of powder at the same time. During the powder laying process,



*A pump valve produced using Aurora Labs' Rapid Manufacturing Technology (Courtesy Aurora Labs)*

building can take place behind each individual powder gate, meaning that the part build can occur on multiple operative surfaces simultaneously.

From its inception, MCP technology has reportedly been designed to be scalable to manufacturing requirements. Aurora's Alpha machine, on which the majority of its testing is carried out, has a single sub-unit. It has now been modified to include the connection of two sub-units working together, effectively doubling the speed capacity of the single-unit configuration.

This scaling process is expected to allow Aurora to scale its process to virtually any size and capacity, with the large format said to be able to build up to 1000 kg/day with multiple sub-units contained within it. By combining MCP and its ability to scale, Aurora stated that it has identified a pathway to very high-speed large format Additive Manufacturing, providing major companies with a solution to their parts needs.

David Budge, Aurora's Managing Director, commented, "This step in the development of the technology is the latest in a long line of impressive developments since the company's inception in 2014. Printing on multiple levels simultaneously at high speed is what we believe will ultimately allow us to print up to 1000 kg in one day."

"A large portion of the groups that Aurora is currently in discussion with are interested in replaceable parts and the capability of replacing them directly using Additive Manufacturing or redesigning them using the advantages of 3D printing with superior materials to deliver a superior product at a cost-competitive price," he continued.

"The primary factor in delivering an end-product cost-competitive with traditional manufacturing is the speed of the machine. This is why Aurora is looking outside traditional 3D printing markets to sectors like mining, oil & gas, marine and automotive. The year ahead is looking extremely exciting."

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## Titomic and Sino-Euro agree on metal powder supply and systems distribution

Titomic Limited, an industrial-scale metal Additive Manufacturing systems provider located in Melbourne, Australia, has entered into a Memorandum of Understanding (MoU) with Sino-Euro Materials Technologies of Xi'an Co. Ltd, Xi'an, China, a company specialising in the production of Plasma Rotating Electrode Process (PREP) spherical metal powder. The MoU covers the supply of metal powders and Sino-Euro's appointment as the distributor for Titomic Kinetic Fusion (TKF) systems and customer support in China.

Titomic reports that it has tested Sino-Euro's aerospace grade PREP titanium powders, stating that they meet the highest quality and international standards for titanium powder. It was added that the potential cooperative research and development of new metal powders will provide ongoing access to cutting-edge material science and next generation super alloy powders.

Sino-Euro is a subsidiary of the Northwest Institute for Non-ferrous Metal Research, a key national research centre in China which has contributed to more than 700 scientific innovations, 120 patents, and over 8500 developed products. It is involved through government cooperation with the USA, Japan, Germany, France and Russia. Sino-Euro focuses on the R&D and application of high-end materials and powder preparation technologies, with over thirty patents granted including China's first Supreme Speed Plasma Rotating Electrode Process™ (SS-PREP) spherical metal powder industrial production line.

The consumption of metals such as titanium alloys in China is primarily driven by the aerospace, chemical, power, desalination and automotive industries. In the aerospace industry alone, Boeing predicts that the growth in air passengers in the region will result in China accounting for 18% of the world's commercial airplane fleet by 2037.

Jeff Lang, Titomic's Managing Director, commented, "We chose to sign this MoU with Sino-Euro for their high-quality aerospace grade PREP titanium powders aligned with their 50+ years of materials science research in titanium and super alloys. This MoU will lead to Sino-Euro being appointed in early 2019 as the sales distributor of Titomic Kinetic fusion systems and Titomic customer support in China. Sino-Euro is well placed as the research leader in China for titanium and super alloy technologies in the world's second largest economy to represent Titomic commercial growth strategies in the global market."

S J Liang, Sino-Euro's General Manager, added, "Titomic is driving new levels of industrial productivity in the manufacturing world with its leading-edge machines, patented process and innovative materials. We are excited to partner with Titomic across the highlighted fields of cooperation to explore innovations in industrial scale Additive Manufacturing."

www.titomic.com | www.c-semt.com

## Prodways sells second Rapid Additive Forging system

Prodways Group, headquartered in Paris, France, has reported the sale of its second Rapid Additive Forging metal Additive Manufacturing system. Through its Prodways RAF subsidiary, the machine was sold to a tier one research institute and will be delivered later this year.

The Rapid Additive Forging technology developed at Prodways is capable of producing large scale parts in various metals, including titanium and steel. Based on a type of Wire Arc Additive Manufacturing (WAAM) process, a blank is created in successive layers, very close to the finished dimensions, which is then machined to obtain the final part.

Rapid Additive Forging technology developed at Prodways is capable of producing large scale parts in various metals (Courtesy Prodways)

The machine offers a closed loop system where manufacturing requires little human supervision. Production parameters are automatically adjusted as the part is being manufactured, ensuring optimal quality and repeatability, key attributes when serving demanding markets such as the aerospace sector.

In addition to the manufacture of its RAF machines, Prodways also uses the technology to produce finished parts and blanks for its customers. The company reported that in recent months it has made sales of testing parts to customers in the defence and nuclear sectors.

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## U.S. Air Force installs multiple AM parts on C-5 Super Galaxy aircraft

The U.S. Air Force's Rapid Sustainment Office (RSO) has installed seventeen additively manufactured parts, including both polymer and metal AM components, on a C-5 Super Galaxy aircraft. Working with engineers at the C-5 Program Office, Air Mobility Command, and the 436th Airlift Wing which operates the aircraft, the RSO installed a variety of parts including new aluminium seal retention handles, redesigned to take advantage of the benefits of Additive Manufacturing.

Engineers stated that they had redesigned the handles to be more ergonomically friendly, lighter weight and more robust to installation variation. They were able to reduce build time and eliminate the two tone, multi-coat paint scheme that has been used since the inception of the aircraft, continuing to reduce costs.

A number of parts were also installed in the cabin and crew bunk areas of the plane, including overhead panels, reading and emergency light covers, window reveals and gasper panels.

"It is innovative ideas such as these that continue to drive down sustainment costs, leading to improved weapon system readiness,"

stated Eddie Preston, a senior materials engineer for the RSO. "If you can imagine sitting on a commercial aircraft, everything around you including parts of the seat you are sitting in, we can print."

Preston added that many of the parts that were replaced were not available for purchase or had long lead times. He said that using AM, parts "may only take a couple of days to print" versus the weeks, months or even years it could take to acquire parts by traditional measures.

In the near future, the C-5 Program Office and RSO teams will reportedly install more than twenty additional metal and polymer additively manufactured components on the aircraft, with metal components set to be made from titanium and other high strength alloys. As the Air Force's Additive Manufacturing 'library' of parts continues to grow, it expects the cost benefits offered by the technology to increase.

The RSO estimates that future field production of these seventeen parts alone, could save tens of thousands of dollars, while improving part performance and continuing to improve weapon system readiness.

[www.airforce.com](http://www.airforce.com) ■ ■ ■



A C-5 Super Galaxy aircraft at Travis Air Force Base, California, USA (Courtesy U.S. Air Force / Tech Sgt Justin D Pyle)

## Funding to develop AI for AM

AMFG, London, UK, has received funding from Innovate UK, the UK's Research and Innovation agency, to further the development of its AI and machine learning technology specifically for Additive Manufacturing.

The Innovate UK funding builds on AMFG's comprehensive workflow management/MES software, which includes request submission, production management and post-processing management.

With a focus on the production of end-use parts, the funding will be put towards two key areas of AM production. The first will look to improve quality assurance, where AMFG will develop methods to improve the analysis of parts during the quality assurance stage, including the use of wide-ranging data sets. The second focus will be to further develop its machine learning technology to optimise production scheduling. This will, for example, enable users to accurately predict failures before they occur.

As the industry matures, the production of end parts is fast becoming a key application of AM. However, there remain barriers to scaling AM for production, including quality concerns and lack of efficiency. These are issues AMFG aims to address through its workflow software. "Currently, Additive Manufacturing still needs to prove that end-part production is viable at scale. Software will be a vital piece of this puzzle," Keyvan Karimi, AMFG's CEO, explained. "We're thrilled to put Innovate UK's funding towards further enhancing our machine learning technology and helping manufacturers manage — and scale — their AM operations effectively." As part of the project, AMFG will be working with key partners, including the University of Nottingham's Centre for Additive Manufacturing (CfAM).

[www.gov.uk/government/organisations/innovate-uk](http://www.gov.uk/government/organisations/innovate-uk)  
[www.amfg.ai](http://www.amfg.ai) ■ ■ ■

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## AdditiveNow joint venture to service oil & gas, mining and major infrastructure sectors

Aurora Labs Limited, Bibra Lake, Western Australia, has entered into an agreement with Advisian Digital, part of the WorleyParsons Group, to form AdditiveNow. The 50/50 incorporated joint venture will aim to provide a complete Additive Manufacturing service, primarily for oil & gas, mining and major infrastructure clients, by combining Aurora's products and technology with an existing network of industry contacts.

AdditiveNow is expected to focus on developing a service offering that will include consultation, engineering and agile manufacturing. The offerings and the timetable for their deployment will be, in part, dependent upon the continued development of Aurora's products, systems and technology.

David Budge, Managing Director of Aurora Labs, commented, "The finalisation of this joint venture is a significant step forward for Aurora and for the 3D printing industry as a whole. We look forward to helping our new broader network of customers to find business advantage

through 3D printing solutions, especially across the mining, oil & gas and major infrastructure sectors."

"As our technology comes to market, Aurora is optimistic that interest in 3D printing technology across these industries increase, and Aurora will follow any growth opportunities," he continued. "We have already identified and initiated discussions with specific customers for efficiency opportunities to reduce their capital committed to spare parts and inventory, potentially replacing aspects of traditional supply chain with 3D metal printing technology."

"This has the potential to result in reducing inventory holding costs, freight and manufacturing lead times. We are looking forward to finding more commercial applications of the technology through this joint venture."

[www.additivenow.com](http://www.additivenow.com)

[www.auroralabs3d.com](http://www.auroralabs3d.com)

[www.digital.advisian.com](http://www.digital.advisian.com) ■ ■ ■

## Norsk Titanium names Littauer as its new CFO

Norsk Titanium, Plattsburgh, New York, USA, has appointed Stephen L Littauer its new Chief Financial Officer. Littauer reportedly offers thirty-two years of executive financial experience with public and private, multi-national companies in the industrial, aerospace and defence industries. He succeeds Bart van Aalst, who has served as CFO for over three years and will now return to his position as a member of the Norsk Board of Directors.

Michael Canario, Norsk's president and CEO, stated, "Steve's unique background in large, public company leadership development, coupled with his experience in private equity companies, will prove a vital asset to Norsk as we increase our presence and impact within the Additive Manufacturing industry. As we welcome Steve, I also want to thank Bart for his role on the executive team, as his passion and commitment have been instrumental in our successes to date."

Most recently, Littauer served as CFO for Ten Cate Advanced Composites and AIP Aerospace. Prior to these roles, he spent seventeen years as a senior-level financial executive with Eaton Corporation and GE Aviation.

"One of the factors that drew me to Norsk is the quality of the team that has been assembled," commented Littauer. "I am pleased to join a company who is positioned to address the needs of lower costs and shorter lead times facing the aerospace supply chain today. I look forward to helping the company in its next phase of growth."

Norsk is an FAA-approved supplier of aerospace-grade additively manufactured structural titanium components. The company manufactures parts at its Plattsburgh Development and Qualification Center (PDQC) using titanium Additive Manufacturing machines based on its Rapid Plasma Deposition™ (RPD™) technology.

[www.norkstitanium.com](http://www.norkstitanium.com) ■ ■ ■



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## Metal Additive Manufacturing enables hollow propeller blades

Naval Group, Paris, France, and Centrale Nantes, Nantes, France, have collaborated on the metal Additive Manufacturing of the first demonstrator model of hollow propeller blades as part of European funded H2020 project on the Realisation and Demonstration of Advanced Material Solutions for Sustainable and Efficient Ships (RAMSSES1).

In order to improve vessel propulsion, the partners are using Additive Manufacturing to design large parts, including propellers of six metres in diameter. The Wire Arc Additive Manufacturing (WAAM) process was used for the production of a one-third scale hollow blade demonstrator, representative of a container ship

propeller. The 300 kg stainless steel part was produced in less than one hundred hours. The team stated that weight gains of over 40% will be achievable by this method compared to conventional processes.

Sirehna, a Centrale Nantes spin-off and subsidiary of Naval Group, is piloting the blade design in order to improve propeller energy efficiency and reduce its environmental impact. Sirehna's work has reportedly led to an overall optimisation of blades, in terms of efficiency and endurance, as well as a significant reduction in radiated noise and vibrations.

Naval Group's Patrice Vinot, Propeller Package Manager for the RAMSSES project, commented on the

challenges of such an application. "Although Additive Manufacturing is increasingly present in industry, the programming and design of complex parts, such as propeller blades for ships, represents a considerable challenge for our teams and our partners," he stated. "The potential of the process revealed by this new case study means that we now anticipate unparalleled performance for the propellers of tomorrow. Taking part in projects such as RAMSSES and coordinating our network of academic and industrial partners will allow us to bring 3D printing into shipyards for the long term."

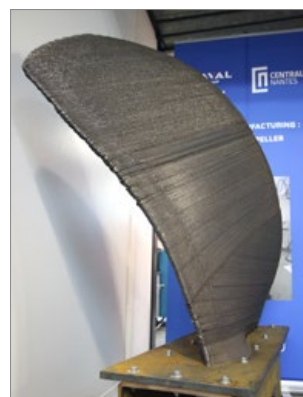
Professor Jean-Yves Hascoët, head of the Rapid Manufacturing Platform at Centrale Nantes added, "Additive Manufacturing has been developed over the last thirty-five years on the Rapid Manufacturing Platform. All these years of research come to fruition through a project like RAMSSES, which represents a real transfer of our technologies into an industrial environment."

RAMSSES is a four-year collaborative programme incorporating twenty-one work packages and thirty-seven partners from twelve countries, including key shipyards (Damen, Meyer Werft, Chantiers de l'Atlantique, Naval Group and more) and European maritime research laboratories.

[www.naval-group.com](http://www.naval-group.com)  
[www.ec-nantes.fr](http://www.ec-nantes.fr) ■ ■ ■



The hollow blade produced using WAAM (Courtesy Naval Group/Centrale Nantes)



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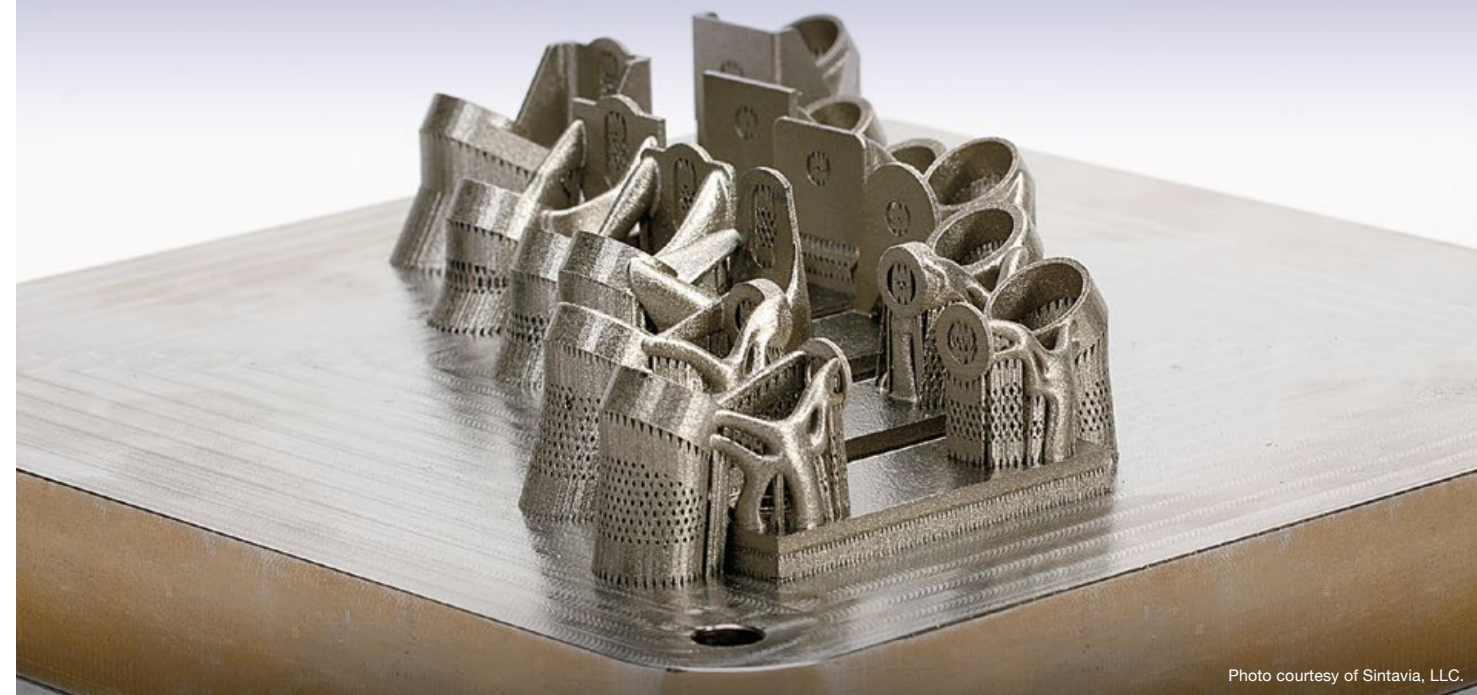


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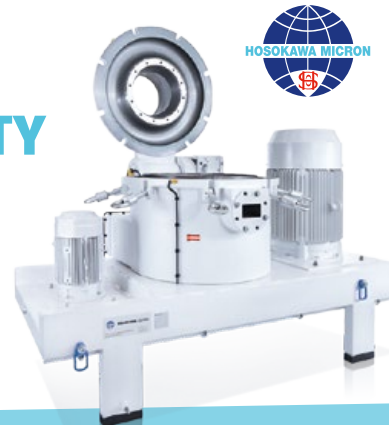
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## Beamler and Erecoin look to focus on blockchain technology for AM

Beamler BV, headquartered in Amsterdam, the Netherlands, and Erecoin, Augsburg, Germany, have announced plans to further develop blockchain technology for the Additive Manufacturing process chain. The partners will aim to create initial application scenarios, with the main focus on defining smart contracts that can be mapped using Erecoin's blockchain solution.

Beamler's platform offers its users access to an extensive industrial AM database, allowing them to source manufacturing services globally. It also aims to provide customers with a comprehensive and up-to-date overview of what is achievable using AM and currently works with 642 types of Additive Manufacturing machine, 853 types of material and 431 manufacturing locations.

"When I heard about the project, I did not hesitate a second and contacted Konstantin Steinmüller. The combination of blockchain and 3D printing will provide valuable benefits for our customers as well," stated Willem-Jan van Loon, Beamler CEO. "I have been working on the subject of blockchain and Additive Manufacturing for some time and therefore already have a clear picture of the necessary steps."

"We are very happy about the support and the cooperation of Beamler," stated Konstantin Steinmüller, Co-founder of Erecoin. "Beamler with its software solution is an extremely important link in the further development of the entire production chain based on the blockchain."

Erecoin was founded as the result of a 3D prototype optimisation project at Konstantin Steinmüller's company CAE-lab GmbH. In many additive applications, Steinmüller believed, bureaucratic issues such as validation, trust and security took centre stage during the development of AM applications, with engineering taking a back seat.

The goal of integrating blockchain into Additive Manufacturing is to eliminate a large proportion of these uncertainties in the AM process chain. Blockchain technology offers the possibility to conclude smart contracts in order to solve legal and technical questions in AM, with the data exchange and rules on the use of the data being integrated. This has the potential to create an efficient, secure and unambiguous relationship of trust between all parties involved in the process chain.

www.beamler.com  
www.erecoin.io ■■■

## Spirit AeroSystems to deliver its first additively manufactured commercial aircraft part

Spirit AeroSystems, headquartered in Wichita, Kansas, USA, has announced the development of its first additively manufactured structural component for the Boeing 787 Dreamliner. The titanium part, a back-up fitting for an access door latch, has been machined and finished at Spirit's Wichita site, and installed in a 787 forward fuselage.

The milestone follows more than nine years of collaboration on technology innovations and applications between Spirit and Norsk Titanium (NTi). "Integrating Additive Manufacturing capability into our production system to build end-use titanium parts expands Spirit's fabrication capabilities and puts us at the forefront of advanced manufacturing," stated Kevin

Matthies, Spirit AeroSystems' Senior Vice President of Global Fabrication. "With our Norsk collaboration, Spirit is bringing the power and benefits of Additive Manufacturing in support of our customers."

NTi's proprietary plasma arc Rapid Plasma Deposition (RPD) technology is used to build up the parts to near-net shape, minimising waste, using less energy and significantly reducing product costs. NTi creates near-net shaped components and Spirit then performs final machining, finishing, inspection and installation.

Spirit AeroSystems is one of the largest manufacturers of fabricated parts for the aerospace industry. The company delivers a fully-integrated forward fuselage structure on the 787



Spirit has installed its first AM part in a Boeing 787 (Courtesy Boeing)

programme, with all flight controls tested and installed. The composite forward fuselage section is built using automated fibre placement machines, winding composite tape into a one-piece fuselage section.

Spirit builds the forward fuselage section of every Boeing commercial airplane in production today, as well as wing and propulsion components.

www.spirit-aero.com  
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## 3DEO to more than double production capacity

3DEO, Inc., a Los Angeles-based metal Additive Manufacturing technology company, has reported significant growth in 2018, its second full year of operation. To meet rapidly expanding customer demand, the company plans to more than double its production capabilities in 2019, adding more of its proprietary metal Additive Manufacturing systems.

During 2018 3DEO printed over 30,000 paid parts for customers across a wide variety of industries including medical, aerospace, defence, consumer, and industrial equipment. The company reported that at the start of 2019, it had secured two additional customer production orders for 24,000 pieces and 28,000 pieces, with both orders scheduled for delivery this year.

"We are very proud of what we accomplished in 2018 working hand-in-hand with end-use customers. We are also very excited for what's to come in 2019. By many key manufacturing and customer metrics, 3DEO's technology is setting the standard for serial production metal 3D printing," stated Matt Petros, CEO and co-founder of 3DEO, Inc.

3DEO's patented Intelligent Layering® Technology is said to drastically reduce final part cost, while meeting the high industry benchmark MPIF Standard 35, achieving tight tolerances and an impressive surface finish. The company believes that Intelligent Layering will open metal AM to the industries that can't afford today's expensive options. Leveraging its unique technology as a parts supplier, 3DEO sells high volume, high value metal parts to manufacturers with a variety of applications across a wide range of industries.

"3DEO's production metal 3D printing technology is proving itself to be highly scalable and robust. In order to be successful with serial production, part-to-part and machine-to-machine repeatability is paramount. In many ways 3DEO's technology is uniquely capable in the industry of metal Additive Manufacturing," added Marty McGough, COO and head of quality at 3DEO, Inc.

"By all measures, 3DEO is rapidly expanding to fill a large void in the market of small complex metal parts. Customers are validating our technology across a variety of industries and we are either in production or quickly moving to production with many clients. Additive manufacturing is finally competing directly with traditional manufacturing, enabling significant volumes to shift over to AM. It is a very exciting time for 3DEO, metal Additive Manufacturing and our customers," concluded Petros.

[www.3deo.co](http://www.3deo.co) ■■■

## Submitting news..

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## EBM specialist Bruce Mclean joins Barnes Group Advisors

The Barnes Group Advisors (TBGA), headquartered in Pittsburgh, Pennsylvania, USA, has appointed Bruce Mclean to its ADDvisor Services team. Mclean was a founding partner of Zenith Tecnica, an Electron Beam Melting (EBM) AM service provider in Auckland, New Zealand, where he served as Senior Engineer and Business Development Manager.

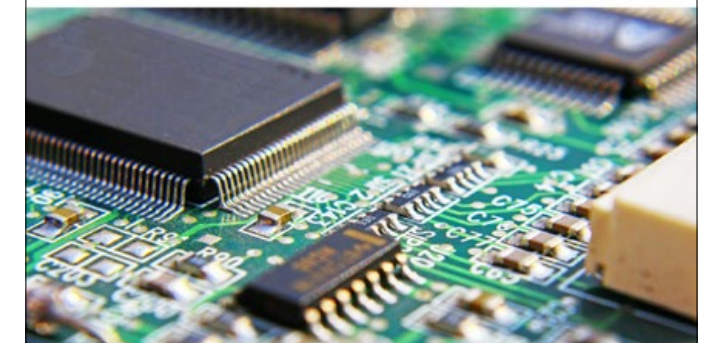
In addition to his role at Zenith Tecnica, Mclean is said to offer around forty years of diverse experience in aviation-related industries, including military and commercial airline operations. Prior to founding Zenith Tecnica, he held positions at Page Macrae Engineering, Waratah Forestry Attachments and Air New Zealand.

"We're thrilled to welcome Bruce to the team, further expanding our global presence," stated John Barnes, Managing Director, TBGA. "His reputation, knowledge, and trust is well established from his involvement in the industrial AM community and aligns perfectly with our core mission and vision."

[www.thebarnes.group](http://www.thebarnes.group) ■■■



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## Ford produces largest ever metal AM automotive part for Ken Block

Ford Performance, Dearborn, Michigan, USA, has collaborated with a team of research engineers based in Europe to design and manufacture what is said to be the largest metal additively manufactured part for a working vehicle in automotive history. The part is installed in the 'Hoonitruck', a 1977 Ford F-150 with a twin-turbo 3.5-litre V6 EcoBoost

engine, owned by Ken Block, star of popular Youtube-based automotive racing series Gymkhana.

To produce the part, an intricate aluminium intake manifold that supplies air from the turbochargers to the engine's cylinders, Ford Performance engineers in the US ran engine performance simulations and collaborated with a team of Ford



*The manifold weighs 6 kg and took five days to build (Courtesy Ford)*

research engineers based in Europe to design the part and conduct structural analysis. The part was then manufactured at RWTH Aachen's Digital Additive Production Institute, Aachen, Germany. The entire build process to produce the manifold, which weighs almost 6 kg, was reported to have taken five days.

Raphael Koch, engineer, Advanced Materials and Processes, Ford of Europe, stated, "We are fortunate to have access to incredible technology, but this was one project that pushed us – and our computing power – to the absolute limit. The manifold has a complex web-like structure that couldn't be made using traditional manufacturing methods. We ended up dissolving the support systems in acid."

"I think Ford did an exceptional job," added Ken Block. "This is my favourite part of the 'Hoonitruck'. You could not have made it any other way."

[www.corporate.ford.com](http://www.corporate.ford.com) ■■■



*The Hoonitruck (top) has been fitted with an intricate aluminium intake manifold (bottom) manufactured at RWTH Aachen (Courtesy Ford)*

## Velo3D partners with Praxair on qualification of metal powders

Velo3D, California, USA, has partnered with Praxair Surface Technologies, Inc. (PST), Indianapolis, Indiana, USA, to develop process parameters for Praxair's TruForm powders and qualify PST as an approved supplier of metal powder for its AM systems.

"PST is constantly looking for ways to help expand the number of applications that are addressable by metal Additive Manufacturing, and Velo3D is a great company to partner with in this effort," stated Andy Shives, Business Manager for Additive

Manufacturing at PST. "Velo3D's technology enables the building of difficult geometries, which opens up new opportunities for Additive Manufacturing across a broad range of applications."

Two of Praxair's TruForm powders, 718 and 64, have already been validated with Velo3D's Sapphire system. "We have a focus on advancing powder and atomisation technology, and this goes hand-in-hand with Velo3D's focus on advancing the laser powder bed process," added Shives.

Velo3D's qualification of powder from leading powder suppliers ensures that its customers can purchase powder directly from suppliers who have demonstrated that their powders work in the Velo3D metal AM system. Stefan Zschiegner, Velo3D's Chief Marketing Officer, stated, "Velo3D was founded to enable customers to manufacture any design they can conceive. Praxair is a trusted alloy solution provider and the right kind of partner for Velo3D's rigorous standards for metal powder quality. Together, we drive adoption of additive for manufacturing."

[www.praxair.com](http://www.praxair.com)  
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## AM helps MIM company drastically reduce product lead time

Metal Injection Moulding (MIM) company MIMtechnik GmbH, Schmalkalden, Germany, is reducing the lead time for prototype MIM products to as little as one week using Binder Jet Additive Manufacturing. The company selected an Innovent+™ Binder Jet AM system produced by The ExOne Company, North Huntingdon, Pennsylvania, USA, to develop prototype fasteners for building hardware for customer evaluation.

Tooling for MIM is traditionally expensive and the lead time for new moulds is usually from ten to four-teen weeks. The use of Binder Jet AM reduced lead time for the prototype product to just one week after the



*The prototyped parts produced on an Innovent+ Binder Jetting system from ExOne (Courtesy The ExOne Company)*

initial customer inquiry, while eliminating prototype tooling costs (typically in the range of €10,000–20,000).

In addition, because the Innovent+ produces parts using the same 316L high density single alloy powders as used in its MIM products, MIMtechnik was able to use its current sintering process on the prototyped parts. This meant that the prototype's properties

matched what the customer could expect from final MIM parts.

The successful delivery of the prototypes to the customer resulted in an order for approximately 600,000 MIM parts in the first year of production, expected to increase to 1.2 million parts in the following years.

[www.exone.com](http://www.exone.com)  
[www.mimtechnik.de](http://www.mimtechnik.de) ■ ■ ■

## Wire Arc Additive Manufacturing titanium pressure vessel for space

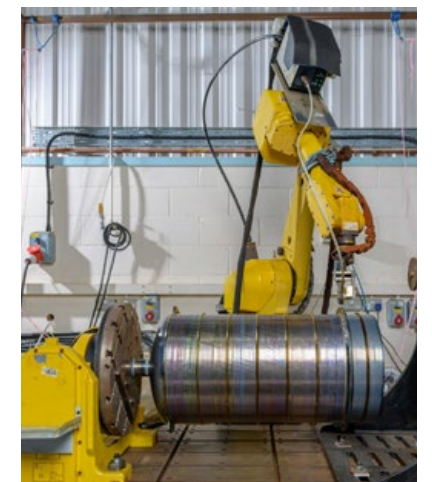
A team comprising Thales Alenia Space, Cranfield University and Glenalmond Technologies, has successfully produced its first full-scale prototype of a titanium pressure vessel to be used in future manned space missions, produced by Wire Arc Additive Manufacturing (WAAM).

The 1 m tall, 8.5 kg part was produced in Ti6Al4V at Cranfield University, before being sent to Glenalmond Technologies for stress-relieving, laser-scanning, machining and ultrasonic inspection. Final inspection was then performed by Agiometrix, using CT for internal quality analysis and an optical scanner, with Thales Alenia Space ensuring that the part met the mechanical requirements and specifications of the application.

The use of WAAM enabled the team to integrate two individual

pieces into a single part, eliminated the need for long-lead-time forgings, and substantially reduced the amount of waste material. If manufactured by conventional methods, the component's production would have consumed roughly thirty times more raw material than its final mass, according to the team members. Using WAAM, more than 200 kg of Ti6Al4V was saved for each item. The team noted that there is room to improve this further, and Cranfield was said to be working on innovative methods to deposit closer to the final thickness.

Following quality checks, the project team is satisfied that the vessel fulfils the technical and quality requirements for its application. A second prototype will now be produced, with the purpose of carrying out a fine tuning of the whole



*The titanium pressure vessel was produced at Cranfield University*

manufacturing cycle to demonstrate the repeatability and reliability of the process, and to push the implementation of the new approach into the flight hardware.

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## GKN Additive opens first customer centre in China

GKN Additive has opened its first customer centre in China. At the state-of-the-art facility in Danyang, customers can learn about all aspects of the metal Additive Manufacturing process and work with GKN Additive's engineers to design and manufacture components during hands-on prototyping workshops. The new location is reported to further extend the reach of GKN Additive's global network, which now includes six R&D and manufacturing locations across Europe, North America and Asia.

"China is the world's largest automotive market and automotive manufacturing country for conventional and new energy vehicles. Automotive development activities have shifted from traditional regions to China, and this leads to an increased demand on new technologies like Additive Manufacturing," stated Guido Degen, President Additive Manufacturing at GKN Powder Metallurgy.

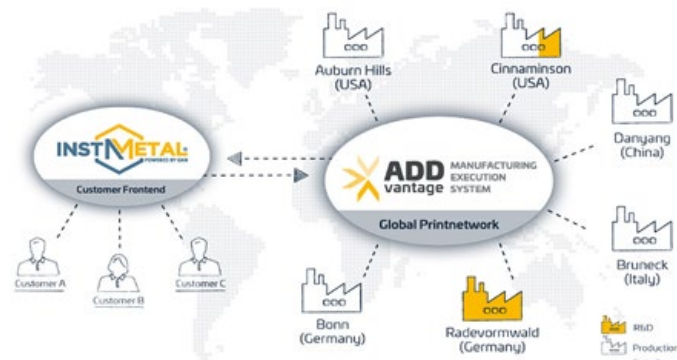
"We believe that metal Additive Manufacturing is one of the future processes that will have great effect

on the automotive industry and electric vehicle production. From saving time-to-market through rapid prototyping to redesigning and rethinking parts and assemblies for additive, to reduced inventories by on-demand replacements – metal AM adds value during the whole component life cycle."

GKN Powder Metallurgy, comprised of GKN Hoeganaes, GKN Sinter Metals and GKN Additive, employs a team of more than 500 people across two locations in Danyang and Yizheng in the coastal Jiangsu province, north of Shanghai. Since entering the Chinese market in 2006, GKN Powder Metallurgy has gained market share each year and is now one of the top five suppliers of the Chinese automotive premium market.

GKN Powder Metallurgy China manufactures highly engineered metal powders and sintered products primarily for automotive engine, transmission and body & chassis applications. In 2018 both facilities supplied millions of VVT rotors, VVT stators and synchroniser hubs to leading automotive customers in China, like Schaeffler, Denso, VW, Getrag and JATCO.

[www.gknpm.com/additive](http://www.gknpm.com/additive) ■ ■ ■



GKN Additive's global network includes six R&D and manufacturing locations across Europe, North America and Asia (Courtesy GKN Additive)

## Optomec acquires Huffman

Optomec, Albuquerque, USA, has announced that it has acquired Huffman, a leading supplier of metal AM systems for the repair of gas turbine components in the energy and aviation markets. Huffman's equipment and software are said to be in use at virtually all major manufacturers of aircraft engines and industrial gas turbines, who use its metal deposition capabilities to restore worn or damaged components at substantially lower cost than newly-made spare parts.

Commenting on the news, Christopher E Thompson, General Manager Product Service at GE Power, stated, "Optomec and Huffman joining forces is exciting news in the Additive

Manufacturing space. Having used products from both companies, I know the complementary strengths of their portfolios and the value they provide to aerospace, defence, and power generation customers. Optomec's innovative and affordable solutions in this space, combined with the robust, production-friendly equipment and intuitive user interfaces provided by Huffman are sure to enable new leaps in free-form Additive Manufacturing for repairs, new part build and hybrid manufacturing."

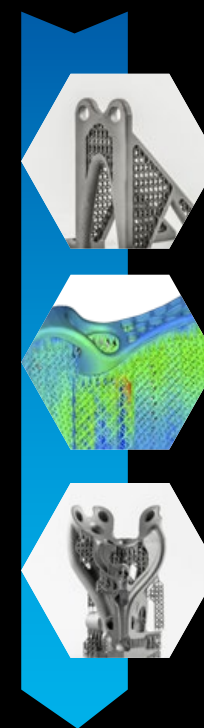
Both Optomec and Huffman deliver a form of metal AM that is known as Directed Energy Deposition (DED). This technology is capable of adding metal to existing parts for repair and

coating applications, extending the useful life of components.

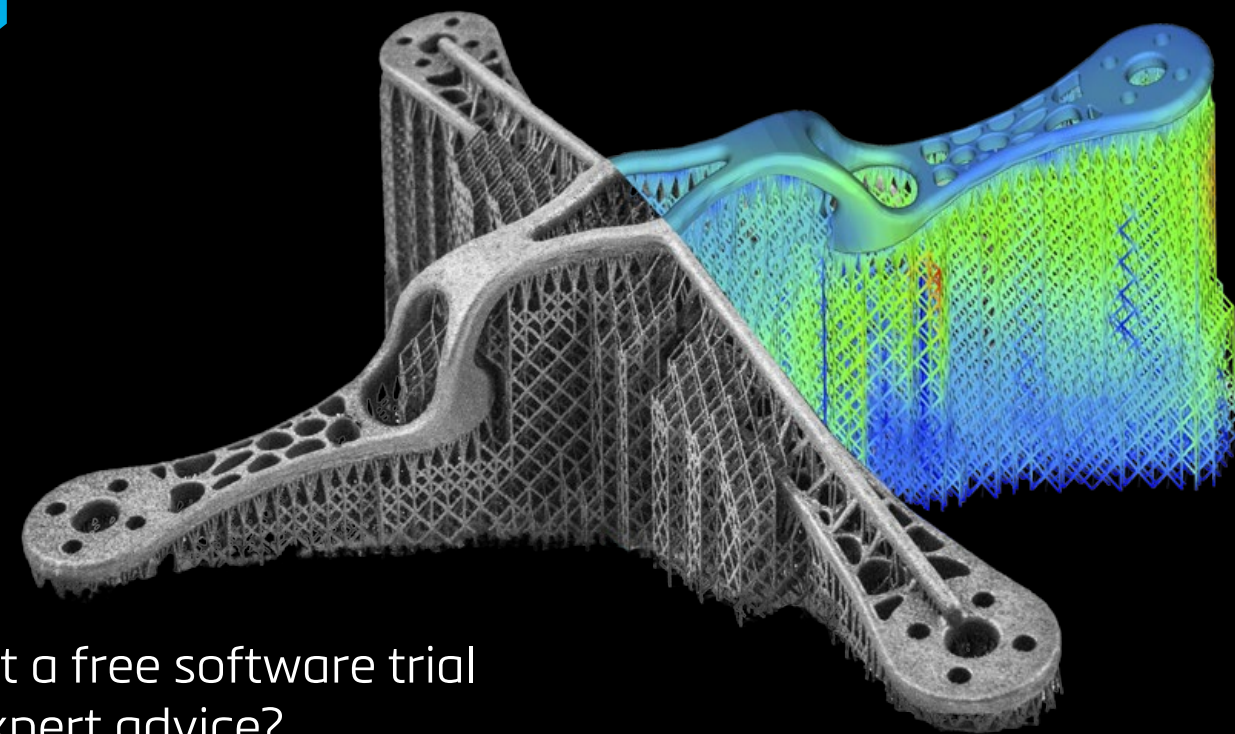
"The opportunity for Additive Manufacturing in repair applications is often overlooked, but when you consider that corrosion and wear cost the US economy \$300 billion per year, and that the global commercial aviation industry spends almost \$100 billion annually on repair, you can get a better sense of the magnitude of these markets," added David Ramahi, President and CEO of Optomec. "With the Huffman acquisition, we aim to expand the use of DED/LENS repair for the existing installed base of more than 100,000 gas turbines and engines, while also leveraging that expertise to drive greater adoption of cost-effective repairs for mainstream industrial applications."

[www.optomec.com](http://www.optomec.com) ■ ■ ■

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**3D SYSTEMS**



## Desktop Metal adds 316L stainless steel to the Studio System portfolio

Desktop Metal, Burlington, Massachusetts, USA, has added 316L stainless steel to the portfolio of materials for use on its Studio System for prototyping and low-volume production. A fully austenitic steel known for its corrosion resistance and excellent mechanical properties at extreme temperatures, 316L is well-suited for medical applications, as well as in highly demanding industrial environments, such as marine applications, food processing and pharmaceutical manufacturing.

Ric Fulop, CEO and Co-founder of Desktop Metal, stated, "The addition of 316L enables engineers to print metal parts for a wide range of applications, including engine parts, laboratory equipment, pulp and paper manufacturing, medical devices, chemical and petrochemical processing, kitchen appliances, jewellery and even cryogenic tools and equipment. Teams are now able to iterate quickly on 316L prototypes, print complex geometries that are not possible with most manufacturing methods and produce end-use parts cost-effectively."

"As innovative companies across multiple industries adopt metal 3D printing, it's critical to help accelerate this growth by expanding the portfolio of desired materials," added Fulop. "Our materials science team is pushing the boundaries to enable printing metal parts for a growing range of applications in as wide a material portfolio as possible. The introduction of 316L is another step on our path to fundamentally change the way metal parts are designed and manufactured."

Desktop Metal added that it currently has more than thirty materials in development. It stated that it plans to introduce additional core metals to its portfolio throughout 2019, including tool steels, superalloys and copper.



Fig. 1 The UHT fuel oil atomiser (Courtesy Desktop Metal)



Fig. 2 A custom made finger splint (Courtesy Desktop Metal)

### Examples of 316L parts manufactured on Desktop Metal's Studio System

Combustion fuel nozzle for marine tankers: The UHT Atomizer, manufactured by John Zink Hamworthy Combustion, is a fuel oil atomiser for use with atomising media such as steam or air (Fig. 1). It is typically installed in HXG marine burners, which are used on steam propulsion boilers on LNG tankers.

316L stainless steel was said to have been a key material for the part due to its excellent mechanical properties at high temperatures. The atomiser can be radically redesigned to function in a more fuel-efficient manner than those produced through traditional metalworking means.

Customised ring splint for medical use: Ring splints, a common medical device, are designed to immobilise or limit the range of motion of injured limbs. Ring splints are typically

made of injection moulded plastic in standard sizes, and parts often break after a relatively short lifetime. However, by additively manufacturing ring splints in 316L (Fig. 2), the devices can be custom-made on-demand to the desired size, with the added benefit of an aesthetic finish and increased durability.

Impeller for harsh environments: Used across a variety of industries, impellers are essential components of pumps to move fluid through systems. Impellers require complex vanes to optimise pressures in the pump for different fluids and applications, with 316L the material of choice for its chemical resistance and mechanical properties.

These impellers are geometrically complex and prototypes typically cost \$1,000 or more. However, with the Studio System, this impeller was additively manufactured in 316L for \$70.

www.desktopmetal.com ■ ■ ■



Fig. 3 An impeller produced on the Studio System (Courtesy Desktop Metal)



## RUAG Space sends first additively manufactured part to the moon

RUAG Space, Zurich, Switzerland, has developed what will be the first additively manufactured part to land on the moon; an aluminium engine mount. The mount will be fitted on the main engine of the 'Beresheet' lunar lander, developed by non-profit organisation SpaceIL, Israel.

"Our 3D part will support landing and lift off of the spacecraft on the moon," explained Peter Guggenbach, RUAG Space CEO. "With 3D printing, our customers profit from a quicker and more cost-efficient production," continued Guggenbach, adding that "weight reduction is a decisive factor in the space industry. The lighter the satellite, the lower the costs. Every kilogram less saves money, since less energy is needed for sending the satellite into orbit."

RUAG Space designed the part and for production contracted Morf3D, based in El Segundo, California, USA, a leader in Additive Manufacturing solutions for the aerospace industry. RUAG Space then qualified the part for service in space.

SpaceIL's mission will represent the first non-governmental landing on the moon. Its total budget is estimated

at \$95 million, provided mainly by philanthropists and the Israel Space Agency (ISA). Beresheet's launch was scheduled for February 18, 2019. After an initial two-month journey in space, Beresheet will land on the lunar surface and begin sending photos and videos back to Earth, as well as data about the moon's magnetic field.

Since 2014, RUAG Space has developed numerous components using Additive Manufacturing technology and offers customers fully reliable products that are qualified for space. The company is a leading independent supplier to the space industry in Europe and has a growing presence in the United States. In total, RUAG Space has around 1,300 employees across six countries.

RUAG Space is a division of the international technology group RUAG. The group develops and markets technology applications in the fields of aerospace and defence for use on land, in the air and in space.

[www.spaceil.com](http://www.spaceil.com)

[www.ruag.com](http://www.ruag.com) ■■■



The additively manufactured aluminium bracket is used to hold the engine in the lunar lander [Courtesy RUAG Space]

## India's largest Additive Manufacturing service bureau adds metal systems from SLM

3D Product Development (3DPD), headquartered in Bangalore, India, reported to be the country's largest Additive Manufacturing service bureau, is to purchase two SLM 280 metal Additive Manufacturing systems from SLM Solutions, Germany. 3DPD already offers a wide range of prototyping technologies, including state of the art SLA and SLS AM systems, as well as multi axes CNC machines, low pressure RIM systems, high end vacuum investment casting and sand casting.

"3DPD has always led from the front by offering the latest 3D printing and Additive Manufacturing solutions to the Indian Industry. With the addition of metal AM from SLM Solutions, once again 3DPD will be in a unique position to be the only Indian Company offering both plastic and metal Additive Manufacturing solutions to Indian market," stated Dr Mukesh Agarwala, Managing Director of 3D Product Development. "SLM Solutions' Selective Laser Melting systems, along with their superior support, are well known to offer the best-in-class quality and throughput," he added.

"India has a high demand for innovative technologies, above all due to the constantly growing industrial sectors. SLM machines enable fast, reliable and cost-effective part production – whether in the medical, automotive or toolmaking sectors, and their flexibility is ideal for a service provider like 3DPD," added Srinivas Shastry from SLM Solutions India.

In addition to Additive Manufacturing, 3DPD offers CNC machining, investment casting and sand casting for both prototyping and low-volume production.

[www.slm-solutions.com](http://www.slm-solutions.com)

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## Renishaw adds new AM Solutions Centres in Spain and Italy

Renishaw, headquartered in Wotton-under-Edge, Gloucestershire, UK, has announced the opening of new Additive Manufacturing Solutions Centres in Barcelona, Spain, and Turin, Italy. The two centres are now operational, with the aim of allowing local companies access to Renishaw's equipment and expertise.

Established in 2016, Renishaw's Solutions Centres are designed to offer businesses access to a secure development environment to build their knowledge and confidence using metal Additive Manufacturing technology. The facilities are equipped with the latest AM systems, including Renishaw's multi-laser machines, alongside all the metrology, finishing and machining equipment required to make a functional part.

Users of Renishaw's Solutions Centres run projects to expand their knowledge of the AM process, understand the product performance impact and assess the capability and costs of the technology. The centres are staffed by local AM specialists, who work closely with customers on the engineering projects. Renishaw offers support throughout the investigation and business case development process, so companies can optimise their designs and gain the required evidence to make investment decisions.

"The Solutions Centres have proved to be a successful way for manufacturers to accelerate learning about this new technology," commented Marc Saunders, Director of Global Solutions Centres at Renishaw. "Early users

of the Solutions Centres, who have benefitted from accessing our facilities, are now deploying Renishaw's multi-laser, productive Additive Manufacturing systems in their own facilities."

"We have opened the new facilities to be closer to our Spanish and Italian customers," he continued. "By expanding the network, we are able to help more customers move forward on the journey to industrial AM."

Renishaw is reported to have invested significantly in its subsidiary network, comprising over seventy offices in thirty-six countries. It has recently expanded to new, larger locations in Barcelona, Spain and Turin, Italy, which enabled the establishment of the new Solutions Centres. The company now has AM Solutions Centres operational in India, Canada, America, China, Germany, the United Kingdom, Spain and Italy.

[www.renishaw.com](http://www.renishaw.com) ■ ■ ■

## Farsoon develops advanced pure copper Additive Manufacturing process

Farsoon Technologies, headquartered in Changsha, China, has announced the development of a pure copper Additive Manufacturing process using the company's metal laser sintering systems. Copper is a soft, malleable, and ductile metal with very high thermal and electrical conductivity, which is widely used in industries such as aerospace, automotive, shipbuilding and electronics. However, the vast majority of copper used in AM is currently based on alloys of copper, not the pure metal.

Many applications can only be unlocked with low-oxygen, pure copper. Pure copper has a high laser reflectance rate of over 90% with standard laser-based AM systems and it is difficult for the laser to continuously and regularly melt pure copper powder, which leads to issues such as interface failure and thermal cracking.

In 2017, Farsoon's Application team joined with industrial partners to begin developing an advanced process to produce pure copper additively manufactured components. The team conducted a large number of tests and obtained the appropriate scanning strategies and process parameters for pure copper. These parameters minimise the adverse effects of the high laser reflectance of pure copper, in order to achieve the perfect part density, an optimised AM process, and excellent performance.

One of the parts resulting from this collaboration was a pure copper heat exchanger with complex spiral geometry and a wall thickness of only 0.5 mm. This part was printed as a single piece, resulting in a far more efficient heat exchanger than that of one made by a traditional



*A pure copper heat exchanger with complex spiral geometry and a wall thickness of only 0.5 mm, produced by Farsoon Technologies*

brazing process. The lightweight design reduced weight by over 30% and cost by 35%.

The developed process parameters work with the full range of Farsoon metal AM systems, and can help to ensure high-quality, cost-effective pure copper processing.

[www.farsoon.com](http://www.farsoon.com) ■ ■ ■

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## Velo3D enhances its Flow process software for metal Additive Manufacturing

Velo3D, a manufacturer of Additive Manufacturing machines headquartered in Campbell, California, USA, has announced updates to its Flow™ process software, specifically designed for the company's L-PBF metal Additive Manufacturing system, Sapphire.

Flow includes tools that help with part orientation, support generation, simulated print predictions, per-surface process application, slice composition and process review.

"Flow takes a refreshing new look at additive software: its ease of use is unprecedented. Understanding how users work and offering just-in time tools is an exciting direction taken by Velo3D," stated Scott Volk, CTO of Incodema3D. "Velo3D's advanced simulation, prediction and correction ensures not only print success, but improved part-to-part quality, accelerating the adoption of volume production."

Velo3D's machines have the ability to print low angles and overhangs below five degrees, as well as large inner diameters and tubes up to 40 mm without the need for supports, eliminating the need for difficult and laborious post-processing cleanup.

Flow key features include a new physics-driven simulation engine built from the ground up, optimised for VEO3D process capabilities and

the Sapphire system. It contributes to achieving a first print success rate of up to 90 percent, preventing many failed iterations. A powerful simulation utility also predicts the print outcome, applying build deformation correction and validating the execution feasibility of the build prior to starting the build process.

The integration of print preparation, simulation and composing capabilities into a single software is said to eliminate historic incompatibilities, significantly simplifying the workflow. Native CAD workflow enables new user experience with smart selection, refinement, and filtering of part features. This enables users to focus their efforts on solving problems on the application level, instead of troubleshooting machine level parameters.

"Build preparation software has always been an afterthought," added Benny Buller, CEO of Velo3D. "Velo3D's strategy is to offer an integrated hardware, software and process solution. The system is process driven, where the software manages the hardware and can predict and control the outcome. It is the only way to fulfill our mission to manufacture any design, assure accuracy and consistency and thus take Additive Manufacturing mainstream."

[www.velo3d.com](http://www.velo3d.com) ■ ■ ■



Velo3D has announced updates to its Flow process software (Courtesy Velo3D)

## Carpenter Technology adds two new directors to its board

Carpenter Technology Corporation, headquartered in Philadelphia, Pennsylvania, USA, has announced the appointment of Viola L Acoff and John Hart to its Board of Directors. Carpenter's board now consists of twelve members, eleven of whom are independent directors.

Dr Acoff is currently the Associate Dean for Undergraduate and Graduate Programs at The University of Alabama's College of Engineering, a position she has held since 2014. For the last fifteen years, she has been a professor in the University's Department of Metallurgical and Materials Engineering, where she also served as Department Head from 2009-2014. Her areas of expertise include Additive Manufacturing, welding metallurgy, physical metallurgy, titanium and nickel alloys, and materials characterisation using electron microscopy.

Dr Hart is an Associate Professor of Mechanical Engineering at the Massachusetts Institute of Technology (MIT). He is also the Director of the MIT Laboratory for Manufacturing and Productivity, and the Center for Additive and Digital Advanced Production Technologies. Prior to joining the MIT faculty in 2013, Hart was Assistant Professor of Mechanical Engineering, Chemical Engineering, and Art and Design at the University of Michigan.

"We welcome both Viola and John to Carpenter Technology's Board of Directors. Their expertise in the materials, engineering, and Additive Manufacturing space further supports Carpenter Technology's strategic objective to be a leading solutions provider across all the markets we serve," stated Gregory A Pratt, Chairman of the Board.

[www.carttech.com](http://www.carttech.com) ■ ■ ■



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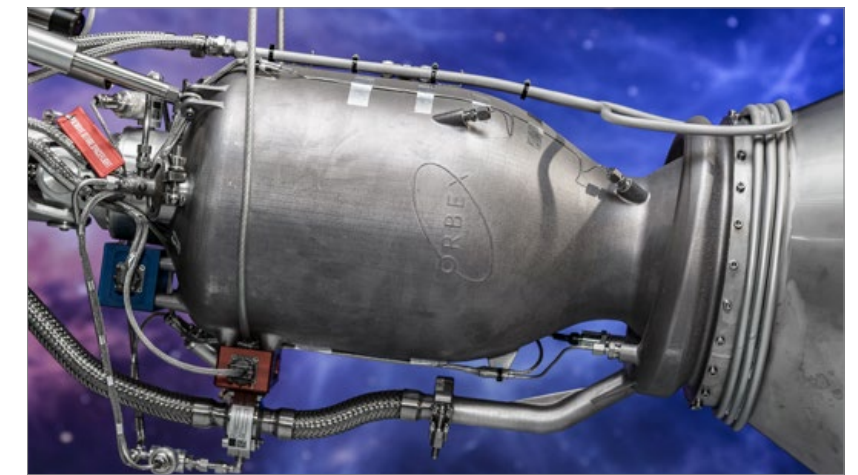
## World's largest metal additively manufactured rocket engine

Spaceflight company Orbex, Forres, United Kingdom, has produced what is reported to be the world's largest metal additively manufactured rocket engine. The engine, developed for the company's Prime rocket, was produced in a single piece on an SLM®800 system from SLM Solutions AG, Lübeck, Germany.

Founded in 2015, Orbex develops satellite launch vehicles and introduced the Prime rocket at the opening of its new headquarters in the Scottish region of Moray. The launcher, designed to deliver small satellites into Earth's atmosphere, is said to use 100% renewable fuel, cutting carbon emissions by 90%, and employs a novel zero-shock staging and payload separation, resulting in zero orbital debris.

By optimising its design for metal Additive Manufacturing, the company was able to create a structure which it reports is 30% lighter and 20% more efficient than any other launch vehicle in its category. Orbex's aerospace engineers partnered closely with the applications engineering team at SLM Solutions during the design process to ensure a successful build. Lukas Pankiewicz, Applications Specialist, headed the consulting team inside SLM Solutions to develop a unique set of parameters optimised for the rocket's geometry.

Alongside the Orbex design team, Pankiewicz consulted on the various design features and orientation options while ensuring the part built successfully with the required material properties and dimensional accuracy. "Our aim during the process was to fulfil the quality expectations of the Orbex team, keep the functionality of the part and make it suitable for Additive Manufacturing," he explained. "Every single support structure used in data preparation has been customised to obtain the



The Prime rocket is said to be the largest metal AM rocket engine ever produced (Courtesy Orbex)

best quality in every section of the engine, taking post-processing into consideration as well."

The SLM 800 is a large-format metal AM system featuring a 260 x 500 mm powder bed that can build parts up to 800 mm tall. This allowed the Prime engine to be built in a special nickel alloy in a single piece. Further, the SLM HUB unpacking system for the SLM 800 integrates contactless powder handling and automated build chamber conveyors, to transfer the finished part to an unpacking station designed to remove powder through vibration and rotation.

Pankiewicz ensured a powder removal strategy was incorporated into the build with purpose-driven delivery channels to be certain as much powder was removed from the build as possible, while reducing material loss. After production, reference samples built together with the engine were analysed in SLM Solutions' metallography lab, where porosity level and distribution were proven to meet the quality acceptance criteria.

The rapid iteration times inherent to the SLM process allowed Orbex to realise both time and cost reductions – saving 90% in turnaround time and over 50% in costs compared to traditional CNC machining production. "This has always been what SLM Solutions is about," stated Dr Axel Schulz, Chief Sales Officer, SLM

Solutions. "Members of our team helped invent the Selective Laser Melting technology!"

"We've always wanted that technology to succeed – which isn't just about selling SLM machines but creating that paradigm shift for the customer to be successful with their process," he continued. "SLM Solutions consulted Orbex on how to make the technology best work for them and transferred that knowledge to ensure their successful implementation as they ramp up to production."

Jonas Bjarnoe, Chief Technology Officer, Orbex, stated, "The SLM Solutions team showed true dedication and in-depth knowledge of our work. I'm looking forward to continuing this collaboration in 2019 and onwards. Orbex and SLM Solutions have solved some important puzzle pieces which will change the space business."

Orbex has received £30 million (\$40 million) in public and private funding from sources including the U.K. Space Agency (UKSA) and venture capital firms Sunstone Technology Ventures and the High-Tech Gründerfonds, as well as strategic investor Elecnor Deimos Space, the European Space Agency (ESA) and the European Commission Horizon 2020 programme. Its staff have professional backgrounds within NASA, ESA and other spaceflight organisations.

www.slm-solutions.com  
www.orbex.space ■ ■ ■



## Sigma Labs joins Fraunhofer IAPT's Additive Alliance

Sigma Labs, Inc., a provider of quality assurance software under the Print-Rite3D® brand, has joined the Additive Alliance of Fraunhofer IAPT, a global research consortium established to advance the development and implementation of Additive Manufacturing. As the first US company to be granted membership in the network, Sigma Labs will have the opportunity to demonstrate its technology to key players in the market.

"We are happy to welcome Sigma Labs as a new member of our Additive Alliance and to strengthen the competences of the network in the field of quality assurance," added Antje Vosschenrich, head of the Additive Alliance at Fraunhofer IAPT.

Established in 2014, the Additive Alliance promotes the exchange of knowledge across the entire process chain and has over thirty members.

[www.iapt.fraunhofer.de](http://www.iapt.fraunhofer.de) ■ ■ ■

## Elcan offers toll recycling of metal AM powders

Elcan Industries Inc., Tuckahoe, New York, USA, has developed a new programme to help its customers with the recycling of Additive Manufacturing powders. The company will guide those new to metal AM with the handling and sieving of these powders, as well as offering assistance on a tolling basis to those not ready to invest in recycling equipment.

Using its proprietary Hi-Sifter technology, Elcan Industries can help companies recycle their AM powders at the desired powder specification.

This means, for example, if the powder is a 44 µm powder, Elcan's technology will sieve the powder at 44 µm.

The company stated that its twenty-five years' experience in sieving has given it the knowledge to process these types of metal powders efficiently and safely. It also has a new state of the art lab that will contain a sieving station with the sole purpose of recycling Additive Manufacturing powders for companies.

The Elcan facility is said to be capable of handling anything from hundreds up to a million pounds of metal powder and offers sieve sizes down to 15 µm. All powders, with the exception of magnesium, can be processed and the company will provide particle size analysis for each fraction of the product as well as sieve analysis as needed.

[www.elcanindustries.com](http://www.elcanindustries.com) ■ ■ ■



Elcan will use its Hi-Sifter technology to help companies recycle their metal powders for Additive Manufacturing (Courtesy Elcan Industries)

## Optomec & Phillips Federal to provide metal AM repair to US government

Optomec, Albuquerque, New Mexico, USA, a provider of production-grade Additive Manufacturing solutions, has signed a partnership agreement with Phillips Federal, the largest supplier of manufacturing equipment to the US government. The agreement will enable Phillips Federal to resell Optomec's Laser Engineered Net Shaping (LENS®) systems - which offer a range of AM solutions for the manufacture, enhancement and repair of components in metals, ceramics and composites - to US government facilities.

John Harrison, Vice President of Phillips Federal, stated, "The agreement enables Phillips to continue to provide the best Additive Manufacturing solutions to maintain the readiness of the military and advance the research and development of new innovations and ideas throughout

our government. We've seen an increase in the demand for Additive Manufacturing solutions and our partnership with Optomec will allow us to continue to offer a full range of solutions."

Optomec LENS systems use Directed Energy Deposition (DED) technology and are said to be able to additively manufacture full parts at a fraction of the time and cost of systems based on Powder Bed Fusion, as well as adding material to existing parts for repair and coating applications to extend the use life of components.

"Our partnership with Phillips Federal will take the LENS technology to US government facilities enabling them to achieve multiple strategic objectives," stated Jamie Hanson, VP of Business Development at Optomec. "Additive Manufacturing technology



Optomec's LENS systems can be used for the building, repair and coating of parts (Courtesy Optomec)

will improve maintenance and repair operations, get equipment operational faster, and improve supply chain capability all at significantly lower cost than traditional methods. Phillips has a very long and successful track record of working closely with customers to achieve their objectives, and together with Optomec, we expect to make a significant impact."

[www.optomec.com](http://www.optomec.com)  
[www.phillipsfederal.com](http://www.phillipsfederal.com) ■ ■ ■



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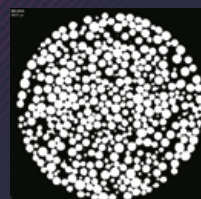
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## S-PREP Spherical Powder

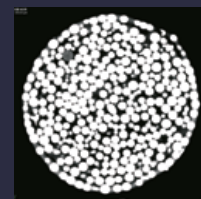
- ★ Ti6Al4V ELI, BT20, Ti6242, Ti1023
- ★ Inconel 718, 625
- ★ 316L, 17-4PH, A100, Duplex
- ★ Co-Cr-W, Co-Cr-Mo, CrCrWMo

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Ti6Al4V ELI



Inconel 718



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## Inert to showcase next generation of its PowderShield system at Rapid + TCT

Inert, headquartered in Amesbury, Massachusetts, USA, has announced it will display the next generation of its PowderShield systems at Rapid + TCT 2019, May 21-23, at the Cobo Center in Detroit, Michigan. Working in a closed-loop configuration, the company's systems allow additive manufacturers the ability to safely post-process components, reclaim and reuse costly metal powders, and maintain a strict atmosphere during the depowdering process.

Inert specialises in solutions for aerospace, medical device, and other Additive Manufacturing applications that use metal powders. The gen 3 model of its PowderShield system will include an updated design and features for efficiency and safety in depowdering.



*Inert will display the next generation of its PowderShield system (Courtesy Inert)*

The depowdering procedure is conducted in an argon atmosphere controlled by Inert's Argon Gas Management System to avoid contamination from oxygen, moisture, or dust and can facilitate other sensitive powder handling and AM processes.

Features include an argon blow off gun, ultrasonic vibration,

unidirectional flow, perforated floor for powder collection, and other customisations. PowderShield can be integrated with automated sieves, powder hoppers, and other third part equipment to create unique, closed loop post processing systems.

[www.inert-am.com](http://www.inert-am.com)  
[www.rapid3devent.com](http://www.rapid3devent.com) ■ ■ ■

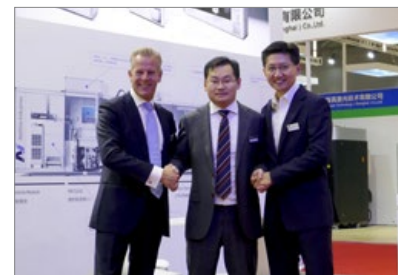
## Additive Industries appoints Sinsun-Tech agent for China

At the opening of the TCT Asia 2019 exhibition & conference at SNIEC in Shanghai, China, Additive Industries has signed an Agency Agreement with Sinsun-Tech Corporation Ltd. Following the recent expansion of Additive Industries into the Asia Pacific region through the setup of a regional Process & Application Development Centre in Singapore, Sinsun-Tech teams up with Additive Industries to develop the Chinese market for industrial 3D metal printing systems.

Sinsun-Tech, founded in 2018, is a specialised supplier of metal Additive Manufacturing and metal treatment solutions based in Beijing. Its founding partners have extensive industry experience in the Chinese market for metal Additive Manufacturing as well as other thermal

processes. The company will support Additive Industries in developing the China industrial market in aerospace, automotive, medical and general machine building markets.

"We focus on professional customers for industrial metal additive manufacturing solutions, and based on the experience and market knowledge we have gained over the years, we are well positioned to introduce Additive Industries and the MetalFAB1 system especially in the aerospace domain where most of the current Additive Manufacturing experience is found," stated Wang Jun, General Manager of Sinsun-Tech. "We are looking forward to work with Additive Industries and develop our commercial strategy with regards to metal 3D production solutions for aerospace as well as other industrial markets."



*From Left to Right: Bart Leferink (Director Global Channel Sales, Additive Industries), Wang Jun (General Manager, Sinsun-Tech Corporation Ltd.) and Mike Goh (General Manager, Additive Industries Asia Pacific Pte. Ltd.)*

"With Sinsun-Tech we add an experienced partner to our network that will work with us to identify and manage these opportunities that will contribute to our accelerated growth," added Daan Kersten, Co-founder & CEO of Additive Industries.

[www.additiveindustries.com](http://www.additiveindustries.com) ■ ■ ■



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## LimaCorporate to establish hospital-based metal Additive Manufacturing facility in New York

LimaCorporate SpA, Udine, Italy, a global medical device company providing reconstructive and custom-made orthopaedic medical implants, is to establish its first hospital-based metal Additive Manufacturing facility. In partnership with the Hospital for Special Surgery (HSS), New York, USA, the new facility will be used to produce a range of complex custom implants.

HSS, a leading orthopaedic hospital, has been sourcing patient-specific custom implants from Lima's headquarters in Italy since 2016. Lima's additively manufactured implants, produced using Electron Beam Melting (EBM) on Arcam systems, feature its proprietary Trabecular Titanium™ biomaterial,

which is said to enhance cell migration and vascularisation, facilitating the transport of oxygen, nutrients, ions and bone inducing factors and promoting new bone formation in osseointegration.

The close proximity of Lima's AM capabilities to the HSS care environment, with the establishment of the new facility, will significantly aid practitioners in their treatment of patients. The facility will be established at HSS's main campus on New York City's Upper East Side and is set to benefit from a combination of Lima's advanced technology and experience, and HSS's expertise in clinical care and bio-mechanical engineering.

The collaboration is therefore expected to foster and accelerate innovation in complex orthopaedic joint care, resulting in a range of new products and solutions for patients across the USA. Leonard Achan, RN, MA, ANP, Chief Innovation Officer at HSS, stated, "The close integration between surgeons and engineers is invaluable for designing and refining joint replacements and identifying new solutions for the most complex patient cases."

Luigi Ferrari, LimaCorporate CEO, added, "We are proud to be the first company to bring 3D printing of implants directly to a hospital organisation, where the collaboration between top ranked surgeons and engineers can drive innovation and easier access to patients in the US. This is what defines Lima. A company that has in the past, and will continue in the future, strive to transform orthopaedics by challenging the status quo."

Lima will be the registered manufacturer for all devices designed and produced at this new, state-of-the-art facility, located at HSS. The facility is expected to be operational by early 2020 and will initially serve hospitals in the region before making the devices available to all providers in the US.

[www.limacorporate.com](http://www.limacorporate.com)  
[www.hss.edu](http://www.hss.edu) ■ ■ ■



Lima's Trabecular Titanium is a biomaterial characterised by a regular, three-dimensional, hexagonal cell structure that imitates trabecular bone morphology (Courtesy LimaCorporate)

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## Optomec announces new LENS controlled atmosphere DED systems

Optomec, headquartered in Albuquerque, New Mexico, has announced the release of its new LENS CS 600 and CS 800 Controlled Atmosphere (CA) Directed Energy Deposition (DED) Systems. The latest additions to the Optomec Laser Engineered Net Shaping (LENS) series offer controlled atmosphere chambers to allow for the processing of both non-reactive and reactive metals, as well as being compatible with the company's latest generation deposition head providing higher power laser processing (up to 3 kW), interchangeable print nozzles, and variable spot sizes.

The LENS CS 600 and CS 800 are reported to be configurable and maximise the process build envelope with a minimal system footprint. The controlled atmosphere chamber

keeps moisture and oxygen levels at less than 10 ppm and the systems come standard with a Siemens 840D controller, allowing operation from three-axis up to simultaneous five-axis motion.

"These new systems come packed with next-generation DED components all born from signature Optomec know-how and built to provide affordable, high-quality metal Additive Manufacturing capabilities for industry's most demanding requirements," stated Tom Cobbs, Optomec LENS product manager. "The LENS CS 600 and CS 800 systems represent the latest in DED processing from precision deposition to cladding applications and extend our product portfolio to continue to provide high-value metal Additive Manufacturing solutions."



The LENS CS 800 offers a 600 x 400 x 400 mm build envelope (Courtesy Optomec)

Optomec LENS systems use an Additive Manufacturing technique called directed energy deposition (DED), where high-powered lasers build structures layer by layer directly from powdered metals, alloys, ceramics, or composites to produce fully-dense parts with excellent mechanical and fatigue properties.

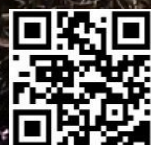
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## CECIMO welcomes EU's focus on Additive Manufacturing in planned trade deal between EU and US

CECIMO, the European Association for the Additive Manufacturing sector, has welcomed the EU's commitment to keep Additive Manufacturing as one of the priority areas in EU-US talks for a trade deal on industrial goods. Forging EU-US cooperation on regulations and standards has significant potential in facilitating the growth of AM technology on both sides, reported CECIMO.

At present, there are non-tariff barriers in the EU-US trade of AM solutions that generate financial and administrative burdens for exporters. Examples of these are lengthy processes to establish rules of origin for products, which are responsible for additional costs and custom delays. Tackling them in the context of this trade deal will further expand

transatlantic AM trade opportunities. Similarly, an agreement that achieves the alignment of technical requirements between US and European standards and regulations in conformity assessment procedures will entail cost savings and a greater level of clarity for trade requirements, all whilst maintaining an equivalent level of protection to what is in place today.

"Addressing barriers to EU-US trade such as double certification issues would boost the growth of AM solutions in both economies. The fact AM has been singled out in the trade discussions right from the beginning is a sign of the importance of this technology for industrial trade today," stated Mr Stewart Lane, Chairman of the CECIMO AM Committee.

"Both Europe and the US are notable actors in the global AM market. CECIMO will continue to cooperate with trade negotiators and convey the views of Europe-based AM exporters on non-tariff barriers encountered in EU-US trade. Our aim is to ensure negotiations progress and deliver a final trade deal that improve access of European AM companies to the US market," added Dr Roland Feichtl, member of the Supervisory Board of KRAUSECO Werkzeugmaschinen and CECIMO President.

The trade discussions stem from a July 2018 agreement between the EU and US. In a progress update in January 2019, the European Commission pointed to AM as a 'specific technology' that needed to be worked on with US counterparts to forge deeper transatlantic regulatory cooperation.

[www.cecimo.eu](http://www.cecimo.eu) ■ ■ ■

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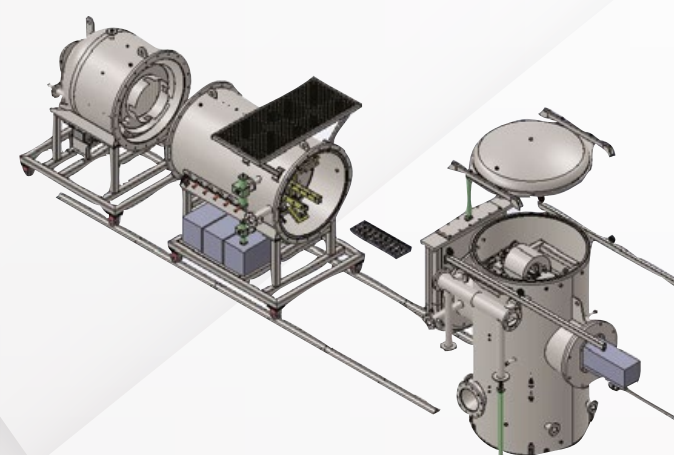
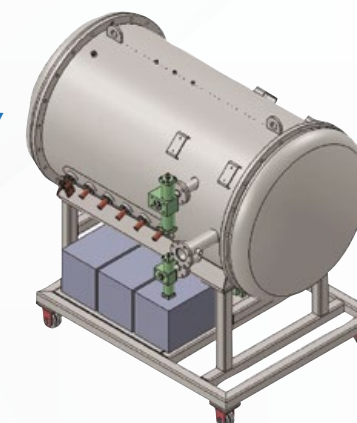
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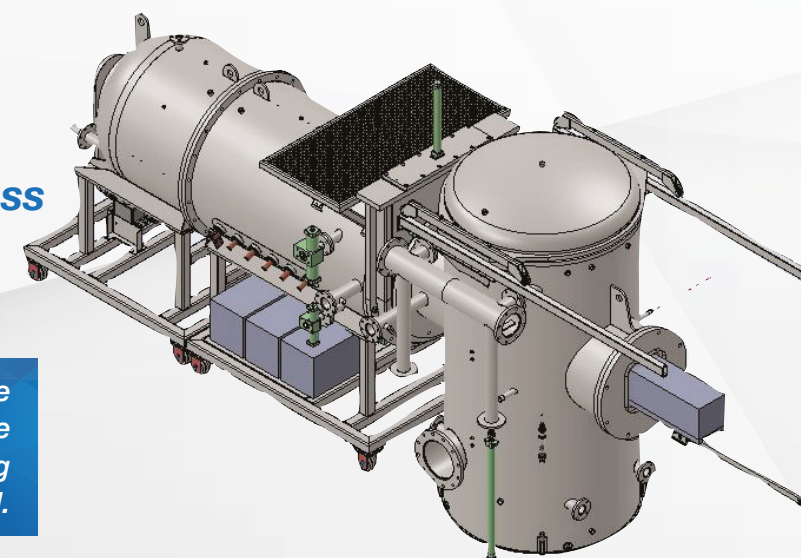


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## Metal AM used to produce exterior wall components for coming Seattle skyscraper

3Diligent, a digital manufacturing services provider based in El Segundo, California, USA, was recently engaged by commercial cladding company Walters & Wolf (W&W), Fremont, California, USA, to manufacture 140 unique aluminium exterior curtain wall nodes by metal Additive Manufacturing. The nodes were designed by W&W to enhance the look and feel of the upcoming Rainier Square Tower in Seattle, Washington, USA.

Expected to be completed in 2020, the new Rainier Square Tower will become Seattle's second tallest building. The structure will comprise a fifty-eight story tower with a unique sloping appearance; with a step back on each building floor, the cladding system for each floor will have a different angle and require complex geometries to fit together perfectly.

W&W worked with 3Diligent from the prototype stage through to production to produce the 140 nodes, which each have varying dimensions and measure up to nearly a cubic foot in size. As geometries changed throughout the building's design, 3Diligent drew

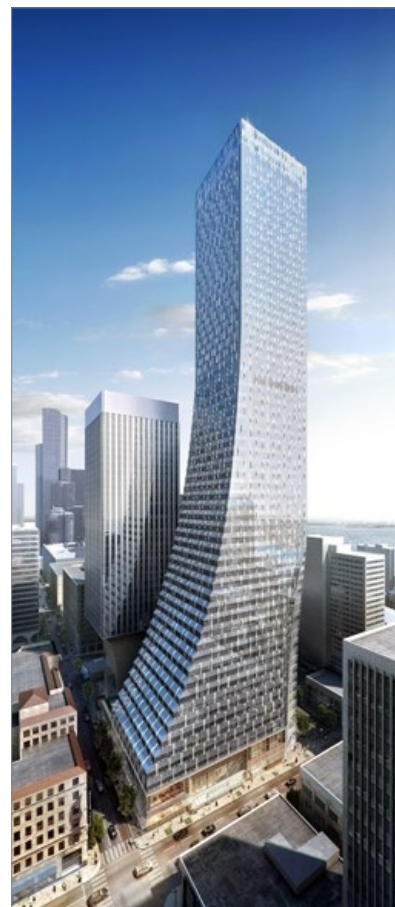
on its metal AM design expertise to ensure each geometry met W&W's exacting specifications.

"From an operations standpoint, we were impressed with 3Diligent's consistency in delivery of highly accurate and complex parts in a timely fashion that was in sync with the production schedule we established early on," explained Tony Parker, Project Executive at Walters & Wolf. "At the end of the day, 3Diligent upheld their end of the bargain – they simply did what they said they would do."

To achieve the unique 'sloped' design of the tower, each piece of the curtain wall needed to be custom fabricated to meet the geometry of that section of the building. Walters & Wolf determined the best approach would be to create V-shaped nodes that ranged in size, that would bring together square cut parts of the curtain wall. After experimenting with a variety of manufacturing processes and receiving responses from some vendors to say that they could not complete the work, Walters & Wolf turned to 3Diligent.

3Diligent presented two manufacturing processes to the cladding company – investment casting and Additive Manufacturing – and delivered first articles from both of the different processes. These were assembled into curtain wall units and sent to an independent testing laboratory in Fresno, California, USA, for performance mock-up testing to ensure the nodes did not experience any cracking or any kind of failure when installed on the building. While the parts don't carry a large structural load, the nodes would need to have good adhesion with silicone and be able to remain watertight and airtight.

After testing, Walters & Wolf selected metal AM as their preferred choice. "It was great that 3Diligent



The new Rainier Square Tower is expected to be completed in 2020 [Courtesy NBBJ]

gave us both investment casting and 3D printing options so that we could choose between them," commented Jon Ishee, the W&W designer assigned to the project. "We prototyped in both technologies and ultimately picked 3D printing because of the dimensional accuracy and structural reliability it gave us."

Cullen Hilkene, CEO of 3Diligent, stated, "We were honoured when Walters & Wolf engaged 3Diligent as its manufacturing partner for this project. Both the tower and these specific parts represent the sort of innovation that 3Diligent strives to enable every day. It was great collaborating with Walters & Wolf on such a compelling project and we look forward to seeing the completed tower in 2020!"

[www.3diligent.com](http://www.3diligent.com)  
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The metal additively manufactured aluminium exterior curtain wall nodes [Courtesy 3Diligent]

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## New metal Additive Manufacturing system based on MIM technology

Qingdao Greenlong Machinery Equipment Co., Ltd., based in Qingdao, China, has developed its first Additive Manufacturing system based on Metal Injection Moulding (MIM) technology. According to the company, the system, titled the P/FFDM 3D Printer, which can be used to build parts in metal, ceramic or plastic, has achieved successful results for the AM of large parts, with most test parts weighing more than 300 g and the largest part said to weigh over 5000 g.

Greenlong developed the machine with the aim of solving a key pain point of MIM – the long lead-times involved in the development and production of tooling for each new product. The machine was developed using plastic Fused Deposition Modelling (FDM) technology as its basis, while drawing on Greenlong's experience as a

maker and user of injection moulding machines.

By using the P/FFDM for the production of MIM tooling, companies which use MIM can significantly reduce product lead times. Further, the machine uses standard MIM feedstock and produces parts requiring debinding and sintering using the same equipment as MIM parts, making it relatively simple for MIM operations to incorporate the new system into their workflow. Greenlong additionally stated that if a product produced on the P/FFDM is found to be wrong or defective, it can simply be broken and reformed into feedstock for a future build.

The company added that the production of components on the P/FFDM machine remains quite slow in comparison to MIM manufacturing,



*Greenlong's P/FFDM 3D Printer, a metal AM system based on MIM technology (Courtesy Qingdao Greenlong Machinery Equipment)*

and can be an inefficient production method for large volumes of parts. However, it was reported that a new machine is now in the 'debugging stage' which will have the capability to produce parts at speeds comparable to MIM. The new machine is set for release in mid-2019. ■ ■ ■

## MELD Manufacturing Corporation launches operator training programme

MELD Manufacturing Corporation, Christiansburg, Virginia, USA, has launched a new training programme that will give participants certification in operating its metal AM machinery. The four-day courses will be hosted at MELD's headquarters and attendees will receive both hands-on machine training and classroom instruction.

MELD's technology is a unique no-melt process for Additive Manufacturing, repairing, coating and joining of metals and metal matrix composites. Participants will be instructed on identifying the required machine settings for a wide range of metals compatible with the technology, and be taken through each step of the MELD process, from digital print file creation to deposition. Nanci Hardwick, MELD CEO, stated,

"This programme creates certified MELDers and delivers the capacity to integrate and innovate with MELD. Our customers have raved about the elegance of the MELD process and the ease of training. We're excited to offer more of these opportunities."

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

The MELD process is reported to deposit material at least ten times faster than fusion-based



*MELD uses a solid-state process which can use metal powders and rods as feedstock (Courtesy MELD Manufacturing)*

metal AM processes and is expected to find applications in a range of areas including the automotive, aerospace, defence and turbomachinery industries, with the company offering machine sales in addition to contract manufacturing and consulting services.

[www.meldmanufacturing.com](http://www.meldmanufacturing.com) ■ ■ ■

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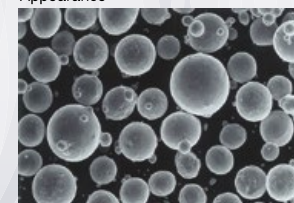
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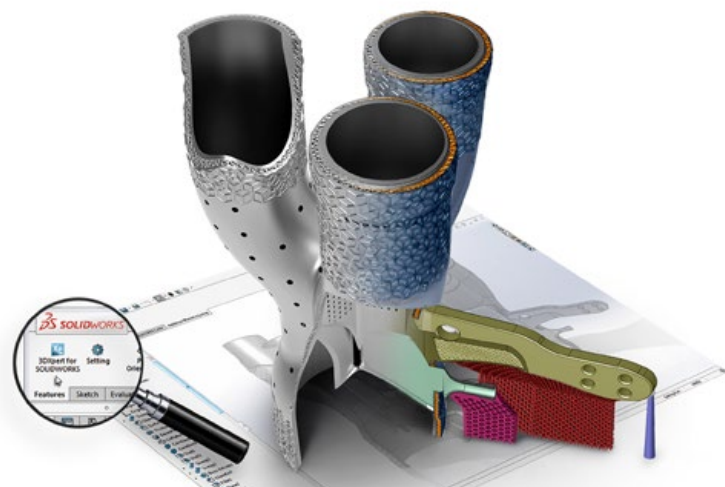
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## 3D Systems launches updated AM design solutions for SolidWorks

3D Systems, Rock Hill, South Carolina, USA, has released two updated software solutions for use exclusively in SolidWorks, published by Dassault Systèmes, Vélizy-Villacoublay, France. The new versions of Geomagic®, for SolidWorks® 2019, and 3DXpert™, for SolidWorks 14, have been designed to help SolidWorks users streamline 3D scan data workflows and optimise and prepare part designs for both polymer and metal Additive Manufacturing.

Geomagic for SolidWorks is said to be the AM industry's only complete integrated 3D scan-to-SolidWorks software solution. The software reportedly helps designers reduce the time required to build CAD models of real-world objects from hours to minutes, by using advanced, automated wizards to quickly and easily create sketches, surfaces, and feature-based editable solid parts inside SolidWorks, directly from 3D scan data.



3D Systems has released updated versions of its Geomagic and 3DXpert solutions for SolidWorks (Courtesy 3D Systems)

## Sigma Labs joins UK's MTC to showcase in-process quality control for AM

Sigma Labs, Inc., a provider of Additive Manufacturing quality assurance software headquartered in Santa Fe, New Mexico, USA, has become a member of the UK's Manufacturing Technology Centre (MTC) based at Ansty Park, Coventry. Through its membership, Sigma Labs will provide expertise and solutions for a number of the centre's projects, as well as gaining access to existing MTC members, including some of the UK's leading aerospace companies.

The MTC was established as part of the UK government's national manufacturing strategy with the aim

of bridging the gap between academic discoveries and real-time industry innovation. It houses some of the most advanced manufacturing equipment in the world, providing integrated manufacturing system solutions for customers across sectors that include automotive, aerospace, rail, civil engineering, oil & gas and defence.

"The MTC manufacturing research centre model uses public and private funding to bring academia and industry together, to pursue challenging, industrially relevant development projects," stated John Rice, CEO of Sigma Labs. "As a member of the

3DXpert for SolidWorks is an add-on for SolidWorks which extends its design capabilities with a complete Design for Additive Manufacturing (DfAM) toolset, equipping designers with tools to prepare and optimise their designs for AM. The new version of 3DXpert for SolidWorks is said to further enhance the direct path from SolidWorks to AM. It enable users to design more shapes in more ways, with new lattice types and extensive control over lattice structures. It is designed to shorten time to market by bringing SolidWorks CAD data directly into 3DXpert for SolidWorks with one click, before reading back to SolidWorks the optimised and build-ready data. Engineering changes are said to be easily applied to build-ready models without losing work completed so far, helping designers to stay within schedule and budget.

By designing for AM, users gain an understanding of manufacturing constraints and the implications of design decisions on the quality and cost of the final part. New 2D / 3D nesting tools, new joint-cut tool and enhanced part orientation and analysis tools help make manufacturing considerations accessible to SolidWorks designers during the design process.

[www.3dsystems.com](http://www.3dsystems.com)

[www.solidworks.com](http://www.solidworks.com) ■ ■ ■

MTC, Sigma Labs will extend its industry footprint further into the exciting research and commercialisation in Additive Manufacturing today. With Europe at the forefront of many innovative and major developments in the metal AM industry, we believe this agreement, our second major research alliance with a European centre of excellence, holds great promise for us and the future of AM. We look forward to interacting with the other member companies in the MTC, and particularly to collaborating with researchers at the National Centre for Additive Manufacturing to demonstrate the capabilities and potential of the PrintRite3D® Inspect® technology."

[www.sigmalabsinc.com](http://www.sigmalabsinc.com)

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## Regional voestalpine AM Centre achieves ISO 9001 Certification

voestalpine Additive Manufacturing Centre Ltd., Mississauga, Ontario, Canada, a business of voestalpine AG's High Performance Metals Division, has achieved certification according to ISO9001:2015 for the

design, simulation and production of additively manufactured components for the power generation, oil & gas and other advanced industries.

The Additive Manufacturing Centre in Mississauga is part of a growing

regional and global network of voestalpine AM Centers (vAMC) said to offer customers 'concept to component' services. Customers who work with a vAMC reportedly benefit from a single partner offering the complete AM value-chain, from powder development to engineering, simulation and modelling, and the latest AM production technologies through to post-processing services such as machining, thermal processing and coatings.

Sami Arsan, VP of voestalpine Additive and Advanced Manufacturing North America, stated, "With this certification customers are assured that their work is being handled in a thoughtful and repeatable manner consistent with desired outcomes. It also provides a sound basis for driving efficient and effective business processes."

www.voestalpine.com ■■■



A metal AM component produced at voestalpine (Courtesy voestalpine AG)

## VBN Components signs major agreement with global engineering group

VBN Components AB, Uppsala, Sweden, reports that it has signed a licence agreement with a non-disclosed global engineering group headquartered in Europe. The agreement implies an exclusive licence within a specific niche of high-strength components, and will result in the installation of manufacturing cells, utilising VBN's patented material manufacturing technique, at

the engineering group's premises worldwide.

The exact details of the agreement remain confidential at this stage; however it was stated that the engineering group currently acquires products, as well as R&D, from VBN. In order to adjust to this new type of manufacturing, VBN will support the customer as it moves to larger in-house series production

with its AM-HSS™ manufacturing technique.

Martin Nilsson, VBN Components' CEO, stated, "This is an incredibly important verification that our 3D printed materials Vibenite® are at top level. After considerable technical testing and analysis, the agreement has been signed and we are very much looking forward to collaborating with this global partner."

"The agreement is a milestone in VBN's success story," he continued. "It is a multi-million deal that will grow steadily with expanding business and deliveries. The engineering group is one of the actors that started collaborating with VBN at an early stage."

"The licence agreement is showing that our initial idea of making better materials with 3D printing, than what's possible traditionally, is really working. The customer gets a better material, much larger product flexibility, shorter lead times and considerably lowered machining costs," he concluded.

www.vbncomponents.com ■■■



Drill bit components manufactured in Vibenite 480 cemented carbide (Courtesy VBN Components)

# ADDITIVE MANUFACTURING



Powder atomization plant



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Printed Inconel air knife

## POWDER ATOMIZATION PLANT FOR ADDITIVE MANUFACTURING

With the launch of the Demo Center for additive manufacturing, SMS group is showcasing its know-how in powder metallurgy and additive manufacturing processes.

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## University of Pittsburgh and General Carbide partner to improve tungsten carbide parts using Additive Manufacturing

The University of Pittsburgh and General Carbide Corporation in Greensburg, Pennsylvania, USA, have partnered to explore the use of Additive Manufacturing in the production of tungsten carbide components. Tungsten carbide is seen as one of the most versatile metal compounds and is highly valued for its durability and strength, making it perfect for cutting tools, boring machines and surgical instruments. However, when additively manufactured, tungsten carbide is susceptible to fractures and breakage when exposed to the extreme laser melting used in the process.

The recent award to the University of Pittsburgh and General Carbide Corporation will enable research into improved base powders and Additive Manufacturing

methods for more effective and economical use of tungsten carbide. The project was financed in part by a \$57,529 grant from the Commonwealth of Pennsylvania's Department of Community and Economic Development (DCED) and the first round of the PA Manufacturing Innovation Program (PAMIP). Cost share from Pitt's Swanson School of Engineering and General Carbide will provide a total funding of \$145,000.

Principal investigator is Markus Chmielus, Assistant Professor, and the student fellows are from the Department of Mechanical Engineering and Materials Science. The award will also fund two materials science and engineering students Katerina Kimes (Graduate) and Pierangeli Rodriguez De Vecchis (Undergraduate) as fellows in fundamental and applied research.

"Additive Manufacturing is increasingly adopted by industry to build highly-complex metal parts, but the rapid local heating and cooling during energy beam-based 3D metal printing produces large thermal gradients which causes tungsten carbide to crack," Dr Chmielus stated. "Binder Jet 3D printing is more effective because it selectively joins powder particles with a binder, one microscopic layer on top of another and without any temperature fluctuations during printing."

Still key to utilising tungsten carbide, however, is that after a part is printed, it needs to withstand a sintering and potentially HIP procedure to densify and harden it for use. To achieve this, Dr Chmielus and General Carbide will investigate various tungsten carbide base powders that can be utilised in a Binder Jet AM system, as well as optimise the printing process and subsequent sintering and hipping.

"This research will enable General Carbide to expand our portfolio with more complex and versatile parts at a lower cost by partnering with the Swanson School and leveraging its expertise in Binder Jet 3D printing and Additive Manufacturing process optimisation," noted Drew Elhassid, Chief Metallurgist and Manager of Lab, Pressing and Powder Production at General Carbide. "Additive Manufacturing is especially useful when needed to create the most demanding but low-count parts that we wouldn't necessarily build on a consistent basis."

"With the Manufacturing Innovation Program, the Wolf Administration aims to connect our best and brightest students with manufacturers to drive new technology and innovation in the manufacturing sector," said Sheri Collins, deputy secretary for technology and innovation at the Pennsylvania Department of Community and Economic Development. "As manufacturing processes become more and more complex, these projects will keep Pennsylvania at the forefront of manufacturing innovation."

[www.engineering.pitt.edu](http://www.engineering.pitt.edu)  
[www.generalcarbide.com](http://www.generalcarbide.com) ■ ■ ■



*It is expected that the research will result in more complex and versatile carbide parts produced at lower cost (Courtesy General Carbide Corporation)*

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	Chicago, IL March 31 - April 4	Booth P2
	Paris, FR 17-23 June 2019	Booth E3

## Markforged adds H13 tool steel for high-strength, high-temp tooling applications

Markforged, Watertown, Massachusetts, USA, has announced the launch of H13 tool steel for its desktop sized Metal X Additive Manufacturing system. It is stated that the availability of H13, also known as EN 1.2344 and SKD61 in Germany and Japan, will enable customers to manufacture parts for high-strength, high-temperature applications, such as metal forming tools, dies and punches, and hardened inserts for fixtures, and even injection moulds with conformal cooling channels.

"We designed the Metal X system to change the way things are made, and the launch of H13 is the next step down that path," stated Jon Reilly, Markforged VP of Product. "For manufacturers of high-volume plastic parts this is a game changer, significantly accelerating the speed at which they can bring new products to market."

H13 is a hot-work tool steel, meaning that it retains high strength at elevated temperatures, and is known for exhibiting excellent hardness, resistance to thermal fatigue, high toughness, ductility, good abrasion resistance, and excellent through-hardenability. Additive Manufacturing in H13 will allow the production of parts with unique and complex geometries, something that traditionally would be very expensive and difficult to do. For example, printing an H13 injection mould that features conformal cooling channels would more effectively move heat away from the mould cavity and provide more uniform cooling, leading to less part-warp, shorter cycle times and higher throughput and, ultimately, lower operational costs.

Since 1982, San Francisco Bay Area-based Grant Engineering has been creating high-quality parts from injection-moulded plastics, producing

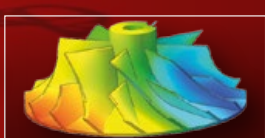
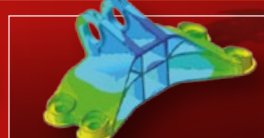
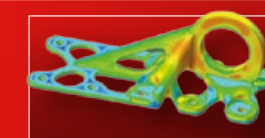
millions of parts per year for their biotech, high tech and consumer product industry customers. Grant is an early adopter of the Metal X printing system who also utilises the Mark 2 for printing end-of-arm tooling and fixtures. Since they received their Metal X system, the company has been printing 17-4 stainless steel injection moulds successfully, with minimal post-processing. Grant Engineering now hopes to further reduce their iteration time and cost for injection moulds printed in H13.

"Injection moulding is the core of what we do," added Randy Grant, co-founder and co-owner of Grant Engineering. "Much like the robots and automation we've already introduced into our workflow, we see 3D printing – especially the Metal X – as a way to keep us hyper-competitive on cost and turnaround time while still delivering the precision and quality we're known for. Being able to 3D print H13 should enable a lot of innovation with injection moulding, we can't wait."

www.markforged.com ■■■

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## POWDERMET2019 and AMPM2019: Full conference programmes now available

The MPIF has released the full conference programmes for POWDERMET2019: the North American Conference on Powder Metallurgy and Particulate Materials, and AMPM2019: Additive Manufacturing with Powder Metallurgy, set to run concurrently at the Sheraton Grand Hotel in Phoenix, Arizona, USA, from June 23–26, 2019.

POWDERMET2019 will feature more than two-hundred technical presentations from global industry experts presenting on PM, particulate materials, and metal Additive Manufacturing. In addition, over one-hundred exhibitors will showcase their technologies and services in the co-located POWDERMET exhibition, and a number of industry networking events such as the 'PM Evening Alehouse' will offer visitors and exhibitors the chance to make contacts within a diverse range of PM fields.

"POWDERMET conferences provide attendees with the opportunity to learn best practices, new solutions and the latest R&D," stated Blaine Stebick, MPIF Technical Board Chairman. "Powder Metallurgy continues to be an innovative technology that inspires the next generation of engineers, especially with the rising influence and interest in metal Additive Manufacturing."

AMPM2019's conference programme will feature worldwide industry experts presenting the latest technology developments in metal Additive Manufacturing. Attendees to AMPM will also have full access to all POWDERMET events including the conference programme, exhibition and networking sessions.

### Metal Additive Manufacturing Tutorial

A new Metal Additive Manufacturing Tutorial will also make its debut during the event. Presented by Todd A Palmer, The Pennsylvania State University, and Joseph T Strauss, FAPMI, HJE Company, Inc., this half-day tutorial will provide a basis for determining process options, uses, properties, applications and opportunities for cost-effective metal Additive Manufacturing.

"Metal Additive Manufacturing has pulled Powder Metallurgy back into the spotlight," commented Stebick. "The AMPM conference provides an essential opportunity for the transfer of technology and exposes engineers to further influence of Powder Metallurgy for design and manufacturing solutions."

The full technical programmes and further details on POWDERMET and AMPM are available via the conference websites. Registration is available at early-bird discounted rates until May 10, 2019.

POWDERMET2019.org | AMPM2019.org ■■■

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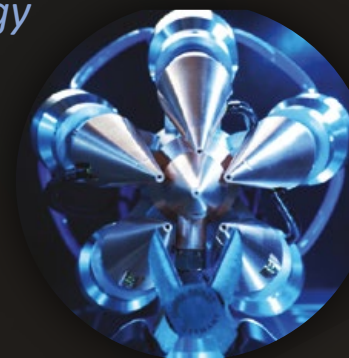


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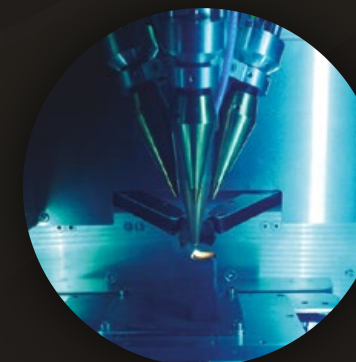
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## Bugatti reveals range of metal AM components developed for its high-performance sports cars

High-performance sports car manufacturer, Bugatti Automobiles S.A.S, headquartered in Molsheim, France, is reported to be using Additive Manufacturing to develop and build a number of functional components for its iconic range. In addition to a previously announced brake caliper, which entered vehicle trials in the first half of 2018, the company has used AM technology to optimise component design, saving weight and increasing performance. Built using AM machines from SLM Solutions Group AG, Lübeck, Germany, the components demonstrate that AM can produce parts for a range of highly demanding applications.

### Titanium brake caliper

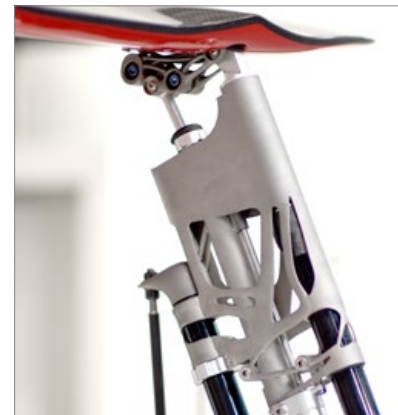
The previously mentioned titanium brake caliper was manufactured on a SLM®500 system from Ti6Al4V, and developed along with Fraunhofer IAPT (formerly Laser Zentrum Nord) and Bionic Production AG. The results from testing the calipers showed that a tensile strength of 1250 N/mm<sup>2</sup> and a material density over 99.7% was achieved. "Proof that additively produced metal components can cope with extreme strength, stiffness and temperature requirements at speeds of over 375 km/h with a braking force

of 1.35 g [13.24 m/s<sup>2</sup>] and brake disc temperatures up to 1100°C," stated Frank Götzke, Bugatti's Head of New Technologies.

### Active spoiler bracket

Bugatti has also developed an additively manufactured active spoiler bracket with Fraunhofer IAPT. Götzke explained, "We always strive for absolute perfection, stylistic as well as technical, as well as considering the perfect synergy of both elements – the tradition of Ettore Bugatti we uphold." It was stated that the AM spoiler bracket aided the 1500 hp vehicle to reach speeds of up to 400 km/h in some 32.6 seconds, later bringing it to a stop within 9 seconds.

The active rear spoiler can be adjusted in height and angle, supporting the sophisticated aerodynamics required to keep the car stable. Bugatti teamed with Siemens to optimise the bracket for production and reduce the number of iterations needed to achieve the required weight and rigidity. Using additively manufactured titanium with a tensile strength of 1250 MPa and a material density of over 99.7%, the spoiler bracket's weight was reduced by 5.4 kg, with an increase in rigidity and no loss of function.



Additively manufactured spoiler bracket reduced weight by 5.4 kg [Courtesy VW Group]

### Motor bracket with integrated water cooling

A small metal additively manufactured motor bracket with integrated water cooling was developed for the Bugatti Chiron and has been installed in all series vehicles since its launch. The Chiron has two separate water-cooling circuits to keep the component and system temperatures at an acceptable level, even under the most extreme environmental and operating conditions. The high-temperature circuit is used to cool the 1,500 hp W16 engine of the car, while the low-temperature circuit ensures that the intake charge cooling temperature remains suitably low.

A bypass flow filter of the NT circuit supplies the console while isolating the electronic components



This motor bracket has been installed on the Bugatti Chiron since launch [Courtesy VW Group]

from the temperatures of the transmission oil tank. The bracket acts as an active heat shield, resulting in a reduction in transferred heat. Its primary task is to engage the gears while opening and closing the two clutches of the seven-speed dual-clutch transmission, while including the control unit.

As a result, the temperature at the electric motor and at the control unit of the pump when driving through a demanding handling course can be lowered from 130°C to 90°C, a reduction of 40°C. The bracket was manufactured in the alloy AlSi10Mg on an SLM 280 Twin system, and was commissioned by SLM Solutions at Rolf Lenk Werkzeugbau GmbH.

### Front axle differential housing

SLM Solutions and Bugatti date their collaboration back to late 2014/early 2015, when SLM Solutions worked with Bugatti's parent company, Volkswagen Group, for the first time.



AM optimised front axle differential housing [Courtesy VW Group]

The project involved the design, calculation and later production of a bionically optimised front axle differential housing. This housing was manufactured by Audi AG at its Ingolstadt and Győr facilities on SLM 280 systems, with the objective of comparing the influencing factors of varying locations in regard to component quality.



Prototype cylinder head covers [Courtesy SLM Solutions Group AG]

### Cylinder head cam covers

Although not yet in production, the SLM Solutions booth at Formnext 2018 featured eight Bugatti W16 cylinder head covers. The parts measuring 285 x 65 x 735 mm each were created in a single build on the company's new SLM®800 machine.

www.slm-solutions.com  
www.bugatti.com ■■■



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## BMW Individual employs metal AM brake callipers

BMW Individual Manufaktur has presented a new one-off vehicle which incorporates metal additively manufactured brake callipers. The BMW Individual M850i Night Sky was designed to mark the Quadrantids meteor shower which took place in January 2019, with the inclusion of illuminated constellations on the centre console and the use of meteoric material, deposited on earth in former meteor showers, in its interior cabin.

The vehicle features metal additively manufactured brake callipers said to feature an intelligent lightweight, bionic design which mimics that

of bones. The brake callipers were developed by BMW Motorsport and reportedly weigh up to 30% less than components produced using conventional manufacturing, with the substantial reduction in unsprung mass said to improve driving dynamics and ride comfort.

The brake calliper design also incorporates the brake fluid channels into the structure of the part, reducing the number of components required. The BMW Individual M850i Night Sky was showcased at the 2019 Geneva International Motor Show.

[www.bmwgroup.com](http://www.bmwgroup.com) ■ ■ ■



BMW used metal AM to produce the brake callipers for the one-off M850i Night Sky (Courtesy BMW M Automobiles)

## U.S. Navy to install metal additively manufactured part on aircraft carrier

Huntington Ingalls Industries (HII)'s Newport News Shipbuilding division, Virginia, USA, has delivered its first metal additively manufactured part to the U.S. Navy for installation on an aircraft carrier. The part is a piping assembly which will be installed on the USS Harry S Truman (CVN 75) and evaluated for a one-year period. The Naval Sea Systems Command

(NAVSEA) last year approved the technical standards for Additive Manufacturing after collaboration with HII and industry partners to test parts and materials, extensive development of an engineered test programme and publishing of the results.

Charles Southall, Newport News' Vice President of Engineering and Design, stated, "We are pleased to

## Gefertec & Linde to investigate influence of process gas and oxygen on AM

Gefertec GmbH Berlin, Germany, and Linde AG, Munich, Germany, are cooperating to investigate the influence of process gas and oxygen percentage on the metal Additive Manufacturing process. Gefertec's 3DMP® technology uses electric arc welding to additively manufacture parts by welding wire feedstock layer by layer; the result of the arc welding process depends heavily on various parameters – especially the process gas.

The companies will investigate the influence of both welding parameters and process gas on final parts, with further partners on the project including MT Aerospace AG, which will perform mechanical testing on the produced parts, and Fraunhofer IGCV, where the AM of parts will take place on a Gefertec system.

The goal of the project is the production of larger parts at high production speeds, in titanium alloy Ti6Al4V. Ultimately the companies plan to produce products which meet the quality requirements of the aerospace industry.

[www.gefertec.de](http://www.gefertec.de) ■ ■ ■

have worked so closely with our Navy partners to get to the point where the first 3D metal part will be installed on an aircraft carrier. The advancement of Additive Manufacturing will help revolutionise naval engineering and shipbuilding. It also is a significant step forward in our digital transformation of shipbuilding processes to increase efficiency, safety and affordability. This is an accomplishment we all should be proud of."

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## Link3D introduces Additive Material Recommendation System

Link3D, headquartered in New York City, USA, has announced the launch of its Additive Material Recommendation System (AMRS), designed to be integrated in the existing Link3D industrial Additive Manufacturing workflow solution to simplify material selection processes.

AMRS will help engineers select the

most appropriate materials based on qualitative and quantitative specifications for production, providing an understanding of material performance across over 1000 materials and over 500 AM machines.

The Link3D platform is designed to enable organisations streamline

their Additive Manufacturing supply chains. This begins from order submission, auto-quoting, production planning and scheduling, post-processing, quality inspection, logistics management across internal and distributed supplier network.

The AMRS offers an intelligent recommendation system that allows new-to-additive engineers select a material most fitting for their AM builds through an intuitive filtering system. Engineers with an existing understanding of AM materials can easily access technical data for quicker decision-making without having to manually review material manufacturer's spec sheets.

As a result, engineers can design and produce higher quality, more economical and functional products. The system allows users to narrow down material selections by filtering qualitative key characteristics and technical material property ranges. Metal key characteristics listed include options for specifying corrosion resistance, oxidation resistance, biocompatible, high temperature resistance, electrical conductivity, ductile and thermal conductivity.

The AMRS also allows for searches based on tensile strength (Mpa), tensile modulus (Gpa), elongation at break (%), material density and hardness. In addition, users can search for materials by manufacturer.

"One of the major recurrent hurdles we're hearing from our customers is how to accelerate the adoption of Additive Manufacturing within their own organisation", explains Renaud Vasseur, VP of Business Development & Sales at Link3D. "We are thrilled that Link3D is introducing an Additive Manufacturing recommendation system that will not only help engineers achieve their design goals, but also increase overall understanding of the additive manufacturing capabilities and workflows."

[www.link3d.co](http://www.link3d.co) ■■■

## BAE Systems Air to employ Simufact Additive for metal AM

The Air division of BAE Systems, headquartered in Farnborough, UK, has selected Simufact Additive software, developed by Simufact, Hamburg, Germany, for the simulation of metal additively manufactured components. In 2015, BAE Systems opened a new Product and Process Development Centre, where it has since conducted trials of the market leading packages for the simulation of metal AM processes.

At the end of this trial phase, the company concluded that Simufact Additive software can deliver good results, and stated that its has gained great confidence from the trials carried out. In addition, BAE Systems is already using other MSC Software products in its facilities, such as MSC Nastran, Patran and MSC Apex. By choosing Simufact Additive, BAE ensures that its

products come from a single source, which has benefits for the process simulation chain.

Paolo Guglielmini, CEO MSC Software, stated, "For MSC Software, BAE Systems Air is a great partner because it shows that we offer best-in-class solutions and, with our MSC One product token system, a complete portfolio of solutions can easily be deployed that works hand in hand with BAE's applications."

When using Additive Manufacturing, BAE systems must face the main challenges of residual stresses and distortions. Before it employed a simulation software, the company reported, it sometimes had to complete five or six build trials, which are costly and time-consuming. With accurate simulation, it is expected to be able to reduce its build trials to just two

per component, with the opportunity to eliminate build trials with a 'right first time' approach in future.

At this stage, the company reported that it is pleased that its Application Engineers will use Simufact Additive for the build preparation of a component in order to achieve the best orientation and support strategy for a particular build. It added that it is now able to reduce distortion in components by more than 70% at the first iteration step.

"We are proud that one of the largest defence contractors in Europe, and a company that is among the world's largest defence entities, decided on Simufact Additive to roll out their Additive Manufacturing processes," added Dr Hendrik Schafstall, Simufact's CEO and Managing Director. "The trust BAE have put in us reinforces our approach and the great work being done by our development team."

[www.simufact.com](http://www.simufact.com)

[www.baesystems.com](http://www.baesystems.com) ■■■

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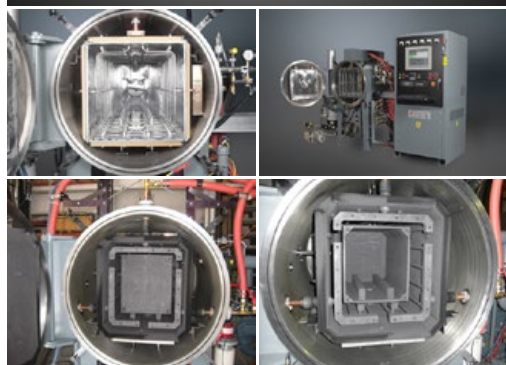
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### Metal Powders Category

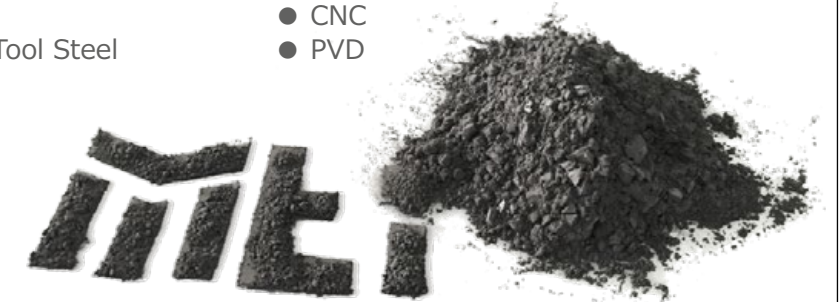
- Cobalt Based Alloy
- Titanium & Titanium Alloy
- Nickel Based Alloy
- Stainless Steel & Iron & Tool Steel
- Aluminum Alloy
- Customized Alloy

### Qualified for Processes

- SLM
- EBM
- DED

### R&D Equipments

- Hot Isostatic Press
- Metal 3D Printer
- CNC
- PVD



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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:** AISi10Mg, AISi7Mg  
**Refractory Metal:** W, Mo, Ta, Nb, Cr, Zr

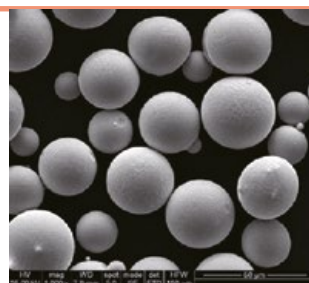
*Additional alloys are available upon request*



**Advanced Atomization System for Metal Powder Production**

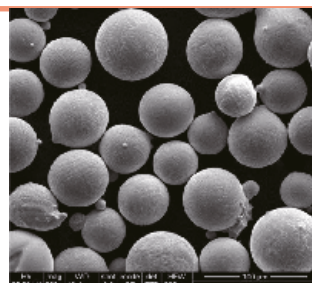
**Ti64 Gr5**

15-45µm



**IN718**

15-45µm



## Powder Characteristics

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

## Capacity

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

## Particle size range(min/max)

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

## Atherton Bikes works with Renishaw for key metal additively manufactured components

Renishaw has reported that it is working with new mountain bike brand Atherton Bikes to produce metal additively manufactured titanium lugs for the company's bike frames. Atherton Bikes was launched in January 2019 by mountain bike World Championship winners and siblings Gee, Rachel and Dan Atherton and co-founded by Piers Linney of UK television programme *Dragons' Den*.

The company's introductory bike range will incorporate carbon fibre tubing, joined with titanium lugs produced on Renishaw's multi-laser RenAM 500Q metal Additive Manufacturing system. Initial production will be at Renishaw's Additive Manufacturing Solutions Centre located in Staffordshire, UK, followed by a transition towards in-house manufacture at Atherton Bikes' own facility. During the development of the new bikes, Renishaw worked closely with the team, providing feedback through the design process to ensure the titanium lugs could be built accurately and successfully.

Also working on the Atherton Bikes project is renowned suspension designer Dave Weagle, along with Ed Haythornthwaite and other members of the former Robot Bike Company, which Renishaw previously worked with to manufacture similar titanium lugs for its R160 bike frame. The lugs for Atherton Bikes are said to be the first bike components to be built on the four-laser RenAM 500Q system. Machining and post processing are managed by Renishaw at its Solutions Centre.

"Renishaw is a world leader in metal Additive Manufacturing machines," stated Jono Munday, Additive Manufacturing Applications



*The Atherton family will now race their own range of downhill mountain bikes during competitions, as well as sell a range of bikes all over the world (Courtesy Renishaw)*

Manager at Renishaw. "Due to our position as a leading metrology business, we are also perfectly positioned to help customers develop an end-to-end solution, from AM build, all the way through machining and post-processing, providing an end-use engineered component."

"Manufacturing the lugs on the RenAM 500Q enables rapid production time," he continued. "This means that the bike frame development can be turned around quickly and customised to the exact requirements of the rider, whether that is the Atherton Racing team on the World Cup circuit

or an individual retail customer. Whereas traditionally a lot of tooling is required, Additive Manufacturing is an entirely digital process, meaning that the lugs can be modified in CAD and reproduced more efficiently."

UK-based Renishaw is a world leading engineering technologies company, supplying products used for applications as diverse as jet engine and wind turbine manufacture, through to dentistry and brain surgery. It has over 4,500 employees located in the thirty-six countries.

[www.renishaw.com](http://www.renishaw.com)  
[www.athertonbikes.com](http://www.athertonbikes.com)



*Titanium lugs, produced on a Renishaw 500Q, will join the carbon fibre tubing of the bike frame (Courtesy Renishaw)*

## CONTACT US

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## Researchers adapt U.S. Air Force-developed steel alloy for metal AM

Researchers at the U.S. Army Combat Capabilities Development Command (CCDC)'s Army Research Laboratory, Maryland, USA, have adapted AF96, a steel alloy originally developed by the U.S. Air Force, to powder form for use in Powder Bed Fusion (PBF) Additive Manufacturing processes. The researchers report that this steel alloy has outstanding qualities with potential applications for ground vehicle replacement parts.

Dr Brandon McWilliams, a team lead in the lab's manufacturing science and technology branch, stated, "This material that we've just printed and developed processing perimeters for is probably about 50% stronger than anything commercially available." For Army applications, the key to the powder alloy's usage will be to certify whether additively

manufactured AF96 parts will work as needed in a battlefield scenario. "We've printed some impeller fans for the M1 Abrams [Main Battle Tank] turbine engine and we can deliver that part – they can use it and it works," stated McWilliams. "But it's not a qualified part."

"In terms of a battlefield scenario that may be good enough to be able to get your tank running again for hours or days if that's important to the mission," he continued, "but, on the other hand, we still need to be able to answer, does this perform as good as the OEM part? Does this perform better?"

The researchers highlighted two strategies for the alloy's use. Firstly, metal AM can be used to produce parts in AF96 for battlefield sustainment, i.e. the replacement of

existing parts and supporting legacy systems. Secondly, the researchers hope to work with the metal AM industry on further applications and systems using the powder. "That's where we're more integrated with the OEMs and industry to see the things they're working on and see how we can make things better to really push the state-of-the-art," McWilliams stated.

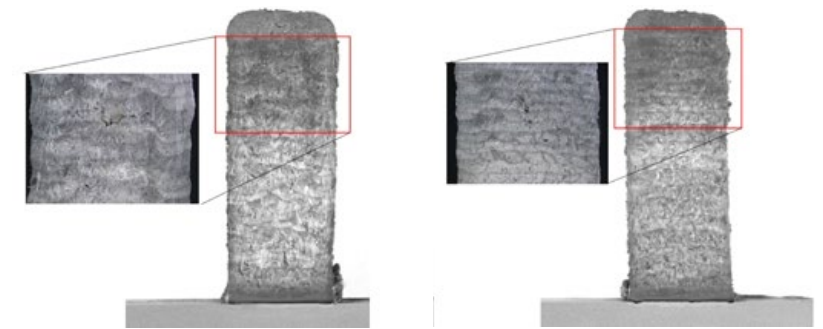
The Air Force initially developed AF96 for application in 'bunker-busting bombs' – bombs of high enough strength and hardness to penetrate hardened targets. For this purpose, a metal was needed that was very high-strength and high-hardness, but which remained economical. The laboratory is now said to be working to model new alloy designs, perform computational thermodynamics and expedite the process to get the materials to soldiers.

www.arl.army.mil ■■■

## Quality assurance tool for Laser Metal Deposition wins EU innovation award

New Infrared Technologies (NIT), Madrid, Spain, has been recognised with the Innovation Radar Prize 2018 in the category of 'Industrial & Enabling Tech' for Clamir, a system designed to improve quality assurance for Laser Metal Deposition (LMD) Additive Manufacturing and cladding processes. With Clamir, NIT is aiming to help achieve 'zero-defect' AM.

During LMD and cladding processes, constant and uncontrolled laser power can lead to unstable manufacturing processes, a lack of repeatability, and ultimately the production of low quality or defective parts, resulting in a loss of time and



Metallographic analysis shows a crack in the uncontrolled process (left), whereas only occasional pores are seen in the Clamir controlled part (right) (Courtesy NIT)

money for the manufacturer. Clamir is said to offer continuous smart monitoring and real-time control of the LMD manufacturing or cladding process. This is made possible by continuous monitoring and measurement of the melt pool geometry using an MWIR infrared camera (1.1–5 µm) attached on-axis to the laser head, and intelligent algorithms. This makes closed-loop control of the laser power possible throughout the

AM process, leading to better quality and repeatability.

The Innovation Radar Prize was presented to Arturo Baldasano, NIT CEO, by Mariya Gabriel, European Commissioner for Digital Economy and Society, and Robert Hofer, Austrian Minister for Transport, Innovation and Technology, in an awards ceremony at the European Commission's ICT 2018 event in Vienna, Austria.

www.niteurope.com ■■■

Arcast

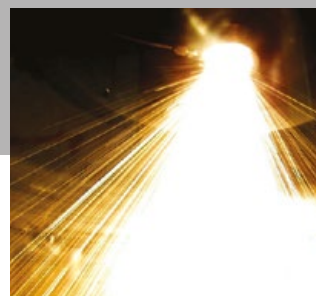
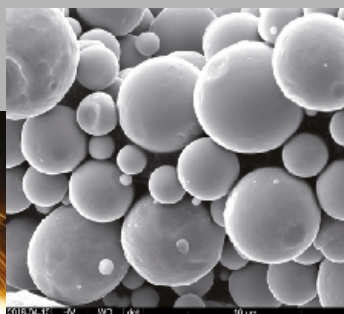
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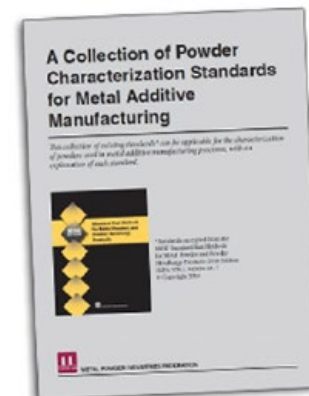


## MPIF publishes powder characterisation standards for metal Additive Manufacturing industry

The Metal Powder Industries Federation (MPIF) has published a collection of nine existing MPIF Standard Test Methods that can be applied for the characterisation of powders used in metal Additive Manufacturing processes. The standards, intended to present and clarify the technology as an aid in conducting business, relate to those activities that concern designers, manufacturers and users of metal AM parts.

Titled 'Collection of Powder Characterization Standards for Metal Additive Manufacturing', the publication includes the following MPIF Standards:

- MPIF Standard 01 - Method for Sampling Metal Powders
- MPIF Standard 02 - Method for Determination of Loss of Mass in a Reducing Atmosphere for Metal Powders (Hydrogen Loss)
- MPIF Standard 03 - Method for Determination of Flow Rate of Free-Flowing Metal Powders Using the Hall Apparatus
- MPIF Standard 04 - Method for Determination of Apparent Density of Free-Flowing Metal Powders Using the Hall Apparatus
- MPIF Standard 05 - Method for Determination of Sieve Analysis of Metal Powders
- MPIF Standard 28 - Method for Determination of Apparent Density of Non-Free-Flowing Metal Powders Using the Carney Apparatus
- MPIF Standard 46 - Method for Determination of Tap Density of Metal Powders
- MPIF Standard 48 - Method for Determination of Apparent



Density of Metal Powders Using the Arnold Apparatus

- MPIF Standard 53 - Method for Measuring the Volume of the Apparent Density Cup Used with the Hall and Carney Apparatus (Standards 04 and 28)

Full details of each standard, explaining the scope, purpose and relevance to the AM industry is available from the MPIF.

[www.mpif.org](http://www.mpif.org) ■ ■ ■

## Innovation Center Additive Manufacturing opened at Fraunhofer IFAM Dresden

Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), Dresden, Germany, has opened its new Innovation Center Additive Manufacturing (ICAM). Based in Dresden, the research institute is combining various technologies for Additive Manufacturing in a newly-constructed technology hall in order to be able to demonstrate to partners and users the wide range of possibilities for the AM of components.

The ICAM houses several systems for Electron Beam Powder Bed Fusion (EB-PBF), including the Q20plus from Arcam EBM, Mölndal, Sweden. This system is said to have the largest build chamber currently available for EB-PBF. In addition, the facility is set to install an Additive Manufacturing Complete and Compact (AMCC) line in the coming weeks. The AMCC line is a prototype production line for the AM of components by Fused Filament Fabrication (FFF), developed by project partner Xerion, Berlin, Germany. While this process is known for the generative manufacturing of plastic components, Fraunhofer IFAM is now expanding its range of materials to include metallic components that were previously not possible.

Fraunhofer IFAM also has several systems available for the three-dimensional screen printing of components. In this technology, based on conventional industrial screen printing, a paste of metal powder is printed layer on layer and is said to offer high precision and have the potential for mass production. The materials fit for the process can reportedly be freely selected and, if necessary, combined in the area of metallic and ceramic materials.

The centre also has equipment for three-dimensional stencil printing where, in contrast to the screen printing method, structured metal foils are used instead of the printing screen to generate components. The institute stated that advantages of stencil printing, compared to screen printing, is the potential for improved surface quality and increased layer thickness.

With the opening of its ICAM, the institute offers partners from industry and research a wide range of services in the form of feasibility studies, the evaluation of powders and the qualification of new materials. Furthermore, it can offer assistance with component development, starting with the powder and continuing through design to production and post-processing. Together with the Fraunhofer IFAM Bremen site, which also has metal Binder Jetting and Laser Powder Bed Fusion (L-PBF) technology, as well as Metal Injection Moulding, Fraunhofer IFAM believes that it now has one of the most comprehensive ranges of technologies for the additive manufacturing of metals.

[www.ifam.fraunhofer.de](http://www.ifam.fraunhofer.de) ■ ■ ■



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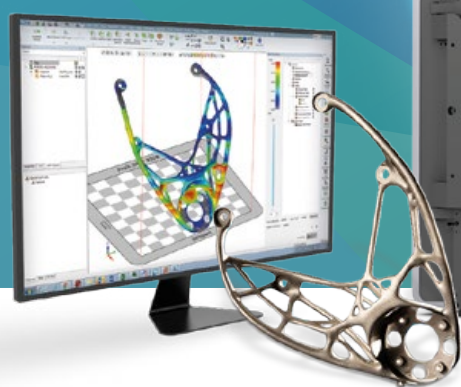
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## Metal Additive Manufacturing eliminates dynamic strain ageing in conventional superalloys

According to a US-based team of materials scientists, the undesirable Dynamic Strain Ageing (DSA) trait, found in conventionally processed superalloys, does not exist in a metal additively manufactured nickel-based superalloy. DSA occurs in metals at high temperatures subjected to stress. If present in conventionally processed materials, the strength of the material fluctuates with applied deformation, resulting in serrated stress-strain curves.

The team, led by Allison Beese, Assistant Professor of Materials Sciences and Engineering at The Pennsylvania State University, State College, Pennsylvania, USA, tested additively manufactured Inconel 625 versus traditionally processed Inconel 625 using neutron diffraction characterisation with mechanical testing at Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Data gathered at the microscopic level gave a picture of the grain-level origins of the serrated stress curve and resulted in a new understanding of the microstructure mechanisms that drive this phenomenon. It is thought that this research, published in Nature Communications, could pave the way for designing materials without Dynamic Strain Ageing. The researchers believe that this could lead to new manufacturing techniques that allow for alloys with tailored properties.

"We saw the characteristic serrated stress curves in conventionally processed Inconel 625 at elevated temperatures, where the flow stress oscillates up and down as the material is deformed up and down," Beese

explained. "That is not an ideal behaviour for materials to have as it could result in early breakage and unpredictable behaviour."

According to the researchers, the conventional alloy had a random crystal structure but the additively manufactured version had a better crystal texture and more finely dispersed particles. "We used a unique experimental setup to interrogate the mechanics at the grain level," Beese continued. "We wanted to understand how that contributes to the difference in macroscopic behaviour that we see between these two forms of Inconel 625 that had the same elemental composition, but were manufactured in different ways. We were able to develop a mesoscopic understanding of DSA's origins, which was previously missing."

The team attributed the lack of DSA in the additively manufactured material to a combination of finer

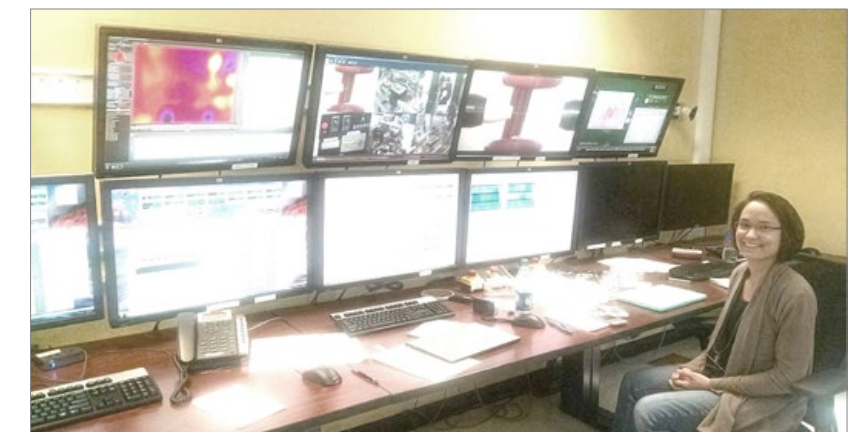
particles distributed within the grains of this material and better crystal texture in the material, resulting in directionally-dependent properties, similar to wood, in which the material has differences in strength across versus with the grain.

Beese commented that additional research could allow the additively manufactured material to be further tuned for desired performance during initial processing, or with the use of heat treatments prior to fabrication to adjust the particles and grain structures. Additively manufacturing superalloys to near-net shape is also useful because superalloys, due to their strength, are difficult to machine. AM reduces the machining requirements, along with the amount of wasted material.

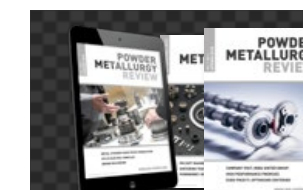
Further, she stated that the research could help improve long-standing models used to design and understand metals that undergo DSA during deformation, and also provide targets for the design of new metallic materials, particularly those fabricated by metal Additive Manufacturing.

[www.psu.edu](http://www.psu.edu)

[www.ornl.gov](http://www.ornl.gov)



Allison Beese, Assistant Professor of Materials Sciences and Engineering at The Pennsylvania State University, during experimentation with Inconel 635 at Oak Ridge National Laboratories (Courtesy ORNL)



Download all issues for free at:  
[www.pm-review.com](http://www.pm-review.com)





## NSL Analytical joins America Makes

NSL Analytical, an independent commercial testing laboratory based in Cleveland, Ohio, USA, has joined America Makes, the US public-private membership organisation focused on accelerating Additive Manufacturing across the nation. America Makes currently manages a portfolio of more than \$100

million in public and private funds for advancing the technology and has more than 180 members from industry, academia, government and non-government agencies.

"NSL is grateful for the opportunity to contribute to the advancement of the Additive Manufacturing industry, and grow the ways they

serve customers through trust, technology, and turnaround," stated the company. "NSL Analytical is committed to helping customers succeed through providing reliable test results quickly and efficiently." The company added that it is looking forward to participating in industry activities that encourage continuous improvement and help expand knowledge of the industry.

NSL has a wide range of testing capabilities suitable for the AM industry. These include powder characterisation, material composition and validation of final parts. The company's testing facilities are accredited and approved for Additive Manufacturing with ISO/IEC 17025 Certification and Scope [ANAB], Nadcap Certification and Scope [PRI], ASME NQA-1 Compliant and GE Aerospace S-400.

[www.nslanalytical.com](http://www.nslanalytical.com) ■ ■ ■



NSL has a wide range of testing capabilities (Courtesy NSL Analytical)

## NASCAR champion Brad Keselowski launches metal hybrid manufacturing company

Former NASCAR champion Brad Keselowski has launched Keselowski Advanced Manufacturing (KAM) in Statesville, North Carolina, USA, a new company focused on advanced manufacturing technologies, with a focus on metal hybrid manufacturing – the combination of metal Additive Manufacturing and subtractive technologies. Keselowski is said to be investing tens of millions of dollars in equipment and expertise to be based at the company's 70,000 ft<sup>2</sup> facility.

KAM currently employs thirty, but it is expected that by the end of 2019 the company will employ up to one hundred people in what it describes as one of the most advanced hybrid manufacturing facilities in the US. Further, KAM is reported to be partnering with several of the world's leading companies, including GE Additive, ALSCO, BIG KAISER, Mazak Corp and Pinnacle X-Ray Solutions. Working with KAM's team of engineers and technicians, their combined efforts are

expected to help KAM lower customer costs and reduce waste, while manufacturing higher quality products.

"The capabilities of new technologies are limited only by our imaginations and willingness to act," stated Keselowski. "Until now, much of this advanced manufacturing technology was considered too complex and too expensive for production level applications. By combining Additive Manufacturing with subtractive capabilities, the goal of KAM is to lead the way for the next industrial revolution by making these technologies more accessible."

With operations having begun in 2018, KAM has already begun working with customers. The company model is aimed at building custom solutions in metal hybrid manufacturing that it states offer a distinct set of advantages, and by partnering with leading equipment and technology companies, KAM hopes to refine elements of the production process to improve both quality and speed.

Rod Meyer, Founder and CEO of Pinnacle X-Ray Solutions, stated, "We are excited to be working with the team at KAM, because we know the hybrid manufacturing model they've developed will help companies worldwide. Our technologies go hand-in-hand. With our advanced CT scanning technology and KAM's expertise in engineering solutions, we're disrupting the traditional manufacturing process."

Keselowski added that the new technology offers an important opportunity to grow a critical sector of the US economy. "Manufacturing built our country, enabling the strength and freedom we've all enjoyed," he explained. "Today, the advancements in manufacturing will spark a new wave of American companies, not only creating jobs, but also solving some of the world's biggest problems – from helping the environment to improving our safety. At KAM, we've assembled the talent, resources and technology to conquer these challenges. I am confident that our work will have a positive impact for generations to come."

[www.kamsolutions.com](http://www.kamsolutions.com) ■ ■ ■

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## IRT Jules Verne selects AlphaStar's Genoa 3DP for AM simulation

IRT Jules Verne, a mutualised industrial research institute based in Bouguenais, France, has selected AlphaSTAR's Additive Manufacturing simulation product, Genoa 3DP, to model and simulate AM processes as well as to minimise trial & error, scrap rate and the overall cost of AM. Created in 2012 as part of France's Investissement d'avenir (Investing for the Future) programme, the Jules Verne Technology Research Institute is dedicated to advanced manufacturing technologies.

IRT Jules Verne required a robust and accurate simulation tool to provide a deeper understanding of material modelling & characterisation and part performance simulation related to the Additive Manufacturing processes, while also aiming to save costs and improve productivity. After evaluating different solution providers, the engineers at IRT Jules Verne identified Genoa 3DP.

"We needed software capable of analysing the materials, modelling the AM process and accurately replicating composite SLS & FFF printing methods," stated Tuan Linh Nguyen, R&D Simulation Engineer at IRT. "With advanced features, such as analysis

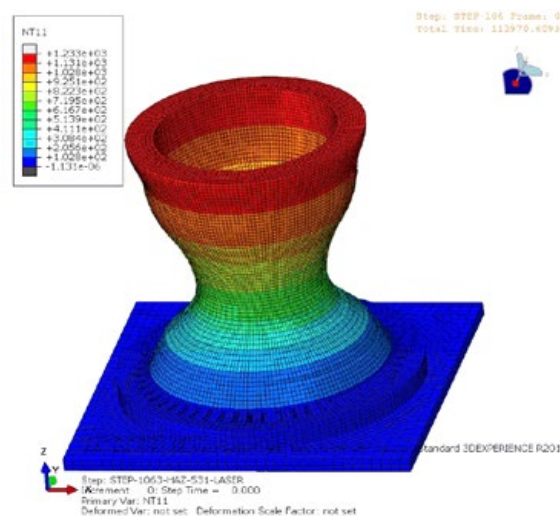
of temperature-dependent material properties beyond glass transition temperature and the high compatibility with our numerical tools, we felt Genoa 3DP was the perfect fit."

"We are delighted to collaborate with IRT Jules Verne and their reputable partners," commented Dr Rashid Miraj, AlphaStar's Director of Technical Operations. "AlphaStar brings nearly 30 years of experience of providing test validated simulation technology so end-users are able to produce reliable analysis to predict the behaviour of advanced materials under various manufacturing processes such as Additive Manufacturing. We look forward to having our solution play a role at IRT."

Genoa 3DP simulates the Additive Manufacturing process to accurately predict the deflection, residual stress, damage initiation and crack growth formation associated with as-built AM parts. Advanced Multi-Scale Progressive Failure Analysis methods are used to replicate the entire AM process from the level of material characterisation to process simulation to in-service qualification.

[www.alphastarcorp.com](http://www.alphastarcorp.com)

[www.irt-jules-verne.fr](http://www.irt-jules-verne.fr) ■ ■ ■



Using multi-scale progressive failure analysis methods to replicate the entire AM process, Genoa 3DP is reported to be able to determine voids, cracks and other manufacturing anomalies (Courtesy AlphaSTAR)

## Bright AM management software dedicated to AM process

Throughput Consulting Inc., Delafield, Wisconsin, USA, a software development company and the creator of Bluestreak™, a Manufacturing Execution System (MES) and Quality Management System (QMS), has launched Bright AM™, a production platform designed to track, manage and support the unique requirements of Additive Manufacturing. The software tracks the process of disparate parts additively manufactured together on a single build plate, as well as enabling the management and tracking of everything from incoming orders to works in progress and delivery confirmation.

Bright AM also supports the incorporation of unique serial numbers on each part and tracks serial numbers through the production process, recording any non-conformance, a critical requirement for such industries as aerospace, aviation and medical.

Todd Wenzel, President & CTO of Throughput and Bluestreak, stated, "Although the Additive Manufacturing industry has been rapidly evolving into a viable production technology, what individual companies are working out for themselves, is quality processes with repeatability. With so many parameters, how do you track, validate processes and ultimately pass certification which is necessary to compete in the bevy of industries of which AM benefits? That's where Bright AM excels."

Bright AM will enable businesses to conform to individual part specification requirements, while automatically creating and maintaining a fully documented audit trail containing specification documents, operating requirements and media attachments. The platform can be customised to mirror the unique business workflows of individual companies.

[www.bright-am.com](http://www.bright-am.com) ■ ■ ■

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## Study explores development of meta-crystals by Additive Manufacturing

The Department of Materials Science and Engineering at the University of Sheffield, South Yorkshire, UK, in collaboration with Imperial College London, is investigating ways in which the use of lattice structures to replace solid materials in metal Additive Manufacturing can replicate the structure of a metallic single crystal, and the limitations this structure can impose on part performance.

Professor Iain Todd, Professor of Metallurgy at the University of Sheffield, reports that the lattice structures used in AM typically have a uniform layout, with nodes all conforming to a regular array with the struts between the nodes all following common planes: and herein lies the problem. In the study published in *Nature* magazine in January 2019, he states that the nodes in the AM lattice are equivalent to the atoms in the single crystal and the struts equivalent to the atomic bonds. In each of these structures, the atomic planes, or nodes, are perfectly aligned.

While in some applications, such as the high temperature end of a jet engine, single crystal materials are ideal because of their ability to withstand deformation at extreme temperatures, the structures have

limitations relating to their mechanical performance. This limitation is also observed in AM parts with a uniform lattice structure: when the structure is put into compression, once the force is sufficient to cause permanent deformation, the lattice shears along one or more of the planes of nodes. With nothing to inhibit this shearing, the collapse becomes catastrophic.

In polycrystalline materials – those with many crystals – the alignment of the atomic planes is random, so when a shear force is applied in a particular direction, a crack will slow down or stop when it meets a crystal where the atoms are aligned differently from the crystal in which the crack initiated. Moreover, it is possible to introduce different materials in the form of phases, precipitates or inclusions used to strengthen the materials; these materials can also help to inhibit crack propagation.

This fundamental metallurgical understanding has inspired scientists at the University of Sheffield and Imperial College London to mimic polycrystalline microstructures instead of single crystal structures in AM lattices, with the aim of developing robust,

damage-tolerant architected materials.

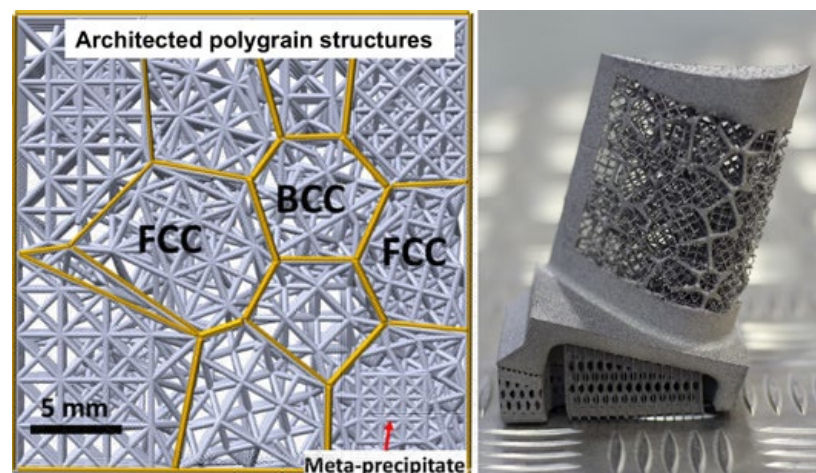
Through the computer modelling of atomic structures, which are then scaled up to create meso-structures based on polycrystalline materials, the engineers believe they could transform the way that materials are designed, and have coined the name 'meta-crystals' for this new method.

Experimental testing of components made from these meta-crystals has reportedly demonstrated that they are highly energy absorbant, with the polycrystal-like material able to withstand almost seven times the energy before failure than the materials that mimic the single-crystal structure. While basic metallurgical concepts are being used to inspire the development of architected materials, researchers are using the creation of architected materials as an alternative approach to study complex metallurgical phenomena.

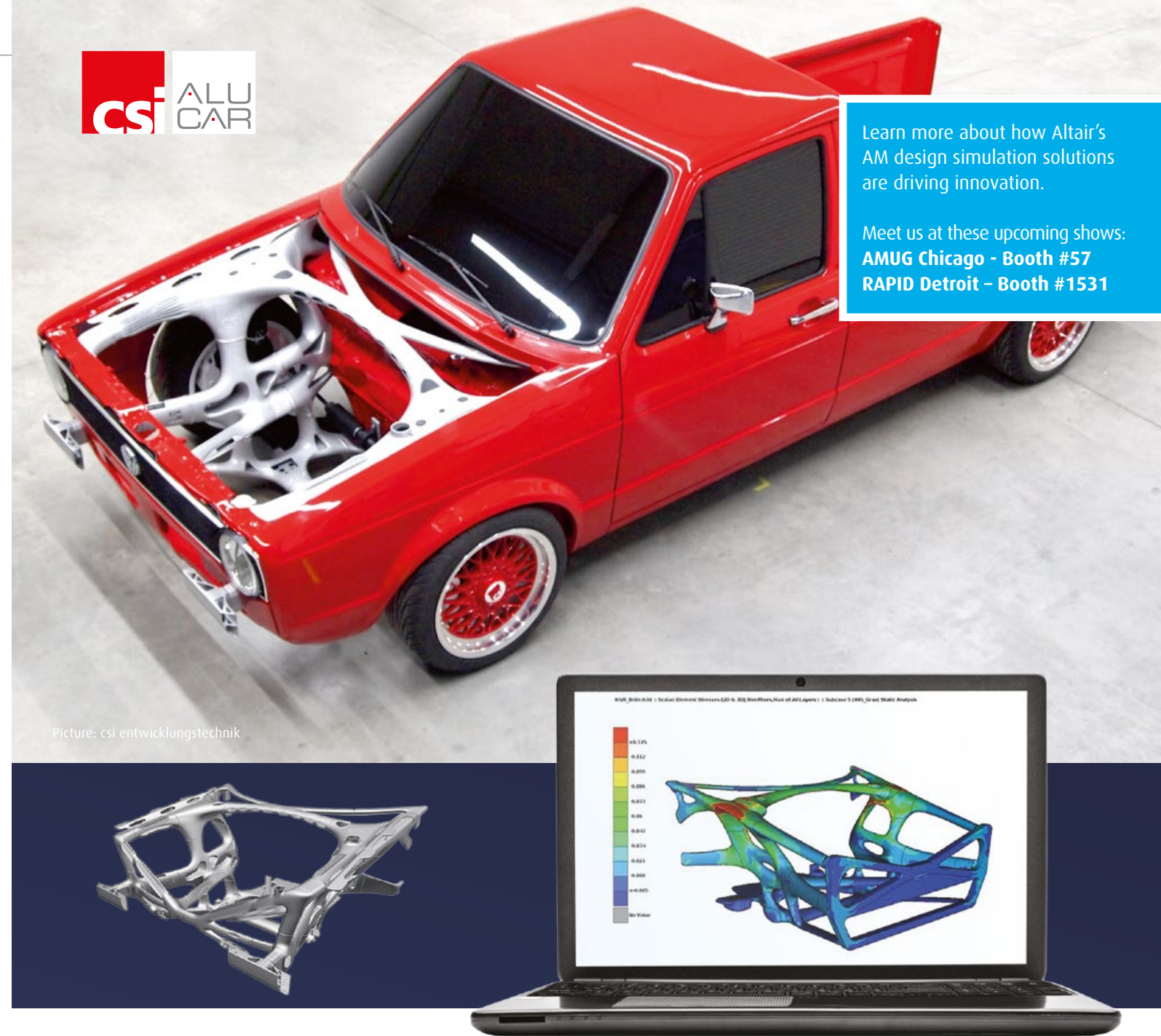
"This approach to materials development has potentially far-reaching implications for the Additive Manufacturing sector," stated Prof Todd. "The fusion of physical metallurgy with architected meta-materials will allow engineers to create damage-tolerant architected materials with desired strength and toughness, while also improving the performance of architected materials in response to external loads. And while these materials can be used as standalone structures, they can also be infiltrated with other materials in order to create composites for a wide variety of applications."

Dr Minh-Son Pham, Imperial College London, added, "This meta-crystal approach could be combined with recent advances in multi-material 3D printing to open up a new frontier of research in developing new advanced materials that are lightweight and mechanically robust, with the potential to advance future low carbon technologies."

[www.sheffield.ac.uk/materials](http://www.sheffield.ac.uk/materials)  
[www.imperial.ac.uk](http://www.imperial.ac.uk) ■ ■ ■



Schematic of polygrain structures (left), and a demonstration artefact showing varying orientations of meso-structures (right) (Courtesy University of Sheffield)



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## Osseus's AM titanium spinal implant sees first patient use

Osseus Fusion Systems, Dallas, Texas, USA, has seen its metal additively manufactured Aries Titanium Spinal Implant used in surgery on a human patient for the first time. Surgeons at Joseph Spine, a centre for spine, scoliosis and minimally invasive surgery in Tampa, Florida, USA, implanted the patient-customised device in surgery in early January 2019.

Osseus's surgeon-inspired AM spinal implants are designed to fit perfectly with the patient's anatomy, and can be produced faster and more economically than traditional methods while reportedly providing better patient outcomes. Dr Samuel Joseph Jr, Founder of Joseph Spine, performed the surgery assisted by Dr Andrew Moulton and stated, "Working with Osseus and utilising

their technology for spinal implants provides us with a great opportunity for superior patient care."

"The future of advanced spine care is in the technology of custom implants as well as creating partnerships with doctors to create customised implants," he continued. "As a surgeon, it's very exciting to participate in the device development process and see your ideas brought to life so quickly. Today we were able to successfully implement this cutting edge, patient-specific spinal implant that addresses the complex anatomy of the spine and the delicate nature of its surrounding structures."

"Through 3D printing we are able to manufacture spinal implants that are customised to the patient. Meaning the size of their disc, the size of their vertebra, how high the vertebra may

be, as well as the curvature they may have in their back we are trying to create," he explained. "With this cutting edge technology we can offer our patients implants such as the Aries L Interbody Fusion Device which can be created at a certain height, a certain length, as well as a certain angle, which offers our patients better, customised care, which results in better outcomes for the patients."

Robert Pace, CFO at Osseus Fusion Systems, commented, "I'm grateful for the invitation from Dr Sam Joseph to join he and Dr Andrew Moulton, of Joseph Spine, as they implanted the first 3D printed Aries-L lateral interbodies earlier this week. As our research showed in the development process, the visibility through the implant under fluoroscopy was excellent and we are very confident it will assist surgeons in verifying fusions postoperatively. This was a company defining day for Osseus and our appreciation for great surgeons like Drs Joseph and Moulton cannot be overstated."

The Aries-L interbody fusion device features a proprietary multi-axis mesh and optimised micro-surface topology, both of which are designed to facilitate fusion. The product's lattice also helps to increase the implant's porosity to 80%, while enhancing in-situ radiovisibility compared with other titanium implants. The implant's anatomic profile, anti-migrational teeth and streamlined insertion are said to promote reduced recovery time by helping to increase procedural efficiencies.

[www.osseus.com](http://www.osseus.com)  
[www.josephspine.com](http://www.josephspine.com) ■■■



The Aries-L interbody fusion device features a proprietary multi-axis mesh and optimised micro-surface topology (Courtesy Osseus Fusion Systems)

## PM and AM of Titanium Conference seeks abstracts

A call for papers has been issued by PMTi 2019, the 5<sup>th</sup> Powder Metallurgy and Additive Manufacturing of Titanium Conference, set to run from September 24–27, 2019, at the University of Utah, Salt Lake City, Utah, USA. This year's event, sponsored by the Metal Powder

Industries Federation (MPIF), will welcome global experts on the PM and AM of titanium and titanium alloys for a technical programme covering a wide range of relevant topics. This conference has previously been held in Australia, New Zealand, Germany and China.

Prof Zhigang Zak Fang, FAPMI, University of Utah, is serving as the Chair of PMTi, alongside Co-chairs Dr Ali Yousefiani, Boeing, Dr James Sears, Carpenter Technology Corporation and Prof H Sam Froes, University of Idaho (retired). Abstracts should be submitted via the conference website no later than April 15, 2019.

[www.tipmam2017.org](http://www.tipmam2017.org) ■■■

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## F1 component manufacturer doubles productivity with the Russell AMPro Sieve Station

Progressive Technology Ltd, Newbury, Berkshire, UK, a company specialising in CNC multi-axis machining, is using advanced modern machinery and Additive Manufacturing to manufacture complex metallic components, primarily for the Formula One (F1) market. After initially entering the F1 market manufacturing low-tech products, Progressive Technology has reportedly trebled its turnover in the last four years and is now creating high-end componentry and servicing most of the teams on the F1 grid.

A full 24-hour shift pattern allows rapid turnaround of parts, and the company invests in the highest quality equipment to optimise its production process. This is reflected in its Additive Manufacturing facility, where Progressive Technology continues to invest in the latest production technology, ancillary equipment and materials to ensure a the production of high-quality products in minimal time.

Progressive Technology opted to produce parts using Laser Powder Bed Fusion (L-PBF) Additive Manufacturing, which it stated provides significant benefits when producing F1 components such as increased strength and the research and development time required to produce new designs with the biggest benefit

coming from weight reduction. A key part of this AM process is, of course, the handling of metal powders used to produce the parts.

Metal AM powders, such as titanium, aluminium and Inconel are commonly used to produce AM parts for F1 cars – to ensure their quality, therefore, all powders must be qualified before use and the unused powder must be reclaimed and requalified after the build process is completed. Dave Cooper, Head of Additive Manufacturing Technologies at Progressive Technology, explained, "The quality of the powder is crucial as it dictates the material properties and is the only way to guarantee a high-quality product, giving confidence to our customers that we're ensuring the quality of materials used to produce the components for their cars."

Initially, the method used to process metal powders at Progressive Technology was said to be very time consuming, with high product wastage. To solve this problem, the company has now adopted an automated solution for powder handling, the Russell AMPro Sieve Station™ produced by Russell Finex Ltd, Feltham, Hounslow, UK.

With the installation of the AMPro, the company reports that it has been

able to double productivity with only half of the labour it previously used. "The turnaround process between jobs used to take well over an hour," Cooper explained. "Using the AMPro has made this significantly shorter, as it makes the powder handling processes automated, allowing operators to focus on other key tasks such as preparing the machine for the next build. This has been a fantastic investment for us – speeding up our day-to-day process and improving our materials' quality – absolutely key when producing high-value parts."

This automated powder handling system can be applied to various stages of the AM process. Cooper continued, "When we receive a new batch of powder from a supplier, the first point of entry to our manufacturing system is through the AMPro, as we quality-check the powder from their containers and remove any contamination before it can enter our process. Sieving incoming powders under inert atmosphere also eliminates the risk of moisture damage. At the end of the build process, the AMPro is used to remove the unused powder from around the parts."

"The AMPro has a very simple one-button operation to recover the powder, and a very fast process – taking around five minutes – which is great for our lead times when we are under pressure to deliver components in rapid time," he added. The system is completely modular, and is designed to integrate directly

with existing build process for most powder-based AM systems. "The system is future-proof as it can continue to evolve alongside our production setup. The AMPro has the potential to expand and change its control interfaces to adapt to new equipment as our machine park continues to grow," Cooper concluded.

Established in 1934, Russell Finex designs machines for the international market and supplies to over 140 countries. In addition to its head office in the UK, the company operates subsidiaries in Belgium, the USA, India and China, enabling it to effectively provide customer service and after sales support. This infrastructure and technical support was key according to Cooper:

"We've had an excellent working relationship with Russell Finex," he continued, "meaning we could collaborate with the design of the system we needed to ensure the end-product was tailored around our experience and setup, rather than an off-the-shelf product. We were able



The AMPro Sieve Station incorporates a fully-automated one-button process (Courtesy Russell Finex)

to trial the AMPro before purchasing and provided with equipment in the interim whilst our systems were finalised, allowing us to get up and running in good time."

Established in 1934 and having worked within the AM industry since the technology's development, Russell Finex applied its eighty-five years of experience in the design and manufacture of industrial sieving solutions

to develop the AMPro Sieve Station, and believes that it offers the widest range of sieving equipment to the AM industry. Standard systems available include standalone units to suit any powder vessel, inert gas purging to preserve powder characteristics and integrated closed-loop powder recovery systems.

[www.progressive-technology.co.uk](http://www.progressive-technology.co.uk)  
[www.russellfinex.com](http://www.russellfinex.com)

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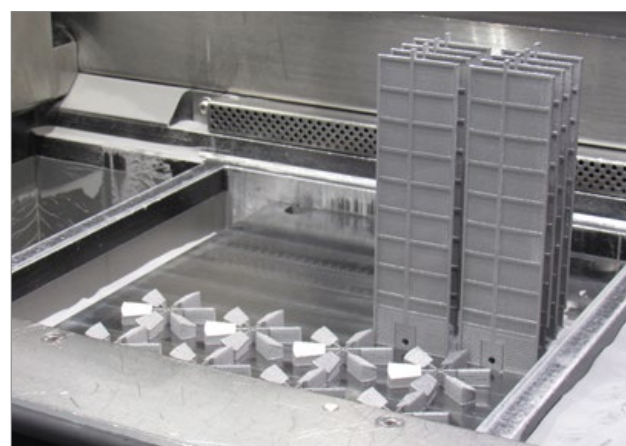
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Progressive Technology use the AMPro to reclaim and requalify metal powder (Courtesy Russell Finex)



The AMPro is used to remove unused AM powder from the build chamber (Courtesy Russell Finex)



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## From rapid prototyping to rocket engines: The evolution of 3T Additive Manufacturing

With two decades of experience in part production using Additive Manufacturing technologies, 3T Additive Manufacturing Ltd, based in Newbury, UK, today enjoys a strong position as an international developer and supplier of cutting edge metal AM components. At a time of transition for the company, *Metal AM* magazine's Nick Williams and Emily-Jo Hopson met with outgoing CEO Ian Halliday and his successor, Nigel Robinson, to discuss the evolution of the metal AM industry to date and the business's plans for further expansion.

In 2019 3T Additive Manufacturing Ltd, formerly known as 3T RPD, celebrates twenty years of additively manufactured part production. Throughout this period, the business's growth has closely tracked the evolution of the AM industry as a whole, moving from the rapid prototyping of plastic products through to end-use part production, the introduction of metal AM and, more recently, a ramping up of production capacity to meet demand for the series production of components.

This year also marks the end of Ian Halliday's tenure at the helm of the business. Having taken over as CEO in 2005 from the company's founder, Tim Plunkett, Halliday has guided the company through a long period of growth that has seen fundamental changes in all areas of the industry, from technical capabilities to materials and end-user markets.

Halliday's experience of Additive Manufacturing, however, extends beyond his career at 3T to the early 1990s where, as Chief Engineer at the Rover Group, he was instrumental in setting up an internal rapid prototyping and rapid tooling

facility. It was under his guidance that Rover Group first investigated Stereolithography (SLA) in 1989, resulting, he explained, in a very fragile and very expensive part from a service bureau that, inevitably, no longer exists. The recognition of what the technology could do led to the establishment in 1991 of an

in-house rapid prototyping operation that was very much ahead of its time. To give a sense of the scale of this early operation, in 1998 the Rover Group produced 2,200 parts by Stereolithography, 3,200 parts by Selective Laser Sintering (SLS) and 9,500 polyurethane parts from silicon moulds.



Fig. 1 3T's headquarters and AM facilities are on the site of the former United States Air Force base at Greenham Common, near Newbury, UK





Fig. 2 Twelve EOS M290 machines form the bulk of 3T's metal Additive Manufacturing capacity

Commenting on the transformation of the AM industry over the last twenty years, Halliday stated, "It is always interesting to look back and reflect on the pivotal change points that you have lived and worked through. Some of these points have been technical step changes, others have been commercial in nature or centred around the wider perception of AM."

"On the technical side, the introduction of the ytterbium fibre laser by EOS was a milestone that enabled the controlled direct melting of a wide range of metallic alloys, whilst *The Economist's* 2011 article 'Print me a Stradivarius' coincided with a tipping point in the awareness of Additive Manufacturing. Together these were undoubtedly catalysts for the rapid growth of the technology."

"Various GE purchases then rocked the industry," Halliday recalled, "starting with the pivotal acquisition of Morris Technologies and its sister company Rapid Quality Manufacturing

(RQM) in 2012. This was later followed by the purchase of Avio Aerospaziale in 2013, Arcam and Concept Laser in 2016."

Halliday also believes that the development of an AM-specific powder supply chain has been crucial for industry growth, citing the arrival of LPW in the metal powder marketplace. "This created price and quality competition that drove down powder prices, which was a critical enabler to growth," he stated.

As the industry moved towards the series production of end-use components for critical applications, quality systems were urgently needed to instil user confidence in the technology. "The introduction of vision systems was part of a realisation that quality systems had to match those of conventional manufacturing processes if metal AM was to become a true manufacturing/production technology." This, stated Halliday, was combined with the introduction of user-friendly software solutions for

build set-up and build simulation that have led to a 'democratisation of AM'. "This final point is as significant in the development of our industry as the reduction in build costs, as it brings down the technical barriers to entry for part manufacture."

### The growth of 3T as a metal AM producer

3T is today a leading European commercial AM parts producer and serves an international portfolio of clients in industries including aerospace, automotive, motorsport, oil & gas and general engineering. It is also one of several EOS 'e-manufacturing partners' and benefits from a close relationship with the German machine builder, operating twenty-four EOS AM machines, including twelve M 290s and four M 280s (Fig. 2). The business is today within the portfolio of Dr Hans J Langer companies.

"Having started with metal Additive Manufacturing in 2007, we quickly established ourselves as one of the prime movers in the industry. The marketplace was not ready for metal AM parts at that time, so 3T had to put a lot of work into educating customers and developing the market," stated Halliday.

"Hiring key skilled AM experts enabled a 'quick start' for us, but the hard work is in building up a team, the quality systems and the infrastructure on minimal investment," he continued. "We secured aerospace OEM series production contracts early on, and this enabled us to grow whilst driving forward quality system development."

In 2008, the company made the strategic move to start manufacturing dental copings, gaining ISO 13485 certification as a direct result. "Although the dental market wasn't ready for AM until at least 2012, the ISO13485 systems made it a lot easier for us to gain AS9100 certification and hence opened the door to the aerospace world," explained Halliday.

3T hired Dr Mark Beard - now with Dutch AM machine producer Additive Industries - in 2012 to help establish a robust R&D team, "something that is strategically critical to any technical company, and something we are very proud of," Halliday stated.

Despite this early entry into metal AM, it wasn't until 2015 that 3T began making a profit from the technology. "This was a major milestone because it showed that the industry genuinely had the future potential that we had believed in up to that point," Halliday recalls. "Now, twelve years after starting with metal Additive Manufacturing, the metals side of the technology generates roughly 75% of the company's total sales."

3T is now strengthening its complete offering to clients, with a New Product Introduction (NPI) team that streamlines the whole component development process and, more recently, a significant expansion of its post-processing operations.



Fig. 3 Metal AM automotive exhaust component concept manufactured by 3T showing the quality of surface finish that can be achieved during post-processing (see upper section)

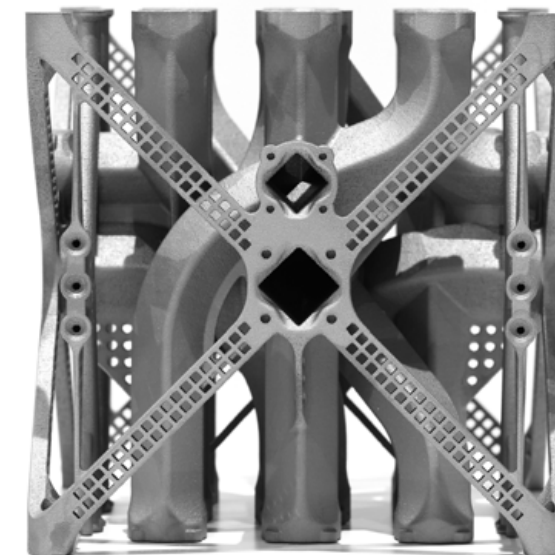


Fig. 4 A manifold concept developed and manufactured by 3T

"The setting up of 3T's New Product Introduction team was important in that it signalled to our customers that we were serious about production metal AM. This capability set 3T apart at the time and continues to be a major benefit to the business."

"The most recent milestone relates to the scaling up of our metal post-processing capabilities. Completing

this process chain enables us to give a complete and highly competent service to our customers, from design to delivery. Coupled with a large Additive Manufacturing capacity, the inclusion of in-house finishing, high-end 5-axis CNC and vacuum heat treatment sets us apart as one of the most capable full process chain AM manufacturers globally."





Fig. 5 This heat exchanger concept effectively demonstrates the complexity that can be achieved in metal AM part production

### Additive Manufacturing: Expectations and realities

As someone who has been involved in Additive Manufacturing for more than two decades, Halliday has keenly observed the changing nature of the industry. Comparing his early expectations with the reality of the industry's growth, he stated, "The most consistent factor has been that the rate of uptake has taken two to three times longer than I had expected – or let's say hoped for. What is obvious to one person is not necessarily obvious to all. The process

of integrating a new technology is cumbersome and slow. It is a people-centric challenge interwoven with the vagaries of technical developments, perceptions and the business world in general. I now know that a major project can take two to three times longer than I expect, but it still surprises me when it does! That said, most of the strategic development models that I envisaged in 2007 were correct, but generally the timescales were too optimistic."

"Of course, my perceived AM uptake model had some surprising exceptions that seemed to break

the rules, but perhaps this simply demonstrated that sometimes, if you don't know there are rules, you just do what you want to," he continued. "One customer didn't care about how we made the part at all, they simply wanted it when they needed it and to the right quality. Their uptake cycle was in effect a matter of weeks, not the usual years that we commonly encounter. The biggest obstacle was the time needed to gain PPAP [Production Part Approval Process] certification for the parts, then straight into production and onto a road-going vehicle."

Halliday suggested that the sale of Morris Technologies to GE was a big surprise, serving to highlight that metal AM was entering a dynamic new era. However, he added, "it has not surprised me that the development of metal Additive Manufacturing has followed the same course as all other new technology introductions and followed the same rules and trends."

Nigel Robinson, who has served until recently as Director of Operations at 3T, will shortly succeed Halliday as CEO. Robinson has seen a rapid expansion in the market for metal AM components in the five years that he has been with the firm, telling *Metal AM* magazine: "The market has evolved dramatically in the years I have been at 3T. In 2014 the majority of our customers were either going through validation of AM as a true solution to their production needs or they just knew they needed to get into it without knowing where to start. The 3T team understands this and our passion is to take our customers through this journey no matter if they are an early adopter or looking for a serial production partner."

Much of Robinson's effort has so far been focused on putting the business on a footing to efficiently manage the introduction and development of new products and meet customer demands in terms of quality and delivery. Commenting on the most significant improvements that have been introduced, and how the 'customer experience' has changed in recent years, Robinson stated, "Our whole customer experience

is changing as their requirements evolve. Today, the AM build process is only part of the story, so implementing the full process supply chain is critical to give our customer turnkey ready-to-use parts."

To facilitate this, recent infrastructure investments have included an in-house powder quality control laboratory, a large heat treatment vacuum furnace, full multi-axis machining equipment, and equipment for automated finishing, hand finishing and final inspection. "The biggest investment, however, comes with the people who work at 3T," stated Robinson. "Recruiting the right people with either experience in Additive Manufacturing or from related industry sectors has been critical to help us meet our customer expectations. As the years have passed our valued customers view 3T as a certified supplier and judge our quality and delivery performance as they would any other conventional supplier in their value chain. In addition, our technical support offering gives customers access to our design for AM courses, application engineering, NPI and R&D teams."

Commenting on the speed of industry expansion, Robinson stated, "We are already seeing many positive results from our investments in NPI and post-processing. However, when you implement a new process sometimes you have no idea of how fast the market will react. As an example, when we implemented our first 5-axis machining centre I told our new machining team to expect a slow ramp up in the first few months. How wrong I was! Within the first week the machine was fully booked and I was pulling a business case for a second one. This is just one of many examples of managing a growing business in a growing sector."

The company recognises that key to continued success are dedicated and skilled employees and, in the context of an environment where there is an AM skills shortage and lively business for the recruitment industry, 3T works hard to retain key staff as well as to plan for future workforce expansion. "We



Fig. 6 The Launcher E1-LOXC00L725 CuCrZr alloy rocket engine chamber and injector manufactured by 3T

will only retain staff if we make their job interesting, fun and give them a secure and positive future," Robinson noted. "So that is central to our philosophy as a business. The 3T team wants our company to be the best place to work in our industry. Although direct AM skills are indeed rare, taking on top people and training them is a good alternative, despite taking one to two years before some of their skills are sufficiently robust. That of course does make our staff more of a target, and hence we go back to the above statement about how to increase our chances of retaining key people."

"In addition to simply taking on qualified engineers and other disciplines, we have a strong and healthy apprenticeship programme, which will help to fulfil our skills requirements in the medium and long term."

### Client case study: Launcher

From NASA and SpaceX to a new generation of smaller companies looking to carve a niche in the expanding small satellite delivery market, the space industry has fully embraced metal Additive Manufacturing. 3T is supporting smaller companies with highly engineered rocket components that rely on its AM materials and production expertise.

"The space sector is one of the most fascinating industries to work with. The natural performance benefits with Additive Manufacturing through weight loss, thermal efficiencies, etc, are well-documented but the industry is forwardly thinking about the next ten years so. Therefore, taking cost out of the product without compromising quality is a critical expectation," stated Robinson.





Fig. 7 View of the inside of the E1 rocket chamber after polishing. It should be noted that this component has a large number of complex internal features

3T and US-based rocket start-up Launcher have developed a close and successful working relationship in recent years, thanks in part to 3T's capabilities in copper AM. Commenting on how this relationship was formed, Robinson stated, "When our collaboration started, the Launcher team was already using Additive Manufacturing to build its thrust chamber (Figs. 6-8), and their first test firing was with an Inconel version that they sourced in the United States. They approached 3T when they heard we could build in copper and the relationship grew from there. Launcher appreciated the collaborative ethos that both companies are based on."

The use of a CuCrZr alloy in the Launcher application was attractive because of its high-efficiency cooling, leading to a longer chamber life and reduced costs compared to conventional production. The copper part was also proven to be twenty times more conductive than the comparable Inconel part, resulting in a coolant temperature of 280°C compared to 153°C for Inconel.

Max Haot, Founder and CEO of Launcher, told *Metal AM* magazine, "As part of our pursuit to build the highest performance additively manufactured liquid rocket engines, we were always hoping that one day we would be able to manufacture our chamber in copper alloy rather than Inconel but had not come across a service provider with this capability. Copper alloy is widely accepted as the highest performance material for cooling liquid rocket engines – Inconel is a compromise. When we heard that 3T was able to do this, we immediately partnered with them and went from quote to successful test fire in less than eight weeks. We achieved the highest performance oxidiser fuel mix ratio for kerosene and liquid oxygen (2.62) for a 45-second duration fire on the first test campaign with the AM engine from 3T." (Fig. 9).

In the case of Launcher and 3T, success can in part be attributed to the dynamic relationship between team members at both companies. Robinson explained, "We have an



Fig. 9 The AM copper alloy rocket engine under test. This liquid oxygen (Lox) regeneratively cooled engine is, states Launcher, now proven as part of its quest to build its next, larger engine, the E-2

application engineer who is a rocket engine fanatic and could relate directly to the customer's requirements and therefore led us to an innovative AM solution. This proactive relationship between our application engineer and the Launcher team was one of the factors to the success of the project."

"We are delighted that our affiliated company AMCM is working with 3T to produce the required large-scale copper parts and we have both identified a number of sectors that would benefit from this size of application. A customised AM machine is on track to deliver 1000 mm Z-height parts within the next few months."

3T made its first copper parts on a standard EOS M 290 in 2014, displaying the 3T heat exchanger at Formnext in 2015. This development served to demonstrate its capabilities in materials development and led the way to its current leading position in the AM rocket engine manufacturing market.

Commenting on how other end-users could learn from Launcher's success to date, Robinson stated, "The Launcher team already had a very good understanding of the benefits and limitations of the use of Additive Manufacturing. However, being involved at the design stage was critical to get the most out of the opportunity of the concept. Our advice to all our customers is where possible to get 3T's application engineers involved at the design stage so we can give advice on maximising the optimisation for DfAM."

Copper is a material that is now becoming increasingly talked about in relation to AM. Commenting on the specific challenges of processing this material, Robinson stated, "Whilst 3T's copper developments go back to 2014, it has taken a number of years to perfect the process. Unsurprisingly, the secret is not just in the build process but the complete production chain, including heat treatment and post-processing. Since launching copper, we have seen various

industries become interested in the material. Particular interest is coming from customers for electrical and cooling applications, where thermal efficiencies are improved through the combination of copper and AM's design capabilities."

### Advice on AM design and applications

After so many years in the business, Halliday is quickly able to distinguish between enquiries that are viable and those that are not. Based on this knowledge, he has some basic advice for designers who are unfamiliar with AM on how to approach both the technology and potential production partners. "Firstly, AM will not solve all your problems, it is simply another manufacturing tool in the toolbox, albeit an excellent one," he explained. "Try and learn enough about the benefits and shortfalls of AM to be able to identify which of the components that you design can

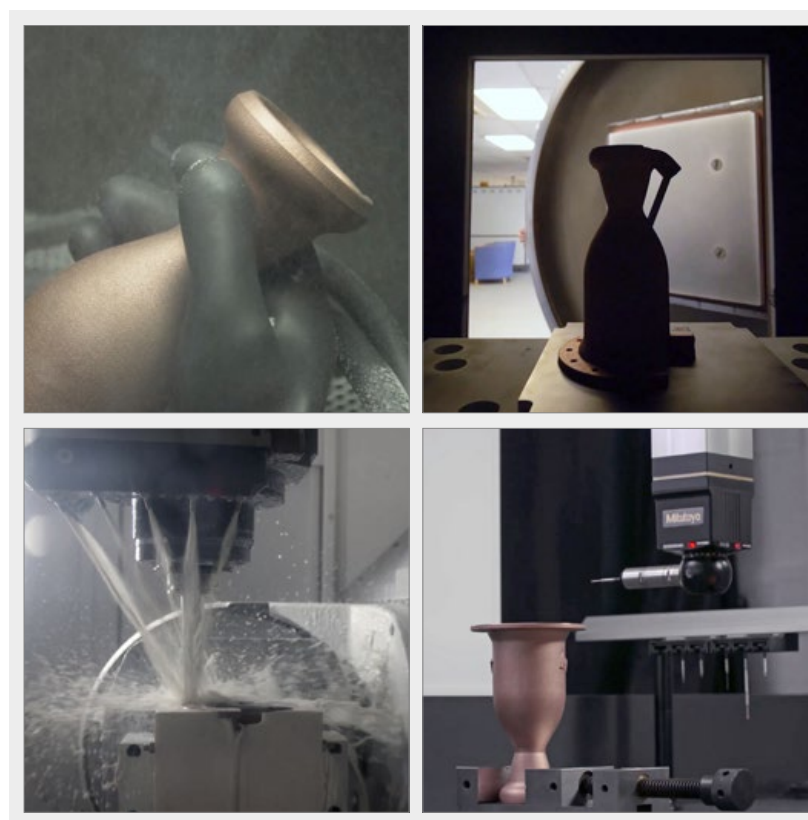


Fig. 8 The rocket engine receives significant post-processing in-house at 3T. Operations include abrasive blasting (top right), vacuum heat treatment (top left), 5-axis CNC machining (bottom left) and full measurement inspection



ABSTRACT SUBMISSION DEADLINE: APRIL 15, 2019

# Call for Presentations

**PMTi  
2019**
**Powder Metallurgy and  
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September 24–27, 2019 • Salt Lake City, Utah • University of Utah

*Global experts on powder metallurgy and additive manufacturing of titanium and titanium alloys will gather for academic exchange and technology transfer.*

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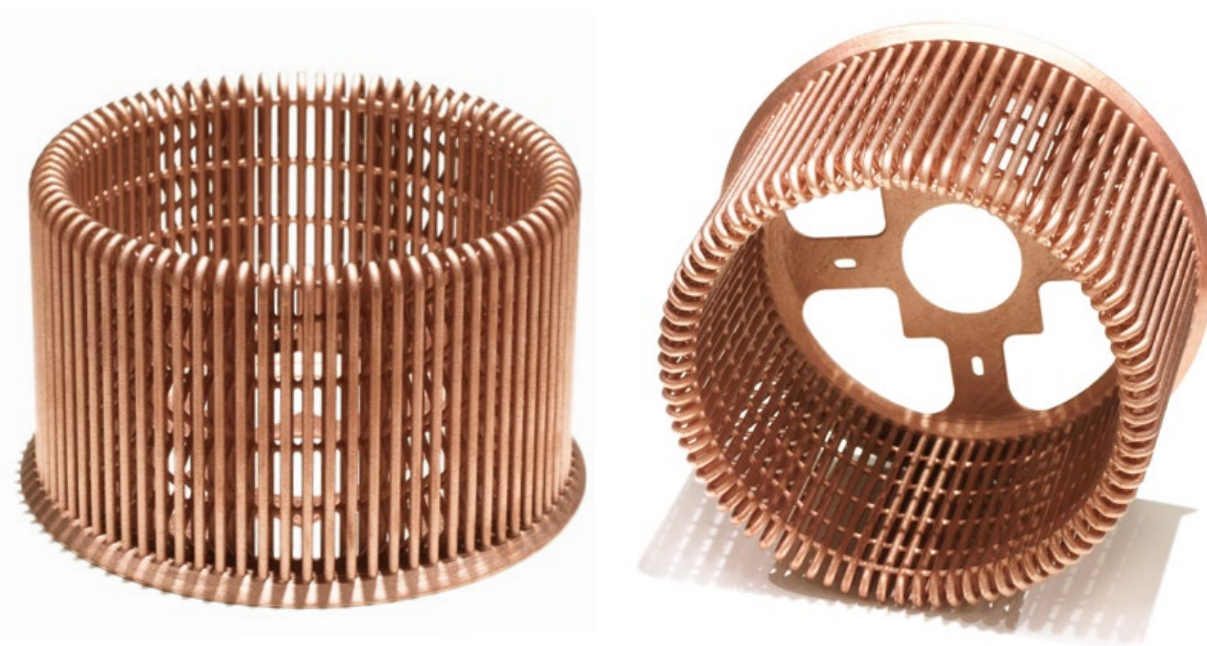
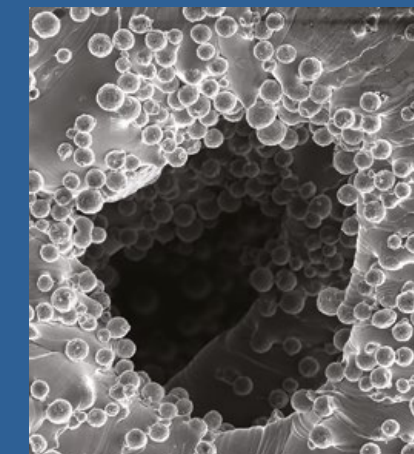


Fig. 10 This copper heat exchanger prototype shows how the thermal capabilities of copper and metal AM can be effectively combined

be genuinely enhanced from the use of AM. This will help you select the right parts for AM, which can then be designed for manufacture by AM, but taking into account the beneficial and necessary use of conventional technologies for finishing, including CNC machining in particular."

"Consider opportunities to combine parts and improve system performance through the use of AM – look more broadly than your own components on a system level if possible. Finally, be passionate about your design and the potential for using AM, but don't expect it to do everything, and always include other manufacturing processes in your thinking."

## The future

3T has ambitious plans for the future that centre on a continuing expansion in internal capacity, whilst supporting key customers with complete AM installations on their own sites and pushing for an international expansion of the 3T business.

Halliday told *Metal AM*, "We are working on all three options, and expect the future of the company to

develop in these directions. The centre of service, R&D, product development and production of 3T will remain in the UK for many years to come. However, if the company is to benefit from the knowledge built up over the last twenty years in AM, we need to multiply the use of that knowledge by supporting our customers through the AM journey to create their own stable production facilities either run by the customer or 3T".

Halliday added, "The development and protection of 3T UK is therefore the priority, however we have already benefitted 3T UK by helping non-competitor customers to develop their own in-house facilities. In addition to training and know how sharing, we are setting up a 3T site in Japan and will do the same in the USA. A global reach has many advantages, increasing opportunities, balancing risk and helping to balance the workload of each individual 'hub' by sharing production demand where viable. These three tenets of the 3T strategy have been a vision for over a decade, so it is uplifting to see the strategy starting to become a reality."

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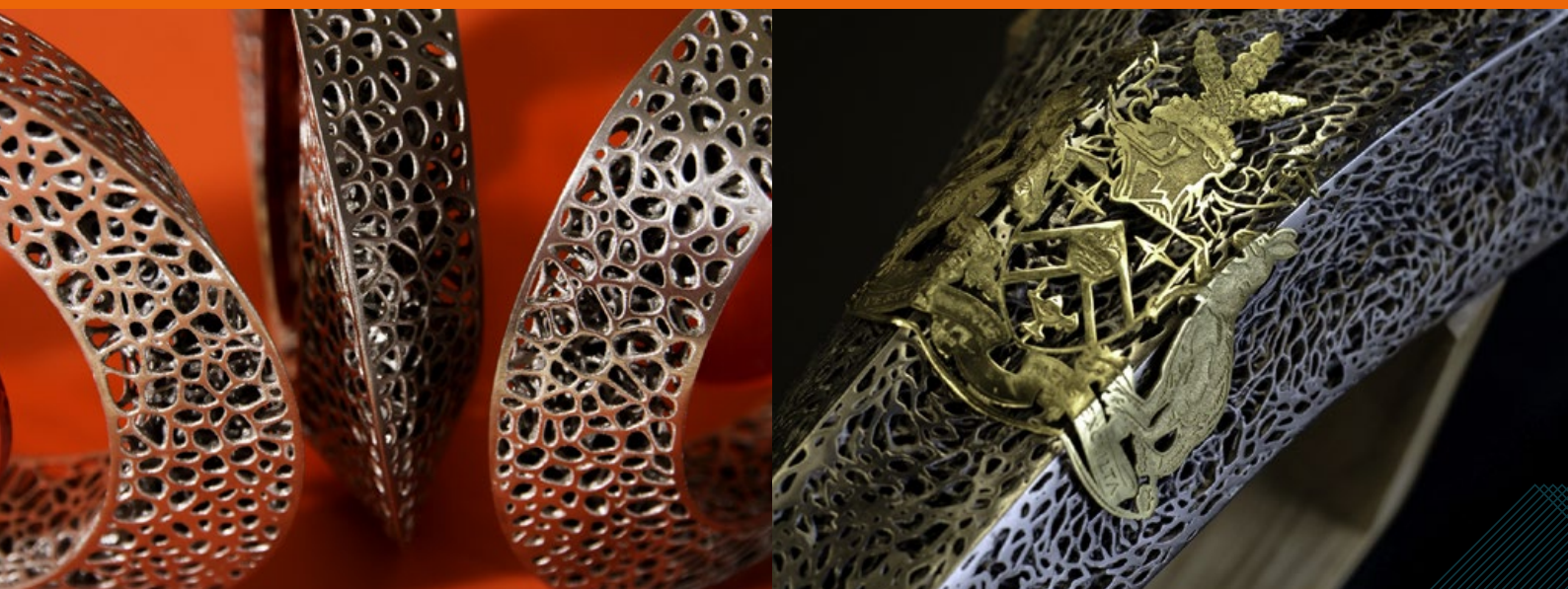




# APICAM 2019

Asia-Pacific International Conference on Additive Manufacturing

June 30 – July 3 2019 | RMIT University, Melbourne



The 2nd Asia-Pacific International Conference on Additive Manufacturing (APICAM) is the not-to-be-missed industry conference of 2019. APICAM was created to provide an opportunity for industry professionals and thinkers to come together, share knowledge and engage in the type of networking that is vital to the furthering of the additive manufacturing industry.

Leading minds in the industry from US, Germany, China, Japan, Australia and other countries will give presentations on pressing issues and the ways in which innovations can navigate challenges. Important areas such as 3D printing and additive manufacturing in the automotive, biomedical, defence and aerospace industries will be covered by experts from each respective field.

The event is being curated by Materials Australia, the peak Australian materials technology body, which has drawn on its considerable pull in the industry to create a world-class event that is a must-attend for anyone involved in the additive materials industry.

The main features of APICAM 2019 will include presentations by experts as well as workshops that will help attendees sharpen their skills and then be able to pass on this knowledge to other industry professionals. The event has been designed to allow for ample networking time so that important knowledge-transfer can take place and partnerships can be created that will enrich the industry.



Enquiries:

**Tanya Smith | Materials Australia**  
+61 3 9326 7266 | imea@materialsaustralia.com.au

The purpose of this conference is to provide a focused forum for the presentation of advanced research and improved understanding of various aspects of additive manufacturing.

This conference will include lectures from invited internationally distinguished researchers, contributed presentations and posters. Contributions will be encouraged in the following areas of interest:

- Additive Manufacturing of Metals
- Additive Manufacturing of Polymers
- Additive Manufacturing of Concretes
- Advanced Characterisation Techniques and Feedstocks
- Computational Modelling of Thermal Processes for Metallic Parts
- Part Design for Additive Manufacturing
- Failure Mechanisms and Analysis
- Mechanical Properties of Additively Manufactured Materials
- New Frontiers in Additive Manufacturing
- Process Parameter and Defect Control
- Process-Microstructure-Property Relationships
- Testing and Qualification in Additive Manufacturing

## Natural resources and national strategies: How metal Additive Manufacturing is taking off in Australia

Australian expertise is today becoming much more commonplace on the international AM scene. From technology and materials suppliers to application developers, companies are growing on the back of world-class research and education facilities, and a business environment where innovation and international trade are rewarded. Combine this with an abundance of AM-relevant natural resources and, as Alex Kingsbury explains, an environment has been created in which AM is thriving.

Australia has had a varied and interesting relationship with manufacturing since its beginnings as a nation in 1901. Given Australia's relatively remote location in the world, it was important to establish a manufacturing base. As a result, protectionist economic policies were implemented that meant that imported goods attracted high tariffs; this had the desired effect, and manufacturing, and therefore a prosperous middle class, thrived right through to the 1970s. At this point, tariffs in Australia were the highest in the industrialised world.

The landscape changed significantly in the 1980s and 90s when aggressive tariff reform was pursued in Australia as part of a worldwide trend towards opening international trade borders. The manufacturing sector necessarily refocused away from domestic supply, towards export. This refocusing of manufacturing was felt hard by many. Ultimately however, the businesses that were already globally competitive prevailed, alongside those that had built resilience into their business models and supply chains. What

remains of the manufacturing sector to this day is a sustainable and vital industry that is globally competitive and export oriented.

This sector has benefitted from the exceptional skills base that has been incubated over a number of decades. Generous government support is also available for companies wishing to

develop intellectual property, participate in research and development activities and connect with offshore trade. The strong and growing university sector not only develops highly capable graduates, but also supports local companies with world class research facilities and research and development programmes.



Fig. 1 The Melbourne skyline reflects the ongoing economic rise of Australia





Fig. 2 SPEE3D offers two machines, the LightSPEE3D shown here and the larger format version, WarpSPEE3D. The company is rapidly pursuing plans for expansion into North America and Europe

This refocusing on manufacturing in Australia comes at a time when metal Additive Manufacturing is maturing and becoming more widespread. For reasons which remain unclear, in adopting nearly every new technology, Australia has lagged approximately five years behind the rest of the world. However, when adoption does occur, it tends to happen very quickly; metal AM has been no different, and just like we saw AM take off globally in 2012, this point was reached in Australia, somewhat predictably, in 2017. Now that the seeds have been sown, we have an interesting range of activity happening 'down under', which this article will profile.

### Leading industrial AM companies

To date, AM activity in Australia has been driven primarily by entrepreneurial activity. For a supposedly 'laid back' nation, Australia has a thriving

start-up scene, albeit mostly in the software, financial technology and biotechnology sectors. Interestingly, some of the most prominent players in Australian AM are equipment suppliers, with key examples being Aurora Labs, SPEE3D and Titomic. All three companies rely heavily on their ability to create value-driven intellectual property, and two of them - Titomic and SPEE3D - have intellectual property in cold spray technology.

#### SPEE3D

Melbourne, Victoria

Byron Kennedy, founder and CEO of SPEE3D, attributes "having ready access to people and knowledge" as enabling the industry to grow in Australia. Kennedy and co-founder/CTO Steven Camilleri are both entrepreneurs at heart; they were looking for more efficient methods by which to rapidly prototype parts for their high-efficiency electric motors

when they visited the cold spray lab at the Commonwealth Science and Industrial Research Institute (CSIRO). The technology struck them as having a lot of potential to replace the casting process, while drastically cutting down lead time.

Having successfully commercialised their electric motor development company, the partners focused on creating a high-speed metal Additive Manufacturing system based on cold spray technology. Aluminium and copper are a strategic focus for the team, as this is where cold spray and their machines will provide the most value. "We have access to some of the lowest cost materials in the world. Bauxite to produce our aluminium feedstock is mined in Queensland, smelted and atomised in Tasmania, and delivered to Melbourne," says Kennedy.

Today, SPEE3D offers two machines, LightSPEE3D (Fig. 2) and the larger format version, WarpSPEE3D. The company is rapidly pursuing plans for expansion into

North America and Europe for sales and service support, but will remain Australian based. The expansion has been key to overcoming one of its biggest hurdles, as Kennedy explains: "12,000 kilometres is a big challenge. We need to provide offshore customers assurance that we'll provide them a high level of service if they buy a machine."

So far, however, that hasn't perturbed FIT AG in Germany, which bought a system to build capability for the technology in Europe in September 2018. In fact, apart from sales to Australian universities, all of SPEE3D's sales have been offshore and include the purchase of a system by Singapore Polytechnic. This is unsurprising, however, as Kennedy notes, "it's essential to be export focused." Various government programmes have supported SPEE3D's growth, and Kennedy is emphatic that this level of support has been enormously helpful.

#### Aurora Labs

Perth, Western Australia

On the other side of Australia in a suburb of the mining city of Perth, Aurora Labs came to being under a similar set of circumstances. Founder and CEO David Budge is also a serial entrepreneur, who was seeking a method which could be used to make AM faster and cheaper. He credits the comparative isolation of Australia as the reason behind the nation's creative resourcefulness. "Australian people are very good at thinking outside the box because we are so far from everything," he says. "Having to wait weeks for someone to fly a part in to fix something means that we skill up pretty quickly. We fix things ourselves and this leads to an inventive culture." This is particularly so in Perth, known for being one of the most isolated cities in the world.

Aurora Labs has ambitious plans. From producing and selling its low-cost laser machines to developing its multi-level rapid manufacturing technology, pursuing low-cost powder production and a recent joint venture

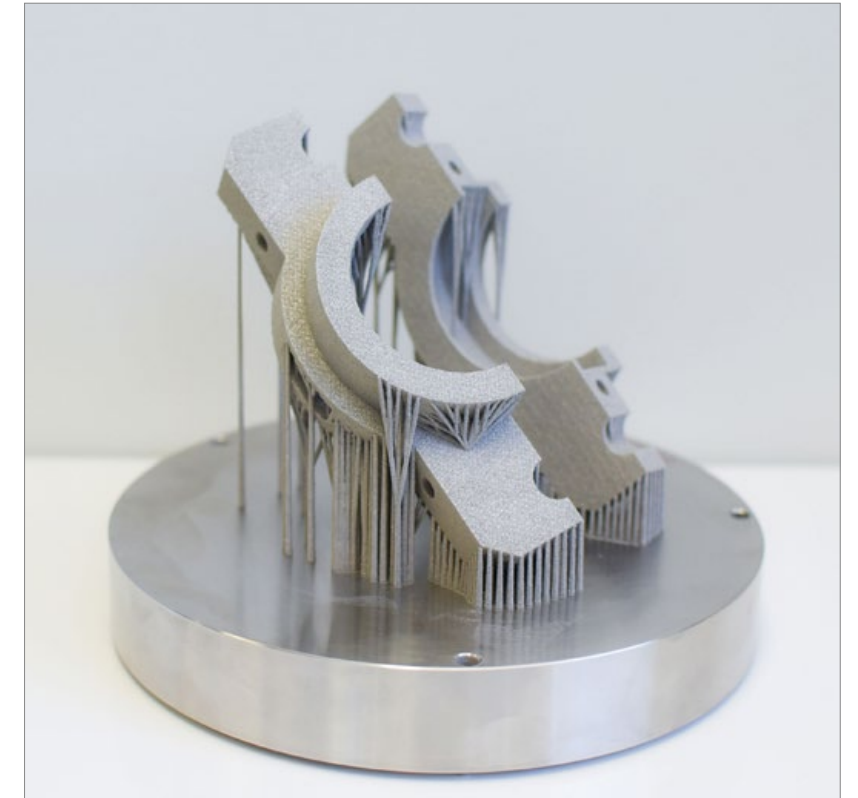


Fig. 3 Aurora Labs' activities include producing and selling its low-cost laser machines and pursuing low cost powder production

with engineering firm WorleyParsons; it's not surprising that a public listing was the best method of raising capital to fund all this activity. Budge is clear on this point: "Accessing capital is challenging. We don't have an established venture capital network like in the US. You either list on the ASX or go overseas." Aurora Labs chose the former and will be staying in Australia. Like SPEE3D, though, they are quickly establishing sales and support offices in a few key locations close to their customers.

#### Titomic

Melbourne, Victoria

Titomic is another high-profile metal AM company that has raised capital to fund ambitious technology development plans. Having secured licences to CSIRO intellectual property relating to cold spray technology, it set about building its very large format cold spray system in Melbourne.

Commercialising cold spray is not straightforward; it is not a thermal process, so the properties of cold sprayed parts differ from traditional, thermally processed objects. Jeff Lang, founder, CEO and Managing Director, is a believer in cold spray's ability to revolutionise manufacturing. Indeed, cold spray has unique characteristics such as the ability to combine dissimilar metals, apply coatings, and create near-net shape parts, all in the absence of a thermal energy source. Understanding that the market will not readily accept cold spray technology as an immediate commercial solution, Titomic's business model starts with a collaborative agreement where the technology is tested against customer requirements.

Like Aurora Labs, Titomic raised its capital on the Australian Securities Exchange (the ASX) by listing as a public company. This early listing tactic is somewhat unique to Australia; whereas elsewhere in the world an early stage technology company would raise capital through private



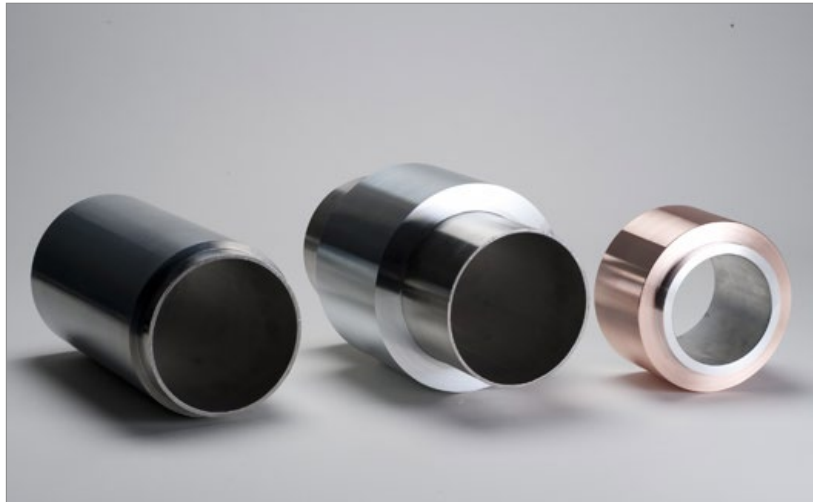


Fig. 4 Cold spray products manufactured by Titomic. Cold spray has unique characteristics such as the ability to combine dissimilar metals, apply coatings, and create near-net shape parts, all in the absence of a thermal energy source



Fig. 5 OMX Solutions markets a range of customised oral maxillofacial implants that use metal Additive Manufacturing as the primary processing technique

or venture capital, in Australia these marketplaces for capital are less interested in investing in manufacturing companies or hardware style businesses. Listing on the ASX provides a secure and easy conduit to smaller investors who have the appetite for higher risk investments. Institutional investors also look to the ASX in Australia for portfolio diversification, and thus the ASX is an easy and transparent route by which to attract this type of investor. While access to capital via the ASX is overall easier, staying in the public spotlight

while developing a technology and its corresponding market can be challenging. It exposes the company to an additional level of scrutiny, and also comes with an additional cost burden.

#### **Anatomics** Melbourne, Victoria

Also unique to the Australian landscape is the public-private funding model that the health sector relies on. Well-resourced public hospitals

act as the backbone of privately funded surgical practice. Competition is healthy, and surgeons rely on innovation and excellent patient care to be successful. This has had the effect of driving much innovation in the medical technology (medtech) field, and therefore in the associated AM technologies. Anatomics, a medical technology business founded by neurosurgeon and entrepreneur Paul D'Urso, was a first mover in this space. Having worked with AM polymers for anatomical models, Anatomics partnered with CSIRO to move into metal AM. Together, Anatomics and CSIRO designed and printed the first titanium heel implant for a cancer patient facing amputation below the knee. This was followed by the first additively manufactured sternum and rib implant for a patient in Spain. D'Urso's company now exports additively manufactured implants to thirty different countries around the world.

#### **OMX Solutions** Melbourne, Victoria

In 2015, a one-off collaboration between oral-maxillofacial surgeon Dr George Dimitroulis and the University of Melbourne was successful in additively manufacturing a jawbone implant for a patient. This work led to the creation of AM-based spin-out OMX Solutions.

Initially created to commercialise the temporomandibular joint (TMJ) implant that was created during the collaboration, the company now designs and markets a range of customised oral maxillofacial implants that use metal Additive Manufacturing as the primary processing technique (Fig. 5). "The TMJ and other maxillofacial implants are perfect candidates for AM," explained Mick Shaddock, General Manager of OMX. "AM addresses the ability to have a patient-specific, perfectly fitting implant. A TMJ implant is challenging as the surgeon is working with a small amount of bone stock, so AM is an excellent solution."

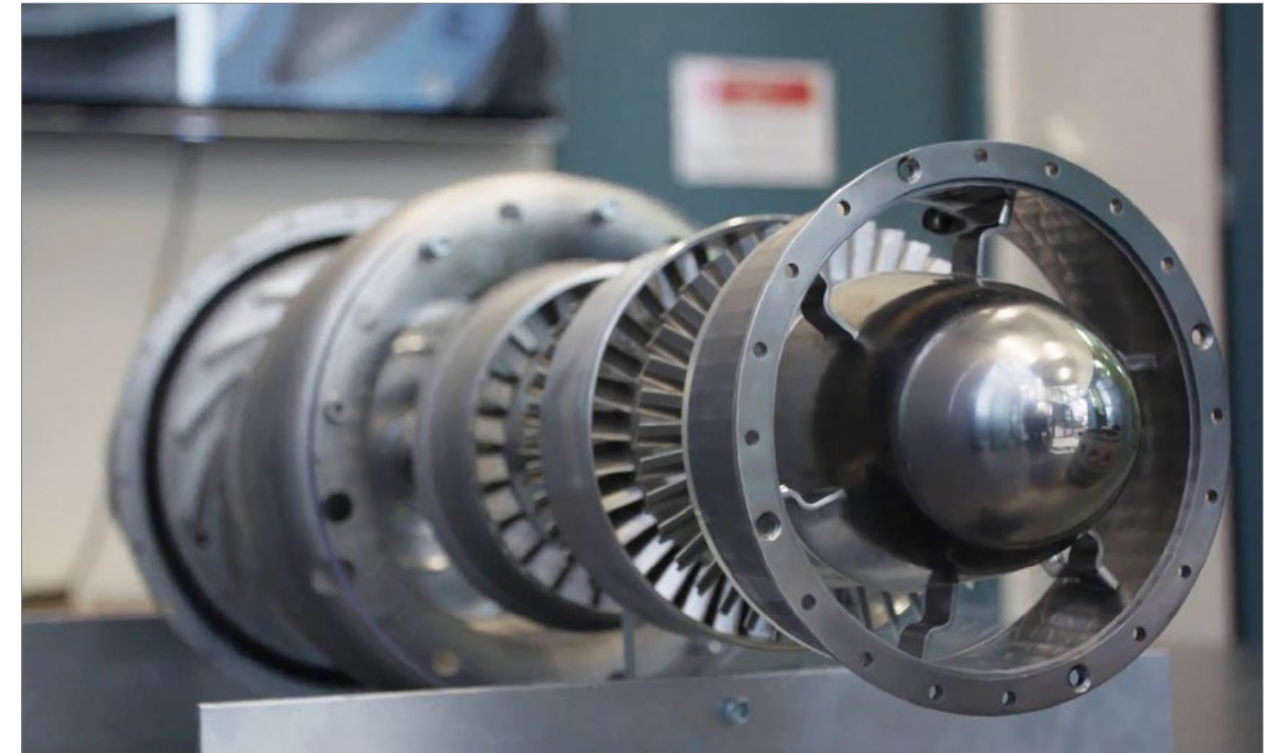


Fig. 6 An additively manufactured auxiliary power unit manufactured by AM specialists Amaero Engineering

Shaddock credits the strong medical technology network in Melbourne for incubating talent and giving rise to much of the innovation in this space. "Melbourne is absolutely the leader in the AM medtech space," he stated. "We have world-class organisations and leading experts at our doorstep here. The expertise is across the industry spectrum and includes academic, research, private and public enterprises and, importantly, a highly interested and progressive clinician base." He is also positive about the government assistance, stating that, "Attracting government funding helps opens doors to domestic expertise and offshore connections."

However, the biggest challenge for OMX, Anatomics and others is the looming change of regulations by the Therapeutic Goods Association (TGA) in Australia. The proposed changes could see a significant shift in the approach to customised implants. Most significantly, the move to limit annual production would effectively quash the business model for customised implants, which relies on medium volume levels to be viable.

Overall, however, there is recognition that the current regulations are in need of updating to manage the unique nature of AM and the implications the technology has for implant manufacture.

#### **Amaero Engineering** Melbourne, Victoria

The defence sector in Australia is currently experiencing unprecedented growth. Many large capability programmes are being awarded in-country and international programmes such as the Joint Strike Fighter have provided many small-to-medium enterprises in Australia with exposure to international supply chains. Additionally, the defence sector's strong links with research institutions have assisted adoption of AM technologies. Amaero Engineering is a Melbourne-based metal AM service bureau that has seen good growth in defence-related work. Early in 2016, it was assessed by global defence contractor Raytheon as ITAR compliant and ready to receive

production orders. It has also established its first offshore manufacturing venture, a partnership with Safran Power Units in Toulouse, France, to print gas turbine components. As a spin-out from Monash University, it has access to a range of large format metal AM systems; this enables it to build parts that many defence partners are looking for both locally and internationally.

#### **Breaseight Engineering** Sydney, New South Wales

The first metal AM service bureau in Australia was Breaseight Engineering. Originally operating as a conventional tool-making and machine shop, Breaseight experienced sales and revenue volatility through the 1980s and 90s and knew it needed to change. "We needed to look at new technologies and improve our business model to align it with the top manufacturing countries in the world," explains Kevin Cullen, Managing Director. "From there, we identified 3D printing as being the technology of the future."





Fig. 7 A high-performance additively manufactured heat exchanger from Conflux Technology

However, it was a long road ahead for Breseight; its first metal AM machine arrived in the early 2000s, when no one knew how to utilise the advantages of AM. "We were ten years too early and had a white elephant hanging over our head," says Cullen. However, Breseight weathered the storm and the investment paid off. It has since added a number of metal AM machines and business is booming, especially as it looks to international markets and partnerships. Of the advantages of being located in Australia, Cullen notes Australia's unique positioning to Asia as being one of the highlights.

#### **Conflux Technology** Warrn Ponds, Victoria

One company that stands out as unique in the Australian context is Geelong-based Conflux Technology. The company was founded by Michael Fuller, an ex-motorsport engineer who was looking for ways to maximise the efficiency of the heat exchangers in Formula One race cars. Utilising AM, he patented a design that used computational fluid dynamics to model the optimum fluid pathways for heat exchange. Fuller and three co-founders were then able to convince AM Ventures in Germany of

Fuller's vision, and in 2017, Conflux secured Series A investment. No other AM company has been able to attract significant overseas funding while remaining in Australia.

The company focuses on AM thermal applications (Fig. 7), and its market is truly global. "99.9% of our enquiries come from North America, Europe and Japan," says Fuller, "customers and stakeholders are applying pressure for us to be more closely located to our target markets; there is a necessity to have regular face-to-face engagements."

For now, however, the lifestyle benefits of being so closely located to some of the world's top surf beaches are the pull factor in attracting top talent. "All the people at Conflux enjoy the lifestyle in Australia," Fuller explains. "We have a very international team." There are technical benefits as well; nearby Melbourne is home to Australia's synchrotron, which the staff at Conflux regularly use to conduct experiments and inspect parts. Without access to such a powerful facility, Conflux would be sending parts overseas to conduct the testing necessary for its products.

#### **Bastion Cycles** Melbourne, Victoria

Metal AM in Australia has recently crossed into the sporting goods market. Representative of the shift in manufacturing, Bastion Cycles founders Ben Shultz, James Woolcock and Dean McGeary were looking for new opportunities when Toyota closed its Technical Centre in Australia. The trio took the skills and expertise honed and developed during their years in the automotive industry and applied it to their passion — cycling.

Their dream was to create a high-performance bicycle made from carbon fibre tubing and additively manufactured titanium lugs. The resulting product is a very high strength, lightweight bicycle that is perfectly tailored to each individual customer (Fig. 8). Initially, they outsourced their AM operation, but have recently brought AM in-house,



Fig. 8 A high-performance bicycle from Bastion Cycles, made from carbon fibre tubing and AM titanium lugs. The resulting product is a very high strength, lightweight bicycle that is perfectly tailored to each individual customer

allowing them to apply their design knowledge to other applications, including sporting equipment for athletes competing in the Olympic and Paralympic games, and motorsport components.

#### **Renishaw Oceania** Melbourne, Victoria

Bastion Cycles has a strong relationship with Renishaw Oceania, the Australian division of Renishaw plc, headquartered in Gloucestershire, UK, which established an AM presence in Australia before most other international suppliers. Mike Brown, Managing Director of Renishaw Oceania, states that this was an intentional move and key to approaching the Australian market. "Renishaw's philosophy was to have the service and support in place before we approached the market," he explains. "Establishing a presence was fundamental to catering to the

rather unique Australian marketplace." Brown attributes this move to Renishaw's success in Australia.

#### **Support from government & R&D**

The positive role that both government and academia have played in the adoption of AM technology has been pivotal in Australia. Much of the AM industry in Australia has either been exposed to AM or assisted in AM projects via a government or research initiative, or both. The move by the research sector in the first instance was absolutely intentional; many research institutes had excellent capabilities in metal-based manufacturing, built up through decades of supporting a traditional manufacturing industry. The advent of metal AM was a logical next step for that capability, and much of the deep expertise in aluminium, steel and titanium crossed over easily into metal AM research.

#### **RMIT University** Melbourne, Victoria

Universities and R&D institutes such as CSIRO also believed that local industry would readily accept the technology and, therefore, that industry-sponsored projects would be forthcoming in time. Historically, Australia has been criticised for having poor research commercialisation outcomes, but in metal AM the translation has been strong. "Universities were and are the place to assist companies wishing to get into that space," says Professor Milan Brandt, Director of RMIT University's Advanced Manufacturing Precinct (AMP) and a pioneer of metal AM in Australia. "RMIT's vision for the AMP was to conduct research into digital and advanced manufacturing as they knew that was where manufacturing was going." This foresight has paid off, and RMIT now enjoys a reputation as one of the leading innovators for AM in Australia.





Fig. 9 AM implant designs developed by RMIT. The university now enjoys a reputation as one of the leading innovators for AM in Australia

RMIT and many other Australian universities have also had success in attracting overseas students, particularly from China, South-East Asia and the Asian sub-continent. This has had the effect of boosting enrolment numbers and added to the university 'bottom line' significantly. State-of-the-art facilities have been instrumental in attracting these students, and growing enrolment numbers have justified further facilities investment. For RMIT, its traction with industry both locally and overseas has made further investment in metal AM not only desirable, but essential to its continued success.

#### University of Sydney Sydney, New South Wales

Numerous universities around Australia are now attracting international collaborations. Recently, the University of Sydney signed a ten year Memorandum of Understanding (MoU)

with GE Additive to accelerate the adoption of metal Additive Manufacturing in Australia, which will see GE Additive invest \$1 million annually in research and development activity. Part of the attraction for GE Additive was the potential for AM to have a positive impact on the economy of Australia; the MoU is centred around the university's plan to develop an advanced manufacturing hub in Western Sydney — the home of many traditional manufacturing businesses. Both GE Additive and Sydney University are aligned on a plan to transform the region via collaboration with local businesses.

#### Innovative Manufacturing Cooperative Research Centre (IMCRC) Melbourne, Victoria

Global medical company Stryker's investment in the Just in Time Implants research collaboration,

a five-year, AU\$12.1 million project involving two Australian universities and a hospital, is yet another example of an international AM-focused collaboration on Australia soil. The project is co-funded by the Innovative Manufacturing Cooperative Research Centre (IMCRC), with David Chuter, IMCRC CEO and Managing Director, stating, "Australia's innovative manufacturing and medtech environment offers research partners a unique setting for ground breaking research programmes. This is highlighted in Stryker, a global organisation who have chosen to collaborate with Australian universities and a local hospital to conduct their innovative research."

The IMCRC was established by the Australian government to assist industry-led research in the manufacturing sector. To date, it has funded AM research projects in medtech, mining, defence and aerospace across Australia. The CRC model co-funds

projects between industry and researchers with the aim of commercialising research in areas in which government believes Australia has competitive strengths. IMCRC activity has led to more than AU\$115 million being spent in R&D investment in Australia on manufacturing projects, and importantly, AM technology is a priority area for the IMCRC.

### Abundant natural resources

It is worth noting that much of the current investment in metal-based technologies is driven by a broader objective than just the rehousing of skills and research capability from a traditional manufacturing sector. Australia is home to some of the most abundant reserves of natural resources in the world, including some of the largest reserves of important and strategic ores for metals such as aluminium, titanium, nickel, steel, and tantalum. Rich in mineral resources, Australia's abundant deposits are currently exported at a minimum value, and value-added products are bought back at two-to-three times the magnitude of the material's initial value. Additive Manufacturing could open up new opportunities in creating an end-to-end value chain, from mineral resource to final product.

#### Clean TeQ Metals Melbourne, Victoria

John Carr, Scandium Marketing Manager for Clean TeQ Metals, which is developing a nickel-cobalt-scandium mine in Australia, is a strong proponent of value-adding minerals before export. "There is a big opportunity to value-add across the board, but there needs to be a mindset shift," he says. Indeed, the mindset shift has to come in the form of new approaches to metal processing technology. For AM in particular, the opportunity to directly produce metal powder for AM processes is compelling. This is what spurred Coogee Chemicals, Perth, Western Australia, to invest in CSIRO-

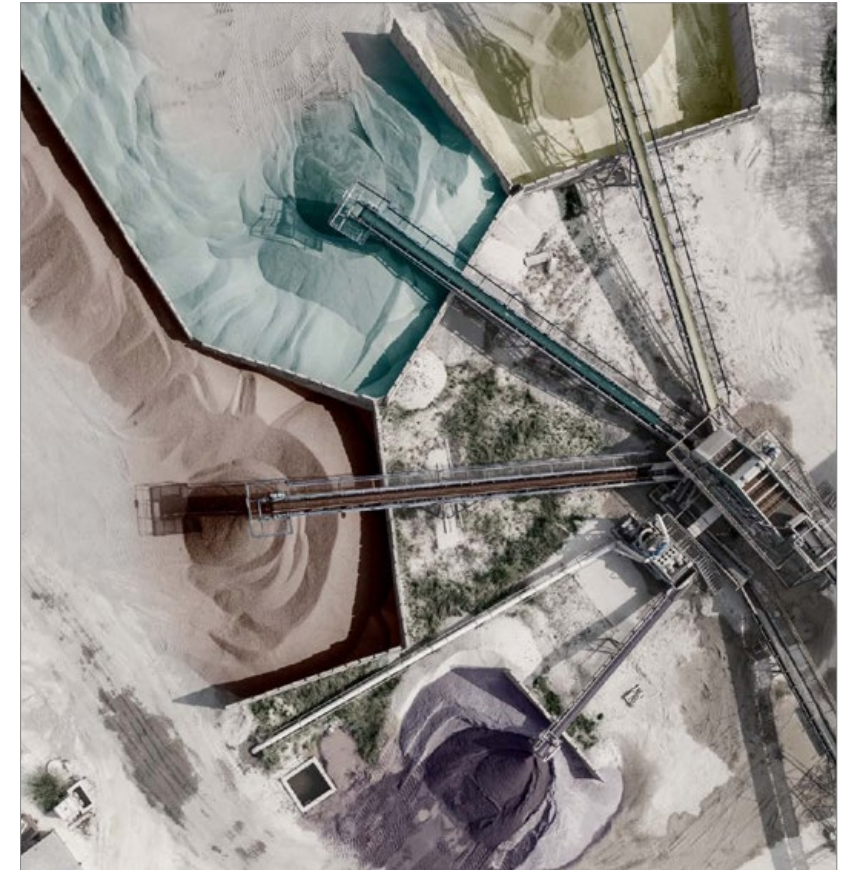


Fig. 10 Clean TeQ's Syerston mine promises a secure supply of crucial metals for AM, including scandium

developed technology — a two-stage process that produces a titanium powder product. The process uses titanium tetrachloride, a chemical produced in Australia from Australian ore, to directly produce titanium particles. Using this material in AM processes has the potential to not only significantly reduce the material cost (due to its simple and continuous operation), but also opens up opportunity for Australia to 're-shore' a titanium industry; that is, develop at home an industry that is currently located overseas.

Meanwhile, Carr and colleagues at Clean TeQ have been actively developing markets for one metal that the company knows has great relevance to AM — scandium. Known as a 'spice element', scandium has a potent strengthening effect on aluminium alloys and is ideal for lightweighting (and therefore many AM) applications. However, the adoption of scandium has been held

back by the lack of a reliable and secure supply. This is something that Clean TeQ is looking to overcome by processing material from its high-grade deposit with its Clean-ix® technology.

"It allows us to more efficiently extract a whole range of metals using one technology platform," explains Carr. "At our mine, we can extract the metals straight from the slurry and are able to combine a number of process steps into one." For Clean TeQ, AM is the ideal end-point for its material, but the path to get there is not straightforward. "We have to play the long game and do fundamental research to fill the gaps in the literature that we can share to generate the interest in aluminium scandium." Monash University in Melbourne and Deakin University in nearby Geelong have been able to help the company fill the gap with alloy development and applications-based research projects.



## The lucky country

Australia has long been known as 'the lucky country', and for good reason. It is the 13<sup>th</sup> largest economy in the world. It is, in essence, a vast island that contains immense brain power, abundant natural resources, and a first-class research sector. Its proximity to Asia puts it in a powerful position for trade, and furthermore, it has a stable, democratic system of government

*“Collaboration with research institutes remains high on the agenda for Australian manufacturers, and AM in particular has been a breeding ground for a number of productive industry-research partnerships....”*

that poses little to no sovereign risk for investors and business owners.

The Australian government not only recognises the importance of manufacturing in its economy, but appreciates that high-tech, high-value advanced manufacturing technologies are the future for Australia's manufacturing sector. Furthermore, the Australian government is proactively encouraging businesses to invest in R&D through generous funding models and tax rebate schemes for research. 'Industry 4.0' or digital manufacturing is front and centre of most modern manufacturers' mindsets. Memory of the slow-

down through the 1980s and 90s, caused by exposure to international markets, is still fresh, and business owners understand the fundamental importance of being globally competitive. With a local population of just 24 million, export is and will remain the holy grail of manufacturing in Australia.

Collaboration with research institutes remains high on the agenda for Australian manufacturers, and AM in particular

has been a breeding ground for a number of productive industry-research partnerships. Australian universities have strengthened off the back of record levels of enrolled students, and in turn have been able to bring world-class facilities and a wealth of knowledge to local and international research projects. This is having a catalysing effect as universities contribute to productive partnerships with local industry.

Yet somehow, those 12,000 kilometres remain one of the biggest challenges. It is known as the 'tyranny of distance' – the geographical remoteness that has defined and shaped the Australian

people. As a positive, this has given rise to a resourcefulness and creativeness that has led to a number of AM-related businesses. Yet on the flipside, the distance works against the need to trade and export internationally. Some manufacturing businesses have become victims of their own success, being almost entirely leveraged overseas. Despite the fact that we live in an increasingly interconnected world, there is still no replacement for a face-to-face meeting and an in-country presence.

Australians are well known for being laid back, but a lesser known fact is that Australians are also very hard working. Those in the metal AM industry will continue to put in long travel hours to ensure that business is conducted face-to-face and that strategic international partnerships are forged. With the continued focus on export, developing intellectual property, and collaborating with universities and research institutes, the metal AM activity that was initially slow to start in Australia, is really starting to take off.

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## Scalmalloy® is too expensive and design optimisation only makes sense in aerospace. True or false?

Additive Manufacturing is not a cheap production process. The software, machine time, materials and expertise required to make the most of the technology all come at a significant cost. The resulting financial pressures may give rise to the temptation to select a material on its price and view advanced topology optimisation as a luxury. As Jon Meyer, APWORKS, and John Barnes, The Barnes Group Advisors, demonstrate, the unique capabilities of AM mean that basing material choice on cost without considering the impact of material performance on the mass of the part is a false economy, limiting the competitiveness of AM and the potential of an application.

"Unobtainium, way too expensive..."

These are common expressions you may hear regarding scandium – if someone has even heard of it. Light metals materials engineers fantasise about the potential of the element as an alloying ingredient in alloys such as aluminium. It was Soviet scientists who developed the first scandium-containing alloys and then, decades later, engineers at Airbus came up with a second-generation alloy called Scalmalloy®.

In AM, metal powders are often said to be expensive, and Scalmalloy is not an exception. But the reality is that in AM, the powder cost is typically less than 15% of the overall part cost, even when considering only the mandatory post-processing (heat treatment, support removal, blasting); if Scalmalloy is going to be successful, then AM is surely the best manufacturing method to use what is considered to be an expensive material, being so efficient in material usage.

Scandium has often been compared to the unicorn of elements, and known primarily to materials engineers in aerospace

and high-end sporting goods. At 21 on the Periodic Table, it sits next to a very popular element, titanium, and yet very few people have ever heard of scandium. For those that have heard of it, they often believe that it is rare, expensive, but good when alloyed with aluminium (Fig. 2).

As an element, scandium is not actually all that rare. Scandium oxide is found as a mineral all over the

Earth's crust, and estimates place it as somewhere between the 16<sup>th</sup> and 26<sup>th</sup> most abundant element on Earth [1]. It is not found in very high concentrations anywhere and occurs naturally as complex chemical compounds (ores) or as scandium oxide hidden in bauxite, also often with other high-value metal deposits such as cobalt, platinum and premium metals. Recently, methods



Fig. 1 This Light Rider electric motorcycle from APWORKS features an additively manufactured Scalmalloy frame



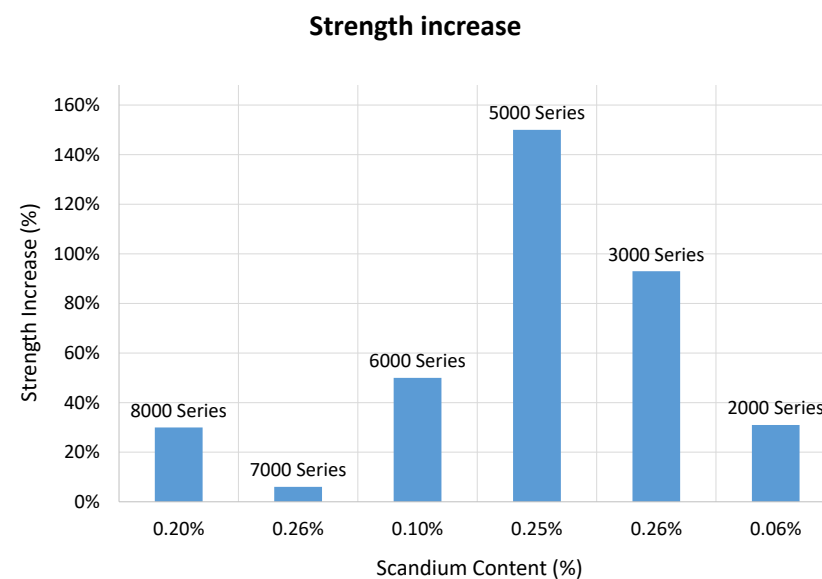


Fig. 2 The strength increase potential vs scandium content in various aluminium alloys

have been developed to refine it from relatively cheap waste streams like 'red mud', a by-product of Bauxite mining, or from 'waste acid' as a remnant of 'white pigment' (titanium dioxide) manufacturing. Today, there is only a very small market for scandium, which keeps the price relatively high due to the need to manage the processing costs over a small volume.

the stockpile has been exhausted, new mining resources – as well as the previously mentioned waste streams – are coming online in stable democracies around the world in what could be a bright new chapter for light alloy metallurgy.

As an alloying element in aluminium, you could say scandium punches above its weight. Minor additions of scandium increase the

***“Soviet MiG designers learned what scandium can do to aluminium and designed alloys around it which were implemented on MiG-21 and MiG-29 aircraft...”***

The history of scandium dates back to the Cold War, and also helps to explain the economics of its supply. Soviet MiG designers learned what scandium can do to aluminium and designed alloys around it, which were implemented on MiG-21 and MiG-29 aircraft. As the Cold War wound down, a surplus of the alloy kept the commercial market from evolving. Now that

strength of aluminium alloys, with even small additions of scandium, less than 0.5%, translating into significant strength increases of greater than 30% [2]. How is this possible? The answer is bound in the metallurgy where the  $Al_3Sc$  precipitate is dispersed into the bulk of the alloy and contributes to two major strengthening mechanisms.

The first well-known and principal strengthening mechanism in AlSc alloys is attributed to supersaturation of Sc in Al and the  $Al_3Sc$  particle, a precipitate, which helps to generate very fine grain structures and to pin grain boundaries and keep the grain size refined. The Hall-Petch relationship tells us that the smaller the grain size, the higher the strength. Scandium also increases the recrystallisation temperature and prevents premature strength loss during annealing. This effect is important because the recrystallisation temperature is raised above 600°C, which is higher than any heat treatments for aluminium alloys.

The second metallurgical effect of Sc that is uniquely used in Scalmalloy relates to precipitation hardening by Sc by very tiny, nanometre-sized coherent  $Al_3Sc$  phases. The intrinsic rapid solidification in AM (mainly achievable in Laser Powder Bed Fusion (L-PBF)) can keep much more Sc in solid solution than incumbent large-billet DC casting. Consequently, this propensity is applied in Scalmalloy to raise strength significantly just by a simple, appropriate annealing heat treatment after melt processing. Scandium introductions have also been shown to improve welding operations by reducing hot cracking [3]. All of these facts become quite important in the context of Additive Manufacturing.

AM is essentially a process of welding materials together, so avoiding hot cracking is essential. Raising the recrystallisation temperature provides the benefit of keeping the grain size refined; especially in AM, where the material will be cycled above or near its melting temperature several times. The ambient environment inside an AM machine chamber could be 200°C, which would begin to heat treat other aluminium alloys, thus giving a different microstructure at the top versus the bottom. Lastly, the  $Al_3Sc$  particle pinning grain boundaries offers another opportunity to retain smaller grain size and thereby higher strength.

Scalmalloy is an aluminium-magnesium alloy concept which contains approximately 0.7% scandium in its most-known baseline composition. When processed correctly using L-PBF we create a material with a very high tensile strength (UTS 520 MPa). Because of the low density of the material, it exhibits excellent specific properties (calculated by dividing the material property by the density), approaching those of the workhorse titanium alloy Ti6Al4V at room temperature. Scalmalloy also exhibits excellent ductility (elongation 13%) and is naturally very corrosion resistant, as well as demonstrating a high degree of microstructural stability with respect to thermal ageing. To achieve similar strength properties, incumbent aluminium alloys require solution treatment and artificial ageing. This can lead to distortion issues on slender parts due to the high temperatures and rapid cooling rates during the quenching step. Scalmalloy only requires a single, one-step heat treatment at much lower temperatures, minimising the risk of distortion.

## The design perspective

In engineering designs where the material properties are fully exploited, the differences in material properties such as strength and stiffness will have a direct impact on the shape and mass of the resulting design. In some engineering problems, the stiffness of the material is the driving factor in meeting a maximum deflection requirement. In other cases, it can be the strength of the material, which is the limiting factor, due to the amount of external load which needs to be transmitted.

In most cases, it is not easy to distinguish prior to analysis which is the driving requirement, as a complex part may need to meet both stiffness and strength requirements over many different loading scenarios, including different operating temperatures. Ultimately what drives the design is which of those requirements is

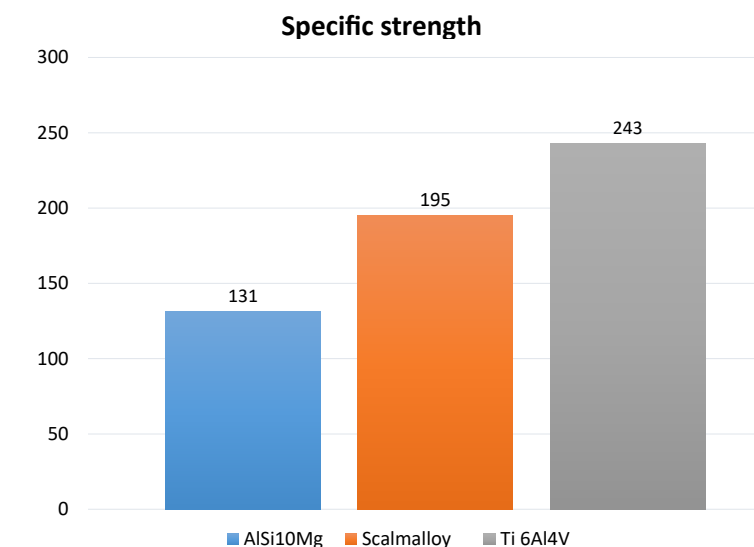


Fig. 3 Comparison of the specific strength of AlSi10Mg, Scalmalloy and Ti6Al4V

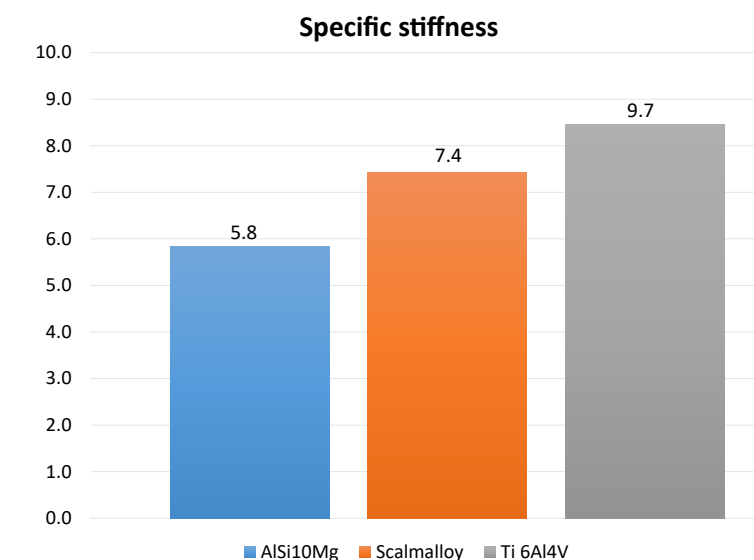


Fig. 4 Comparison of the specific stiffness of AlSi10Mg, Scalmalloy and Ti6Al4V

the hardest to satisfy and hence dictates the final geometry and mass of the part. A material which exhibits good specific properties for both strength and stiffness, coupled with a low density to minimise parasitic mass from non-structural features, is therefore most likely to offer the optimum solution over a wide range of different engineering problems.

Scalmalloy has close to the same specific strength as Ti6Al4V at room temperature, and significantly higher strength at room

temperature than AlSi10Mg (Fig. 3). This means that in designs where the required strength is limiting the design, Scalmalloy will be lighter than AlSi10Mg at nearly the same mass as Ti6Al4V. The specific stiffness advantage is present but not as strong, meaning that, for applications where stiffness is key, Scalmalloy will be lighter than AlSi10Mg, but still heavier than Ti6Al4V (Fig. 4).

The third characteristic, which is relevant to overall part mass, is the density of the material itself, as this determines the mass of any



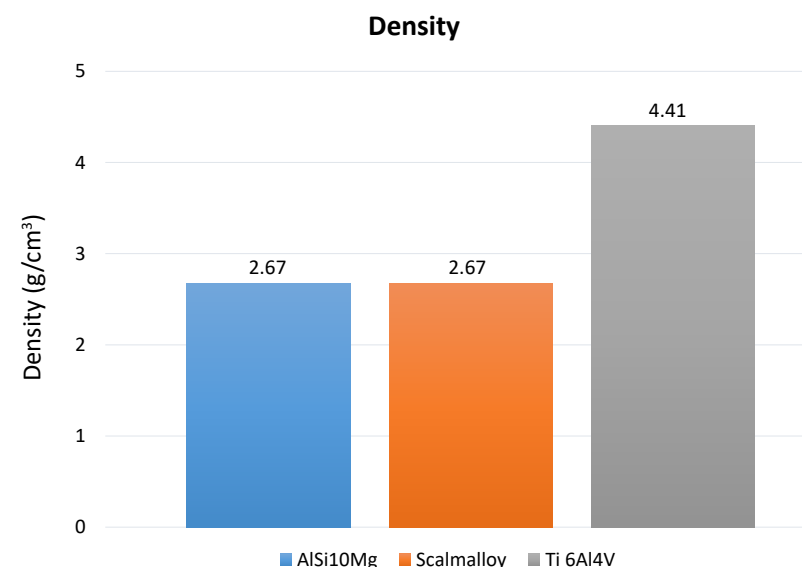


Fig. 5 The densities of AlSi10Mg, Scalmalloy and Ti6Al4V

features for which the geometry is not dictated by strength or stiffness, but is instead mandated by the functional design. In this case, Scalmalloy and AlSi10Mg will be similar in mass and about 40% lighter than Ti6Al4V, owing to their lower densities (Fig. 5).

Last but not least, it is worth mentioning that Scalmalloy has the same easy machinability as any other Al-alloy, which is important because interface milling and drilling operations are still necessary even on AM parts. Titanium alloys are known to be very 'difficult' during machining, requiring careful and rigid clamping in combination with well-adjusted machining parameters to avoid undesired part damage.

#### Mass doesn't matter to me, my customer doesn't care how much it weighs...

When considering traditional manufacturing processes, particularly subtractive ones, it is true that mass saving normally costs you money and, unless you place a monetary value on saving mass, then it is not worth doing. Additive Manufacturing is different for two key reasons. Firstly, in an AM process, the amount of material you consume is

proportional to the mass of the part. This means that your raw material cost is reduced when you save mass in the design. Secondly, the time it takes to build the part is proportional to the mass of the part and almost independent of its complexity.

The build time is one of the largest driving factors in the part cost, due to the relatively low productivity of most AM systems and the relatively high capital cost of the equipment. If you reduce the mass of the part, you reduce the raw material consumption and build time, which means you reduce the product cost. This is what we like to call the 'virtuous circle' of mass saving and cost saving in AM, and is one of the reasons why Design for AM (DfAM) is so important.

It is true that Scalmalloy powder is still much more expensive than AlSi10Mg powder, but it is a common mistake in Additive Manufacturing to place too much emphasis on the feedstock material's cost. Compared to legacy manufacturing methods, most of the cost is on the process side. Material costs are typically much lower because the processes are near-net shape and minimise material consumption. Typically, powder cost is less than 15% of the part cost.

This led us to ask the question – if the material properties of Scalmalloy are higher, how much lighter could you design the part to be in AM? When does the value of Scalmalloy justify its cost?

To explore this case, APWORKS teamed up with Michael Bogomolny at Paramatters Inc., a California-based generative design software company, to perform a case study for a brake caliper design, using topology optimisation to minimise the mass of the design using the properties of each material.

#### Optimisation is expensive, AM is best for low-volume production... this doesn't make any sense

AM excels at low production volumes, so investing significant amounts of design effort in optimising parts does not traditionally make for a good business case, as there are simply not enough parts to amortise this non-recurring engineering effort. The virtuous circle often breaks down once the development cost amortisation is included.

The Paramatters software focuses on automating the optimisation and design process as much as possible in order to minimise this up-front cost. In particular, it eliminates the 'design interpretation' step where you look at the output of your fancy topology optimisation and effectively restart your design from scratch, using the faceted mess in front of you as 'inspiration'. Picasso would enjoy that step, but for most of us it is a nightmare...

Paramatters has instead developed an approach where design optimisation is performed at a very high-resolution using a degree of computing power accessible only by cloud computing. This means that the output of this optimisation is a nice smooth geometry, which can simply be taken and built without the need to redesign from scratch. The software can even generate a STEP file output – as well as standard STL mesh format – so that it is possible to add features or incorporate the part in a traditional CAD assembly. The time and labour saving is

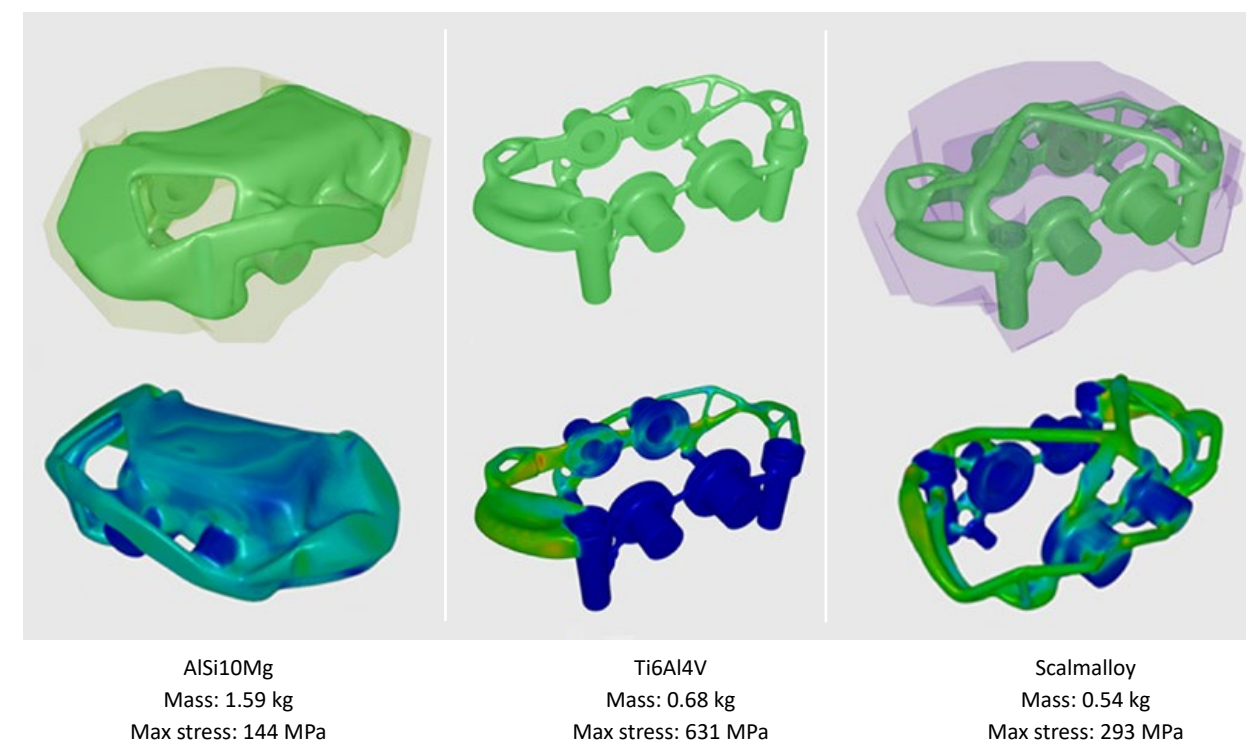


Fig. 6 AM optimised solutions in AlSi10Mg, Ti6Al4V and Scalmalloy created using the Paramatters software

significant, so could this broaden the scope of application of design optimisation to lower production volumes?

Using Paramatters' software, we optimised against a set of load cases with the objective of achieving a minimum mass solution with a constraint on maximum stress. The stress constraint applied was 70% of the yield strength. We ran three cases, where one used AlSi10Mg, one used Ti6Al4V and the other used Scalmalloy. We then performed a manufacturing cost analysis against each solution so that we could compare the mass and cost of the solutions. Finally, we performed a break-even analysis versus the development cost of performing the optimisation, to understand at what production volume this approach makes sense.

#### Optimisation results

The design was optimised and we compared the standard 'milled' design aluminum baseline with the AM optimised solutions in AlSi10Mg, Ti6Al4V and Scalmalloy.

The Scalmalloy version of the part weighed 0.54 kg, just over one third of the 1.59 kg mass of the AlSi10Mg part. For comparison, a similar highly optimised, high-end aluminium racing caliper weighs in the range of 1.2–2.3 kg. In performance terms therefore,

the AlSi10Mg solution looks quite competitive in terms of mass, while the Scalmalloy version is far lighter than the benchmark (Fig. 6). The original baseline milled design prior to optimisation had a mass of 4.54 kg, so we have removed a lot of mass in both cases (Fig. 7).

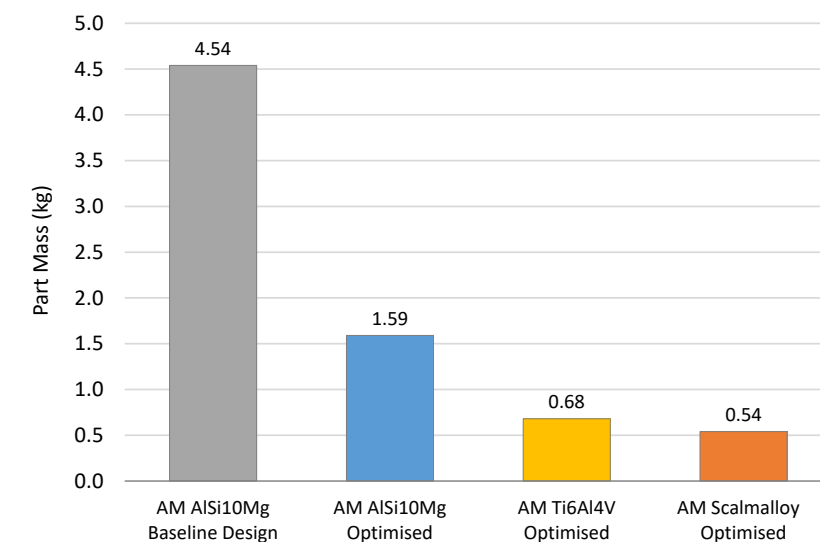


Fig. 7 Mass of the parts shown in Fig. 6 plus the 'baseline' milled design



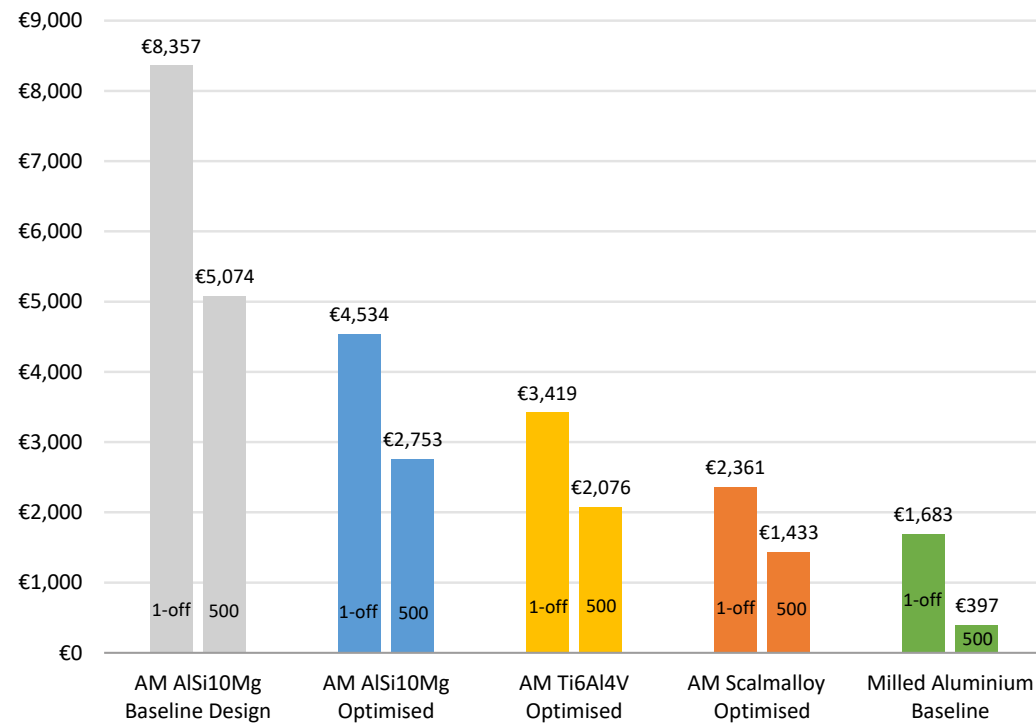


Fig. 8 Comparison of part manufacturing cost for a single part (1-off) and a short series of up to 500 parts

The Ti6Al4V solution came in slightly heavier than the Scalmalloy solution, at 0.68 kg. This result was initially surprising in that we had expected the Ti6Al4V solution to be the lightest due to the slightly higher specific

Reserve Factor (RF) of 1.12, meaning that they all had 12% additional strength margin versus the stress constraint set in the optimisation. This suggests that the optimisations were all of a similar

This platform takes into account the orientation and support of the parts and provides full production costing. For the milled baseline part, we used the best pricing we could find from a CNC machining cost estimation tool in order to compare apples with apples.

The cost breakdown in Figs. 8 and 9 shows that the increased material cost of Scalmalloy is much more than compensated for by the reduced build time due to the lower mass of the Scalmalloy part, with the raw material still only accounting for 12% of the final part cost.

As a reference, the baseline milled design produced in AlSi10Mg without any optimisation is more than three times as expensive to produce as the optimised Scalmalloy design. This illustrates quite well the importance of DfAM and the folly of simply printing conventional designs and expecting to have a competitive product.

Don't misunderstand – these are not cheap parts. The milled benchmark is €397 in volume

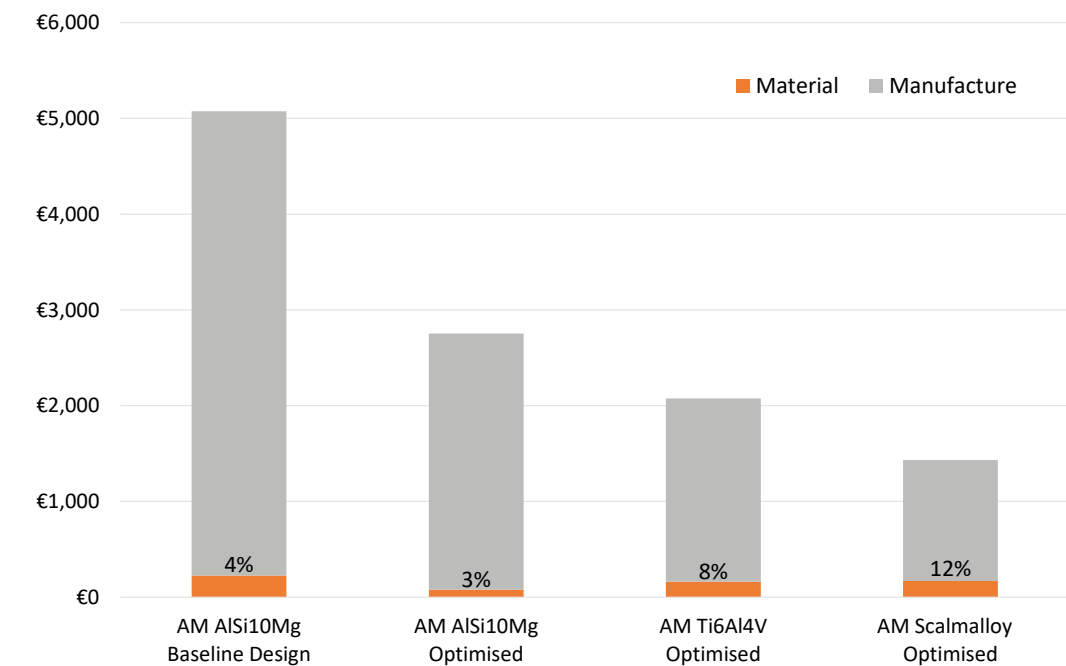


Fig. 9 Cost breakdown per part for more than 500 parts

production, and even the top-end racing calipers are retailing in the range of €5,000, which, of course, includes a healthy margin. AM solutions would certainly need to justify their higher cost with either functional performance or customisation potential, which is valued by the end-user.

The point is that, if you offered all of these AM options to the high-end racing market, they would either take none of the AM options or take just the optimised Scalmalloy one. It is lighter, which offers additional value for the customer in terms of unsprung mass, and it is cheaper to produce. In short, using optimisation coupled with Scalmalloy does not guarantee that you can produce an economical AM product, but it certainly increases your chances of doing so.

In any scenario where you are considering using AM for a production part, you are presumably doing so for a good reason (normally because it enables your functional design in some way), in which case taking the additional step

of minimising the mass in order to reduce your production costs seems like a no-brainer. If your end-user

values low mass as a performance metric, then you win on both fronts (Fig. 10).

***“The increased material cost of Scalmalloy is much more than compensated for by the reduced build time due to the lower mass of the Scalmalloy part...”***

properties versus Scalmalloy. However, it seems that the higher density of the material is adding more parasitic mass in the areas of the design which are ‘non-design space’ and are sized based on the functional requirements of the part. This is enough to make the design heavier than the Scalmalloy solution.

All of the optimised designs were analysed using the Finite Element Method (FEM) and all had a similar

quality in terms of how effectively they utilised the available material properties.

### The economics bit

But what about the manufacturing cost? In this case, we used the APWORKS AMXpert platform to compare the pricing for each part.

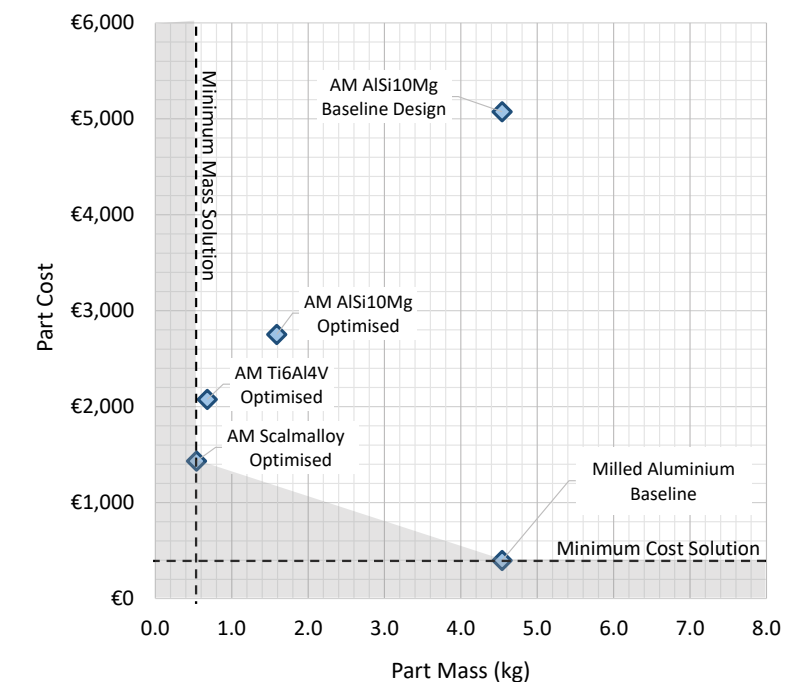


Fig. 10 Part cost compared with part mass for AlSi10Mg, Ti6Al4V and Scalmalloy based on short series production of 500 parts



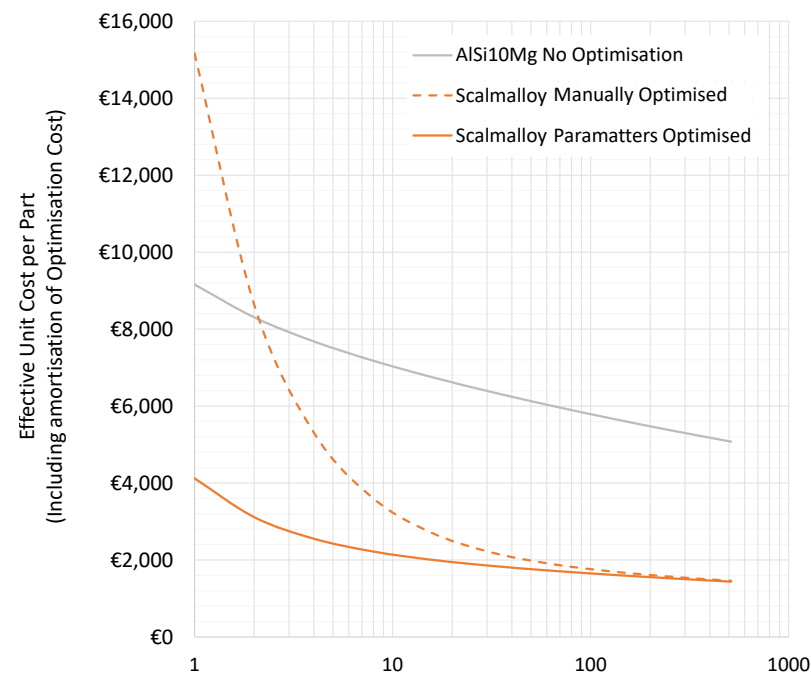


Fig. 11 This volume/cost plot demonstrates that the optimisation effort using Paramatters with Scalmalloy pays for itself in terms of recurring cost savings even if only one part is produced

#### But what about the cost of performing the DfAM optimisation itself?

Because Paramatters uses cloud-based computing, the cost of the design process is related to the complexity of the optimisation

Paramatters tokens (€132) for AlSi10Mg, eight hours and forty-eight tokens (€192) for Ti6Al4V, and five hours and forty tokens (€160) for Scalmalloy. These are modest amounts if you consider the number of expensive engineering hours

*“The difference in investment between optimising a small and a large part is relatively insignificant, but, of course, the benefits in terms of mass saving are directly proportional to the part size...”*

problem being solved, including the physical size of the part, the number of load cases and the resolution of the solution requested. The answer, again, is ‘it depends.’

For our example part, optimisation took four hours and used thirty-three

saved. By comparison, a traditional topology optimisation and design interpretation for a part such as this might take 120 hours of expensive engineering resource and about three weeks to perform – if you are lucky.

#### So, when does it make sense to use the Paramatters software, and when does it make sense to use Scalmalloy?

Well, of course, the answer to those questions depends on how many parts you plan to make and how big those parts are. The second half of that statement may not be immediately obvious, but the cost of performing a topology optimisation is not directly proportional to the size of the part. The difference in investment between optimising a small and a large part is relatively insignificant, but, of course, the benefits in terms of mass saving are directly proportional to the part size. This means that the crossover volume at which optimisation makes sense depends on the size of the part to be optimised, among many other factors. In simple terms, a part that is half the mass requires roughly double the number of parts to payback the same recurring cost savings for a given investment in mass optimisation. As with everything in this article, this is an oversimplification, but not a bad guide to bear in mind when considering when it might make sense to optimise a part.

From the volume-cost plot (Fig. 11), it is clear that, in the case of our original caliper problem, the optimisation effort of using Paramatters with Scalmalloy pays for itself in terms of recurring cost saving, even if only one part is produced. In this case, even the traditional optimisation approach coupled with Scalmalloy is worthwhile provided you are producing a few parts. Of course, in different cases the crossover will move around, but the point is that the use of Paramatters can make optimisation viable even at very low production volumes. If it is worth designing, it is probably worth optimising.

#### Summary

This study was a whole lot of fun and the results were interesting to us in a number of ways. It also threw up some results which surprised us. Firstly, we never anticipated that a

difference in material strength would have such a significant effect on the appearance of the parts. We expected them to look similar, with only some difference in feature bulkiness. In fact, the lower strength material needs to exploit more of the design space boundary and so yields quite a different appearance.

Secondly, we originally expected that Ti6Al4V would yield the lowest mass solution due to its slightly higher specific properties, but in fact there was sufficient ‘parasitic volume’ in the design, due to mandatory features, that its higher density resulted in a heavier optimised part than the Scalmalloy solution.

Finally, we never expected that topology optimisation could pay-back on such low volumes of parts. This says something about the lean workflow implemented by Paramatters, but perhaps it says even more about how dominant part volume is in driving the cost of Powder Bed Fusion AM parts and how expensive it is to produce one cubic centimetre of material. If you are designing Powder Bed Fusion AM parts, you really need to account for every cubic centimetre in the design and ask yourself why it is there. If it does not need to be there, remove it.

It is also clear that using topology optimisation makes sense when you understand the load cases to which

your part will be subjected, the material properties you are working with, and the geometric space which your part can occupy. Using Scalmalloy makes sense when you optimise your design to take advantage of the material properties.

Together, these solutions offer significant advantages over traditional approaches, thanks to the virtuous circle effect of mass savings resulting in manufacturing cost savings, but only when applied to engineered products which can exploit their benefits fully.

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## Safety management in metal Additive Manufacturing: Observations from industry

In the following article, UL LLC's Balakrishnan V Nair discusses key safety issues in metal Additive Manufacturing, identifying some of the principal sources of risk associated with production operations and sharing safety concerns as encountered in UL's work with metal AM clients globally. In addition, Nair highlights some of the benefits that many AM facilities have enjoyed as a result of the successful implementation of sound safety practices.

According to *The Wohler's Report 2018*, sales of metal AM systems increased by nearly 80% between 2016 and 2017, making metal AM a key driver in the overall adoption of AM technologies and systems intended for industrial applications [1]. However, although AM has the potential to transform modern industrial production, it also raises new considerations for manufacturers and users that include potential safety issues.

The introduction of Additive Manufacturing into mainstream manufacturing brings with it new safety issues concerning workplace safety, health and the environment. In general, these safety concerns in metal AM facilities can be attributed to one or more of the following sources:

### Materials

Metal powders used in AM processes are typically microscopic in size (< 100 µm) and often pose toxicity, reactivity, combustibility and instability hazards. Dust clouds, formed for example by the accidental swirling of powders, have the potential to

catch fire and explode under certain conditions. Other hazards include health-related risks resulting from inhalation, ingestion or contact with the skin.

### Equipment

Some of the equipment used in metal AM involves potentially hazardous energy sources such as lasers and

electron beams. As AM technology evolves, the design of production equipment is becoming more and more complex. Typical equipment hazards include electrical energy hazards, irradiation hazards, entrapment, thermal hazards and others. Some of these hazards can be life threatening if not properly mitigated.



Fig. 1 Although AM has the potential to transform modern industrial production, it also raises new considerations for manufacturers and users that include potential safety issues



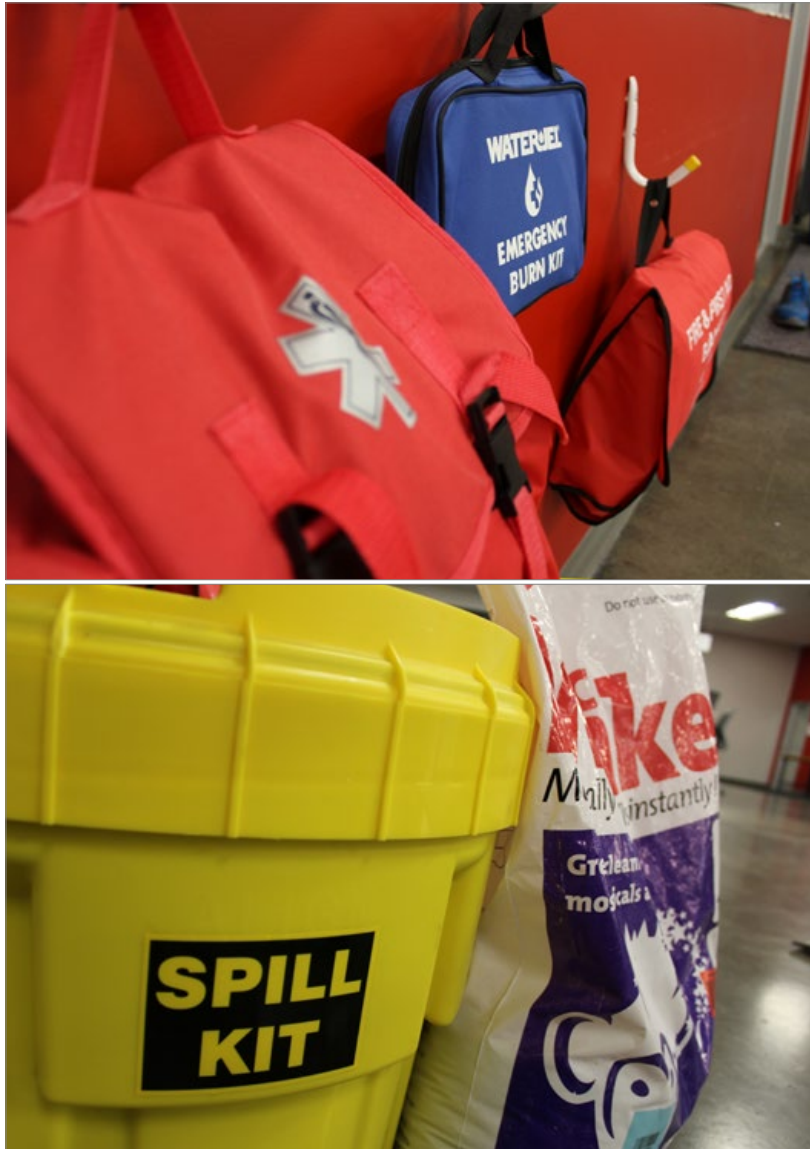


Fig. 2 Safety considerations range from the complete design of a new facility to the installation of emergency response supplies such as fire blankets and spill kits that are appropriate to the risks presented by AM production

### Facilities

Manufacturing production equipment is often tightly grouped to maximise space utilisation and increase production efficiency, which can result in an unsafe work environment. In addition, certain AM production processes use gases such as argon and nitrogen, which are capable of displacing the ambient air in a localised workspace, thereby potentially depriving operators of sufficient breathable air. The lack of a monitoring system for safe oxygen levels can have catastrophic results on worker safety. Furthermore, the use of reactive powders

such as aluminium or titanium has led to debates among authorities having jurisdiction (AHJs) and code officials regarding the most suitable types of fire suppression systems. Robust facility design and safe work practices are thus critical to achieving overall safety.

Besides the risk to human health and safety, metal AM production can also contribute to environmental degradation. For example, if not properly designed, metal AM workplace ventilation systems can exhaust contaminated gases and toxic compounds, impacting atmospheric

air quality. The improper disposal of metal AM waste materials can contaminate soil and groundwater reserves. This can have a potentially adverse effect on plants, animals and aquatic life.

### Safety incidents involving metal powder

Unfortunately, the true scale and scope of the inherent risk posed by the potentially explosive nature of dust formed from the metal powders used as the feedstock in AM have been amply demonstrated in a number of factory and workplace incidents, involving fires or explosions directly linked with powdered metals. Just a few examples are:

#### AM facility

A 2013 fire and explosion at a Massachusetts Additive Manufacturing company, which injured one employee, was traced to the ignition of titanium and aluminium powder. The U.S. Occupational Safety and Health Administration (OSHA) ordered the company to pay nearly \$65,000 in penalties for failing to eliminate known sources of potential ignition [2].

#### Metal powder plant

A Tennessee-based facility that produced atomised steel and iron powders experienced multiple iron dust flash fires and a hydrogen explosion that led to the loss of the lives of five workers. Workers reported that flash fires were commonplace at the facility, but that they had not been trained to understand the extent of the hazard or how to address it [3].

#### Aluminium wheel plant

An explosion at an aluminium wheel plant in Indiana that resulted in one fatality and injured six others was linked to the ignition of finely powdered aluminium in the facility's dust collection system. A subsequent report on the incident found that inadequate housekeeping in the foundry area and poor maintenance of processing equipment led to the dust accumulation that caused the explosion [4].



Fig. 3 Proper protection against exposure to metal powder dust is of fundamental importance during metal AM operation and maintenance

#### Scrap facility

A West Virginia facility that milled and processed scrap titanium and zirconium experienced a fire and explosion attributable to the accumulation of combustible metal dust in a mechanical blender that generated heat and sparks due to poor maintenance. The incident involved three fatalities and injured a contractor working at the facility [5].

### Current landscape - AM standards and regulations

As is often the case with new technologies, efforts to develop standards and regulations applicable to AM processes and equipment are a work in process. Standards development organisations (SDOs) around the world are actively involved in processing the knowledge gained from actual experience in working with AM technologies and developing

new standards or revising existing ones to reflect that knowledge. As a result, the standards landscape for metal AM and AM in general

[6]. Updated in June 2018, the AMSC Roadmap details all existing AM-related standards as well as AM standards under development.

*“the standards landscape for metal AM and AM in general is continuously in flux as additive technologies continue to evolve and industry learns more about their effective application...”*

is continuously in flux as additive technologies continue to evolve and industry learns more about their effective application.

In an effort to help both SDOs and the AM industry navigate the dynamic standards landscape, the America Makes & ANSI Additive Manufacturing Standardization Collaborative (AMSC) has developed a *Standardization Roadmap for Additive Manufacturing*

Importantly, the AMSC Roadmap also assesses gaps in current standards and prioritises specific areas in which additional standards development efforts are needed (the AMSC Roadmap is available at the ANSI website for downloading).

But, while extensive efforts to develop relevant standards for various aspects of AM production activities continue,





Fig. 4 Metal powder fires must be extinguished using appropriate media. Water-based fire extinguishers, with some materials, have the potential to actually exacerbate a fire caused by metal powders

little attention has been paid to safety and environmental issues specifically associated with the use of AM. Instead, AM-related safety issues are currently addressed in accordance with laws and regulations that apply to facilities and equipment across the manufacturing industry. In the U.S., for example, workplace health and safety falls under the general scope of the Occupational Safety and Health Administration (OSHA). Safety issues related to the transportation and handling of potentially hazardous materials are addressed in both OSHA regulations and those of the U.S. Department of Transportation (DoT), while environmental issues associated with the generation, treatment, storage and disposal of hazardous waste are addressed

under the scope of regulations by the Environmental Protection Agency (EPA). Regulations related to workplace safety or the environment may be more rigorous in some state jurisdictions and may impose stringent limits on activities that contribute to environmental pollution and contamination. Building inspectors and other officials in local jurisdictions may also apply the requirements of specific electrical safety codes or occupancy classification requirements to AM facilities. But, while compliance with federal, state and local safety and environmental regulations is not optional for adopters of AM technologies, greater clarity is needed on specific actions that operators of AM production facilities can take to help ensure the safety of their workers or to protect the environment.

### What UL is finding at AM facilities

At UL, our understanding of the unique safety issues facing AM facilities has developed over the last several years through engagement with various stakeholders in evaluating the potential use of AM technologies in their supply chain. In our experience, the most common safety challenges facing our AM clients include:

#### Facility design and construction issues

Manufacturing facilities incorporating AM technologies face a higher risk of experiencing hazardous conditions than traditional manufacturing operations. Yet, many of the facilities we have visited or inspected are neither designed nor constructed to help mitigate those specific risks. This is most often the case when manufacturers introduce AM technologies into existing manufacturing facilities designed for conventional production technologies.

#### Unsafe powder storage and handling practices

We frequently come across practices that fail to account for the unique safety risks associated with the storage and handling of powder feedstock materials used in AM production. Storage containers are often placed in close proximity to heat sources and hot surfaces, or near equipment that can generate ESD or sparks. Workers fail to take sufficient care in unpacking powdered material containers or in transferring them to and from AM production equipment.

#### Insufficient or inappropriate fire suppression systems

Metal powder fires must be extinguished using appropriate media. Existing manufacturing facilities may only be equipped with conventional sprinkler or fire suppression systems that use water or other substances to extinguish the fire or control its spread. These forms of fire suppression have the potential to actually exacerbate a fire caused by metal powders.



Fig. 5 Those new to metal powders need to be aware of the significant risks associated with the storage and handling of powdered materials

#### Wrong or inadequate Personal Protective Equipment

The Personal Protective Equipment (PPE) used in Additive Manufacturing facilities should preferably be made of anti-static materials to help minimise charge accumulation and subsequent electrostatic discharge hazards. At the same time, PPE should also be fire- and heat-resistant to protect workers in the event of a fire or explosion. And workers should be equipped with breathing-protection systems that filter out airborne powdered materials, especially when they are subjected to direct exposure to metal powders and residues. All employees should also have received thorough training on safe and effective use as well as in different strategies for PPE usage. But unfortunately, many AM facilities UL inspects fall far short on each of these issues.

#### General lack of AM-specific safety knowledge

Finally, UL has found a general lack of awareness or understanding on a broad range of safety issues specific to AM production, not only among facility operators and

delays, escalated spending and even frustration for those involved.

Undoubtedly, not every AM facility is characterised by all of these deficiencies. Some facility owners and operators have made great progress in recent years in understanding and

*“UL has found a general lack of awareness or understanding on a broad range of safety issues specific to AM production, not only among facility operators and workers but also with AHJs and local officials...”*

workers but also with AHJs and local officials who are responsible for enforcing federal, state and local regulations and codes. This often leads to confusion, unexpected

addressing the unique safety risks associated with AM. However, as the use of AM technology increases, there is clearly more work to be done to standardise safety practices





Fig. 6 An essential sight at a well equipped AM facility

specific to AM facilities and to help educate producers, regulators, users and the general public about the inherent risks of the process.

### How UL is working to address AM safety

UL has been at the forefront of efforts to address safety issues in AM facilities. UL professionals have been participants in AMSC activities since the collaborative's founding in March 2016. Our team also made significant contributions to the development of the initial edition of the AMSC Roadmap published in February 2017, as well as the second edition published in June 2018. We are also actively involved with ASTM F42 Subcommittee on EHS and the ISO/ASTM TC261 Working Group on EHS and participate in regional working groups for AM standards development.

UL launched its AM Facility Safety Management Program in 2016 to help facility owners and operators develop

a comprehensive approach to AM safety. The programme works directly with facilities to develop an AM safety management plan, which evaluates and addresses risks specific to materials, equipment and facilities, employing a four-step process:

1. Identify the hazards — The programme begins by investigating AM-specific hazards related to fire, explosion and potential toxicity, among others.
2. Assess the likelihood of occurrence and severity of impacts of each hazard — This step allows for the risk quantification and the prioritisation of mitigation efforts for each identified risk.
3. Identify methods to eliminate or mitigate hazards — In this step, specific control measures are developed that, when implemented, will eliminate or reduce to an acceptable level the identified hazards and potential effects

4. Regularly assess compliance with an established safety management plan — The last step involves regularly-scheduled checks to verify ongoing compliance with the plan's provisions, as well as the plan's continued validity

To formalise this four-step process, UL published UL 3400, *Outline of Investigation for Additive Manufacturing Facility Safety Management*. As the first set of guidelines specifically addressing safety issues in AM facilities, the standard can be especially helpful to organisations that are new to AM, or in the early stages of adopting or integrating AM technologies into their facilities. Manufacturers with in-depth experience in AM technologies and production activities can seek certification in accordance with the requirements of UL 3400.

Finally, as part of ongoing efforts to foster the continued development of AM technical and business professionals, UL has established a robust multi-tiered training programme focused on safety. The programme includes advanced hands-on training courses that address AM design set-up, design optimisation, machine set up, part production, post-processing, part inspection, testing and validation and facility and process safety.

### A metal AM success story

Today, a number of AM facilities representing the aerospace and defence manufacturing sectors have been certified to UL 3400. One organisation recently certified to UL 3400 helps to illustrate the potential challenges facing the adoption of AM technologies, as well as the value of the approach detailed in the standard. Our client, an aerospace industry leader in the application of metal AM technologies, sought advice on building a state-of-the-art design and manufacturing facility that would effectively bridge the gap between materials research and the manu-

facturing floor, thereby enabling the company's engineers to design and produce better quality parts faster and at lower cost.

The path to UL certification gave the company the opportunity to thoroughly evaluate its facility in accordance with the safety practices outlined in UL 3400 and the advanced framework provided by UL's facility safety services. The evaluation not only served to validate the company's current safety practices, but also helped to identify improvements needed to make existing safety practices more scalable and resilient, while still supporting the goal of increasing the overall speed and efficiency of product development.

As a result, the company has solidified the basis for its AM production efforts and set the stage for even more advances in the application of AM technologies. Equally importantly, UL 3400 certification has served to assure the company's industrial partners that the company regards employee safety as its highest priority.

### Conclusion

Already well adopted by industry for the creation of prototypes and the small-volume production of high-value parts and components, metal AM technologies are on the verge of transforming our approach to large-scale production operations. Along with the application of other advanced and emerging smart industrial technologies, metal AM has the potential to improve the quality of manufacturing while also reducing production costs, improving time to market and increasing resource conservation.

For its long-term success, however, wider adoption of metal AM technologies heavily depends on an increased focus on the unique health and safety issues that these technologies present. The collaborative efforts of industry and SDOs will be essential in helping to ensure that appropriate safety guidelines

and standards for metal AM continue to be developed and evolved which address new and emerging safety challenges in the future.

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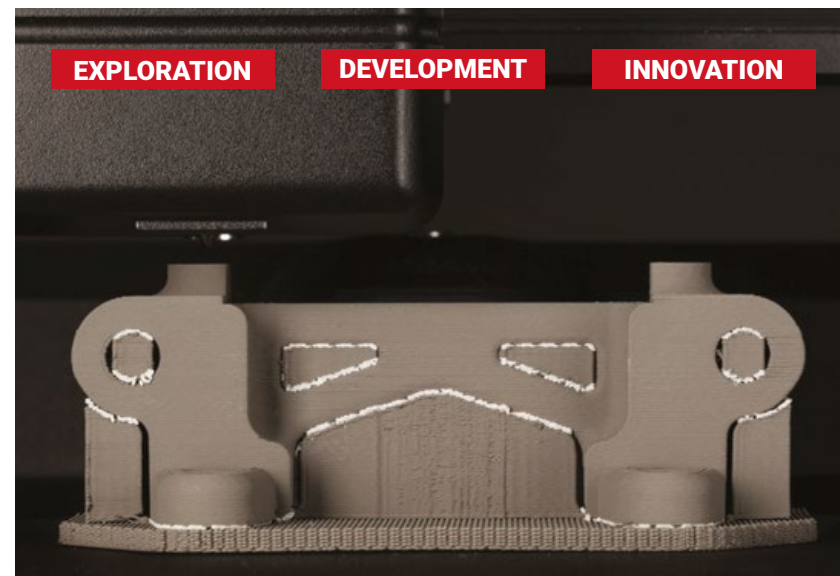
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## Senvol: How machine learning is helping the U.S. Navy optimise AM process parameters and material performance

In a bid to better understand the impact of process parameters on material performance, the U.S. Navy turned to Senvol to develop data-driven machine learning software for Additive Manufacturing. As Zach Simkin and Annie Wang explain, such an approach allows the user to overcome the time and expense required by a conventional trial-and-error process, whilst delivering remarkably accurate results that have the potential to accelerate application development.

How do process parameters impact material performance? Answering this question is one of the U.S. Navy's main goals with respect to Additive Manufacturing. In order to provide the answer, it has previously resorted to following a difficult and time consuming process which relies on trial and error and design of experiments (DoEs). This is a common approach, and a pain point that many companies experience, but the primary drawback of trial and error and DoEs is that they are extremely expensive and time-consuming.

To be able to analyse data that had already been generated and to learn from those data, thus reducing the degree of trial and error and DoEs required, the Navy hired Senvol to develop data-driven machine learning software for Additive Manufacturing. This software will be made commercially available not just to the Navy, but to any company or organisation. This article provides a background to the data-driven approach being taken, as well as offering some of the Navy's use cases for the software.

#### Data-driven machine learning approach

Machine learning is a type of Artificial Intelligence (AI) that allows a computer to perform a task (e.g., recognise a pattern, make predictions) without being explicitly programmed to do so. A computer capable of machine learning 'learns'

to perform the task by being 'trained' using training data. For example, a training data set that includes information on process parameters (such as laser speed and laser power) and process signatures (such as melt pool depth) can be used to train a machine learning algorithm to predict melt pool depth based upon a given laser speed and laser power.



Fig. 1 Ti-6Al-4V (Ti64) specimens built on a Laser Powder Bed Fusion machine. The specimens were later tested and used as training data for Senvol's machine learning software



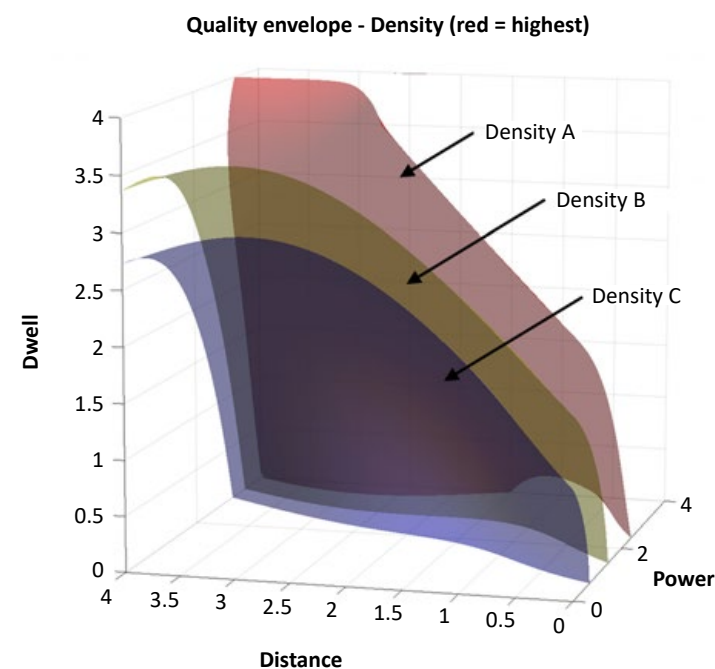


Fig. 2 The output from the Senvol ML software showing what are referred to as 'quality envelopes'

Senvol ML, Senvol's machine learning software for Additive Manufacturing, takes a data-driven approach. Using this approach, the software works by modularising Additive Manufacturing data into four modules:

- **Module 1**  
Process parameter data (e.g., laser power, scan speed, hatch spacing)
- **Module 2**  
Process signature data (e.g., in-situ monitoring data such as melt pool temperature or melt pool depth)
- **Module 3**  
Material property data (e.g., microstructure, density, porosity, surface roughness)
- **Module 4**  
Mechanical performance data (e.g., tensile strength, fatigue life)

The software takes data from any one of the four modules as an input and predicts what any one of the other remaining modules should be. For example, if a user inputs a certain set of process parameters, the software can then predict what

the surface roughness will be. If a user inputs a target fatigue life for a particular application, the software will determine what process parameters to use on the Additive Manufacturing machine in order to achieve this target.

Senvol's data-driven approach is juxtaposed against the physics-based approach which is more commonly seen in the Additive Manufacturing industry today through various simulation software offerings. Senvol believes that data-driven approaches and physics-based approaches are complementary. There are pros and cons to both, and many reasons why a company might choose to use one approach over the other.

In the physics-based approach, a relationship is defined by a formula. An input is then inserted into the formula, which calculates the output. In a data-driven approach, on the other hand, the relationship between inputs and outputs is not defined by a formula. Rather, empirical data are used for both inputs and outputs and the machine learning software then infers what the relationships are.

One of the biggest benefits to a physics-based approach is that it shows causation, whereas a

data-driven approach only shows correlation. Senvol chooses to take a data-driven approach, however, because doing so enables its software to analyse data from any Additive Manufacturing machine, material, or process. Physics-based models are typically specific to a particular process or material, whereas Senvol's software does not have that limitation – it is able to analyse the appropriate data regardless of whether the process involves, for example, a metal alloy on a Laser Powder Bed Fusion (L-PBF) machine, or a polymer on a material extrusion machine.

The following sections of this article will present several specific use cases for the Senvol ML data-driven machine learning software, each of which demonstrates how an Additive Manufacturing user can reduce the cost and time required to achieve the desired end state.

### Determining the correct process parameters to achieve a target material property

One common use case for the U.S. Navy is to identify the appropriate process parameters to achieve the target density for a part or component. To help solve this problem, Senvol ML was utilised.

In this case, the training data used were stainless steel 316L cubes manufactured on a Renishaw AM250 L-PBF machine, with stainless steel being a material of high interest to the Navy. Each cube was manufactured using a different parameter set, with seventy-five cubes manufactured in total. The following process parameters were varied across the cubes:

- Laser power (three variations)
- Laser dwell time (five variations)
- Point distance (five variations)

The output from the Senvol ML software (Fig. 2) shows what are referred to as 'quality envelopes'.

What the quality envelopes tell the user is that, if you want to achieve a particular density, your combination of process parameters needs to fall somewhere in the given quality envelope. Note that the specific density values were redacted for this article and are therefore referred to as 'Density A', 'Density B' and 'Density C'.

In this case, the software showed that if the Navy wanted to achieve Density A, then its combination of laser dwell time, point distance and laser power needed to fall somewhere on the red surface. Similarly, if the Navy wanted to achieve Density B, then its combination of those three process parameters needed to fall somewhere on the yellow surface.

### Predicting material properties and mechanical performance from process parameters

In addition to its need to determine the correct parameters to achieve a required density, the Navy often encounters the opposite need; to predict a part's density given the particular process parameter set that will be used in its manufacture. The training data used in this example was the same as for the previous example - stainless steel 316L cubes manufactured on a Renishaw AM250 machine.

In this particular case, there were seventy-five data points. The Senvol ML software takes a subset of those data points – in this case, sixty – and trains its algorithm on those sixty data points. The remaining fifteen data points are not seen by the software and are used for validation purposes. In other words, after the software has been trained on the sixty data points, it predicts what the remaining fifteen data points should be. The predicted values are then compared against the actual empirical values to determine how well the software predicts. In this case, an  $R^2$  (which is the coefficient of determination and measures the

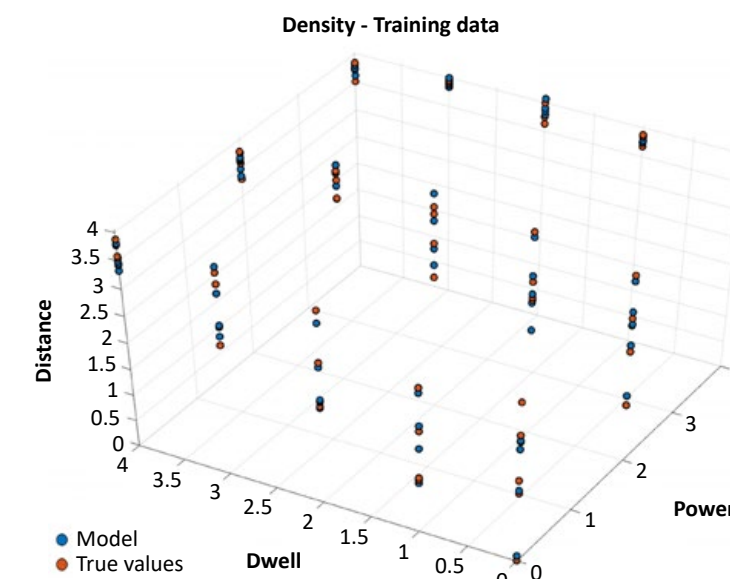


Fig. 3 Output from Senvol's machine learning software (Senvol ML) comparing model predicted values (blue) against actual empirical values (red). The proximity between the red and the blue values demonstrate that the model is predicting actual empirical values very well. In this case,  $R^2=0.94$ , which indicates high predictive reliability

strength of the relationship between a model and the dependent variable) of 0.94 was achieved, which indicates that the Senvol ML software predicts very well (Fig. 3).

This is a particularly important example, as one of the most common misconceptions about machine

mechanical performance as well.

In the following example, fatigue life was predicted based upon part orientation. In this case, the training data used were titanium Ti6Al4V (i.e., Ti64) specimens manufactured on an Arcam A2X Electron Beam Powder Bed Fusion (EB-PBF) machine. There

*“...after the software has been trained on the sixty data points, it predicts what the remaining fifteen data points should be. The predicted values are then compared against the actual empirical values to determine how well the software predicts.”*

learning is that tremendous amounts of data are needed in order to derive any meaningful results. That is not always the case, as demonstrated here, where Senvol ML was able to make very strong predictions with only seventy-five data points.

The Senvol ML software can be used not only for predicting material properties, but for predicting

were sixty-four specimens in total and each specimen was manufactured using one of four orientations: X, Y, Z, and XY 45°.

In this case, the software achieved an  $R^2$  of 0.86. In addition to providing an  $R^2$  value, which indicates the model's overall performance, the Senvol ML software went into much greater detail.



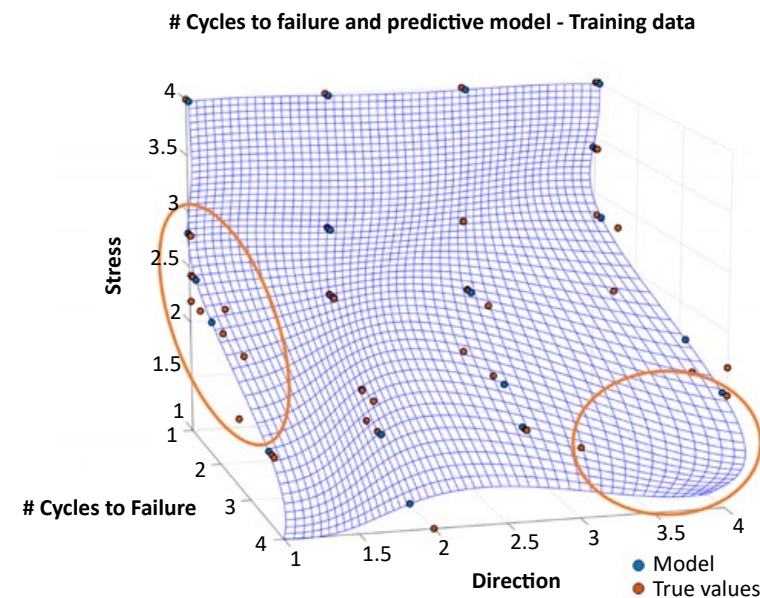


Fig. 4 Output from the Senvol ML software showing the user which specific areas of the model are more or less reliable than other areas

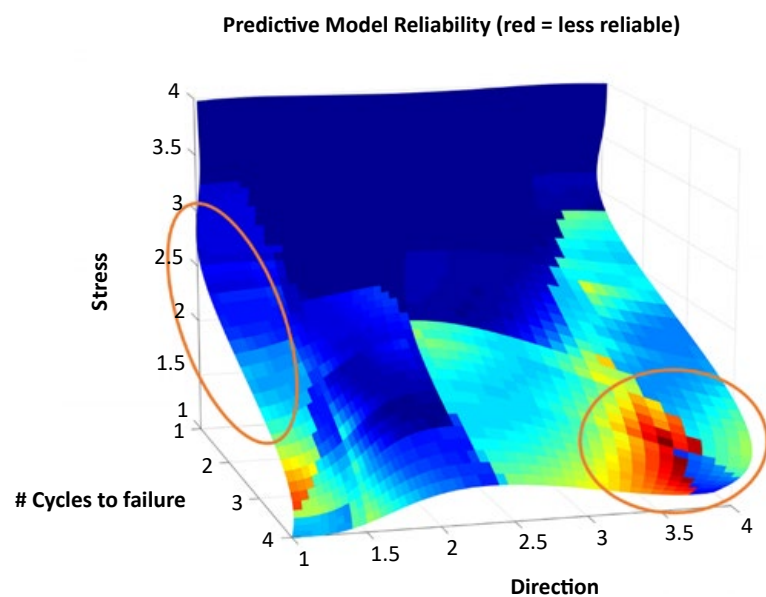


Fig. 5 A heat map of the data shown in Fig. 4

Output from the Senvol ML software (Fig. 4) shows the user which specific areas of the model are more or less reliable than other areas. The areas circled in orange are less reliable than the other areas of the model. In the orange circle on the left, this is because the data points do not fit the curve very

well, which means that there is a relatively large amount of noise in the data in that particular area of the model. In the orange circle on the right, there are no empirical data at all. In cases like this, the model extrapolates on what it believes the outcome will be, but because there is no empirical data

to validate the extrapolation, the prediction is considered relatively unreliable. Another way of looking at this information is on a heat map (Fig. 5).

Areas shown in dark blue have relatively high reliability and areas shown in red or orange have relatively low reliability. This information enables a user to be more targeted in their data collection going forward. Senvol ML employs a capability it refers to as 'data collection protocol' to recommend, specifically, what the user's next build should be. Analysing the data that have already been generated, the software determines how to be as efficient as possible in subsequent data collection efforts.

Today, most companies set up DoEs at the beginning of a project. They then complete the first build, followed by the second build, and so forth, without really modifying the plan as they go. This can often be very inefficient and costly. The Senvol ML software learns 'as you go', enabling users to be much more targeted and smarter in their data collection efforts. Therefore, if a user already has great predictive reliability in certain areas of the model, they need not waste time and resources generating more data in those areas. Rather, Senvol ML enables the user to focus resources on carrying out builds in areas of the model where the reliability is not as high and can be improved.

### Using in-situ monitoring data to simulate non-destructive tests

The Navy would like to reduce, or perhaps even eliminate, the need for non-destructive tests. To accomplish this goal, the Navy has been using the Senvol ML software to analyse the relationships between in-situ monitoring data and X-ray Computer Tomography (CT) data.

In the following example, the training data used were stainless steel 316L specimens manufactured on a 3D Systems ProX® DMP

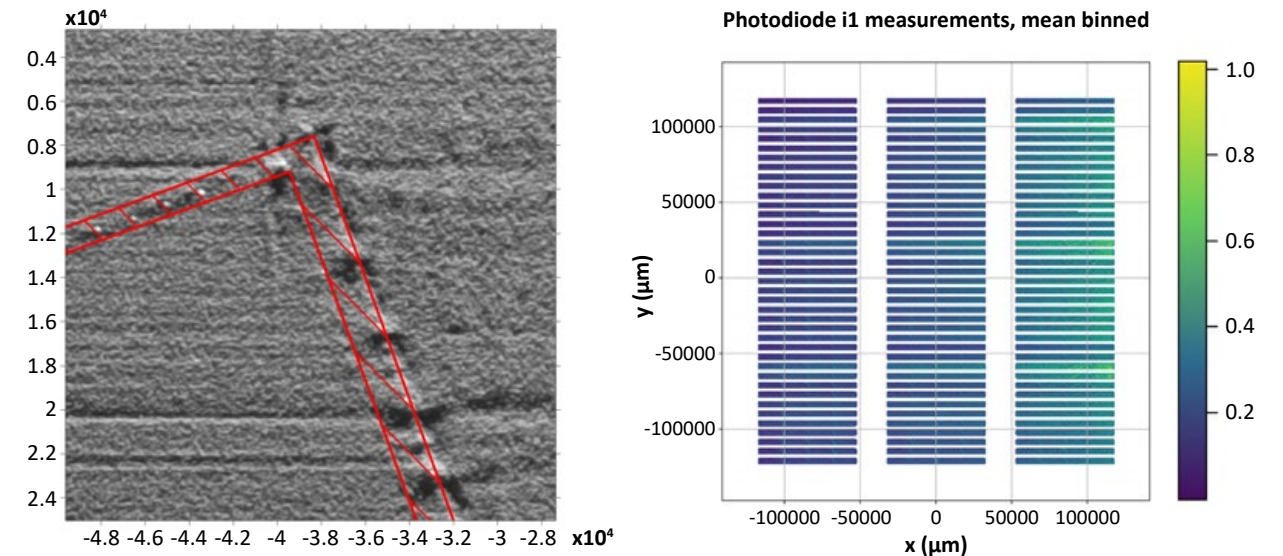


Fig. 6 Senvol ML's computer vision algorithm analyses high-resolution photographs of the build surface (left) and locates 'photodiode irregularities' (right) in the photodiode data

320 Laser Powder Bed Fusion machine. The machine that was used is located at Pennsylvania State University, which is Senvol's academic partner on its Phase II STTR with the Office of Naval Research (ONR). Each specimen was manufactured using one of thirteen different parameter sets and there were 117 specimens in total. Three process parameters were varied across the 117 specimens: laser power (five variations), scan speed (five variations), and hatch spacing (five variations).

The ProX DMP 320 is equipped with 3D Systems' DMP Monitoring, which incorporates two different in-situ monitoring systems, DMP Vision and DMP Meltpool. Jared Blecher, an engineer in 3D

Systems' Advanced Development Group, explains, "We integrated a high-resolution camera into DMP Vision to record images at each layer of the build surface, both before and after recoating. Then we supplemented these data with information gathered from the DMP Meltpool system, which is comprised of two off-axis photodiode sensors and collects data on the light intensity emitted from the build surface. Collectively these two streams of data provide a full picture of the build's characteristics."

The Senvol ML software is equipped with computer vision algorithms that analyse in-situ monitoring data in real time. In Fig. 6 (left), Senvol ML's computer

vision algorithm analyses high-resolution photographs of the build surface (from DMP Vision) to locate what it refers to as 'optical irregularities', such as hills, streaks or valleys. Similarly, in Fig. 6 (right), the algorithm locates 'photodiode irregularities' in the photodiode data (from DMP Meltpool).

Senvol's software also includes a computer vision algorithm that automatically detects defects in X-ray CT scans. These defects show up as dark spots (e.g., a pore) in an otherwise light-coloured area (e.g., solid part). For each voxel, the Senvol ML software looks at what happened in the preceding layers and learns the relationship between observed patterns and defect formation (or not).

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In Fig. 7, the top image shows raw data from an X-ray CT scan, with a defect (identified by a human) circled in red. The bottom left image shows the output from Senvol ML's computer vision algorithm, which automatically detected the defect in the X-ray CT scan (circled in red again).

To illustrate how the software works, a grid (orange) is overlaid on top of the image to divide it into voxels. The computer vision algorithm determines which voxels contain a defect and which voxels contain no defects (note: the grid is not to scale and is simply meant for illustrative purposes). The Navy intends to use this analysis to predict whether or not a defect will be observed in a given voxel based on the pattern of irregularities observed in the in-situ monitoring data. Over time, as the Navy trains the software with in-situ monitoring data, the software's predictions will be able to reduce, or possibly even eliminate, the need to use X-ray CT.

Allison Beese, Assistant Professor of Materials Science and Engineering and Mechanical Engineering at The Pennsylvania State University, and the school's Principal Investigator on its work for Senvol's STTR with the Navy, explained, "X-ray CT scans are relatively expensive to produce. By learning the relationships between in-situ monitoring data and X-ray CT scan data, the Navy may be able to reduce the amount of X-ray CT scanning that it does, which could lead to potentially significant cost savings."

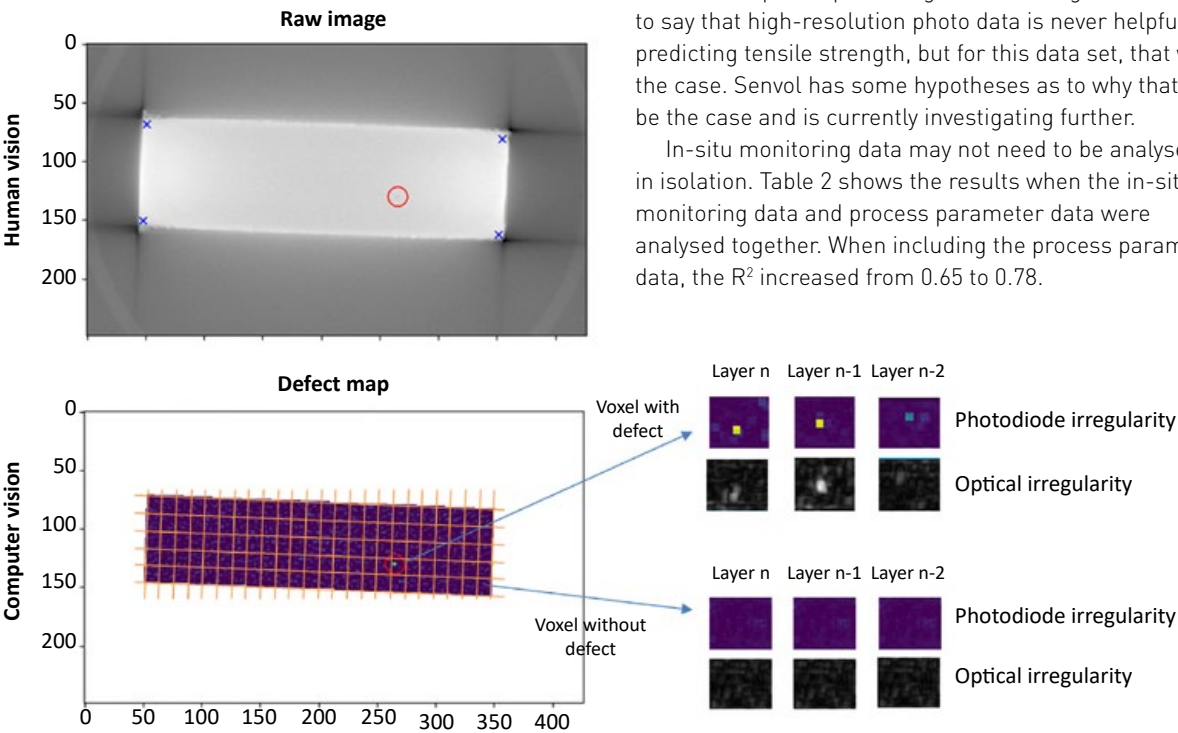


Fig. 7 The top image shows raw data from an X-ray CT scan, with a defect (identified by a human) circled in red. The bottom left image shows the output from Senvol ML's computer vision algorithm, which automatically detected the defect in the X-ray CT scan (circled in red again)

Predicting mechanical performance from in-situ monitoring data

Another use case of the Navy's is to predict mechanical performance from in-situ monitoring data. In one example, the Navy has tried to predict tensile strength. The training data used in this example was the same as for the previous example (stainless steel 316L specimens manufactured on a 3D Systems ProX DMP 320 machine).

The Senvol ML software analysed the in-situ monitoring data and showed the marginal contribution of each variable (see Table 1). In this case, there are four total photodiode irregularity variables (two features for each of the two photodiodes) and one optical irregularity variable.

Of particular note is that an R<sup>2</sup> of 0.65 was achieved using only the photodiode data (see second to last column on the right). When also including the optical irregularity variable (from the high-resolution photographs of the build surface), the R<sup>2</sup> remained at 0.65 (see last column on the right).

This highlights two interesting developments within Senvol ML. Firstly, the fact that the software was able to predict tensile strength with an R<sup>2</sup> of 0.65 based only on the photodiode data is surprising and positive. 0.65 is, in itself, not a particularly high R<sup>2</sup>; however, when it is considered that the analysis was based on data from only one sensor type and from only one build, this is quite remarkable. It can be presumed that as more data is fed into the software, the accuracy of the predictions will continue to increase.

Secondly, in this case the high-resolution photo data were not helpful in predicting tensile strength. This is not to say that high-resolution photo data is never helpful in predicting tensile strength, but for this data set, that was the case. Senvol has some hypotheses as to why that may be the case and is currently investigating further.

In-situ monitoring data may not need to be analysed in isolation. Table 2 shows the results when the in-situ monitoring data and process parameter data were analysed together. When including the process parameter data, the R<sup>2</sup> increased from 0.65 to 0.78.

Photodiode i1 Irregularity	1	0	0	0	0	1	0	1	0	1	1
Photodiode i1 median	0	1	0	0	0	1	0	0	1	1	1
Photodiode i2 Irregularity	0	0	1	0	0	0	1	1	0	1	1
Photodiode i2 median	0	0	0	1	0	0	1	0	1	1	1
Optical Irregularity	0	0	0	0	1	0	0	0	0	0	1
R <sup>2</sup>	0.258	0.057	0.165	0.002	-0.044	0.354	0.173	0.26	0.038	0.647	0.646
RMSE	8.957	10.1	9.499	10.39	10.63	8.356	9.456	8.946	10.2	6.18	6.186

Table 1 Analysis of the in-situ monitoring data showing the marginal contribution of each variable

Learning from previous data and transferring that learning to new AM machines and materials

When the Navy, or indeed any organisation, qualifies an Additive Manufacturing machine, it needs to generate a certain amount of data to do so. This is typically a substantial and expensive undertaking. What happens, though, if the machine gets a software update, which may or may

not make changes to the machine that the organisation is not aware of? Does the organisation need to regenerate the same amount of data in order to requalify the machine?

Using Senvol ML, the answer is no. Transfer learning is a concept that enables a user to transfer some of the learnings from a particular machine and material combination to a new, or unseen, machine and material combination. For example, let's say a company has been using a particular alloy on an EOS

machine and has generated a large body of data. If it then purchases a Concept Laser machine to run the same alloy, it does not need to start from scratch. Using Senvol ML's transfer learning capability, it is possible to apply some of the learnings that it already has from the data on the EOS machine to the Concept Laser machine. This speeds up development cycles and helps companies to reduce the amount of money that they need to spend generating data.

Laser power	0	0	0	0	0	0	0	0	0	0	0	1
Scan speed	0	0	0	0	0	0	0	0	0	0	0	1
Hatch spacing	0	0	0	0	0	0	0	0	0	0	0	1
Photodiode i1 irregularity	1	0	0	0	0	1	0	1	0	1	1	1
Photodiode i1 median	0	1	0	0	0	1	0	0	1	1	1	1
Photodiode i2 irregularity	0	0	1	0	0	0	1	1	0	1	1	1
Photodiode i2 median	0	0	0	1	0	0	1	0	1	1	1	1
Optical irregularity	0	0	0	0	1	0	0	0	0	0	1	1
R <sup>2</sup>	0.258	0.057	0.165	0.002	-0.044	0.354	0.173	0.26	0.038	0.647	0.646	0.781
RMSE	8.957	10.1	9.499	10.39	10.63	8.356	9.456	8.946	10.2	6.18	6.186	4.863

Table 2 The results when the in-situ monitoring data and process parameter data are analysed together. When including the process parameter data, the R<sup>2</sup> increases from 0.65 to 0.78



## Vision

Many companies and organisations have multiple sites with a range of different Additive Manufacturing machines. This is true for the Navy as well as for many manufacturing companies. Senvol's vision for its Senvol ML software is that an organisation will have one instance of the software such that the various sites and Additive Manufacturing machines within it are all contributing data to the software. As more data is generated across the organisation, the Senvol ML software will continually improve and the predictive reliability will continue to become more accurate. This is particularly beneficial because it will mean that everyone across an organisation will benefit from

their colleagues' data, regardless of whether or not they are located at the same site.

## Additional work

Senvol's use of its Senvol ML software is not confined to the Navy. The company also has projects underway with Oak Ridge National Laboratory (ORNL), the Defense Logistics Agency (DLA) and the National Institute of Standards and Technology (NIST). Additionally, it is currently running an Alpha programme with a select group of companies that have been provided early access to the Senvol ML software's capabilities. Any company or organisation interested in joining the Alpha programme is encouraged to contact Senvol directly.

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## Understanding build failures in Laser Powder Bed Fusion: An overview

Build failures remain a major challenge in metal Additive Manufacturing, particularly on large parts for which build times are measured in many days rather than hours. They come at a high price in lost machine time, wasted material and delayed deliveries. Olaf Diegel and Terry Wohlers explain a number of reasons for such failures in Laser Powder Bed Fusion processes. In many cases, one can reduce their risk through effective part and support design, parameter control and machine maintenance.

Contrary to much of the marketing hype of the past, it is not easy to make absolutely anything with AM. Producing good parts by AM requires a detailed understanding of the different processes and how to design for them. In fact, making parts by metal AM can be difficult and, in the majority of cases, using metal AM to manufacture parts should only be considered if the process adds value to the product. Every operator of metal AM systems knows that build failures are not uncommon, and learning how to predict and minimise them is a critical part of the process. To be able to do this, it is important to understand the causes of metal AM build failures. Also important is gaining an understanding of the strategies used to minimise the chance of failures.

### Part distortion

An estimated 70% of all metal AM failures occur from physical distortion of the part. These failures can occur from thermal stresses and distortion caused as the part distorts enough to

interfere with the recoater. Another cause are support structures, also referred to as anchors, when they are insufficient and detach from the part or build plate, allowing the part to rise and interfere with the recoater (Fig. 1).

In general, thermal and distortion-related failures affect the outcome in two ways: the distorted part breaks away from the support material during the build. It then rises enough to crash into the powder-spreading mechanism. If

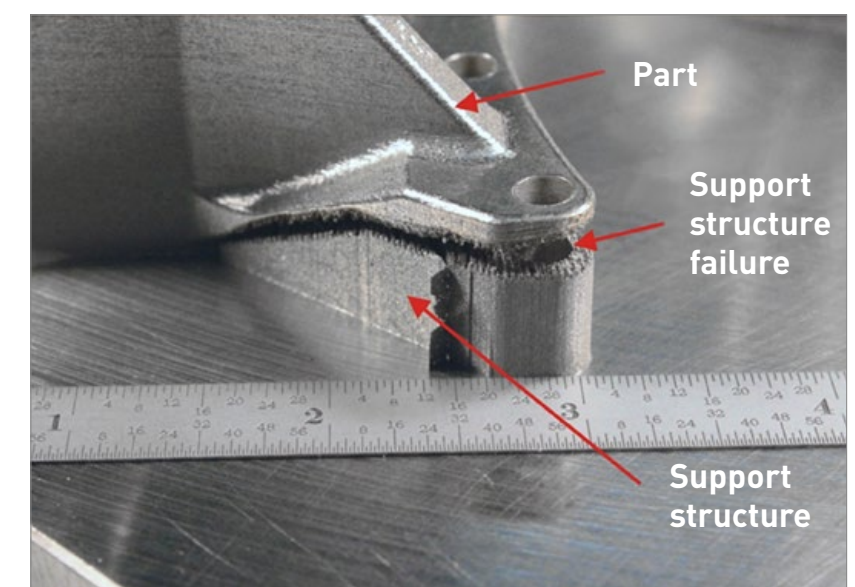


Fig. 1 Distortion example: this part exhibits support structure failure and excessive distortion [Courtesy Autodesk, as published in 'Distortion in metal Additive Manufacturing: Modelling and Mitigation', Metal AM Vol. 3 No. 1]





Fig. 2 A small chip in a recoater blade can cause multiple defects in the parts being produced

the mechanism uses a soft recoater blade (typically silicone, rubber, or carbon fibre brushes), the raised piece of the part can damage the blade, for example by creating a chip in it. In this case, the build may finish, but parts will have internal or external defects (Fig. 2).

### Part distortion considerations

Good Design for Additive Manufacturing (DfAM), machine operator experience and simulation software can help to avoid physical crashes.

### Part design can reduce build failures

The most common reason for distortion in a metal AM part is thermal stress, which results in part deformation. With good DfAM practices, it is possible to minimise the factors that cause significant thermal stress in the part. They include minimising large masses of mate-

rial, avoiding sudden changes in horizontal cross-sectional areas, and avoiding sharp internal corners.

### Operator experience

Experienced machine operators are intuitively aware of where high stress is likely to occur in a part. They can then add extra,

the build plate. Over time, operators also develop an innate feel for how best to orient the part to minimise crashes.

### Simulation

Many software products have become available for simulating the metal AM build process to predict stresses, distortion, and shrink lines. The software available is quite powerful and can save many builds from crashing by running a simulation in a specific orientation and showing where stress will occur. The operator can then reinforce these areas with extra support material. Some software products will automatically strengthen support structures. Others will also automatically suggest alternative build orientations, depending on factors such as build time, cost, and amount of necessary support material. A downside of most available simulation software is that it is relatively slow; a simulation can take from several hours to even days to run. As algorithms improve and computing power increases, however, simulation is sure to become a common tool at many organisations.

### Metal powder-related failures

#### Too little powder

Most metal powder bed fusion systems spread layers of metal powder. The powder feed system dispenses a

overflow bin, which means that slightly more powder is supplied by the feed system than is required to cover the platform. However, this is a fine balance. Dispensing too much powder per layer can deplete the powder supply before the end of the job, leading to an incomplete build. Too little powder per layer results in a short-feed situation, where the powder does not entirely cover the build platform. This can cause defects in areas where no powder is available for the energy beam to melt.

Today, this is managed by the operator carefully watching the job at the start of the build. This helps to ensure that the correct amount of powder is being supplied to adequately cover the build platform. Many metal AM systems now include an imaging system that takes a picture of each layer of the part. In the future, these imaging systems may analyse each layer and instruct the machine to take corrective action. In the case of a short-feed situation, the machine would simply repeat the powder-spreading procedure for that layer.

### Insufficient powder capacity in machine

As described previously, too much powder for each layer may result in an incomplete build. Strangely, some metal AM systems cannot hold enough powder in their supply hoppers to complete a full-height build job. They require the system to be paused and refilled before powder runs out. During such pauses, the build chamber and enclosed parts can cool. This can leave visible marks in the parts and alter material properties.

### Build platform distortion

A machine's build plate is a slab of a material of specific minimum thickness. It is made in an alloy that is compatible with the material being used. The plate is secured within the build chamber, coated with a layer of powder, and parts are grown upon it. If the build plate is not flat, it will result in an uneven coating of powder. This can produce weak points in areas where the powder is less fused to the build plate. The build may fail immediately, or later as thermal stresses tear weakened supports off the build plate.

The surface of the build plate must also be prepared to have the correct surface roughness. This is commonly done by hand with a sander or with a bead-blaster. If it is too smooth, the first layer of powder may not adequately coat the surface. If it is too rough, the powder may not form a smooth layer, with some being recessed into the rougher areas of the plate.

### Inert gas-related failures

All metal Powder Bed Fusion systems use inert gas, usually nitrogen or argon, or a vacuum during the build process. This gas management can, on occasion, be the source of build failures.

# AMAM

Association for  
**Metal Additive  
Manufacturing**

Guiding the future of  
the metal AM industry



### What Is AMAM?

The Association for Metal Additive Manufacturing (AMAM) is composed of companies that lead the direction of the metal additive manufacturing (AM) industry. It is one of six trade associations that comprise the Metal Powder Industries Federation (MPIF), the world's leading trade organization serving the interests of the metal powder producing and consuming industries.

### Why Join?

- ✓ Guide the future of the metal AM industry
- ✓ Interact with industry colleagues including competitors, suppliers, and more
- ✓ Create and maintain industry standards
- ✓ Market the industry to the public
- ✓ Develop activities such as publications and training

### Who Can Join?

- ✓ Manufacturers of metal AM components
- ✓ Metal AM raw material suppliers
- ✓ Equipment manufacturers and service providers that support metal AM

### How to Join

Visit [amamweb.org](http://amamweb.org) for a membership application and additional details on AMAM or contact Dora Schember at [dschember@mpif.org](mailto:dschember@mpif.org) or by calling 609-452-7700 x 110.



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*“Experienced machine operators are intuitively aware of where high stress is likely to occur in a part. They can then add extra, or stronger, support material to areas at risk to mitigate stress.”*

or stronger, support material to areas at-risk to mitigate stress. Additional support material can prevent parts from detaching from supports, or pulling supports off

certain amount of powder, which is spread across the build platform by a powder-spreading mechanism, usually consisting of a wiper blade or roller. Excess powder is swept into an



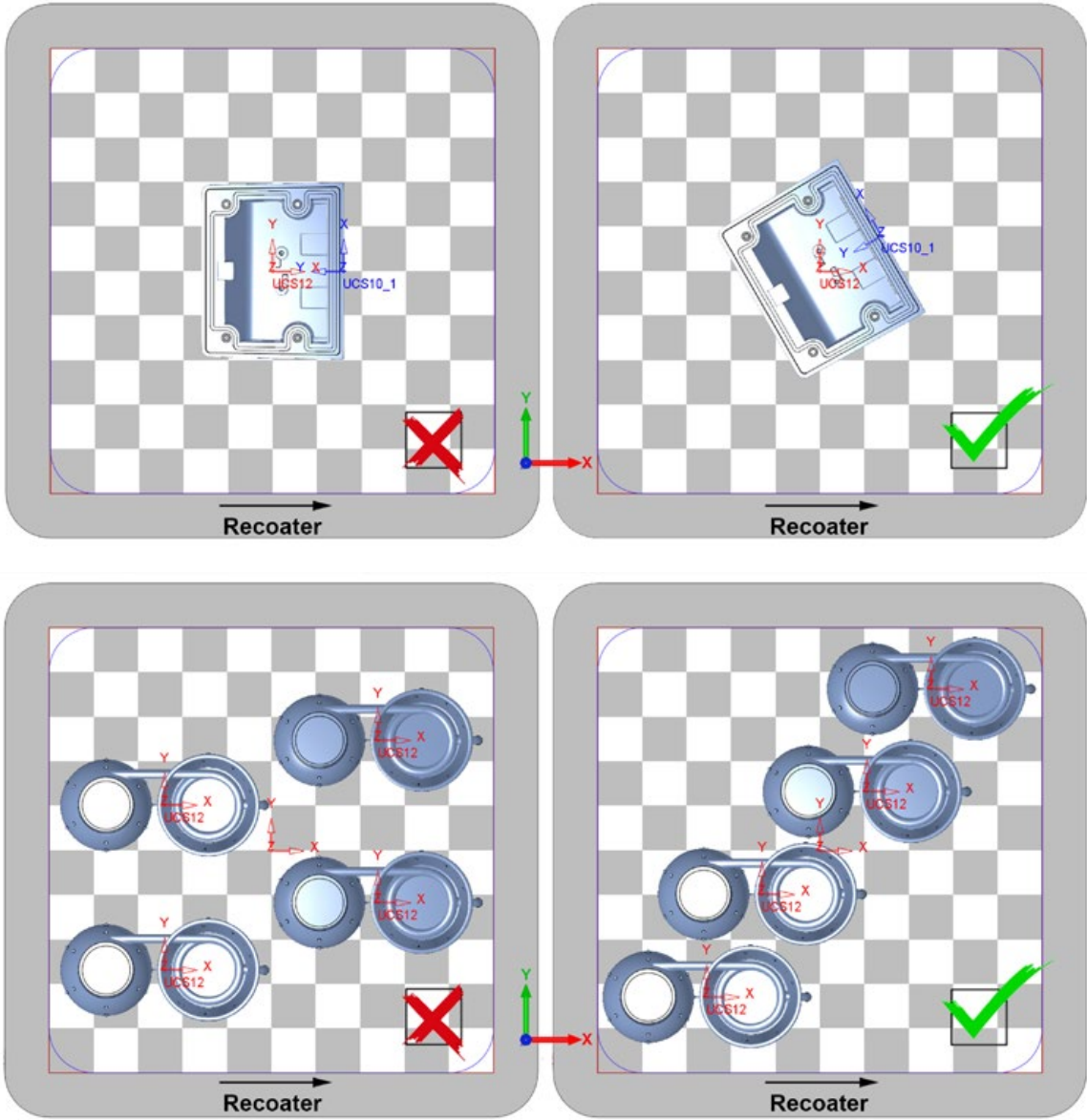


Fig. 3 These images show alternatives to positioning parts in a build chamber. It is important to reduce resistance to the recoater blade by not placing parts parallel to the blade because it can cause sudden resistance. It is much better to stagger multiple parts to prevent the recoater blade from reaching the parts at the same time

Gas supply failure

Enough gas must be available to supply the entire duration of the build. Most machines will pause the job if gas runs out, allowing the operator to switch gas supplies. This can still cause problems if the machine pauses while the operator is not present. If the system pauses for more than around five minutes, cooling of the built parts will cause visible shrink lines and potential mechanical defects in the part when the job resumes.

This is easily resolved through good gas-management practices. Many systems can be equipped with two separate gas supplies and an automatic changeover valve. This ensures that good gas supply continues while an empty cylinder is changed.

Condensation on laser window

As the machine is producing parts, small powder particles and other compounds are ejected from the melt pool. In a perfect world, these

particles are carried away and filtered out by the flow of inert gas above the build plate. However, not all of the condensate is removed by the gas flow, leaving the remainder to coat certain sections of the build chamber. If the laser window gets coated with the condensate, the energy beam is no longer transmitted at full power, and this can cause build failures.

Most manufacturers recommend cleaning the laser window before every build to minimise this.

Machine maintenance

With AM systems, cleanliness is next to holiness. A machine that is not cleaned between builds is prone to build failures. If residual powder is not vacuumed away after each build, it can attach to various moving parts of the machine. Rogue powder can later drop onto the build surface or be blown onto the laser window. All system manufacturers recommend a thorough cleaning of the machine after every build.

If the gas filter becomes clogged by condensate, the gas flow above the build platform becomes inadequate. This can cause the problem described earlier or cause the system to shut down due to a lack of gas. A good maintenance schedule for all filters in the AM system can dramatically reduce the risk of this problem.

Incorrect build parameters or part orientation

Build preparation software for metal AM is still far from being automated. Build jobs rely heavily on operator experience to set up the job in the best way. The ‘best way’ is also subjective because it depends on many factors, such as the shortest possible build time, best surface quality and least amount of support material. The operator is required to determine many crucial build parameters, which include part orientation, support structure type and location, and optimum laser scan strategies. All of these parameters are currently based as much on intuition and experience as they are on science.

Good DfAM training and experience are currently the only remedies for this. In the future, as software improves and becomes more automated, these build failures will decline.

Power failure

Electrical interruption can cause major problems for AM facilities, as with most manufacturing operations. Even micro power failures, lasting only a fraction of a second, can disrupt days worth of production and result in poor quality, scrap, and missed shipments. Areas with unstable power supply can experience crippling reliability issues with AM systems.

One solution to this problem is to install an Uninterruptible Power Supply (UPS) to protect your AM systems. A UPS is generally used as a way of ensuring a continuous supply of quality power to the AM systems. A UPS can prevent brown-outs, spikes and other power fluctuations from killing the computer running the machine.

A UPS is not a true power backup system, which is often impractical for metal AM systems. This is because metal AM systems use lot of power; many are equipped with lasers that draw hundreds or thousands of watts of electricity. Most UPSs cannot supply this level of power for more than a few minutes. If a metal AM system is paused for more than about five minutes, the part will often experience inconsistencies that make it unusable.

Conclusions

The risk of build failures can be minimised through relatively simple preventive measures. As AM system software improves and simulation software becomes faster and easier to use, build failures are likely to decline. In the meantime, be aware of the three keys to ensuring good performance of metal AM systems. They are having:

- A good knowledge of design for AM
- An intimate understanding of how a machine behaves
- A devotion to keeping the machine pristinely clean.

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## MAMC2018: Vienna hosts ASMET's third Metal Additive Manufacturing Conference

The third Metal Additive Manufacturing Conference (MAMC2018), organised by the Austrian Society for Metallurgy and Materials (ASMET) and voestalpine, took place in Vienna, Austria, from November 21–23, 2018. The event, which attracted an international audience, covered a broad range of metal AM technologies and considered the technical challenges that need to be overcome to make the industry more economically competitive with conventional manufacturing. Prof Dr Bruno Buchmayr, Dr Bruno Hribernik, Dipl.-Ing Gerhard Panzl and Prof Dr Jürgen Stampfl review the event for *Metal AM* magazine.

The third Metal Additive Manufacturing Conference (MAMC2018), organised by the Austrian Society for Metallurgy and Materials (ASMET), Leoben, Austria, and voestalpine, Linz, Austria, saw more than 220 international participants meet in Vienna, Austria, from November 21–23, 2018, to discuss current topics relating to metal AM. The event's growth, up from 150 participants at MAMC2014, clearly reflects the growing interest in this field. The MAMC2018 conference programme saw forty-six oral presentations given on topics relating to recent developments in materials, processes, applications and business in the metal Additive Manufacturing industry. In addition, a co-located exhibition showcased many of the most recent industrial developments in the field.

The worldwide market for AM-related products and services has seen significant growth in the past year, with overall revenues growing to \$7.5 billion according to *The Wohlers Report*. Of specific interest is the significant increase in

the number of metal AM machines sold. As reported by Wohlers, sales grew from 980 machines in 2016 to over 1,750 systems in 2017. Since such systems are typically used in industrial settings, this increase is an encouraging sign of the industrial uptake of the technology.

The continued development of AM within the Austrian market was demonstrated in the first plenary talk at MAMC2018. In their talk, 'Challenges of Additive Manufacturing in High Performance Markets,' Stefan Seidel, Managing Director, Pankl Racing Systems, and Dr Michael



Fig. 1 More than 220 international participants met in Vienna, Austria, from November 21–23, 2018 for the MAMC2018 conference



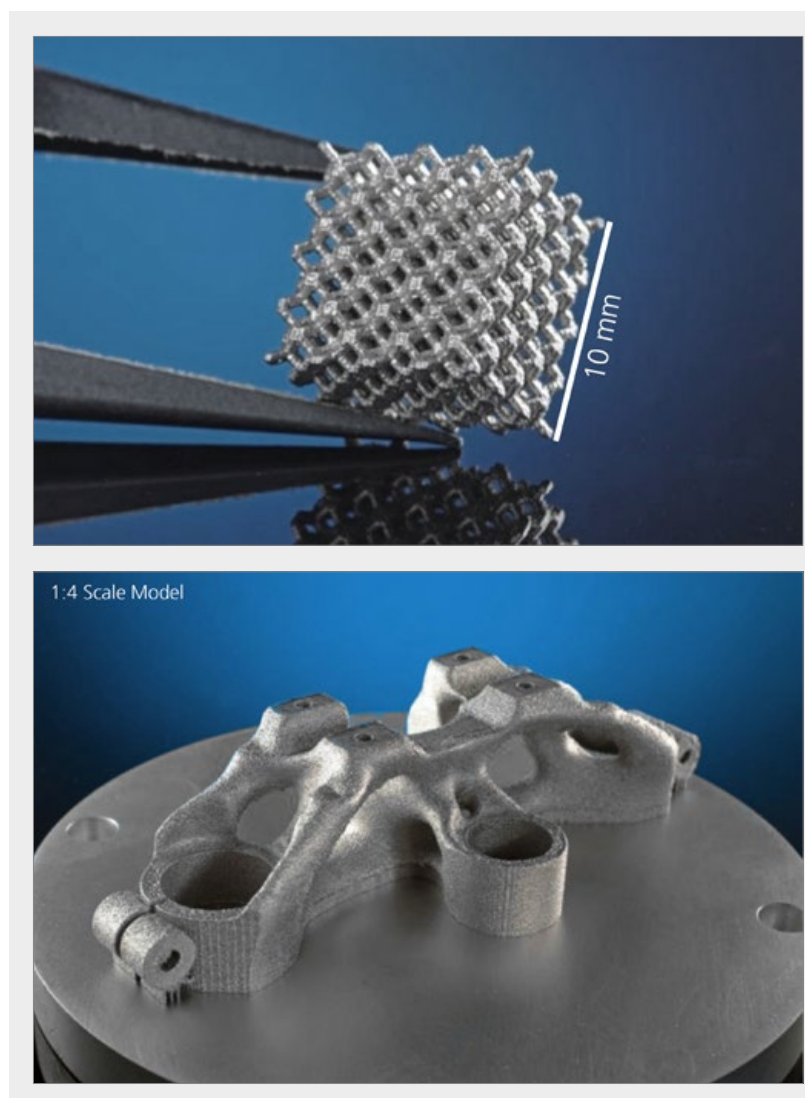


Fig. 2 Magnesium parts made by AM (Courtesy Fraunhofer ILT)

Rotpart, member of the management board of voestalpine Böhler Edelstahl, gave an insight into the integration of AM in an industrial setting. Pankl and voestalpine both see significant benefits in the use of metal AM for high-value added products in fields like aerospace, mechanical engineering and energy.

The companies are currently involved in a cooperation based out of the Pankl Additive Manufacturing Competence Center (PAMCC) in Kapfenberg, Austria, which looks to develop the complete value chain and push the limits of Additive Manufacturing in order to establish the technology as an effective production method within the challenging fields of aerospace and high-performance

automotive. The speakers brought up critical issues for these fields which need to be targeted if AM is to become a reliable and widely-used industrial production solution, such as the requirement for 'zero failure tolerance' in critical applications.

### Metal AM process developments

#### Optimising existing processes

A number of metal AM processes were covered during the conference, with the widest-used being Laser Powder Bed Fusion (L-PBF). Prof Bruno Buchmayr, formerly Head of the Chair of Metal Forming at Montanuniversität Leoben, presented

the 'Results and conclusions on metallic materials made by AM within the Austrian leader project "addmanu"'. The project, sponsored by The Austrian Research Promotion Agency (FFG), ran over a period of three years from 2015–2018 and involved more than twenty research partners. It incorporated aspects of the design, processing and applications of additively manufactured metal, polymer, ceramic and hybrid material components.

Focusing on metal AM, Buchmayr presented the project's conclusions on new powder materials, hybrids, topology optimisation, joints between dissimilar materials, the fabrication of small channels and surface modifications using AM. Regarding potential application fields, demonstrator examples were shown for mechanical engineering, injection moulding tools, lightweight automotive components, nozzles for aerospace technology and composites with special properties produced for satellites. Those materials evaluated by the project are now being commercialised by voestalpine Böhler Edelstahl, and the project team was also said to have demonstrated that high-performance metals, such as hybrid systems with high thermal conductivity, can be processed by L-PBF.

In a talk titled 'Digital photonic production along the lines of Industry 4.0,' Prof Dr Reinhart Poprawe, Fraunhofer Institute for Laser Technology (ILT), Aachen, Germany, pointed to the importance of throughput, process control and cost-effectiveness for the further development of the field, stating that processes such as Laser Metal Deposition (LMD) and multi-beam L-PBF will play an important role in this context. In addition, Poprawe noted the importance of material innovations for the further development of metal AM (Fig. 2).

Richard Görgl, Joanneum Research, Niklasdorf, Austria, focused on 'LMD as a complementary technology to Selective Laser Melting (SLM).' Because LMD is, in principle, a welding process, it was stated that parts manufactured

using the technology have high hardness, density, Young's modulus, etc. Görgl looked at the technology's applications and capabilities in laser cladding, repairing and reshaping and Additive Manufacturing, comparing the strengths and limitations of the technology against those of L-PBF for component production.

Fused Filament Fabrication (FFF) was addressed by Dr Christian Kukla, from Montanuniversität Leoben's Industrial Liaison Department, in his presentation 'Material extrusion with filaments for the production of metal parts and feedstock.' FFF can be used to shape parts with feedstocks similar to those used in Powder Injection Moulding (PIM), resulting in the production of green parts which must be debound and sintered. The use of filaments imposes a strict set of requirements on the feedstock, such as the flexibility to be spooled, stiffness to avoid buckling and a constant diameter to ensure a consistent mass flow. However, it also enables the use of a wide range of metal powders, which are already available in the market, and employs the already established and standardised process of sintering, resulting in a homogeneous microstructure. During his presentation, Kukla offered his insight into the available powders, feedstocks, equipment and respective processing parameters for FFF, along with a number of examples of part shrinkage rates, densities, surface quality and other mechanical properties.

#### Developing new processes

Looking at the development of new processes, Dr Michael Kitzmantel of RHP-Technology GmbH, Seibersdorf, Austria, introduced 'XL multi-material AM using an economic blown powder process,' in which a plasma transferred arc system is used as a heat source in combination with powder feeding for the production of parts. Kitzmantel offered examples of how the technology can be used to manufacture parts from different materials, such as titanium alloys, iron-based alloys and nickel-based alloys, and the capability of the



Fig. 3 Metallic green parts manufactured by LMM (Courtesy Lithoz)

technology to produce multi-material components and gradient structures when two powder feeders are used simultaneously.

Gerald Mitteramskogler, Lithoz GmbH, Vienna, Austria, presented the first results achieved with a new process known as Lithography-based Metal Manufacturing (LMM), in which a photopolymer filled with metallic particles is selectively cured with a light engine based on digital light processing (Figs. 3-4). In his paper, 'Lithography-based Additive Manufacturing of functional metal components,' Mitteramskogler compared LMM to Metal Injection Moulding (MIM), in that both technologies require debinding and sintering in the green state and achieve similar relative densities (up to 98.5%). Mitteramskogler stated that LMM enables the production of highly complex parts in 316L, to good geometrical accuracy and with a very low surface roughness, resulting in mechanical properties comparable to conventionally manufactured 316L.



Fig. 4 Internal detail of the design shown in Fig. 3 (Courtesy Lithoz)

#### Post-processing of AM parts

Methods for post-processing and quality assurance were also discussed in detail during the conference. In a paper titled 'Surface engineering for parts made by Additive Manufacturing', Markus Hatzenbichler, Fotec, Vienna, offered insight into the surface engineering



of stainless steel and titanium parts produced by L-PBF and Electron Beam Melting (EBM), demonstrating that surface properties such as roughness can have a significant influence on the mechanical properties of a part, especially when parts are loaded dynamically.

For the L-PBF process, AlSi10Mg, SS316L and Ti64 powder were used on an EOS M280 machine and, for the EBM process, only Ti64 powder was used on an Arcam Q20 machine. In general, the 'as-built' surface roughness of AM parts is rather high compared to conventional milled parts and, due to the powder bed process, semi-molten particles are always attached on the side surface. In this project, various (abrasive or coating) surface treatment technologies like shot peening, (electro-) chemical polishing or anodisation were applied and analysed in order to make a proposal for the most promising surface finishing scenarios, consisting of different treatments.

Lowering the surface roughness was not the only important aim; other issues, such as the geometry of the sample, surface quality in terms of particles and cracks or similar roughness on the top and side surfaces, have to be considered in space applications. To determine the impact of the chosen surface finishing scenarios, SEM images of the surfaces were taken and mechanical properties such as tensile strength and fatigue of the 'as-built' and surface treated parts were measured and compared. Furthermore, the stress corrosion cracking behaviour was analysed.

### Developments in metallurgy for AM

To be successful in their application, metal AM parts must possess comparable mechanical and technological properties to conventionally fabricated components. Achieving these properties involves the whole

process chain, from powder production to post-processing. A number of the presentations given at MAMC2018 addressed these topics, from powder production and characterisation to process optimisation and control, as well as the development of new alloys.

Speaking on 'The application of powder rheology for AM powders', Gerhard Panzl, Montanuniversität Leoben, looked at the impact of feedstock properties on L-PBF process control and part quality and the important role played by powder rheology in understanding the behaviour of new and recycled metal powders. Since the costs of powder materials are a significant factor in the economic viability of AM components, powder recycling strategies are an important opportunity to enhance the economic efficiency of the process. However, recycling strategies can have a considerable influence on the characteristics and behaviour of metal powders. In his talk, Panzl investigated the use of powder rheology methods including

the pressure drop method, weighted cohesion strength measurements and tensile strength measurements to predict the behaviour of metal powders in powder bed-based AM processes.

It is widely accepted that steel grades with high hardness levels are difficult to process in powder bed-based fabrication technologies. Fengchen Xia and Liang Wu, voestalpine Additive Manufacturing Center, Düsseldorf, Germany, and Jasmin Saewe, Fraunhofer ILT, Aachen, Germany, each offered insights into their work with high-grade tool steels and the possibility to create crack-free samples. In his talk, 'On the formation of process-induced defects in H13 processed by laser beam melting', Xia addressed the potential of H13 in AM due to its high thermo-fatigue and crack resistance. By presenting a detailed discussion on the processing conditions which can lead to pores, cracks and lack of fusion in L-PBF-processed H13, and theoretical models on the effect and optimisation strategies derived from an understanding of these conditions, Xia hoped to contribute to the development of effective guidelines for the robust processing of H13 by AM.

In his presentation, 'Laser beam melting of H13 tool steel', Wu detailed a comprehensive parameter investigation by which appropriate laser parameters were identified for the L-PBF of H13. In addition, he presented an evaluation of the material's microstructure under different heat treatment conditions, focusing in particular on phases and defects at all length scales, from macro to nanoscale, and the corresponding mechanical properties. Using simulations, the mutual relationship between chemical composition, process conditions, microstructural and mechanical properties was discussed and clarified. In the future, Wu stated that these experimentally confirmed parameters should be valid for the AM of components in H13 by L-PBF, and can be implemented for a simulation model allowing for the prediction of laser parameters for new combinations of alloys.

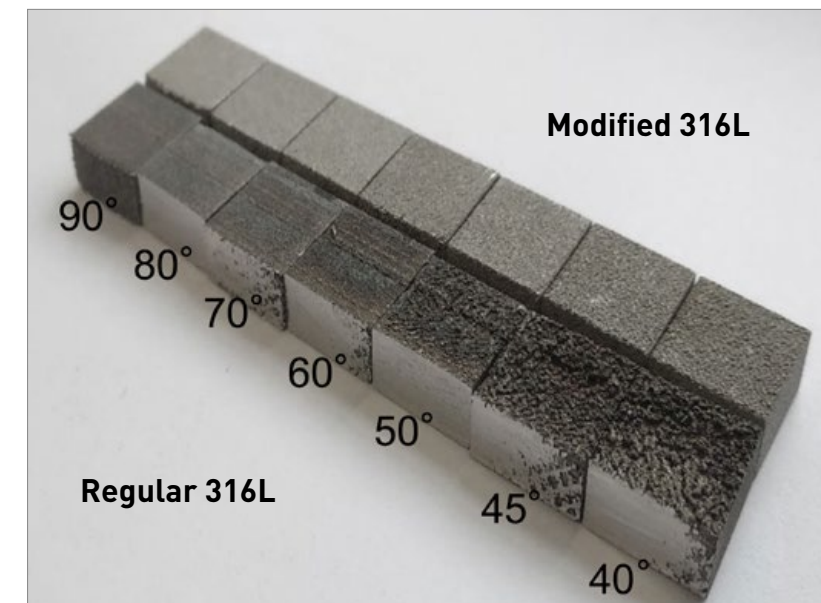


Fig. 5 Improving the downskin surface quality of stainless steel 316L (Courtesy M Skalon, TU Graz)

In Jasmin Saewe's presentation, 'Feasibility investigation for Laser Powder Bed Fusion of high-speed steel AISI M50 with base plate preheating system', she sought to demonstrate that the L-PBF of dense, crack-free parts with a hardness over 60 HRC (as-built), from high speed steels (with a carbon content higher than 0.5 wt.-%) is possible. In addition, the influence of typical L-PBF process parameters – in particular, preheating temperature – on the microstructure of the part was evaluated. Jochen Giedenbacher, of the University of Applied Science Upper Austria, also discussed how preheating of the substrate plate or the build chamber influences the build job and the final component in his presentation, 'Investigations on the microstructure and mechanical properties of gas atomised hot work tool steels manufactured by Selective Laser Melting using powder bed preheating.'

Looking to more familiar materials, Vincent Vignal, Laboratoire Interdisciplinaire Carnot de Bourgogne; Alex Lanzutti and Francesco Andreatta, University of Udine; Mateusz Skalon, Technische Universität Graz; and Quentin Portella, ICD-LASMIS/University of Technology of Troyes, looked

at optimisation procedures which can help to extend the fields of application of 316L stainless steel. Vignal investigated the microstructure, passivity and corrosion behaviour of the material when manufactured by L-PBF, while Lanzutti looked at the high-temperature tribological behaviour of L-PBF-processed 316L parts. Andreatta investigated the material's corrosion behaviour, comparing AISI 316L stainless steel produced by AM against wrought AISI 316L, finding that the AM material presents a dual phase microstructure, as well as the presence of small defects, which affect its corrosion behaviour. Skalon presented a paper on the influence of increasing inclination angle on the surface quality of the downskin of cubic samples produced by L-PBF in 316L (Fig. 5). A balling phenomenon was quantified and compared using the roughness test, and was found to be dependent on the inclination angle.

Besides the research and optimisation of known materials presented throughout the conference, a number of presentations looked at the development of new alloys. Horst Zunko, voestalpine Böhler Edelstahl, Kapfenberg, Austria, gave insight on the

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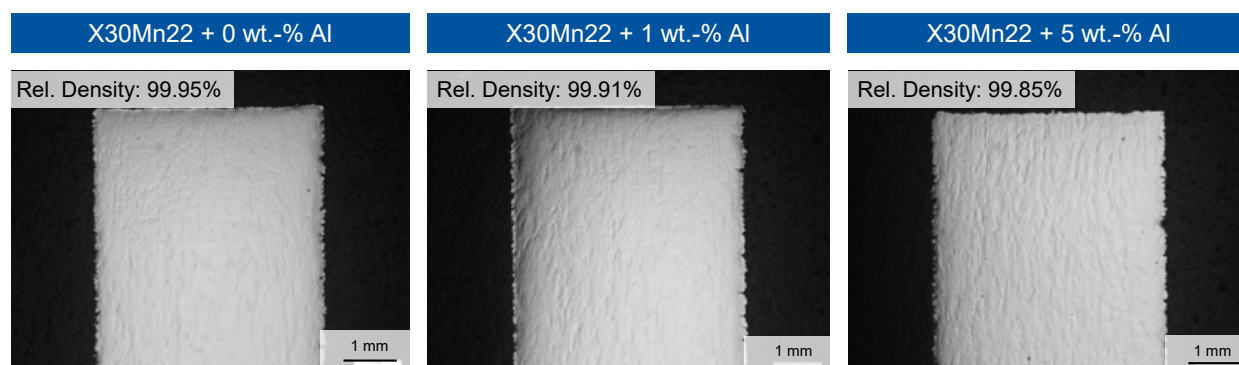


Fig. 6 Test specimen of AHSS steels with different Al-content produced by L-PBF (Courtesy S Ewald, RWTH Aachen)

development strategy for advanced maraging steels, investigating the typical powder characteristics and microstructure of a number of materials in this category, and Michael Görtler, Joanneum Research, Graz, Austria, discussed the manufacturing of NdFeB permanent magnetic alloys by L-PBF, which could enable cost-efficient batch production of powerful magnets with customisable stray field distributions and enhanced functionalities, such as cooling channels for applications in high-temperature environments.

Drawing on the proven success of the L-PBF as a suitable production technology for medical implants, Maximilian Voshage provided

tion was influenced by dry mixing of alloying elements to a base alloy, it is possible to adjust the stacking fault energy (SFE) for tailored mechanical properties when producing parts by L-PBF, overcoming some of the shortcomings related to conventional processing of high-manganese steels (Fig. 6).

### Applications, design and business models for AM

#### Industrial

From an industrial perspective, the suitability of an application for Additive Manufacturing is highly dependent on the economic and/or technical benefits offered by the

position of metal AM, as well as different types of generative design concepts such as form synthesis, topology optimisation and lattice and surface optimisation. The use of AM for both low- and high-volume part production was also addressed, with a particular focus on the use of L-PBF to produce tools and dies for the engineering, automotive and furniture industries at high volumes, reducing product lead times and costs significantly.

#### Biomedical

In his paper titled 'Additive Manufacturing for digital dentistry', Jurgen Stampfl, TU Wien, compared metals, ceramics and polymers with regard to their relevance in the expanding field of digital dentistry. Applications such as orthodontics, restorative dentistry and implants, where personalised and highly aesthetic parts are demanded, are one of the key driving factors behind the uptake of AM in biomedical applications. This presentation focused in particular on the processing and characterisation of the relevant materials and provided a comparison of the most relevant AM technologies (stereolithography, L-PBF and inkjet printing) in terms of the quality and mechanical properties of the produced parts, mechanical properties of the finished parts, throughput and cost-per-part.

Innovations in material development are another driver behind the suitability of metal AM for

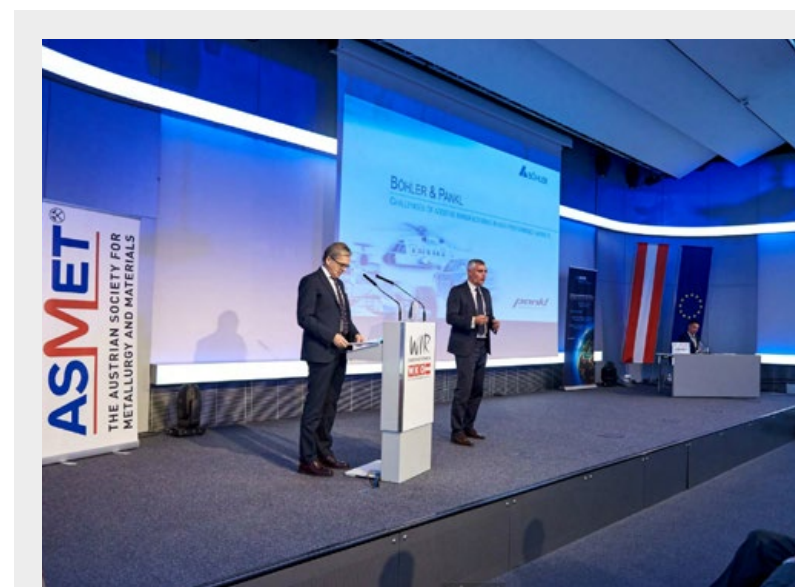
biomedical applications and, in a presentation titled 'Formation quality, mechanical properties and processing behaviour of pure zinc (Zn) metal parts produced by laser based manufacturing for biodegradable implants,' Maximilian Voshage, RWTH Aachen, presented recent results achieved using biodegradable metals (zinc alloys) for metal additively manufactured medical implants.

According to Voshage, recent studies have shown that Zn-based metals exhibit potential for biodegradable medical implants due to the beneficial combination of biocompatibility, biodegradation rate and mechanical properties. However, only a few recent reports are available on the Additive Manufacturing of Zn and each shows that either the obtained density is too low, or the process window is quite narrow due to excessive evaporation.

Voshage's paper aimed to clarify the effect of processing parameters on densification during the Laser Powder Bed Fusion (L-PBF) of pure Zn and the method by which a high density can be obtained in a reasonable process window. The final average values of hardness, elastic modulus, yield strength, ultimate strength and elongation in the pure zinc AM part were measured as 42 HV, 23 GPa, 114 MPa, 140 MPa and 10.1% respectively, with density over 99.9%.

#### Design for lightweighting

Another key application area in which AM offers a considerable advantage is in the lightweighting of components and structures. In his presentation, 'Additive Manufacturing of microlattice structures at the resolution limit of the Selective Laser Melting process,' Michael Görtler, Joanneum Research, discussed the possibilities and limitations for the fabrication of microlattice structures for lightweight applications. The production of parts with integrated lattice structures is one of the key methods by which lightweight parts



The MAMC2018 conference featured a small exhibition as well as more than forty technical presentations

*“From an industrial perspective, the suitability of an application for Additive Manufacturing is highly dependent on the economic and/or technical benefits offered by the technology in comparison to traditional manufacturing.”*

information on the development of biodegradable implants made of pure zinc, detailed later in this report. Simon Ewald, RWTH Aachen University, demonstrated that for Advanced High Strength Steels (AHSS), where the powder composi-

technology in comparison to traditional manufacturing. Nader Asnafi, of Örebro University, presented '3D metal printing from an industrial perspective – product design, production and business models.' This paper summarised the current



can be produced, and can also significantly enhance the functional properties of a part, for example by encouraging bone ingrowth in medical implants.

Depending on the required load bearing efficiency and desired stiffness, the production of very thin struts and small unit cells can be necessary. However, microlattices with defined strut diameters below 300 µm cannot be produced by industrial L-PBF machines by default. To manufacture very thin microlattice structures, parameter studies have to be performed in advance and design rules must be followed.

Görtler presented the preliminary stages of microlattice fabrication on a commercial EOS M280 L-PBF machine and described the manufacturability of lattice strut elements for varying inclination angles and diameters. In the study, CAD rules were given based on the identified limits of the technology, enabling the manufacture of L-PBF compatible lattices with optimised parameters. Görtler and his team then compared the relative densities of the fabricated lattice structures against the CAD data and measured the mechanical properties of the structures using compression tests.

### Conclusion

When compared to MAMC2014 and 2016, it is clear from the content of the technical programme in 2018 that significant progress has been made by the AM industry with regard to materials, the overall understanding of the AM process and the exploitation of new application areas using the technology's unique capabilities.

While the majority of AM processes remain less economical than conventional production methods, and might struggle to compete in high-volume industrial manufacturing, for lightweight, highly-designed applications such as those in the aerospace and space sectors, there can be a clear argument for the use of metal AM, which offers outstanding solutions for lightweight constructions with design features that would not be achievable by conventional manufacturing.

Furthermore, a growing recognition of the full process chain can be seen across the conference programme, with a number of presentations focusing on multiple points across the Additive Manufacturing process chain, from the initial material development to the final stages of post-processing. As the industry develops its ability to optimise and control the AM process at every step, it becomes possible to meet ever more challenging design criteria, such as strict requirements on the surface quality of parts for space flight. With such capabilities frequently exceeding those achievable by conventional manufacturing methods, AM continues to strengthen its position to exploit new and diverse applications.

The development of new, economical technologies such as those discussed during MAMC2018 also offers a route by which metal AM can become economically competitive with conventional manufacturing. While such technologies are not yet commercially available, it can be expected that the lower cost, and thus lower barrier to entry, will increase metal Additive Manufacturing adoption rates in a wider industrial context.

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### Proceedings

Details of the presentations can be found in the conference proceedings, which can be ordered from the ASMET secretariat (Yvonne.Dworak@asmet.at).

### MAMC2019

ASMET will hold the fourth Metal Additive Manufacturing Conference (MAMC2019) in Örebro, Sweden, from November 25–27, 2019.

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## Euro PM2018: The processing and properties of additively manufactured aluminium alloys

A technical session at the Euro PM2018 congress, organised by the European Powder Metallurgy Association (EPMA) and held in Bilbao, Spain, October 14–18, 2018, specifically addressed the processing and achievable properties of aluminium alloy parts built by Additive Manufacturing. In the following report, Dr David Whittaker reviews the four papers presented in this session.



### Effects of Si content on densification and properties of Al-Si alloys processed by Selective Laser Melting

The first paper, from Takahiro Kimura and Takayuki Nakamoto (Osaka Research Institute of Industrial Science and Technology, Japan) and Kazuki Sugita, Masataka Mizuno and Hideki Araki (Osaka University, Japan), investigated the effects of silicon content on the densification and properties of Al-Si alloys processed by Selective Laser Melting (SLM), otherwise known as Laser Powder Bed Fusion (L-PBF) [1].

L-PBF with aluminium alloy powders is attracting attention as a manufacturing method for lightweight components and thermal control parts (heat exchangers, heat sinks) for aerospace, machinery and automotive applications, taking advantage of their low density and/or high thermal conductivity. However, the effects of alloy elements on the processability and properties of aluminium L-PBF materials have not been thoroughly understood. It is well known that Si,

one of the main alloying elements in aluminium casting alloys, can strongly affect both the flowability of the melt and mechanical properties of cast materials. Based on this knowledge, the authors have proposed the hypothesis that the Si content in Al-Si L-PBF materials may have significant effects on densification behaviour during the L-PBF process and on the

properties of the materials. However, systematic studies on the effects of Si content in Al-Si L-PBF materials have rarely been reported.

In the reported study, the effects of Si content on the relative density, microstructure and mechanical and thermal properties of Al-Si binary alloys processed by L-PBF were systematically investigated.



Fig. 1 The Euro PM congress series has become a leading technical event for metal AM researchers (Photo © Andrew McLeish / Euro PM2018)



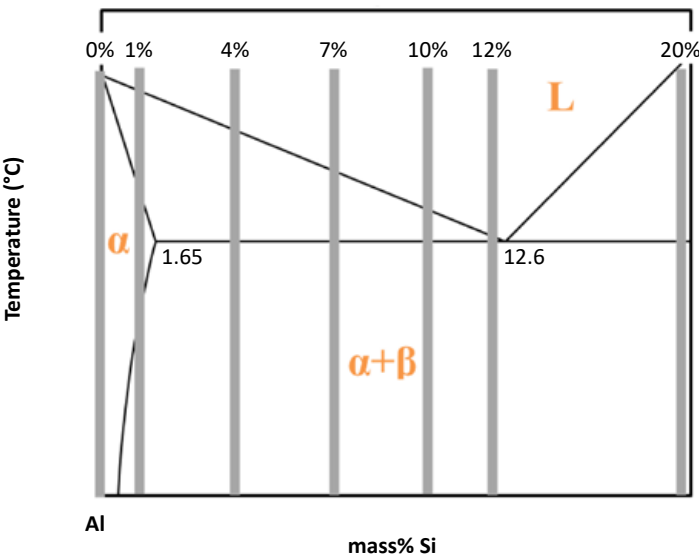


Fig. 2 Chemical composition of the Al-xSi powders on a schematic Al-Si binary phase diagram [1]

The aluminium powders used in the study were Al-xSi (x = 0, 1, 4, 7, 10, 12, and 20 mass%) alloy powders. As shown in Fig. 2, these powders were of solid solution (x = 0, 1), hypo-eutectic (x = 4-10), near-eutectic (x = 12) and hyper-eutectic (x = 20) compositions in the Al-Si binary alloy system. All the powders had almost the same particle diameter distribution and similar spherical morphologies. An L-PBF machine, the EOSINT M280, having a 400 W class ytterbium fibre laser with a beam diameter of approximately 0.1 mm, was used to

fabricate the L-PBF specimens. The preheating temperature of the base plates was 35°C. Optimum laser scan parameters for each Al-xSi powder were obtained by changing the values of the laser power, scan velocity and scan distance (interval between laser scan lines) at a fixed layer thickness of 0.03 mm. The L-PBF specimens were cylindrically shaped (diameter: 8 mm, length: 15 mm). The optimum laser scan parameters were defined as the conditions under which the highest density could be obtained. Table 1

Specimen	Power (W)	Scan velocity (mm/s)	Scan distance (mm)
Al-0Si	370	1600	0.1
Al-1Si	200	600	0.1
Al-4Si	250	1200	0.08
Al-7Si	250	1600	0.1
Al-10Si	300	2000	0.08
Al-12Si	250	1800	0.1
Al-20Si	250	2000	0.08

Table 1 Optimum laser scan parameters for each Al-xSi powder [1]

shows the optimum laser scan parameters for each Al-xSi alloy. From optical microscopy assessments, it was determined that the Al-0Si (industrial pure aluminium), Al-4Si, Al-7Si, Al-10Si, Al-12Si and Al-20Si L-PBF specimens contained no defects. However, micro-cracks were generated along the stacking direction in the Al-1Si L-PBF specimen. The relative density values of the Al-0, 4-20Si L-PBF specimens were almost 100%. On the other hand, the relative density of the Al-1Si L-PBF specimen was lower (at approximately 97%) due to the micro-cracks. To investigate the mechanism behind the generation of the micro-cracks, verification experiments were conducted. A single bead, formed by a single-line laser scan of an Al-1Si powder layer with a thickness of 0.05 mm, was deposited. A few cracks were observed, regardless of laser scan parameters. This suggested that the cracks were generated in the single bead state, meaning extremely brittle characteristics of the Al-1Si melt during the laser melting process. Fig. 3 shows an IPF (inverse pole figure) map of a vertical plane of the Al-1Si L-PBF specimen, analysed by EBSD. It is important to note that the cracks occurred along the grain boundaries and the crystallographic directions on either side of the cracks were different. The fracture surface of a vertical tensile L-PBF specimen of

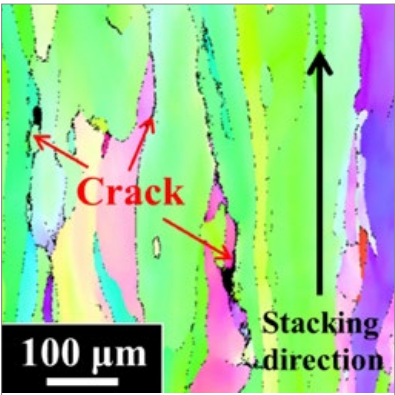


Fig. 3 IPF map of a vertical plane of the Al-1Si L-PBF specimen analysed by EBSD [1]

the Al-1Si alloy showed an equiaxed solidified microstructure with grain sizes smaller than 200 μm. These results show that the cracks were generated before the solidification was complete (i.e., during crystal growth in the solid-liquid co-existing state). From these verification results, the authors concluded that the micro-cracks found in the Al-1Si L-PBF specimen were solidification cracks, which were formed due to thermally induced tensile stresses caused by local heating (thermal gradient) from the laser irradiation, i.e., the solidification cracks in the Al-1Si L-PBF specimen were generated when the thermally induced tensile stresses and/or strain exceeded the tensile strength and/or elongation of the Al-1Si alloy melt, which had the brittle characteristics in the solid-liquid co-existing state. Additionally, due to the low flowability of the Al-1Si melt, there was no possibility of cracks healing by liquid infiltration. Optical microscopy also showed that all the Al-xSi L-PBF specimens had a semi-circular macrostructure on the vertical planes. The size and shape suggested that the macrostructure was of laser traces surrounded by solidification boundaries. From SEM images, it was noted that the microstructure changed significantly with increasing Si content. The Al-0Si (industrial pure aluminium) L-PBF specimen had a finely dispersed granular microstructure (~0.3 μm), which was considered to be Al, Si and/or Fe oxides. The Al-1Si L-PBF specimen exhibited a granular microstructure of the oxides with partially-linked crystallised Si phase. The images of the Al-4-12Si L-PBF specimens showed fine elongated cellular dendrites (approximately 0.5 μm in cell size) parallel to the stacking direction (i.e., the thermal flow direction). These cells were primary crystallised α-Al phase and the cell boundaries were crystallised Si phase. The volume fraction of the crystallised Si phase increased with increasing Si content. This fine cellular microstructural morphology is a peculiarity of L-PBF materials,

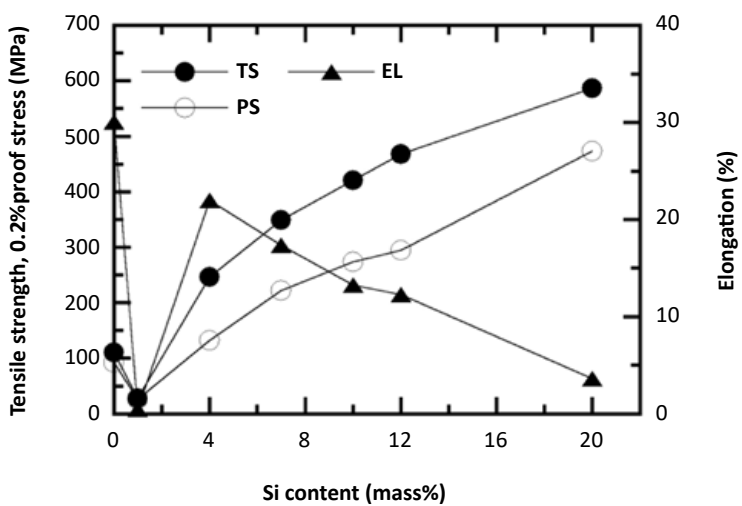


Fig. 4 Ultimate tensile strength (TS), 0.2% proof stress (PS) and elongation (EL) of AlxSi L-PBF specimens fabricated under the optimum laser scan parameters [1]

due to the ultra-rapid solidification caused by laser irradiation. The Al-20Si L-PBF specimen, on the other hand, showed a characteristic petaloid microstructure of primary crystallised β-Si phase within an Al/Si eutectic phase matrix. Fig. 4 shows the ultimate tensile strength (TS), 0.2% proof stress (PS) and elongation (EL) of the Al-xSi

increased monotonically and finally reached 580 MPa for the Al-20Si L-PBF specimen. The PS showed a similar trend to the TS. The PS increased steadily with increasing Si content from 125 MPa for the Al-4Si L-PBF specimen to 425 MPa for the Al-20Si L-PBF specimen. The EL of the Al-0Si L-PBF specimen was almost as high as that of

**“The EL of the Al-0Si L-PBF specimen was almost as high as that of pure aluminium wrought material (approximately 30%) and the EL then steadily decreased with increasing Si content above 4 mass%...”**

L-PBF specimens. The Al-0Si L-PBF specimen had a TS of 110 MPa, which is higher than that of pure aluminium wrought material, due to the observed granular microstructure. Meanwhile, the Al-1Si L-PBF specimen had an extremely low TS of 25 MPa due to the micro-cracks generated along the stacking direction. As the Si content increased above 4 mass%, the TS

pure aluminium wrought material (approximately 30%) and the EL then steadily decreased with increasing Si content above 4 mass%, in contrast to the TS and PS behaviour. On the other hand, the EL of the Al-1Si L-PBF specimen (approximately 1%) was significantly lower than the other specimens due to the micro-cracks. In the Al-4-12Si L-PBF specimens,



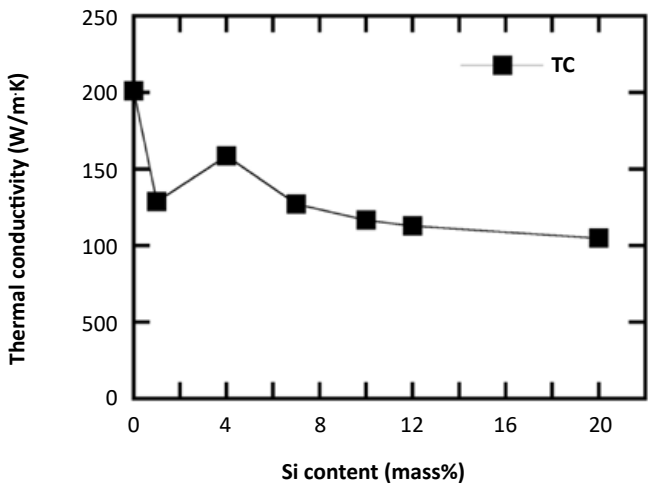


Fig. 5 Thermal conductivity [TC] of Al-xSi SLM specimens fabricated under the optimum laser scan parameters [1]

the volume fraction of the crystallised Si phase (cell boundaries) increased with increasing Si content. The increase in the TS and PS of the Al-xSi L-PBF specimens with increasing Si content was therefore attributed to a composite reinforcement effect due to the increased amount of secondary crystallised Si phase. Additionally, the increase of solid-solute Si in the aluminium matrix may also have strengthened the Al-xSi L-PBF specimens. On the other hand, the crystallised Si phase caused discontinuities in the aluminium matrix and this led to a decrease in the EL since such discontinuities can lead to fracture. In the Al-20Si L-PBF specimen (hyper-eutectic composition), the primary

crystallised phase was  $\beta$ -Si instead of  $\alpha$ -Al. Since the primary crystallised  $\beta$ -Si phase is generally hard, the TS and PS values became higher and the EL value lower. Fig. 5 shows the thermal conductivity (TC) of the Al-xSi L-PBF specimens. The TC shows a similar trend to that of the EL in Fig. 4, i.e., the TC decreased from 200 W/m·K for the Al-0Si L-PBF specimen to 105 W/m·K for the Al-20Si L-PBF specimen. The decrease in the TC was mainly attributed to the increase in the solid-solute Si in the aluminium matrix. This is because the lattice strain, induced by the solid-solute Si, acted as scattering sites for conduction electrons, leading to an increase in the thermal resistivity.

	Al (wt%)	Si (wt%)	Mg (wt%)	Mn (wt%)	O2 (wt%)	D10 ( $\mu$ m)	D50 ( $\mu$ m)	D90 ( $\mu$ m)
AlSi10Mg	Bal.	10.10	0.43	0.003	0.012	11.0	30.4	58.7

Table 2 Properties of the used AlSi10Mg powder [2]

Hatching distance [mm]	Speed [mm/s]	Powder [W]	Build Layer Thickness
0.065-0.2	750-3100	175	30 $\mu$ m

Table 3 The laser parameters used for processing AlSi10Mg in the TruPrint 1000 machine [2]

How porosity is affected by different residual oxygen concentrations in the building chamber during Laser Powder Bed Fusion (L-PBF)

Next, Kai Dietrich and Gert Witt (University of Duisburg-Essen, Germany), Dominik Bauer and Pierre Foret (Linde AG, Germany) and Veronika Krumonova (Technical University Munich, Germany) reported on a study of how porosity is affected by different residual oxygen concentrations in the build chamber during L-PBF [2].

In L-PBF, the laser process takes place in an argon or nitrogen inert gas atmosphere depending on the material used. Therefore, the build chamber is purged with the appropriate gas until an oxygen concentration of around 1000 ppm is reached. This leaves an additional 3728 ppm of nitrogen and traces of hydrogen and humidity, from the powder or the filter, in the atmosphere if the chamber is purged with Argon 5.0. Aluminium-based alloys form oxides, leading to different properties than were expected. Although gases can have a great influence on the chemical and mechanical properties of metals, little research has been reported with regard to the L-PBF process. Due to the importance of the atmosphere during L-PBF, the reported study has therefore investigated the variation in hardness, porosity and microstructure obtained with different oxygen concentrations (100 ppm and 1000 ppm) during the laser process.

The experiments were carried out with Electrode Induction Melting Gas Atomised (EIGA) AlSi10Mg powder. SEM assessment of this powder revealed many satellites attached to the surface, possibly influencing the particle flowability. Table 2 shows the particle size distribution (PSD) as well as the chemical composition. The D10 of 11  $\mu$ m points towards a high number of small particles in the powder.

Using a Trumpf TruPrint 1000 machine, a parameter study was performed with two different oxygen values in the build chamber (100 ppm and 1000 ppm), while flushing with Argon 5.0. 300 Cubes (8 x 8 x 10 mm<sup>3</sup>) were produced with different parameters (Table 3), while keeping the build layer thickness stable at 30  $\mu$ m.

Fig. 6 shows an overview of the investigated densities in relation to the laser speed. For most of the curves, porosity of the 100 ppm oxygen samples is lower overall than for 1000 ppm. Fig. 7 reveals that the density at lower laser speed (around 900 mm/s) is lower at 100 ppm oxygen than with the higher oxygen concentration. At around 1100 mm/s, there seems to be a cross-over point and the density of the 100 ppm samples becomes higher than those with 1000 ppm. At 100 ppm oxygen, the porosity at lower speed mainly consists of spherical pores, which are most likely gas pores. Increasing speed seems to reduce gas porosity at first, resulting in a lack of fusion pores at higher speed. The highest density was reached at around 1300 mm/s. Enlarging hatch distance does not appear to influence gas porosity significantly. For 1000 ppm oxygen samples, the gas porosity is similar for all laser speeds.

The observed results can be explained by means of the Marangoni flow. Surface tension gradients lead to a driving force for a liquid to flow from a region of low surface tension to one of higher surface tension, as there is a larger force pulling it in this direction. In general, the surface tension of liquids decreases with temperature due to increased thermal vibrations, leading to a lower level of cohesion. Within L-PBF melt pools, the highest temperature will be at the centre of the pool where the laser is incident on the metal powder and will decrease outward, leading to a flow from the melt pool to the outside. This can lead to widening and flattening of the

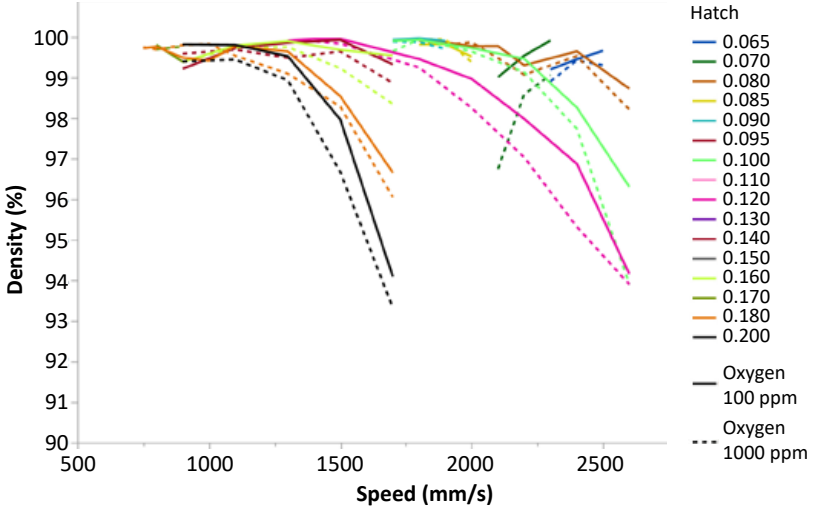


Fig. 6 Density at 175 W laser power. Solid lines symbolise 100 ppm oxygen in the build chamber, dotted lines 1000 ppm [2]

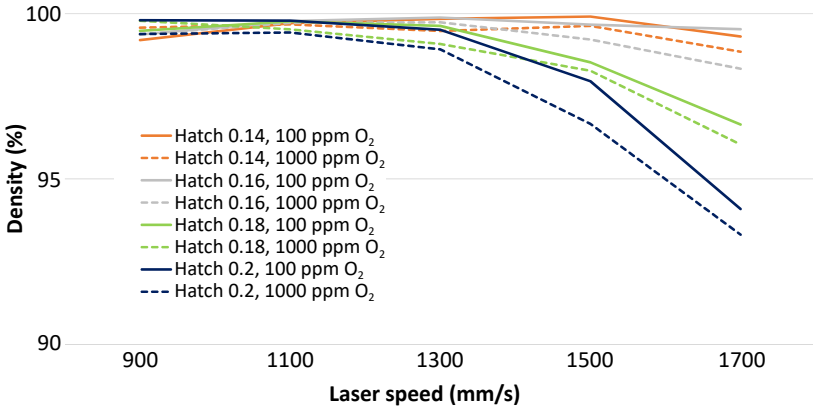


Fig. 7 Densities of AlSi10Mg parts with 175 W laser power and varying oxygen concentration (100 ppm and 1000 ppm) [2]

liquid zone. At the edge of the melt pool, a flow along the Solidus-Liquidus line is caused by shearing forces. These flows clash at the middle of the melt pool and rise to the surface. Oxygen is known to influence the surface tension of the melt pool. The more oxygen in the atmosphere, the lower the surface tension will be. This will inhibit the Marangoni flow, because of more similar surface tensions of the melt pool and the surrounding region. Forming an oxide layer on the melt pool will also lead to a reduced flow effect. At lower oxygen concentrations such as 100 ppm,

the surface tension, and therefore the Marangoni effect around the melt pool, will be higher. This leads to increased gas pore formation as reported in the literature. On the other hand, the melt pool will become deeper. At lower laser speed, the laser spot will remain on one point for longer. The Marangoni flow might therefore exert an influence for a longer time, which can lead to more gas pores. By increasing the laser speed, the effect diminishes, therefore increasing part density. By obtaining the same or better density while using around a 50% higher scanning speed, it is possible to decrease build time.



Density (%)		Hatch (mm)	Speed (mm/s)	Hardness (HV10)	
1000 ppm	100 ppm			1000 ppm	100 ppm
99.85	99.95	0.08	1800	140 ± 3	140 ± 2
99.85	99.86	0.08	2000	142 ± 1	141 ± 2
99.86	99.87	0.08	2200	139 ± 2	140 ± 2
99.51	99.63	0.08	2400	135 ± 1	137 ± 3
98.20	98.71	0.08	2600	131 ± 1	132 ± 2
99.87	99.91	0.09	1700	138 ± 2	136 ± 1
99.86	99.96	0.09	1800	140 ± 2	140 ± 1
99.69	99.88	0.09	1900	134 ± 1	138 ± 2

Table 4 Hardnesses of AlSi10Mg samples with 175 W laser power; three measurements within each sample [2]

Table 4 shows the average hardness of the 100 ppm and 1000 ppm samples at hatch distances between 0.08 mm and 0.09 mm. This range was chosen because the densities of these samples are similar and the hardness is not greatly affected by the porosity.

The hardnesses of the 100 ppm and 1000 ppm oxygen samples are similar. Differences in oxide concentrations in the samples seem to be too low to greatly affect hardness.

The authors drew the following conclusions from the reported results:

- Reducing the oxygen concentration in the build chamber will result in an overall higher density
- Gas porosity at low oxygen concentrations seems to depend on the laser speed; the higher the speed, the lower the gas porosity
- At lower oxygen concentrations, the laser speed can be increased while maintaining or even increasing density
- Oxygen might have a small influence on the hardness

In terms of future work, simulation might be carried out to confirm the influence of oxygen on surface tension during the L-PBF process.

Mechanical properties of aluminium alloys produced by metal AM

Laura Cordova and Tiedo Tinga (University of Twente, Netherlands) and Eric Macia and Monica Campos (University Charles III of Madrid, Spain) turned their attention to the mechanical properties of Al alloys processed by metal Additive Manufacturing [3].

L-PBF is a promising alternative for the fabrication of aerospace components where weight reduction, high accuracy and complexity are required to achieve optimal performance. Since the development of L-PBF technology, aluminium alloys have proved to be challenging materials to process due to their high conductivity and high reflectivity. Additionally, when aluminium powder is processed by L-PBF, density is usually compromised by a high level of porosity, products can suffer deformation and hot cracking as a consequence of stress concentration, and high surface roughness is obtained due to poor flowability.

The reported work offered an innovative method for evaluating the effect of porosity and inclusions on fracture behaviour. In-situ testing was presented as a valuable approach to relate local plastic deformation and fracture mechanisms to various porosity distributions.

The two alloys included in the reported study were AlSi10Mg and Scalmalloy®, an aluminium-scandium alloy with enhanced mechanical performance developed specifically for the L-PBF process and aerospace applications.

Al-Si alloys are characterised by excellent weldability and high corrosion resistance. Their attractive mechanical properties and low weight make them suitable for a large number of applications, especially in the aerospace industry. The addition of magnesium to the Al-Si alloy strengthens the matrix by Mg<sub>2</sub>Si precipitation. The Al-Sc solid solution in Scalmalloy forms Al<sub>3</sub>Sc precipitates acting as an age hardener, leading to high strength. Sc is reported to increase the weldability of Al alloys, mainly for alloys susceptible to hot cracking and extended heat-affected zone formation.

AlSi10Mg and Scalmalloy tensile test specimens were manufactured by L-PBF in the XY and Z directions using an SLM Solutions SLM 280 AM machine. Prior to the build, an overnight (12 h) vacuum drying process was carried out to reduce the moisture level in the metal powders. The printing parameters used to build the specimens were optimised to obtain maximum density. The AlSi10Mg alloy had a stress relief at 300°C for 120 min and Scalmalloy a stress relief for 90 min at 180°C and a precipitation hardening treatment of

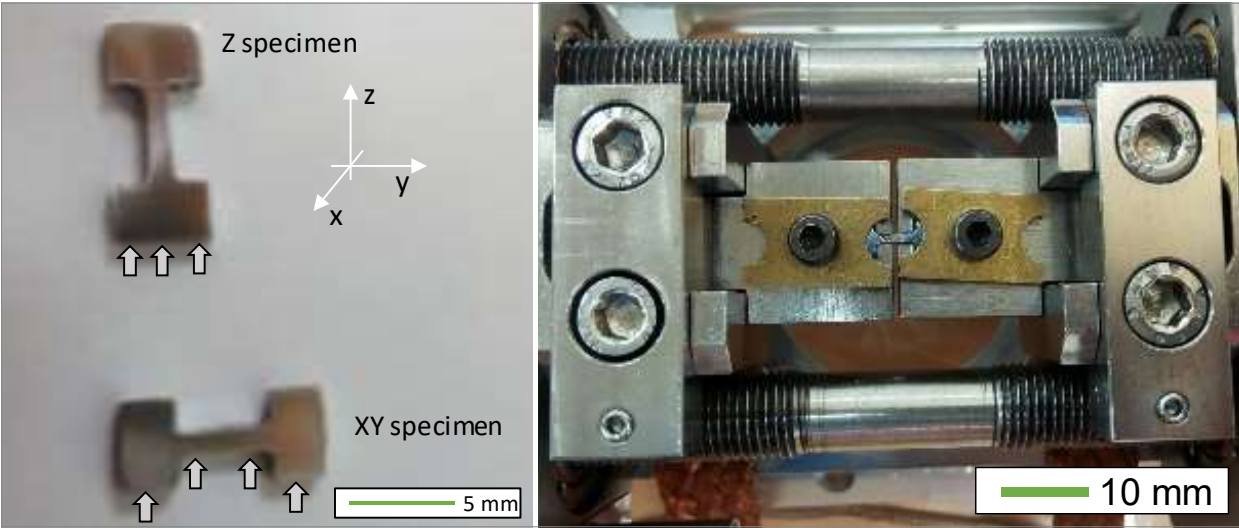


Fig. 8 L-PBF-manufactured specimens (left) and micro tensile test set-up (right) [3]

240 min at 325°C, since the strength of this material is derived mainly from precipitation hardening.

In order to compare the performance of AlSi10Mg and Scalmalloy in two build directions (XY and Z), the mechanical properties were evaluated. Micro tensile and Vickers hardness tests were conducted. Fig. 8 (left) shows the geometry of the micro-specimens tested with the micro machine. The thickness of these specimens was 1 mm. Although this geometry is not standard, due to the nature of the L-PBF process these specimens are more cost-effective to build than the larger dog-bone shaped specimens which are traditional. Note that, although micro tensile tests are useful in determining the stress-strain curve, maximum strain and ultimate tensile strength (UTS), the results should not be compared with results from other methods.

Sample preparation was a key step before beginning tensile testing, due to the high roughness of L-PBF specimens. Silicon carbide (SiC) paper, diamond solution and OPS colloidal silica were used to grind and polish the flat surfaces (Fig. 8, left). The cross-sections were shaped and polished with a three-square file. The rougher part of the printed specimens corresponded to the area where the supports were placed. For the XY

specimens, the supports were located on the 10 mm side and, for the Z specimens, they were on the 4 mm side (Fig. 8, left). The supports help to attach the specimens to the build plate while scanning and melting the metal powder.

Fig. 8 (right) shows the micro machine used to perform the tensile tests at IMDEA Materials, Spain. This equipment has a maximum load of 10 kN. Since aluminium alloys have a

tests, one for each condition, were conducted inside a Scanning Electron Microscope (SEM) to capture images of the specimen at different points on the stress-strain curve.

An automatic micro indentation testing system was used to compare the hardnesses of AlSi10Mg and Scalmalloy. Since aluminium alloys are relatively ductile, the indenter was loaded to 1N (HV0.1). A patented visual method automatically traced

“A patented visual method automatically traced the sample edge of a live image, enabling the positioning of indents and patterns directly onto the overview image of a part...”

relatively low tensile strength, a load of 1 kN was sufficient for the experiments. The clamping system speed during the test was set to a strain rate of 2 μm·s<sup>-1</sup>.

Ex-situ and in-situ tests were conducted with the micro machine. UTS and maximum strain were obtained from the ex-situ tests using four specimens for each material and building direction. The in-situ

the sample edge of a live image, enabling the positioning of indents and patterns directly onto the overview image of a part.

The tensile test and Vickers hardness measurements provided quantitative results to compare the studied materials built in the XY and Z directions. From the tensile tests, σ - ε (stress-strain) curves were obtained (see Fig. 9). On average,



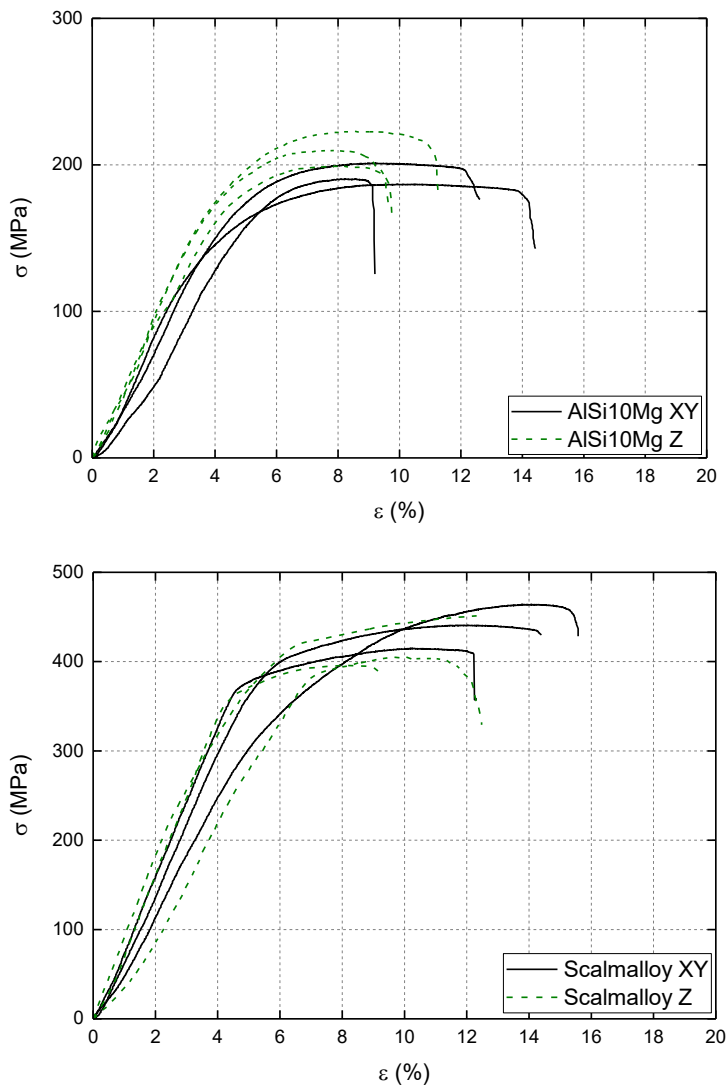


Fig. 9 Tensile test results of (left) AlSi10Mg XY and Z build orientation, (right) Scalmalloy XY and Z build orientation [3]

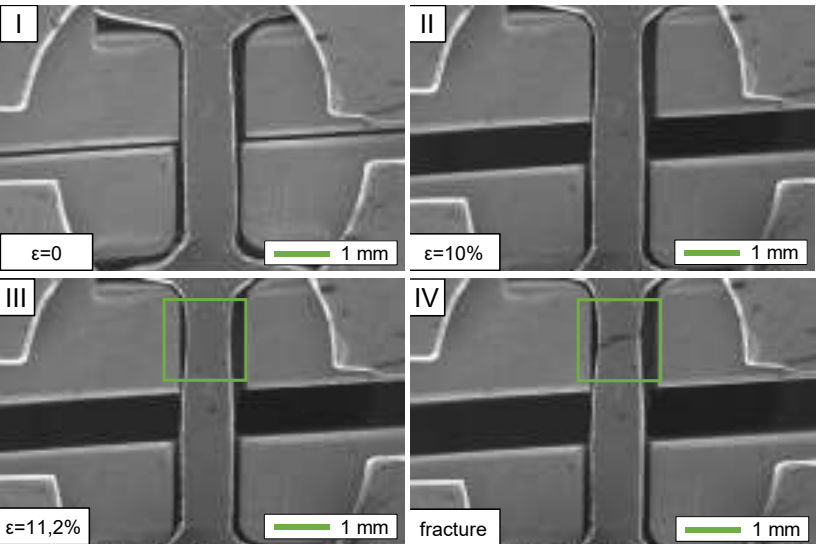


Fig. 10 AlSi10Mg, build direction XY [3]

Scalmalloy showed tensile strength values almost double those obtained for AlSi10Mg. Due to the high porosity and anisotropic properties, the materials showed some scatter in the results. The building direction appeared to have little influence on the mechanical properties for AlSi10Mg and Scalmalloy, although the maximum strain ( $\epsilon_{break}$ ) was generally higher for the XY direction.

Fig. 10 shows the in-situ test of an AlSi10Mg specimen, manufactured in the XY direction, deforming in tension. In Fig. 10(III), neck formation can be noted, with the material elongating until final fracture (IV). The images taken with the SEM also showed the superficial defects present in this specimen. Although there were large-sized inclusions from the manufacturing process, the fracture occurred in the middle of the neck. The tensile forces formed a neck close to the top side instead of crossing areas of high porosity.

Fig. 11 shows the average microhardness (HV0.1) results for Scalmalloy and AlSi10Mg in the XY and Z build directions. Five indentations for each condition were conducted in the clamping area, over flat surfaces without porosity. Similarly to the tensile strength and strain, there were not large differences between the XY and Z build directions for the hardness values. Nevertheless, Scalmalloy exhibited higher hardness (HV) values than those obtained for AlSi10Mg; almost double, as for the tensile strength values. The error, obtained for Scalmalloy Z build direction, was relatively high due to the porosity and anisotropy arising from the L-PBF process.

Table 5 shows the mechanical properties of conventionally manufactured (cast) AlSi10Mg and the state-of-the-art AM properties for AlSi10Mg and Scalmalloy. Conventionally manufactured AlSi10Mg shows similar properties to those reported in the literature for AlSi10Mg AM; however, the AlSi10Mg tested in this study showed considerably higher strain values and lower UTS values.

The values stated in Table 5 for AlSi10Mg and Scalmalloy refer to the minimum properties, reached using Additive Layer Manufacturing in the weakest direction of the material. The values of the mechanical properties were generated with tests on specimens that had been heat treated and machined.

The differences between the values from the literature and the results from this study were mainly due to differences in heat treatment/ time and specimen geometry. The results showed slightly lower UTS values but higher strain than the values from the literature. In the case of the XY direction, this value was twice that from the literature for Scalmalloy and five times that for AlSi10Mg. Also, the hardness values found in the literature were higher than those obtained from the tests.

The fracture surfaces of the AlSi10Mg and Scalmalloy specimens showed a ductile fracture micro-mechanism. The fracture surfaces of both materials were covered by dimples. However, in the case of AlSi10Mg, there were two different sizes of dimples and, due to the high porosity of this material, the crack could propagate faster through the pores. On the other hand, Scalmalloy showed a less homogeneous surface, with the presence of limited cleavage areas. In both alloys, the shape and size of dimples in the XY direction differed from that in the Z direction.

Both alloys showed constriction before fracture. In general, AlSi10Mg contained more porosity and larger voids. Porosity on the surface helps to initiate and propagate the cracks. In L-PBF, the specimens are built layer-by-layer, but each layer is also processed line-by-line. So, if either a low laser power or a high scan speed is used, or the spacing between the lines is large, the melting of the additively manufactured layer can be insufficient, resulting in the formation of pores. Small spherical pores can also be attributed to gas entrapped during melting. This gas may originate from the powder bed or from powder reactions. In the

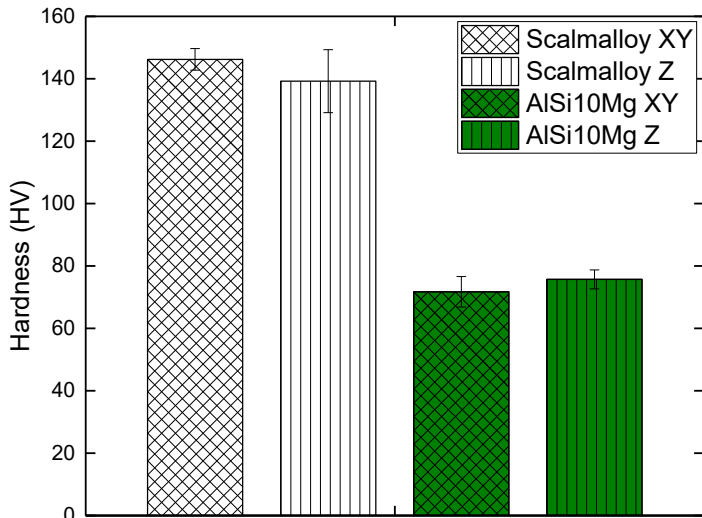


Fig. 11 Vickers hardness HV0.1 [3]

Materials	UTS (MPa)	$\epsilon_{break}$ [%]	HV
AlSi10Mg XY	202 ± 13	15 ± 2	72 ± 5
AlSi10Mg Z	224 ± 20	12 ± 2	76 ± 3
Scalmalloy XY	462 ± 17	16 ± 2	147 ± 3
Scalmalloy Z	440 ± 25	13 ± 2	139 ± 10
AlSi10Mg casted [10]	300 - 317	2,5 - 3,5	86
AlSi10Mg AM [8]	335	3	127
Scalmalloy AM [9]	490	8	177

Table 5 Summary of AlSi10Mg and Scalmalloy mechanical properties [3]

case of Al10SiMg, Mg can be evaporated in the L-PBF process. Density optimisation is therefore necessary to avoid a lack of fusion, resulting in keyhole pores, or gas entrapment, resulting in metallurgical pores.

A digital microscope was used for identification of the porosity at 100 x magnification. Generally, the porosity measured on the surface near the crack exhibited higher values than in the cross-section. This can be explained by the fact that the surface belongs to the printing surface and therefore contains more imperfections. In the cross-section for direction XY, the porosity was due to gas entrapped within the melting pool, whereas, for direction Z, this could happen because of scanning defects.

### Heat treatment of additively manufactured aluminium alloys

Finally, Jukka Simola, Maija Nystrom, Eero Virtanen and Juha Kotila (EOS Finland Oy, Finland) reported on a study of the heat treatment response of additively manufactured aluminium alloys [4].

Direct Metal Laser Sintering (DMLS), otherwise known as Laser Powder Bed Fusion (L-PBF), of aluminium is being adopted extensively by the machine building, automotive and aerospace industries. The unique characteristics of the layer-by-layer AM microstructure provide equal or even enhanced properties, when compared to





Fig. 12 Optical micrograph of as-built EOS F357 sample, showing melt pool lines crossing fine alternating aluminium-silicon cell structure. The growth direction of the lighter grey Al dendrites is revealed by elongated cells/grains in the vertical orientation. Scale bar is 20 µm. Etched with Groesbeck’s etch [4]

conventional manufacturing methods, such as casting. In the reported research, EOS AlSi10Mg and EOS F357 aluminium-silicon (Al-Si) alloys, manufactured by L-PBF, were studied. Their AM microstructures can be characterised by finely-dispersed alternating phases of aluminium cell-like structures, surrounded by a silicon-rich eutectic network. Melt pools, i.e., laser scan tracks, make slight variations across the microstructure. The heat affected zones along melt pool lines show slight coarsening of the otherwise homogeneous microstructure. Build orientation can be observed from the tendency of the alloy to form more elongated cells along the direction of the heat flow (from top to bottom in Fig. 12 for the EOS F357 alloy).

Heat treatment of aluminium alloys has traditionally been used for strengthening as well as for improving the thermal stability of aluminium alloys. The response to heat treatment is dependent on the microstructure. Shorter T6-type heat treatments have been reported in the literature and some of these concepts were applied in this research.

The traditional T6 heat treatment for aluminium consists of solution annealing and ageing steps. A super-saturated solid solution of solute atoms in the aluminium matrix is achieved by fast quenching. Some Al alloys may harden naturally, but, in order to ensure stable properties at room temperature, an artificial ageing step is typically employed at

elevated temperatures. Strength and thermal stability of the alloy can be optimised by varying ageing times and temperatures. Peak ageing (T6) will usually produce the highest yield strength, thanks to the formation of coherent fine-scale precipitates.

In many cases, the solution annealing step is not necessary. For example, many Al alloys can be quenched directly from hot working operations and the alloy is then already in a near-supersaturated state. For AM materials, the extremely high solidification rates can also increase solute supersaturation in the as-built condition. Peak-aged or over-aged tempers, such as T5 or T7, could also be produced without a need for the solution annealing step in order to provide higher strength or better thermal stability for the AM parts.

In AM processes, the current trend is towards higher productivity and high build rates, sometimes at the expense of increasing the overall porosity and defect rates. The amount of porosity in AM parts is, in most cases, higher than for wrought grades but lower than for castings. Microstructural changes during conventional heat treatments can also have negative effects on the extraordinary properties of AM parts, and new approaches to heat treatment are needed. A shortened solution annealing step was therefore studied in the reported research, in order to balance the mechanical properties achievable by heat treatment.

Within the study, EOS M290 and EOS M400 L-PBF machines were used to manufacture horizontal and vertical tensile bars. Nitrogen was employed as the shielding gas for the EOS F357 sintering process and

Material	Chemical Composition	Al	Si	Fe	Cu	Mn	Mg	Ti	Be
EOS F357	(wt.%)	Balance	7,07	0,06	<0,01	<0,01	0,55	<0,1	<0,0005
EOS AlSi10Mg	(wt.%)	Balance	9,60	0,13	<0,01	<0,01	0,41	<0,1	<0,00005

Table 6 Chemical compositions of the test materials EOS F357 and EOS AlSi10Mg [4]

argon was used as the shielding gas for the EOS AlSi10Mg process. The chemical compositions of the two alloys are given in Table 6.

A build job layout, consisting of 42 vertical and 42 horizontal samples, was prepared and manufactured using the EOS M400 L-PBF and EOS M290 machines. Samples were heat treated using a laboratory furnace. The target temperatures were of 540°C for F357 and 525°C for AlSi10Mg. The furnace was pre-loaded with a thermal ballast (28 mm thick 2.7 kg aluminium plate) to promote faster heating of the specimens loaded into the hot furnace. Solution annealing treatments of 6 h (conventional SA) and 30 min (short solution annealing, SSA) were used for the tensile samples. Microscopy samples were subjected to SA, holding times ranging from 15 to 360 min. After SA/SSA, all samples were quenched in 20°C water with a volume of around 30 l. No significant heating of the quenching medium was observed. Warping during quenching was not observed, thanks to the good racking procedures used. Artificial ageing was performed after an inoculation time of 20-24 h at room temperature, used to promote the formation of finer G.P. zones.

Ageing was carried out at 160–165°C for 6 h. Solution annealing and ageing heat treatment onset times were calculated from the point in time, when samples reached a temperature within 6°C of the target. Quench delay was kept to a minimum and samples were immersed in water within 10 sec after opening the furnace door. After ageing, samples were left to cool in open air.

Tensile test results for as-built and heat treated samples are presented in Table 7. The samples heat treated for 6 h, according to traditional convention, had good strength values, but elongation values, especially in the xy-direction, were seen as having room for improvement.

Metallographic examination showed that the onset of microstructural changes was almost immediate after reaching the target temperature in solution annealing. The break-up of the as-built lamellar cell structure

ISO EN 2002-001: 2005 (E) Annex C, (Method 2)	Rp0.2 [MPa]	Rm [MPa]	[A%]
As built EOS F357, z-direction	256	395	5,7
As built EOS F357, xy-direction	256	370	8,4
Long T6 EOS F357, z-direction	275	334	12,1
Long T6 EOS F357, xy-direction	281	336	4,8
SSA T6 EOS F357, z-direction	263	337	12,5
SSA T6 EOS F357, xy-direction	270	335	12,5

Table 7 Tensile test results for as-built, long T6 (SA time 6 hours) and SSA T6 (SSA time 30 minutes) samples [4]

led to the formation of dispersed silicon particles, located on grain boundaries. The build direction also became more apparent due to the elongated appearance of individual aluminium grains.

The break-up of the continuous silicon network was found to be linked with a ductility increase. Fractographs were prepared from vertical (Z-direction) tensile bars of AlSi10Mg in the as-built and SSA T6 conditions. The behaviour in the heat treated condition could be seen from SEM fractographs Larger

micrographs of EOS AlSi10Mg, it could be noted how the particle sizes and the size of pores both grew with the coarsening microstructure. The development of spheroidised dark grey silicon particles from the Si network was also visible. Similar observations were made for the EOS F357 alloy. Formation of new pore sites was already observed after roughly 10–15 min of solution annealing. Longer soak times at solution annealing temperatures were found to increase the maximum pore size as well as the overall grain size. According to

**“Microstructural changes during conventional heat treatments can also have negative effects on the extraordinary properties of AM parts, and new approaches to heat treatment are needed.”**

areas of continuous Al-matrix could be seen to help in the formation of fracture dimples or voids. Some cracked silicon particles could also be observed in the fracture surfaces. The as-built fracture surface comprised faceted surfaces, aligned along the melt pool tracks. The fracture was therefore deemed to have propagated along the melt pools.

Solution annealing soak time tests were performed for the EOS F357 and EOS AlSi10Mg alloys. From

published data, the grain growth rate should reach a plateau between 3–4 h of solution annealing and similar observations were made in this study.

The formation of pores and their subsequent growth can be attributed to many possible sources and was not within the scope of this reported study. However, by reducing the overall porosity by 30% with a simple process improvement, the elongation was found to improve further and, at the same time, the scatter of the



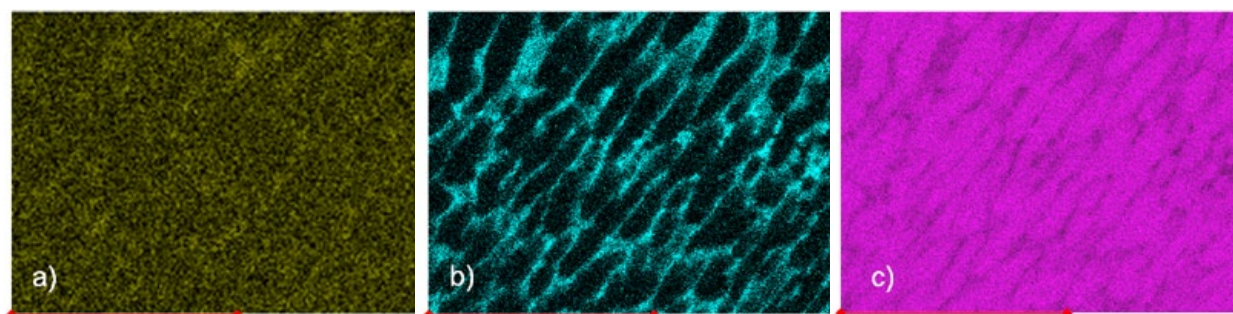


Fig. 13 Elemental EDS map of the distribution of alloying elements in the as-built EOS F357 alloy a) Mg, b) Si and c) Al. Scale bar is 10  $\mu\text{m}$  [4]

mechanical property results was reduced. In order to determine how the shorter solution annealing time affected the distribution and size of the strengthening  $\text{Mg}_2\text{Si}$  phase, EDS maps were created for different heat treatment states of the EOS F357 samples: these states comprised as-built, SSA for 10 min and quenched, SSA for 30 min and quenched, solution annealed for 5 h and quenched and, finally, SSA for 30 min, quenched and aged for 6 h. In Fig. 13, the distribution of main alloying elements Si, Mg and Al in the as-built sample are shown. A rather uniform coverage of magnesium was found, with a slightly higher intensity of Mg observed in conjunction with the silicon network.

According to the literature, 15 min of solution annealing is sufficient to dissolve all available Mg in the Al matrix in AlSiMg alloys. However, a large portion of magnesium was seen to agglomerate with silicon in close relation to the newly formed, spheroidised Si particles. Some  $\text{Mg}_2\text{Si}$  particles apparently formed at this stage and their size would become coarser as the solution annealing was continued. At 10 min and 30 min, a significant amount of Mg was found in small clusters. The longer 5 h solution annealing time was found to help the remainder of Mg to dissolve and be more evenly distributed into the Al matrix. The coarsening of the microstructure was very apparent at this point, as evidenced in the

distribution of Si phases and also in the size of the Si particles. The formation of larger  $\text{Mg}_2\text{Si}$  particles during the solution annealing from the earlier Mg clusters could be observed.

The silicon needed to form  $\text{Mg}_2\text{Si}$  particles would be more sparsely distributed after longer solution annealing times, although some of it may have remained in solid solution. It is questionable whether the silicon from these particles in a coarser microstructure would be available to be taken back into solution in the matrix in order to be able to form fine  $\text{Mg}_2\text{Si}$  precipitates during artificial ageing. It has been reported in the literature that, by the rupture of the Si network, the spheroidised Si particles originate mainly from high angle grain boundaries. Si particles dissolved in the matrix would therefore have originated from low angle grain boundaries only. The resulting mechanical properties may not be optimal for alloys with higher Mg contents, such as F357, due to the lack of free silicon in the matrix.

Overall, the authors drew the conclusion that, for AM parts manufactured from aluminium-silicon casting alloys, a soak time of 20–40 min (depending on the thickness of the parts) at solution annealing temperature can be proposed. After a rapid quench by water immersion, the ageing treatment can be designed to provide the desired properties of under-aged, peak-aged or over-aged and stabilised conditions.

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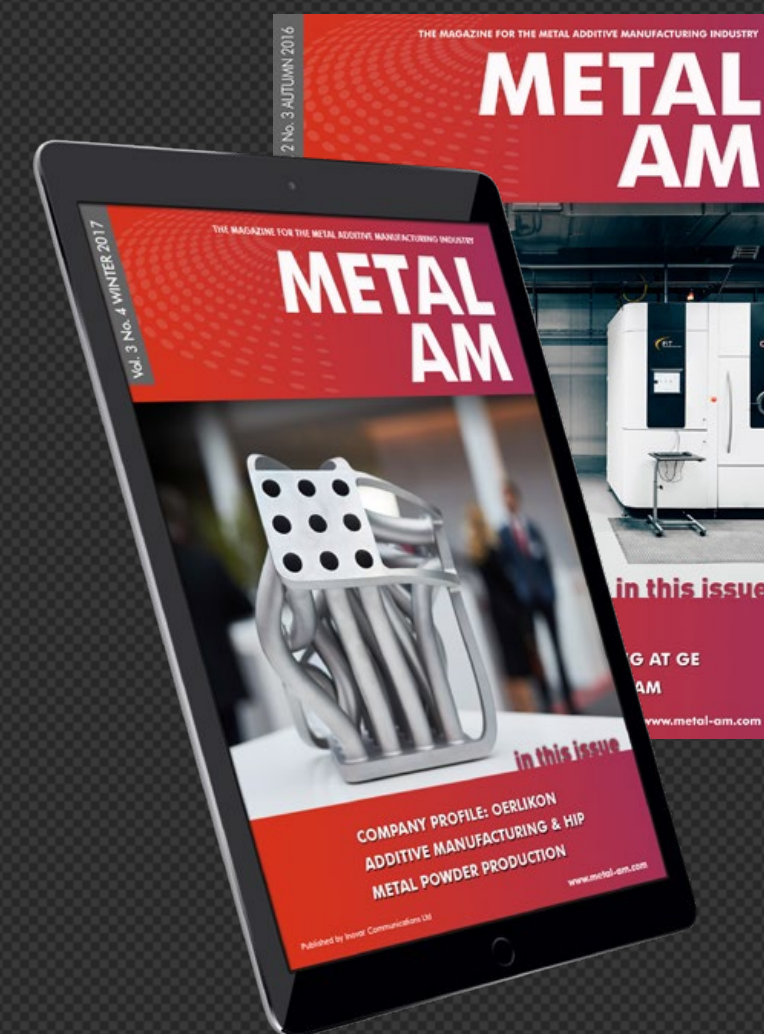
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