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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

HONEYWELL AEROSPACE

DESIGN FOR AM: CASE STUDIES

METAL POWDER RECYCLING

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METAL ADDITIVE MANUFACTURING

Designing the value into Additive Manufacturing

The knowledge that an engineer has to possess in order to successfully produce parts by AM differs fundamentally from conventional manufacturing processes. For those new to AM, the complexities of the Design for Additive Manufacturing (DfAM) methodology can be particularly daunting.

Today, there is growing recognition amongst end-users that simply putting a part designed for conventional manufacturing through an AM machine is doomed to failure. The skills and knowledge required to create a part specifically for AM rely on the designer embracing a completely new mind set that draws on a wide range of previously unconsidered factors.

Case studies are one way that those who are further ahead on the DfAM journey can share their experience and knowledge with those who are new to the technology. In this issue of *Metal AM* magazine we feature two very different application-focused reports, both of which offer invaluable insight into how companies have successfully leveraged DfAM to transform existing applications.

Using AM for these applications has brought major benefits, from performance improvements to weight reduction and, in one case, a dramatic reduction of the total number of components in a product sub-assembly from a hundred to one.

If your company is starting out on the AM journey and you plan to visit the formnext exhibition in Frankfurt, Germany (November 14-17), please drop by our booth (3.0 G65). We'd be very interested to learn about your metal AM experiences.

Nick Williams
Managing Director
Metal Additive Manufacturing

Cover image
An F125IN turbofan engine manufactured by Honeywell Aerospace (Courtesy Honeywell)

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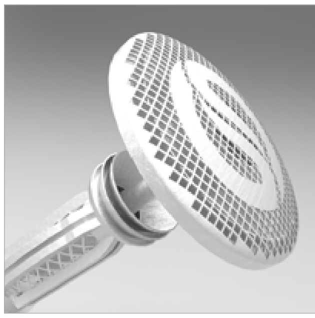

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With dedicated AM facilities in five countries, Honeywell Aerospace is at the forefront of the development of new commercial aerospace applications for AM, along with the supply chain needed to implement series production. Dr Dhruv Bhate visited Honeywell's Phoenix facility and met with Donald Godfrey, an Engineering Fellow at Honeywell and the person most credited with directing the company's progress in AM.

93 RapidTech + FabCon 3D: Innovations in binder-based AM and advances in conformal cooling

From June 20-22, 2017, the German city of Erfurt became a centre of gravity for AM, hosting the annual RapidTech conference and FabCon 3D exhibition. Dr Georg Schlieper reports on a number of trends in metal AM process technology and applications, including binder-based AM technologies and innovations in toolmaking.

103 Design for AM: Increasing part value through intelligent optimisation

Paying the right amount of attention to Design for Additive Manufacturing (DfAM) can make the difference between economic success and failure. In this case study, Terry Wohlers and Professor Olaf Diegel, both of Wohlers Associates, reveal how industrial mining machine manufacturer Atlas Copco has used DfAM to increase the value of a hydraulic manifold.

109 Design for AM: Transforming RF antennas through intelligent optimisation

AM presents the opportunity to completely rethink a product's design, transforming its functionality and reducing manufacturing complexity. In the following article, Optisys LLC reveals how, through intelligent design optimisation, the company has used Additive Manufacturing to develop the next generation of RF antenna systems for aerospace and defence.

115 AMPM2017: Understanding the impact of powder reuse in metal Additive Manufacturing

An issue of significant current interest to the Additive Manufacturing world, which can potentially impact both the quality and cost-effectiveness of built parts, is whether there is a limit on the number of times that metal powders can be cycled around an AM process. Dr David Whittaker reviews three presentations on the topic from AMPM2017, the fourth annual Additive Manufacturing with Powder Metallurgy Conference, held in Las Vegas, USA, June 13-15, 2017.

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GE Additive
Sparking a new era in design and manufacturing
Through innovation, collaboration and consultation, GE Additive has built a network of people and businesses that are advancing additive manufacturing. Not just for us, but for everyone. We've taken our additive experience and made it even stronger, bringing together machine and material providers as well as design experts to help you incorporate additive technology into your operations. Together, we're helping guide manufacturing in a bold new direction.
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industry news

Digital Metal begins commercial production of its high precision binder jet metal AM system

Digital Metal®, Sweden, a Höganäs Group company, has begun commercial production of its high-precision binder jet metal Additive Manufacturing system which it states can produce smaller and more intricate components than any previous technology. The DM P2500 has a 2500 cm^3 print volume and manufactures parts in 42 µm layers at 100 cm^3/h, without the need for any support structures. This makes it possible to manufacture small objects in high quantities - up to 50,000 parts per print run - and in a wide variety of shapes, geometries and internal and external finishes. The system delivers a resolution of 35 µm and an average surface roughness of Ra 6 µm before additional finishing processes are applied.

Digital Metal has been using this proprietary binder jet metal AM technology in-house for four years to produce bespoke and precision small-scale components. To date, the company states that it has produced approximately 200,000 pieces for customers in several industries, including aerospace, luxury goods, dental tools and industrial equipment manufacturing.

Sintering takes place after the production process and is adaptable for a variety of materials. Powder removed before sintering can also be reused for subsequent jobs, making it one of the most sustainable AM technologies available today. This results in high yield and low scrap rates, meaning downtime is kept to a minimum and there is no powder degeneration.

Ralf Carlström, General Manager, Digital Metal, stated, "Our heritage, knowledge and experience in metal powders, combined with the development and evolution of our cutting-edge printer technology, has enabled us to succeed where others have failed. With the DM P2500 we are bringing to market a tried and tested 3D metal printer."

Honeywell Aerospace and Digital Metal are said to be exploring a number of joint AM projects which will merge Honeywell's expertise in aerospace engineering with Digital Metal's AM technologies. "The binder jetting technology Digital Metal uses to print small metal parts has the potential for various applications within the Honeywell Aerospace program," explained Don Godfrey, Engineering Fellow – Additive Manufacturing, Honeywell Aerospace. "We believe this will also be critical to applications in other key areas of the broader aerospace industry."

Digital Metal has also stated that it will provide all ancillary equipment required with each machine, as well as introductory and ongoing training and support.

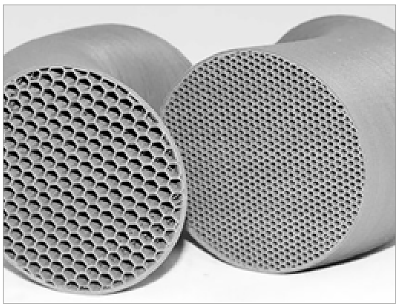
Digital Metal adds titanium option

In addition to stainless steels 316L and 17-4PH, Digital Metal has also extended its material range to include titanium Ti6Al4V. Titanium is widely used in the Additive Manufacturing industry as it combines high strength, high hardness and ductility with high corrosion resistance. The use of titanium can offer a 45% weight reduction compared to conventional steels. Digital Metal's Ti6Al4V is said to meet ISO 22068 standard.

www.digitalmetal.tech

Digital Metal DM P2500 (Courtesy Digital Metal)

BASF establishes Additive Manufacturing company, launches Ultrafuse 316LX for fused filament fabrication of metal parts



BASF's Ultrafuse 316LX is suited to a broad range of applications for functional prototyping and small series production (Courtesy BASF)

BASF SE, Ludwigshafen, Germany, has announced the formation of a new company, BASF 3D Printing Solutions GmbH, to focus on establishing and expanding the company's business with materials, system solutions, components and services in the field of Additive Manufacturing. This wholly-owned subsidiary of BASF New Business GmbH will be headquartered in Heidelberg, Germany, at the site of InnovationLab GmbH.

BASF 3D Printing Solutions will work closely with researchers and application engineers from BASF and external partners, such as universities and potential customers, in order to develop the right solutions for a wide array of requirements.

"The field of 3D printing for industrial applications is highly dynamic and still emerging," stated Volker Hammes, Managing Director at BASF New Business and future Managing Director of BASF 3D Printing Solutions. "This means there is a need for agile, start up-like structures with interdisciplinary teams and quick decision-making processes. Combining the customer-focused 3D printing activities in one location at a dedicated business is an important success factor."

Ultrafuse 316LX

BASF has also introduced Ultrafuse 316LX for use in fused filament fabrication (FFF) systems for the production of metal parts. Ultrafuse 316LX is metal-polymer composite filament with a non-slip surface allowing its application in any bowden or direct drive extruder. Its high flexibility is said to allow it to be funnelled through complex idler pulleys as well as guide roller filament transportation systems.

Once formed, the parts undergo a standard debinding and sintering process introduced to the Metal Injection Moulding (MIM) market by BASF in the 1980s. Catalytic debinding removes the polymer from the part and sintering in pure hydrogen or a vacuum results in the finished metal part. The whole process is said to be faster and less expensive than offered by existing SLM systems. Ultrafuse 316LX is available in 1.75 and 2.85 mm diameter filament. According to BASF, no changes to the FFF hardware are required to process the material. Currently only a 316L stainless steel option exists, but BASF states that other metal options will be developed.

The filament is said to be suited to a broad range of applications for functional prototyping and small series production. BASF lists various applications including watches, decorative parts and medical equipment.

www.basf.com

SLM Solutions receives €43 million order for fifty machines

SLM Solutions, Lübeck, Germany, is reported to have signed its largest ever single order contract for fifty machines from its SLM 280 series, amounting to €43 million. The systems will be sold via a sales partner in China. Previously, the largest single order received from a customer was for ten machines from the SLM 500 series in June 2017, also in China.

"We are delighted to have won the largest single contract ever in the history of SLM Solutions," commented Uwe Bögershausen, board member at SLM Solutions Group AG. According to the company, the order is an important step in promoting further growth in Asia and underscores the strong global demand for additive production facilities suitable for industrial applications.

The fifty machines will be sold up over the period 2017-2020. According to SLM Solutions, it is one of the largest orders ever placed in China in the area of Additive Manufacturing.

"This contract shows that we are absolutely right in focusing on developing long-term customer relationships and underpins our long-term growth trajectory as an independent German company," Bögershausen continued. "The order also underlines the high suitability of SLM's machines for the industrial production of parts in high quality."

SLM 280 machines represent the fastest selling series currently produced by SLM Solutions. In addition to offering users the ability to customise machine parameters, SLM 280 machines offer a high level of productivity through the parallel use of up to two lasers, each with a maximum 700 W output. The machine performance enables users to optimise production costs per component manufactured while still allowing full scope for geometrical design.

www.slm-solutions.com

AP&C unveils state-of-the-art powder manufacturing facility in Canada

Arcam AB, Mölndal, Sweden, has announced that its powder manufacturing subsidiary, AP&C, officially opened a new facility in Saint-Eustache, Quebec, Canada. The new manufacturing plant will employ more than one hundred new employees by the end of the year, making it one of the largest employers in the region and marking a significant growth for AP&C, which has quadrupled in size over the last two years.

With a present total production capacity of 750 tons and planned production capacity of 1,250 tons at full capacity, the new plant is poised to meet the growing demand for titanium powders in terms of quality and capacity. "The need for high end titanium powder is driven by the fast growth and adoption of Additive Manufacturing," stated Magnus René, Arcam CEO. "Arcam, AP&C and GE Additive are determined to serve the industry through cost-efficient solutions, thus converting traditional manufacturing into Additive Manufacturing. A requisite is to offer highest quality powder for production at competitive cost and in sufficient volumes."

A subsidiary of the Swedish firm Arcam AB, a GE Additive company, AP&C has invested a total of $31 million CAD in this highly-automated plant, aided by financial contributions from Canada Economic Development, Montréal International, Investissement Quebec and the Quebec Ministry of Economy, Science and Innovation.

"Our new facility represents a new and inspiring phase for Arcam and GE Additive and a major step for AP&C at a time when we strive to respond to the growing demand for Additive Manufacturing", stated Alain Dupont, President of AP&C. "We are very pleased that the factory was delivered on time and on budget, thanks to the dedicated efforts of our team who led the development project. We are also especially thankful to our investors and partners without whom this accomplishment could not have been possible."

www.arcam.com | www.advancedpowders.com

AP&C's new facility will produce titanium powder (Courtesy GE)

Voestalpine expands its metal AM activities to Asia and North America

Voestalpine AG, Linz, Austria, has expanded its metal Additive Manufacturing activities into Asia and North America. The company has reportedly invested a total of €50 million into the opening of a new metal AM research centre in Singapore, the construction of a new AM technology institute in Taiwan and a production plant in Canada.

This expansion follows the successful launch of the group's Additive Manufacturing Centre in Düsseldorf, Germany, in September 2016. While the Düsseldorf team specialises in the Additive Manufacturing of small, lightweight, finely-structured parts and tools, Voestalpine's Additive Manufacturing Centre Singapore is focused on the manufacture and repair of objects weighing up to 600 kg.

"In line with our global service strategy, we are successively establishing metal Additive Manufacturing services close to our customers. The focus is on applying different Additive Manufacturing processes to best meet their individual requirements," stated Franz Rotter, Member of the Voestalpine AG Management Board and Head of the High Performance Metals Division.

Voestalpine's Taiwan-based Technology Institute Asia, set to open in August 2017, will be the group's third research centre for metal AM. Meanwhile, construction is underway on the group's first NAFTA-based production plant for high-tech Additive Manufacturing in Toronto, Canada. To keep up with the increasing demand for high-quality metal powders for AM, Voestalpine is also investing and expanding capacity at its subsidiaries Böhler Edelstahl GmbH & Co KG, Austria, and Uddeholms AB, Sweden.

Following the installation of state-of-the-art atomisation lines for powder production at the two sites in 2016, a total of €20 million is currently being invested in similar systems. Voestalpine reported that it is currently developing new high-strength, corrosion resistant powder types for increasingly sophisticated applications.

"Voestalpine, with its comprehensive knowledge in manufacturing metal powder and in the design, development and production of ready-to-install components, is a global pioneer in 3D printing," stated Wolfgang Eder, Voestalpine CEO. "We want to consistently push ahead with our activities in this area by setting up new research and development centres in non-European growth markets."

www.voestalpine.com

Renishaw reports record 2017

Renishaw plc, Gloucestershire, UK, has announced its preliminary results for the year ended June 30, 2017. According to the report, the company achieved a record revenue of £536.8 million, with an underlying growth of 14%.

The company saw a 25% increase in adjusted profits to £109.1 million before tax, compared to £87.5 million in the previous year. Capital expenditure was £42.6 million, of which £24.2 million was spent on property and £18.4 million on plant and equipment. Renishaw's metrology business, incorporating the company's Additive Manufacturing product line, reported revenues of £503.4 million, compared to £398.9 million in the previous year. Growth continued in all sectors, with the Far East achieving the highest level of sales at £237.9 million, up 28%.

Adjusted operating profit for the metrology division was £115.9 million (previous year: £90 million). During this period, the company launched its RenAM 500M Additive Manufacturing system and opened two new AM solutions centres in Germany and the USA.

Renishaw's healthcare segment saw an overall revenue of £33.4 million, up 18% from £28.4 million in 2016. Investment into research and development continued, with total engineering costs reaching £9.2 million compared to £7.9 million in 2016. The company's medical dental product line experienced good growth with a continued focus on the sale of Additive Manufacturing technologies and equipment into the healthcare market. However, despite good growth, the business reported an adjusted operating loss of £7.2 million and has yet to move into profit.

Opening of new AM experience centre in Germany (Courtesy Renishaw)

Renishaw reported that it will continue to invest for the long term and is expanding its global marketing and distribution infrastructure, along with increasing manufacturing capacity and research and development activities. During the past year, the company completed construction on its new US headquarters in Chicago, USA, as well as its new facilities in Detroit, USA, and expanded and refurbished its facilities in Spain, Sweden, Hungary, Germany and France.

www.renishaw.com

H.C. Starck announces new metal powder programme for AM

H.C. Starck Surface Technology and Ceramic Powders GmbH, Laufenburg and Goslar, Germany, is introducing a new range of gas atomised metal powders. Titled AMPERPRINT®, the new range will be designed specifically for metal Additive Manufacturing.

The AMPERPRINT range of powders will include nickel, cobalt and iron based powders of all major standard compositions, as well as customised solutions. According to H.C. Starck, its high-end technology concept will enable production to be ramped up efficiently while keeping physical and chemical powder properties consistent.

For optimal results, H.C. Starck reports that its gas atomised metal Additive Manufacturing powders are fully dense, have an excellent flowability, a spherical shape and high reproducibility. They will be available in a wide range of particle size distributions covering the full range of AM processes, including but not limited to Selective Laser Melting (SLM), Electron Beam Melting (EBM) and Laser Metal Deposition (LMD).

Shashi Shukla, CEO of H.C. Starck Surface Technology and Ceramic Powders GmbH, stated that the introduction of the AMPERPRINT concept is a further milestone to strengthen H.C. Starck's position in the continuously growing AM market. To fulfil customer requirements, H.C. Starck has also launched a new website dedicated to AM.

AMPERPRINT powders from H.C. Starck (Courtesy H.C. Starck)

www.hcstarck.com
www.amperprint.com

Titomic aims to commercialise rapid titanium AM process

Titomic Ltd, Melbourne, Australia, is commercialising a process for the Additive Manufacturing of large scale titanium parts which it claims will be thirty times faster than other metal Additive Manufacturing processes. The new technology, which it calls Titomic Kinetic Fusion (TKF), was jointly developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Force Industries.

The TKF process applies titanium and titanium alloy powders onto a scaffold surface to rapidly produce titanium or titanium/composite products and parts. Due to the nature of the process, powder particles do not need to be of a uniform micron size, as is required in alternative AM techniques. Titomic states that the cost of this powder is approximately a fifth to a tenth of the cost of traditional AM powders, resulting in components up to 50% cheaper.

Jeffrey Lang, Titomic's CEO and CTO, told *The Australian*, "This has been used as a coating technology but we are turning it into an Additive Manufacturing process, so instead of just coating a surface we actually build a part."

A new facility is scheduled to open in December 2017, with trials beginning in the first quarter of 2018. The site in Melbourne will house a TKF system with a 40.5 m^3 build area, reportedly making it the largest Additive Manufacturing machine in the world. "The facility we are building at the moment will have a metal 3D printer that's 9 m x 3 m x 1.5 m, so we are talking about Additive Manufacturing on a scale that no one can comprehend at this stage," concluded Lang.

www.titomic.com

The TKF process applies titanium and titanium alloy powders onto a scaffold surface to rapidly produce titanium or titanium/composite products and parts (Courtesy Titomic)

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GKN adds innovative new metal powder for high strength AM applications

GKN plc has introduced a new case hardening steel powder optimised for metal Additive Manufacturing applications. According to the company, the new 20MnCr5 powder offers high strength and ductility as well as excellent wear resistance. GKN hopes that the material will enable it to explore new markets, especially for spare parts in the automotive sector.

Extensive testing and development has been carried out to optimise AM process parameters for maximum density and productivity and minimum surface roughness. Supported by microstructural analysis and mechanical testing, GKN's researchers state that they have achieved a density of 99.9% in finished parts made from 20MnCr5. While high residual stress can be a challenge, the company states that this too has been successfully reduced through process parameter optimisation. The case hardening process used on 20MnCr5 was also developed with a focus on standard requirements for surface hardness and case-depth profile.

Thanks to its increased core strength and wear resistance, GKN believes that the availability of 20MnCr5 for Additive Manufacturing will benefit a range of components, including gears, camshafts, universal joints and link applications. Following completion of the first small batch of one hundred gear wheels for a leading gear box supplier, the company reports that it has received a number of enquiries regarding the material's AM capabilities and now has several collaborative projects in development.

A primary application for 20MnCr5 will be in aftermarket sales for the automotive industry. The material is highly suitable for the manufacture of spare parts on-demand. GKN will also offer hybrid production, combining AM with different manufacturing techniques to achieve optimum results. A key advantage of 20MnCr5 is its ability to be combined with all weldable materials, making it possible to offer spare parts in low volumes at reduced costs.

"New materials developed by GKN are challenging established paradigms about material performance and robustness. Our cutting-edge materials and innovative manufacturing processes enable us to offer our customers around the world valuable, effective solutions to extreme product challenges," explained Guido Degen SVP Business Development & Advanced Technology.

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Tekna and WeAre Group collaborate to produce metal powders for AM in France

Tekna Plasma Systems, Canada, and WeAre Group, France, have announced plans to begin manufacturing high-quality metal powders for Additive Manufacturing applications in the aeronautics and space industries. Powder production will begin within the existing industrial facilities of Tekna Plasma Europe, Tekna's French subsidiary.

WeAre Group, formed by French companies Chatal, E.S.P.A.C.E., Comefor, Bouy, Ferella and Prismadd, stated that the agreement will enable its companies to secure a powder supply for their metal AM activities. Tekna manufactures turnkey plasma systems used to produce a range of metal powders. In addition to the plasma systems, the company also produces metal powders including Ti64, tungsten carbide powder, tantalum powder and molybdenum powder. Tekna stated that it hopes to leverage the partnership with WeAre Group to consolidate its position in the aerospace and space markets.

www.tekna.com

www.weare-aerospace.com

ExOne reports growth in AM machine sales and expands material options

The ExOne Company, North Huntingdon, Pennsylvania, USA, has released its financial results for the first half ended June 30, 2017. The period has seen Additive Manufacturing machine sales 22% higher than the first half of 2016, with revenue of $8.5 million, up from $7 million in the same period of 2016. Total first half sales were reported at $21.7 million, an increase of 7% on the $20.2 million in the first half of 2016.

ExOne's gross profit for the first half 2017 was reported at $3.6 million, down 33% from the $5.4 million reported for the first half 2016. R&D expense was $4.3 million in the first half 2017 compared with $3.8 million in the first half 2016, with the increase primarily occurring in the second quarter. Adjusted EBITDA was an $8.6 million loss in the first half of 2017, compared with a $5.0 million loss in last year's first half.

Following these results, ExOne revised its 2017 revenue outlook. "We are revising our 2017 revenue outlook modestly, to a range of 20% to 25% growth. Our guidance is based on our backlog and anticipated growth in the second half, particularly in the fourth quarter," stated Jim McCarley, ExOne CEO. "In the third quarter, we expect the Exerial™ beta machine sales will unfavourably impact earnings and we will continue to make investments in organisational and R&D activities. However, we remain convinced that these costs will prove to be good investments and we remain on track to reach positive Adjusted EBITDA by the end of the year. Additionally, we expect a total cash balance in excess of $20 million at year end."

ExOne adds 17-4PH material for binder jet AM

ExOne also announced that it has made available 17-4PH stainless steel (SAE Type 630 / UNS S17400) for metal Additive Manufacturing at its North Huntingdon production service centre. 17-4PH is a chromium-nickel-copper precipitation hardening stainless steel used for applications requiring high strength and a moderate level of corrosion resistance.

The properties offered by 17-4PH are desirable for a wide range of applications in a variety of industries, including aerospace, automotive, defence and medical equipment. Manufacturers who supply components in 17-4PH will now have the opportunity to benefit from the advantages of AM using ExOne's binder jetting technology.

The new addition will complement the other AM-capable stainless steel alloys currently available at the production service centre, which include bronze-infiltrated 420 stainless steel, bronze-infiltrated 316 stainless steel and 316 stainless steel highly sintered.

www.exone.com

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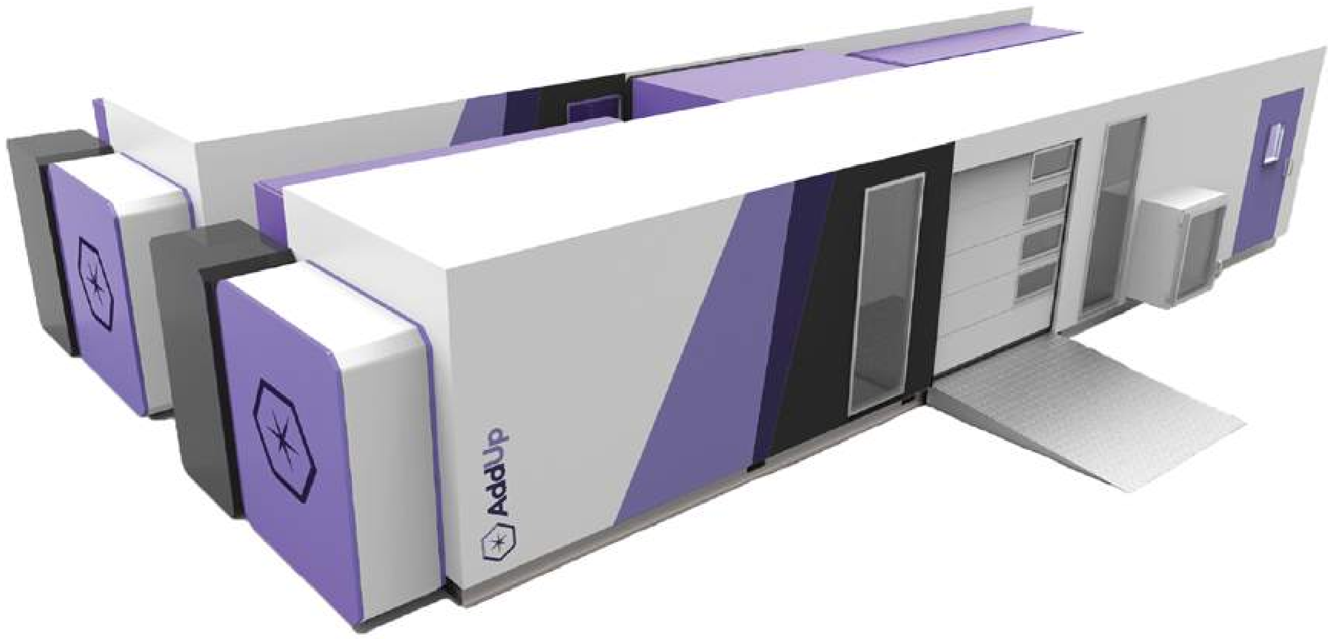

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Airbus and Arconic install first metal AM part on series production commercial aircraft

Airbus and Arconic Inc. have installed a metal additively manufactured titanium bracket on a series production aircraft. The bracket, which is being produced at Arconic's Additive Manufacturing facility in Austin, Texas, USA, is installed on the Airbus A350 XWB, the company's newest widebody commercial aircraft. While aeroplane makers have been using Additive Manufacturing for some time, until recently this has primarily been for components inside the cabin. Equipping airframes with metal AM parts is a newer field.

In addition, the bracket's installation on a series production commercial aeroplane, as opposed to a test aeroplane, marks a significant step forward in the qualification of more complex metal AM parts for production aircraft. While metal additively manufactured cabin brackets and bleed pipes are already flying on Airbus's A320neo and A350 XWB test aircraft, this reportedly marks the first installation of a titanium additively manufactured bracket on a commercial aircraft for series production.

Jeremy Halford, President of Arconic Titanium and Engineered Products, commented, "Arconic is proud to partner with Airbus to advance aerospace Additive Manufacturing. Our comprehensive capabilities, from materials science leadership to qualification expertise, helped make this achievement possible. We look forward to continuing to advance the art of the possible in additive for aerospace."

The bracket is produced at Arconic's AM facility in Austin, Texas

This AM titanium bracket is the latest product of Airbus and Arconic's ongoing partnership, which was founded in December 2016 with the signing of three agreements for Arconic to produce titanium and nickel additively manufactured parts for commercial aircraft, including the A320 platform and A350 XWB.

www.arconic.com
www.airbus.com

Trumpf adds Fraunhofer's extreme high-speed laser deposition welding process

Trumpf, headquartered in Ditzingen, Germany, reports that it plans to incorporate the new Extreme High-Speed Laser Deposition Welding (EHLA) method, developed by Fraunhofer Institute for Laser Technology (ILT), into a number of its Additive Manufacturing systems. According to the company, EHLA is significantly faster than conventional Laser Deposition Welding.

Depending on component size, Trumpf stated that it has various laser machines which are candidates for EHLA. The company's TruLaser Cell 3000 is suitable for small and medium-sized components, while the machines in the TruLaser Cell 7000 Series are suitable for large ones. Apart from these turnkey systems, manufacturers can also integrate the EHLA method into their existing systems.

"For EHLA, we can draw on similar techniques to those we've been using for Laser Deposition Welding," explained Antonio Candel-Ruiz, an expert in laser surface methods at Trumpf in Ditzingen. "The Fraunhofer Institute for Laser Technology developed and patented EHLA with the primary aim of executing coating processes very quickly with low layer thicknesses for rotationally symmetric components."

"For large-area coating tasks, lasers have until now lacked the necessary speed," stated Candel-Ruiz. In addition, the minimum layer thickness achievable using conventional Laser Deposition Welding is around 500 µm. In conventional laser deposition, the laser generates a weld pool on the surface of a component and fuses the metal powder, coaxially added simultaneously, to create the required shape. The powder then fuses with the surface, gradually forming a protective coating.

By contrast, in the EHLA method, the laser strikes the powdery filler material above the weld pool, heating the material nearly to its melting point while it is still on its way to the component. Consequently, the particles melt faster in the weld pool. This makes it possible to use energy much more efficiently.

Whereas normal laser deposition welding can coat only 10-40 cm^2 per minute, the EHLA method achieves rates of over 250 cm^2 per minute. In addition, much thinner coatings with layer thicknesses of 10-300 µm are now possible. What is more, EHLA permits a much finer laser focus, rendering the process considerably more energy-efficient.

www.trumpf.com

GE Additive seeks to certify new AM production partners

GE Additive has announced that it is actively selecting companies to become certified additive production centres for its customers. The company has stated that it is working to certify several companies by the end of 2017, creating a network of additive production capabilities across many industries and regions. The announcement follows a similar agreement in June 2017, where a MoU was signed with Oerlikon, Switzerland, making Oerlikon a GE Additive preferred (non-exclusive) manufacturer.

"We are not currently in the business of making additive parts for other companies," stated Mohammad Ehteshami, Vice President and General Manager for GE Additive. "We want to accelerate Additive Manufacturing by providing machines, materials and engineering consultancy services to them. However, we do recognise that there is a huge demand for additive parts, so we feel that setting up these certified production centres will allow us to meet the growing demand for additive components."

Each certified production partner will operate additive machines from Concept Laser and Arcam, use material from AP&C and benefit from orthopaedic best practices developed at DTI. The centres will be held to the highest quality standards and will receive guidance and advice from GE's additive design and manufacturing experts – enabling them to deliver world-class additive parts and service, the company stated.

www.geadditive.com

Toolcraft selects Simufact to simulate metal AM process

Toolcraft, Hamburg, Germany, has selected Simufact, Georgensgmünd, Germany, to provide metal Additive Manufacturing process simulation software with the aim of optimising its manufacturing techniques. AM processes will now be simulated prior to beginning the build process in order to move from trial-and-error to a more predictive production process.

"We have tested Simufact Additive extensively and saw that the solution is going to help us in our daily practice," stated Christoph Hauck, Managing Director of Toolcraft. "Our clients expect us to examine the feasibility of 3D printing orders in the early project phase – the simulation of the manufacturing process is the key to this."

Simufact Additive calculates distortions and residual stresses within components, shows the risk of aborted build jobs and enables users to minimise the number of physical attempts required to achieve a successful build. The software also covers post-processing simulations including heat treatment, support removal and Hot Isostatic Pressing. So far, the technology has been used primarily in the aerospace and automotive sectors.

www.simufact.com | www.toolcraft.de

Carpenter Technology reports financial results

Carpenter Technology Corporation, Pennsylvania, USA, has announced its financial results for the fourth quarter and fiscal year ended June 30, 2017. Net sales for the fourth quarter 2017 were reported at $507.7 million, said to be the highest achieved in two years. Fiscal year 2017 net sales were $1,797.6 million, down from $1,813.4 million in 2016.

Carpenter's Performance Engineered Product division, the segment of the company that includes the Dynamet titanium business and the Carpenter Powder Products business, achieved net sales in fiscal 2017 of $366.6 million, up from $358.7 million in 2016. Operating income for this division was $8.5 million, compared to a $5.5 million loss in the previous year.

"Overall, fiscal year 2017 was a successful one as we continued to build upon our foundation for long-term sustainable growth through our progress in becoming a complete solutions provider, as well as our expansion in core growth areas including titanium powder and Additive Manufacturing," stated Tony Thene, Carpenter's President and CEO.

www.cartech.com

New plasma atomisation process for MIM cut powders from PyroGenesis

PyroGenesis Additive, a division of PyroGenesis Canada Inc., Montreal, Canada, reports that it has developed a new plasma-based process to produce metal powders which will enable MIM cut powder production at higher volumes. According to the company, the new process may have a greater impact on the powder production market than its original plasma atomisation technology, developed in 2001. The company stated that whilst 'MIM cut' is a particularly small metal powder size, traditionally used for Metal Injection Moulding (MIM), and usually features particle sizes between 5-20 µm, it has in recent years become increasingly used in binder jet AM systems.

PyroGenesis has previously produced powders for Electron Beam Melting and Laser Sintering, while MIM cut has until recently been considered an undesirable by-product of the company's standard plasma atomisation process, which produces powders in the 15-106 µm range.

Peter Pascali, President and CEO of PyroGenesis, stated, "Several months ago, the company was approached by a number of companies who were interested in MIM cut titanium powder, whereby it became apparent to us that the appetite for this ultra-fine powder was significant. As a result, we decided to make adjustments to our plasma atomisation technology in order to try and shift the particle size distribution towards the low end of the spectrum and produce powders in the range required."

According to Pascali, the new plasma atomisation process has the ability to produce extremely narrow size distributions which can easily be shifted to any particle size required for Additive Manufacturing. It gives the company significant control over powder sizes produced and offers higher powder production rates at lower cost. "MIM cut powders can now be produced in very large quantities with little-to-no waste," he stated, "thereby growing with and enabling those requiring ultra-fine powder and meeting their strategic growth needs. We believe this breakthrough is, if not more significant, then at least as significant as our original plasma atomisation technology," he added. "We believe we have not even scraped the surface of what this new process can do with regard to production rates and powder quality."

Pascali added that PyroGenesis Additive now produces MIM cut titanium powder Grade 5, the grade currently requested for use in Binder Jet AM. The new process also has the potential to produce MIM cut titanium powder at Grade 23, the highest grade titanium powder.

www.pyrogenesis.com

Volkswagen pick-up fitted with additively manufactured front-end structure

Altair, APWorks, CSI Entwicklungstechnik, EOS GmbH, Gerg and Heraeus have used the front-end structure of a classic VW Caddy pick-up to demonstrate the full potential of industrial Additive Manufacturing in the automotive industry.

The final structure is very light, stable and at the same time features a high degree of functional integration. In this joint development project known as 3i-Print, the companies involved covered every step of the development process, from design, simulation, optimisation and manufacturing to post-production of the part. From conceptual design to final vehicle, the project was completed in only nine months.

The value of Additive Manufacturing for the automotive industry

Driving innovation and impacting decisive development processes, metal AM will play an integral role in large-scale manufacturing over the next few years. The technology is already being deployed in a wide range of industries and the constant evolution of production and design techniques using AM will make the technology even more cost-effective and efficient in the future. As such, the use of industrial metal AM will continue to grow, particularly in the automotive industry.

The true value proposition of Additive Manufacturing in automotive engineering can only be realised with considerations extending far beyond structural mechanics and lightweight construction. This functional integration – implementing as many technical features as possible with as few components as possible, with the resulting added value – is an additional key advantage that makes the use of AM lucrative for the automotive industry. With the Caddy concept, the 3i-Print project aims to demonstrate future technological possibilities.

Organic design for load-bearing structures

In view of the growing trend towards electrification in the automotive sector, heat management as well as the reduction of design space and overall weight were crucial factors when designing the front-end section. Moreover, structural requirements relating to vehicle safety, performance and comfort needed to be addressed.

Accordingly, parts of the additively manufactured front are load-bearing structures that include details for both active and passive cooling – for example with a channelled airflow to cool batteries and brake systems. In addition, functions linked to heat management, passive safety and fluids storage have been integrated in the organic, load-driven design of the front-end module (Fig. 1).

Combined expertise along the process chain

With these goals in mind, the experts at CSI Entwicklungstechnik began designing, developing and building the front-end structure. The company develops high-quality modules for vehicle bodies, interiors and exteriors for both manufacturers and suppliers in the automotive sector.

Fig. 1 The front-end structure of this VW Caddy has been completely redesigned using Additive Manufacturing

Fig. 2 A number of components prior to removal from the build plate

Gerg is a leading supplier of innovative solutions in the area of prototyping and small-scale series for the automotive and aerospace industries. In this project Gerg was responsible for connecting the additively manufactured components and the creation of the final frame.

With its focus on the development and broad application of simulation technology to synthesise and optimise designs and processes, Altair's software solutions were used to design, optimise, simulate and develop the structure.

After the successful simulation and design of the concept, APWorks took care of the final dimensioning of the components for AM. APWorks contributed its knowledge of file preparation and handled the actual Additive Manufacturing of the structural elements (Fig. 2). As a subsidiary of Airbus, the company is very familiar with state-of-the-art manufacturing processes and enables various industries to implement best practice concepts from the aerospace sector.

When producing the front end, APWorks relied on a system developed by EOS, a leading technology supplier of the industrial AM of both metals and polymers. Metal powder specialist Heraeus supplied and qualified the high-strength aluminium alloy Scalmalloy®, developed by APWorks, to manufacture the components. APWorks provided support for the manufacturing process by developing the ideal parameter sets for the EOS M 400 system. Thanks to the combined use of AM and this innovative material, the project is said to successfully demonstrate the possibilities of functional integration that traditional manufacturing methods are unable to offer (Fig. 3).

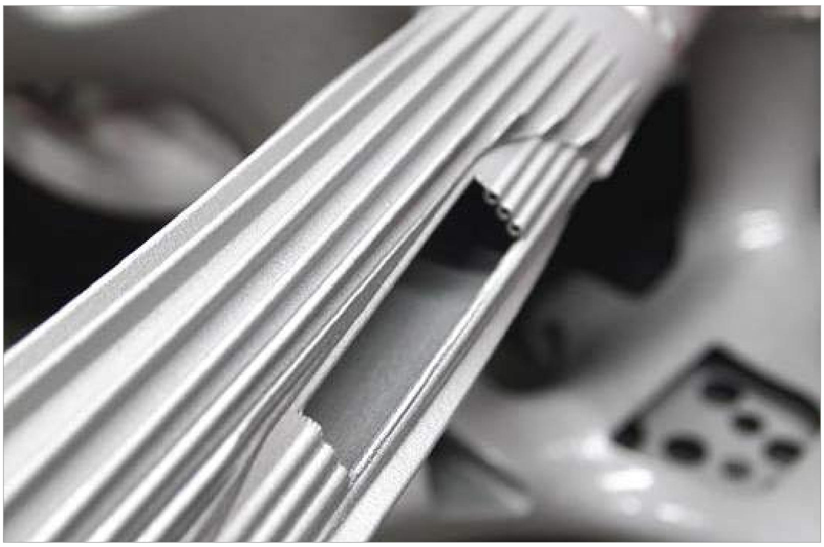


Fig. 3 Detail showing the complexity of the AM structure

The 3i-PRINT project, a forum for innovative prototype concepts

Initiated by CSI Entwicklungstechnik, the 3i-Print project acts as an agile engineering platform for research and development enabling innovative prototype concepts. The idea is based on the use of new development tools and methods, including industrial AM. The project's goal is to demonstrate and fully exploit the potential of state-of-the-art manufacturing methods. The 3i-Print project is an open platform for collaboration that quickly enables the implementation of new ideas.

Stefan Herrmann, responsible for light weight design within the body in white team at CSI, stated, "We are proud to present the Caddy with an exemplary new additively manufactured front-end structure. The new structure and the contrast between old and new impressively demonstrates the potential that 3D printing and functional integration offer, particularly for the automotive industry."

Herrmann continued, "I would also like to emphasise the agile, time-efficient route from the initial idea to the fully converted vehicle, which was completed within only nine months. Each of the participating companies is a leader in its field. The outstanding collaboration and combined expertise has made the 3i-Print project a resounding success."

Among other events, the Caddy can be viewed at formnext 2017 in Frankfurt, Germany, November 14-17, 2017.

www.3i-print.com

Indutherm focuses research efforts on lightweighting and steel alloys for AM

Powder production and classification technology company Indutherm, Walzbachtal, Germany, has reported that is involved in a number of research projects relating to lightweighting and innovative steel alloys for laser-based metal AM. The lightweighting of parts in automotive and aerospace applications offers significant opportunities; however, according to Indutherm, the availability of suitable metal powders for laser-based AM can mean that components which would benefit from the technology can't be manufactured in this way.

Laser Additive Production of High-Strength Aluminium Structures (LHASA ZIM) is a network project aimed at the development and qualification of new aluminium alloy powders for the metal AM of high-strength components. In its role in the project, Indutherm is focused on developing an explosion-proof powder atomising system for aluminium alloy powders. While the company's existing systems are suitable for a wide range of alloys (based on Cu, Fe, Co, Ni, Pd, etc), highly reactive metals and alloys impose new requirements on the design of spraying systems. According to Indutherm, the key to developing a new, safer gas atomisation plant is to anticipate the behaviours of new alloys during atomisation and use these assumptions as the starting point for the new design. At present, a pilot plant is being put into operation at the University of Bremen, Germany, allowing initial validation tests and process development.

The StahlVarianz project is sponsored by the German Ministry of Education and Research and relates to the development of continuous process chains for the laser-based AM of complex, varied and highly functional products using innovative steel materials. In its role, Indutherm is primarily concerned with the development and testing of plant and process technology for powder atomisation that meets most of the requirements imposed on alloys and their applications. An additional aim of Indutherm's research is to increase the output of metal powders suitable for use with laser-based AM systems and to avoid satellite formation. The research includes the melting, atomisation and characterisation of alloy variants to establish process parameters.

Having recently joined the Transatlantic Cluster for Lightweight project, the company states that it now hopes to form new transatlantic partnerships, gaining access to the world's largest research institutes for lightweighting technologies.

www.indutherm.de

NanoSteel launches new tool steel for metal Additive Manufacturing

NanoSteel, Rhode Island, USA, has announced the launch of its first tool steel developed for the laser powder bed fusion Additive Manufacturing process. BLDRmetal™ L-40 is a case-hardening steel powder that provides high hardness and ductility (case hardness >70HRC, 10%+ core elongation) and is said to print easily on standard commercial equipment. The alloy reportedly provides superior performance to M300 maraging steel and offers an alternative to difficult-to-print tool steels such as H13. According to NanoSteel, BLDRmetal L-40 is designed to be used for parts including tools, dies, bearings and gears.

NanoSteel demonstrated the new tool steel's capabilities by printing a 20 cm roll thread die set, which it states outperformed dies machined from D2 and M2 tool steels. "We tried nearly every combination of material and conventional CNC machining process to create our dual-thread die sets, none of which could cut or grind the complicated dual-thread geometry," stated Mark Doll, President and CEO of Perfect Lock Bolt America Inc., a manufacturer of self-loosening resistant dual-thread fasteners. "The NanoSteel solution delivers exactly what we are looking for, including excellent surface finish, flexibility, as well as strength and hardness for maximum die life. This is a welcomed technological innovation to the fastener industry. We have been pleased with our testing and are slated to start production this year," he concluded.

NanoSteel developed this high hardness alloy through rapid development at CFK GmbH, a leading AM service provider whose expertise NanoSteel says was instrumental in developing the die from concept to finished part. "For us, the most important attributes of NanoSteel's BLDRmetal L-40 are that it is easily implemented and creates crack-free high hardness components, which sets it apart from the many other tool steels we have tested," commented Dr-Ing Christoph Over, CEO of CFK.

Harald Lemke, Vice President and General Manager of NanoSteel Engineered Powders, stated, "Launching BLDRmetal L-40 after successfully producing the roll thread dies ensures the commercial viability of the new alloy for customers investigating the use of AM. We don't stop at material design, but create joint solutions with our customers, facilitating the process from material selection and prototyping to fully qualified production parts."

www.nanosteelco.com

Desktop Metal partners with Morris Group for distribution in thirty US states

Desktop Metal, Massachusetts, USA, has selected Morris Group, Inc., Connecticut, USA, as a top tier 'Diamond Partner' supplier of metal Additive Manufacturing systems in thirty US states. Desktop Metal's Studio System™ will be the first AM system Morris Group, traditionally a CNC machining supplier, has made available to its customers.

"We are very pleased to represent Desktop Metal and excited to introduce this ground-breaking 3D printing technology to metal cutting manufacturers in our distribution area," stated Brad Morris, President and CEO of Morris Group. "Our organisation brings more than seventy-five years of manufacturing experience, knowledge and customer support to the table."

The Studio System uses Bound Metal Deposition, a proprietary process, to build near net shape parts. The Studio System features swappable media cartridges and quick release print heads for seamless material changes, and was designed for use with a variety of materials from steels and copper to superalloys such as Inconel.

www.desktopmetal.com
www.morrisgroupinc.com ■■■

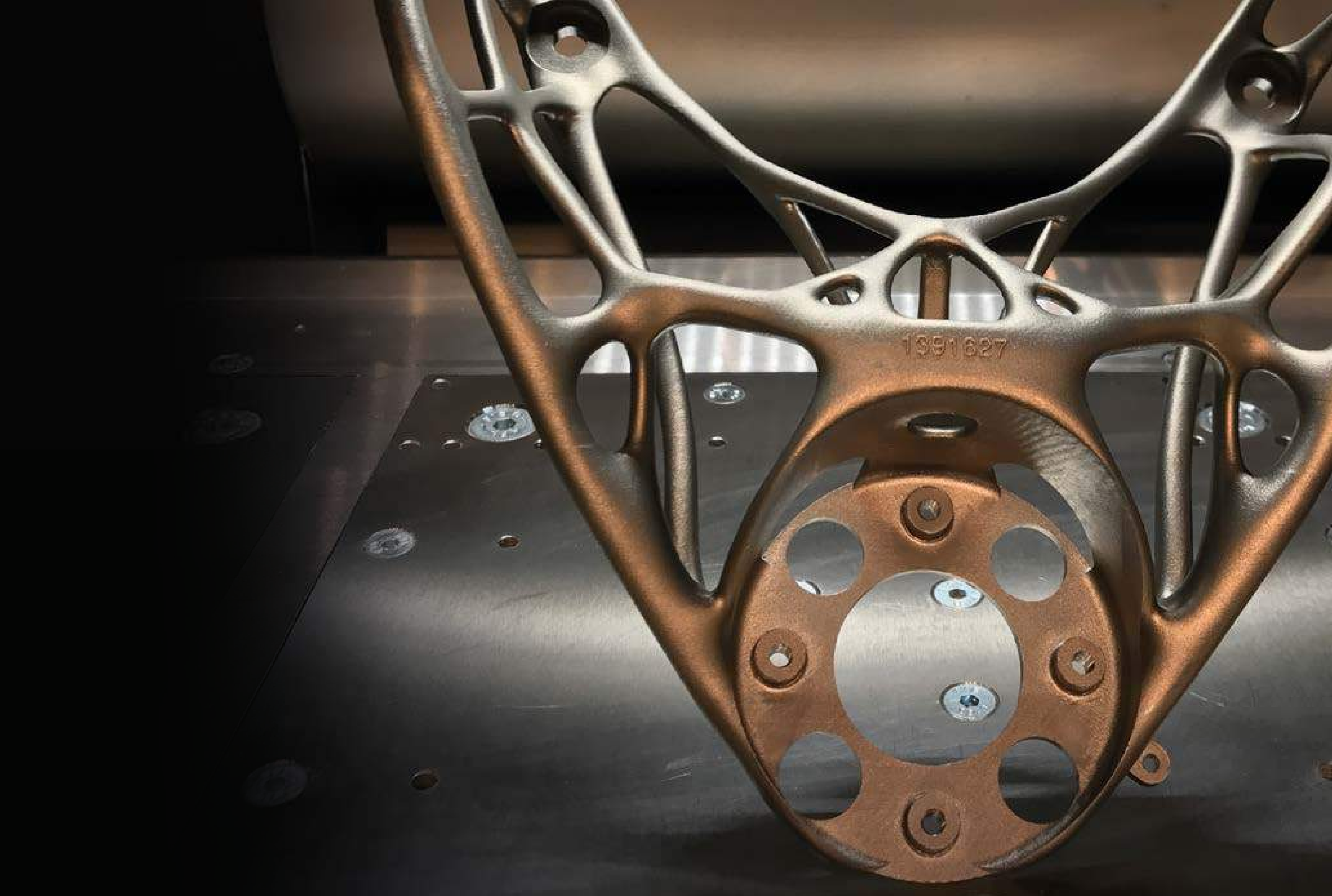
Sciaky adds Siemens PLM software

Sciaky, Inc., Chicago, Illinois, USA, has announced that it will adopt Product Lifecycle Management (PLM) software technology from Siemens to support its Electron Beam Additive Manufacturing (EBAM) system. The adoption of Siemens PLM software is expected to enable Sciaky to offer its current and future customers a solution that integrates with the same technology used by companies globally, to enhance product development decision making and produce better products.

Among the Siemens software which will now be available to Sciaky's customers is NX™ software, an integrated solution for CAD/CAM/CAE, and NX™ Nastran®, a CAE analysis solver technology. Bob Phillips, VP Marketing at Sciaky, commented, "Sciaky is excited to join Siemens PLM Software's partner community. The strength of our two organisations working together will deliver significant value to our customers."

Sciaky's EBAM systems can produce parts ranging from 8 in (203 mm) to 19 ft (5.79 m) in length, at gross deposition rates ranging from 7-20 lbs (3.18-9.07 kg) of metal per hour. The company produces components in titanium, tungsten, tantalum, Inconel, nickel alloys, niobium and stainless steels.

www.sciaky.com ■■■



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Thales opens metal Additive Manufacturing facility in Morocco

French aerospace company Thales has opened a new Additive Manufacturing facility in Casablanca, Morocco. The 'Industrial Competence Centre' will specialise in metal AM and currently houses two Selective Laser Melting (SLM) systems. The company reports that it will use these machines to produce an initial series of metal AM parts in aluminium and titanium, widely used in the aerospace sector. In the medium-term, Thales is planning to acquire ten machines.

The opening of the centre forms part of the Kingdom of Morocco's Industrial Acceleration Plan 2014 to 2020, which supports the development of an innovative ecosystem involving Thales and its local suppliers. Spread across an area of 1000m², in the Midparc zone in Casablanca, the facility is expected to employ around twenty engineers and technicians in the future.

Thales has a long-standing partnership with Morocco. The company opened its local office in Rabat in 2006 and is active in Morocco in defence, aerospace, transportation and security, and has forty-five employees in the country. "With an existing aerospace ecosystem of subcontractors, Morocco has everything needed to become Thales' global centre of expertise in Additive Manufacturing," stated Pierre Prigent, Thales Country Director in Morocco. "The use of a secure digital platform provides the industrial Competence Centre with the latest innovations in terms of connected industry and smart plants, and will improve the competitiveness of the solutions offered to our customers."

Moulay Hafid Elalamy, Morocco's Minister of Industry, Investment, Commercial and Digital Economy, added, "Thales is bringing state-of-the-art technology and a high added value profession to Morocco: it is a genuine source of pride for us to deliver this leap forward to the country's industrial sector. This new project is proof that the Moroccan economy is achieving a diametric shift in its industrial sector, which is driving the creation of highly specialised jobs in the country."

www.thalesgroup.com ■■■

Thales has opened a new Additive Manufacturing facility in Casablanca, Morocco (Courtesy Thales Group)

DMG MORI launches new metal Additive Manufacturing machine

DMG MORI CO., LTD., Nagoya City, Japan, has begun taking orders for its new Lasertec 30 SLM metal Additive Manufacturing machine. The system was developed in collaboration with Germany's Realizer GmbH, which joined the DMG MORI Group in February this year.

According to DMG MORI, the Lasertec 30 SLM can achieve highly accurate Additive Manufacturing with a build volume of 300 × 300 × 300 mm and a layer thickness of 20-100 µm, enabling users to manufacture small workpieces such as impellers and dental crowns. The machine is said to be especially suitable for the production of high-mix, low-volume parts or complex-shaped workpieces.

The Lasertec 30 SLM is also DMG MORI's smallest AM system to date. Its small footprint was reportedly achieved by incorporating fewer movable axes and simplifying overall machine construction. The new machine employs a cartridge-type powder material supply and collection system, which is said to make it possible to achieve powder recycling rates of 95%–98%.

www.dmgmori.co.jp ■■■

PSI celebrates thirty years in gas atomisation technologies

In 2017, Phoenix Scientific Industries Ltd (PSI), Hailsham, East Sussex, UK, celebrates its thirty year anniversary. The company is best known for its activities in gas atomisation equipment for the production of metal powders and, in particular, close-coupled atomisation for very fine powder manufacture.

PSI was founded in 1987 with the goal of developing gas atomised metal powders for the then-emerging Hot Isostatic Pressing (HIP) industry. Since then, the company has continuously developed its technology in response to the evolving application areas for gas atomised metal powders, notably in the Metal Injection Moulding industry and more recently in metal Additive Manufacturing processes.

The company was founded by Bill and Jan Hopkins and backed by Lucius Cary of venture capital company Oxford Technology. It has grown from building small research machines for universities to supplying multi-million dollar production systems for large corporations. Today, the company has installed systems in twenty one countries on seven continents. PSI has a history of devoting much of its resources to R&D, believing that innovation is the key to success in a world of ever faster technology dissemination. To date, the company has been involved in research projects internally, single-client and collaboratively, both in the UK and internationally.

A sister company to PSI, Metal Powder and Process Ltd (MPP), was recently formed with the purpose of developing and producing novel powder alloys for demanding applications, placing the company in a strong position to address world demand for new PM applications requiring high purity spherical metal powders. PSI is also involved in a number of collaborative research projects addressing the need to develop new advanced metal powders and innovative production processes, as well as building a knowledge base on how these powders perform in today's advanced applications.

The Autumn 2017 issue of PIM International features an in-depth report on PSI's thirty-year story and recent move into metal powder production. For more information on the company and its developments, download your free copy of the digital edition here.

www.psiltd.co.uk

PSI's production-scale Hermiga system (Courtesy PSI Ltd)

AM components feature in new Ariane 6 Vinci thrust chambers

The latest generation of the Ariane space rocket launcher, scheduled to enter service in 2020, will reportedly offer an increased payload carrying capacity and the flexibility to perform a wide range of missions with high reliability. Production has now begun on the rocket's Vinci engine at ArianeGroup (formerly Airbus Safran Launchers) in Ottobrunn, Germany. The Vinci engine, which is incorporated in the upper stage of Ariane 6, will take over thrust capacity once the rocket has escaped Earth's gravitational field using its main stage and solid fuel boosters. The engine has been designed to be both energy-efficient and reignitable, crucial for ensuring optimal propulsion in space.

Both Powder Metallurgy and Additive Manufacturing techniques are used to manufacture components in the Vinci engine, which the engine's designers report improve cost and time efficiency. "These two methods have substantial advantages compared to cast or forged products, as components involving complex structures can be produced in large numbers, without the need for mechanical reworking," stated Denis Regenbrecht, who is responsible for the Ariane programme at the DLR Space Administration, Germany. "The elimination of expensive manufacturing stages and simplification of the engine structure have cut the costs significantly."

Cost-efficiency measures such as these are said to be imperative to the production of all space equipment, which must be economically viable as competition to provide space-faring technologies increases and economic support is withdrawn. "European launcher systems face growing levels of competition in global markets," continued Regenbrecht, "which will intensify the price pressure in future. Ariane 6 is a response to this situation, as its launch costs will be approximately half of what they were with its European predecessor, Ariane 5."

www.arianespace.com

www.dlr.de

Vinci thrust chambers for the new Ariane 6 (Courtesy DLR)

Camber Spine Technologies receives FDA clearance for AM implants

The SPIRA Open Matrix ALIF implant

Camber Spine Technologies, Wayne, Pennsylvania, USA, has announced that it has received 510(k) clearance from the US Food and Drug Administration (FDA) to market its SPIRA™ Open Matrix ALIF device, a unique, interbody fusion implant consisting of spiral support arches and Surface by Design™ technology. This clearance marks Camber's tenth line of spinal implant systems to be released in the US market.

SPIRA was designed specifically to increase fusion rates and stabilisation and the spiral support arches decrease subsidence by load sharing over the entire endplate, while also maximising bone graft capacity. The Surface by Design technology is a deliberately designed roughened surface that facilitates bone growth through an optimised pore diameter, strut thickness and trabecular pattern.

"Camber Spine is very excited to be launching our first in a series of spinal implants using [...] Additive Manufacturing. This specialised manufacturing technology allows us to create these truly unique patented structures featuring open arched matrices and proprietary surfaces designed to enhance fusion and promote bone growth. In the coming months we will be launching a series of five SPIRA spinal interbody cages for cervical, lateral and posterior lumbar spine. Extremity implants and custom implants for salvage and complex deformity implants are also under development," stated Daniel Pontecorvo, CEO of Camber Spine.

"We believe that the addition of SPIRA and ENZA MIS Integrated interbody devices to our product portfolio create a foundation of patented implant solutions that will drive the growth of Camber Spine," Pontecorvo added.

The Camber Spine SPIRA Open Matrix ALIF is indicated for use in skeletally mature patients with degenerative disc disease at one or two contiguous levels from L2-S1. SPIRA Open Matrix ALIF is intended to be used with additional FDA-cleared supplementary fixation systems.

www.cambermedtech.com

First metal AM spare parts produced at Mercedes-Benz Trucks

Mercedes-Benz Trucks, Stuttgart, Germany, has produced and successfully tested its first metal additively manufactured spare part. The part, a thermostat cover, will now enter service on trucks and Unimog models from older series. The manufacture of the company's first successful metal AM replacement part follows the production of a number of polymer AM components.

Mercedes-Benz Trucks began developing its metal Additive Manufacturing process with the production of rarely-ordered aluminium parts. Using AM, the company was able to achieve parts with almost 100% density, greater purity than conventional die-cast aluminium parts, very high strength and thermal resistance – making the process particularly suitable for small batches of mechanically and thermally stressed components.

With the addition of metal AM technology, Mercedes-Benz Trucks' ability to quickly meet orders for replacement parts will be greatly enhanced. In the past, the production of metal replacement parts has been dependent on the availability of the type of tool used in their original manufacture, making the cost of obtaining replacement parts for older models prohibitively high, especially in small batches. The use of AM has the potential to allow the geometry of parts to be input and reproduced using the same universal platform, making their production cost-efficient even at low quantities.

"Mercedes-Benz Trucks is reasserting its pioneering role among global commercial vehicle manufacturers," stated Andreas Deuschle, Head of Marketing & Operations in Customer Services & Parts at Mercedes-Benz Trucks. "We ensure the same functionality, reliability, durability and cost-effectiveness with 3D metal parts as we do with conventionally produced parts."

This means that even for classic models, high-quality replacement parts could soon be available worldwide. The new thermostat cover, for example, is only used in truck and Unimog models whose production ceased around fifteen years ago. This part can now be delivered affordably to any country on request, in the required numbers and at consistent quality.

The availability of low-volume production processes also has the potential to eliminate the need for high-cost warehousing and high-volume transport of large batches of 'back-up' replacement parts for discontinued models, further reducing part costs and delivery times for both company and customers.

www.mercedes-benz.com

Mercedes-Benz Trucks' first metal AM spare part (Courtesy Daimler AG)

VBN Components supplies wear resistant AM materials to water-powered drilling project

The EIT RawMaterials consortium, Berlin, Germany, has financed a collaboration between Swedish-based companies VBN Components and LKAB Wassara to use VBN's unique wear resistant materials for the Additive Manufacturing of water-powered drilling equipment. The aim of the project is to facilitate more rapid product development for LKAB Wassara.

VBN's range of wear resistant metal AM materials, titled Vibenite®, consists of Vibenite 150, a multipurpose material with a hardness range of approximately 55-63 HRC, Vibenite 280, a material well suited to cutting applications with a hardness range from approximately 63-70 HRC, and Vibenite 350, a stainless material with high hardness and high chromium content.

According to VBN, the collaboration with LKAB Wassara has so far produced part of a thin walled DTH (Down-the-Hole) Hammer using metal Additive Manufacturing, with further testing necessary to verify the tool's properties. If necessary, the design will be optimised, material-wise and geometrically, before further development.

"Our expertise in material properties, combined with the flexibility of 3D Printing, allows us to easily adjust the production process according to our clients' needs," stated Martin Nilsson, CEO of VBN Components. "We combine the excellence of LKAB Wassara with our own know-how to develop new methods within water-powered drilling."

www.vbncomponents.se

VAC-U-MAX introduces compressed-air powered vacuum system

VAC-U-MAX, located in Belleville, New Jersey, USA, has announced the latest addition to its industrial vacuum cleaning range for combustible dusts. The new MDL15 Air-Vac features the exclusive VAC-U-MAX Venturi power unit, reported to offer the lowest compressed-air consumption on the market today.

The MDL15 features a 68 litre collection drum and, with no electrical components or moving parts, is said to be ideal for high volume recovery of fine powders and combustible dusts. The system features manual blow-back filter cleaning with static-conductive PTFE pre-filter and secondary cartridge filter, and static-conductive casters. Dust, debris, and fine powders are collected in off-the-shelf static-conductive polybags, eliminating the common issue of a 'mushroom cloud' that comes with drum dumping.

The MDL15 is equipped with a static-conductive compressed-air hose, ATEX-certified vacuum hose and complete cleaning tool kit assembly for floors, walls, machinery and overhead cleaning.

www.vac-u-max.com

Elcan celebrates 25 years and reports new method for metal powder recycling

Elcan Industries, Tuckahoe, New York, USA, is celebrating 25 years in metal powder classification. Since its founding, the company has expanded from a small warehouse in New Rochelle, New York, to its current Tuckahoe facility, which comprises state of the art test labs, toll processing and complete sales support.

The company recently reported that it has developed a new method for recycling powders for AM which uses the company's Hi-Sifter sieve technology. The system is aimed at reducing the time it takes to recycle powders for Additive Manufacturing. The equipment is completely stainless steel and is reportedly the only equipment on the market capable of achieving efficiencies of 98+% in a single pass.

Elcan offers its recycling equipment for sale as well as offering companies the opportunity to send powders to its Tuckahoe facility for sieving. This could allow companies to regain value from powders which are in storage or awaiting lengthy recycling.

www.elcanindustries.com

CalRAM receives Nadcap accreditation for metal AM

CalRAM, California, USA, has been awarded Nadcap accreditation for Additive Manufacturing by the Performance Review Institute (PRI). According to CalRAM, this is the first-time a company has received dual accreditation for Laser Powder Bed Fusion and Electron Beam Powder Bed Fusion.

As well as possessing Nadcap accreditation, CalRAM is AS9100 certified. Shane Collins, CalRAM's Director of Additive Manufacturing Programs, commented, "Four months after stating our intent to pursue accreditation, to receive this critical milestone in pursuing AM excellence is a phenomenal feat, particularly noting this has been completed on the very first attempt."

Sergio Hernandez, Director of Quality Assurance for the initiative, added, "This accreditation is a critical strategic element for CalRAM to reinforce our high standards of excellence in the AM community".

Nadcap is a global co-operative accreditation program for aerospace engineering, defence and related industries. Accreditation is industry-managed and brings together technical experts from both industry and government to establish requirements for accreditation, accredit suppliers and define operational programme requirements.

calraminc.com

Additive Industries expands team

Dr Mark Beard (Courtesy Additive Industries)

Additive Industries, Eindhoven, the Netherlands, has announced that Dr Mark Beard has joined the rapidly expanding Additive Manufacturing machine maker and software developer. The former Technical Director at 3T RPD, a leading UK provider of metal Additive Manufacturing services, Beard will head the growing Process & Application Development team at Additive Industries.

"With over ten years of experience in Additive Manufacturing Mark will play an important role in execution of our ambition to become a top three OEM of industrial metal Additive Manufacturing systems," stated Daan Kersten, CEO of Additive Industries. "In his position he will contribute significantly to the success of the business cases of our customers in demanding markets like automotive, aerospace, medical implants and high tech equipment parts."

Beard holds a Master degree in Mechanical Engineering and a PhD in Material Science from the University of Exeter, UK. "I am very happy about joining such a dynamic and progressive company. I look forward to being part of all the future exciting developments they have planned," added Beard.

Additive Industries produces the MetalFAB1, reported to be the first integrated metal Additive Manufacturing machine that, in addition to its core 3D print process, adds heat treatment, automated build plate handling and storage in the industrial grade production system. The MetalFAB1 uses a powder bed fusion AM process with multiple lasers.

www.additiveindustries.com

DP Technology launches ESPRIT® Additive Suite for process simplification

DP Technology, Montpellier, France, has launched the ESPRIT® Additive Suite, designed to simplify the full Additive Manufacturing process, from CAD model to final part. According to DP Technology, the suite features programming, optimisation and simulation for direct metal deposition, powder bed and subtractive manufacturing. It is expected to be available to customers beginning in mid-2018 and will reportedly deliver machine-optimised job files and complete control of the Additive Manufacturing process.

For hybrid machine tools — CNC machines with additive capabilities — the ESPRIT Additive app for direct metal deposition will offer integrated programming and simulation for multi-tasking, multi-function, multi-channel additive and subtractive machine tools and integrate with the ESPRIT CAM system.

The ESPRIT Additive app for powder bed fusion systems will operate as a versatile printer driver to support the full process of Additive Manufacturing, from orienting the part and creating supports to optimising the build, slicing and nesting and generating a job file.

"This decade has been characterised by the widespread, mainstream use of 5-axis machining processes, but we are about to enter the decade of additive: within ten years, we anticipate that ten percent of machines will have additive capabilities," stated Chuck Mathews, Chief Technology Officer and Executive Vice President at DP Technology.

"We are redefining the meaning of 'full-spectrum' with the ESPRIT Additive Suite, which provides a new workflow and new process for a new class of machines, both additive and hybrid."

www.espritadditive.com

3D Metalforge receives ISO accreditation for maritime, oil & gas and energy

Metal Additive Manufacturing company 3D Metalforge, Singapore, has been awarded ISO 9001:2015 certification by DNV GL, a global accredited third party certification body focused on the maritime, oil & gas and energy industries.

The accreditation recognises 3D Metalforge for its understanding of the industry's requirements and its consistent and sustainable business approach. According to DNV GL, the ISO9001 standard emphasises risk-based thinking and promotes the adoption of a process-oriented approach.

With ISO9001 certification, 3D Metalforge stated that it will be able to enhance business sustainability and customer satisfaction, as the associated reduction in errors offers benefits in terms of cost and waste savings. The certification is also a recognition of 3D Metalforge's ability to build stakeholder trust by delivering products and services that meet customer, statutory and regulatory requirements.

Matthew Waterhouse, 3D Metalforge CEO, commented, "We understand that quality standards as well as consistent and sustainable business practices, are top priorities for most of our world-class customers. Through our strong partnership approach, 3D Metalforge hopes that our ISO9001:2015 certification will provide added confidence to our customers and stakeholders as we collaborate to jointly navigate new opportunities and challenges in the world of metal Additive Manufacturing."

www.3dmetalforge.com

EOS launches stainless steel 17-4PH powder

Additively manufactured prototype (apart from the internal springs), produced with the EOS StainlessSteel 17-4 PH (Source: Exactech)

EOS GmbH has announced the launch of its StainlessSteel 17-4PH IndustryLine metal powder for use in its metal Additive Manufacturing systems. The material consists of an iron-based alloy powder and a specially developed process parameter for manufacturing on the EOS M 290 metal system.

The StainlessSteel 17-4PH IndustryLine powder is said to be a high-strength, easily curable, highly corrosion- and acid-resistant material, which is therefore ideal for manufacturing surgical and orthopaedic instruments. Parts can be additionally processed, micro-blasted and polished directly after the Additive Manufacturing process or after heat treatment.

The quality of each batch of the metal powder delivered is guaranteed by quality assurance processes, which are reported to be parts of the extensive quality management system used at EOS for systems, powdered materials and processes.

"We were impressed by both the quantity and quality of the data that EOS provided for its IndustryLine process and material," stated Zachary Bryan, PhD, test developer and metallurgist at the US-based customer Exactech. "We have manufactured various instruments based on EOS StainlessSteel 17-4PH IndustryLine and achieved the desired material properties. Exactech is planning to use this material for the small-scale manufacturing of medical instruments and intends to do so in collaboration with EOS."

"Planning security and reliability are top priorities for customers who are engaged in serial manufacturing. For its StainlessSteel 17-4PH IndustryLine, EOS provides reliable and statistically proven data for the most important material properties of finished parts," stated Dr Tobias Abeln, Chief Technical Officer at EOS.

"This significantly raises quality standards in Additive Manufacturing. The customer can use the data 1:1 to qualify the technology for large-scale production and therefore minimise the time required as well as cut the cost of in-house material and process qualification," concluded Abeln.

www.eos.info


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Italian project to focus on industrial integration of metal AM

A new project is being established in the Lombardy region of Italy to focus on the integration of metal Additive Manufacturing technology within industry. The Metal Additive for Lombardy (MADE4LO) project will consider the entire value chain, from equipment supply to the finished product, creating a new model for an AM factory.

The project will last thirty months and has received a total investment of €6.6 million. There are eleven partners in the project, including two universities (Politecnico di Milano and Università di Pavia), three large industrial companies (Tenova, BLM, and GF Machining Solutions) and six SMEs (TTM Laser, 3D-NT, GFM, Fubri, Co. Stamp, and Officine Meccaniche G. Lafranconi).

A pilot line is to be established at the Politecnico di Milano with three demonstrator AM systems for different classes of applications. A heat treatment furnace will be installed at Tenova's Pomini factory. Integrated systems, demonstrating additive and subtractive finishing, will be provided by GF and a metal powder atomiser will be at CSM in Castel Romano. The project will create a network of R&D accessible to SMEs in the region.

www.regione.lombardia.it

Chinese surgeons use titanium AM to replace cervical vertebrae

(Photo: Thepaper.cn)

Surgeons at a hospital in Shanghai, China, have completed what is claimed to be the world's first cervical vertebrae replacement operation with additively manufactured titanium bones, reports the *People's Daily Online*.

The 28-year-old patient was diagnosed with chondrosarcoma, a rare type of bone cancer that attacks cartilage. A tumour was found on her neck, encroaching on six of the seven bones of the cervical vertebra. Doctors at Shanghai Changzheng Hospital decided to remove all six bones and replace them with additively manufactured alternatives.

The team, led by specialist spinal surgeon Xiao Jianru, chose titanium alloy and used AM technology to produce patient specific customised bone replacements.

http://en.people.cn

EU-funded project launched for development of Al alloy for structural aircraft parts

An EU-funded project, AlForAMA, is underway to develop an aluminium alloy for aircraft structural parts manufactured using metal Additive Manufacturing technology. The main goal of the project is to develop an innovative high strength aluminium alloy suitable for laser powder bed systems, with improved weldability and increased mechanical and corrosion resistance in comparison to the cast grades of Al alloys currently employed.

According to the project brief, the alloy's development will focus primarily on tailoring its chemical composition to improve the processability and/or mechanical responses of well-established commercial aluminium alloys, and on defining the processing of the raw powder material. Raw materials produced in a powder form will be obtained by an atomisation process or by a mixing procedure of different starting powders. After SLM processing, a suitable heat treatment will be defined for the new alloy by considering its specific microstructural characteristics.

The AlForAMA project is being coordinated by Lortek in Ordizia, Spain with the participation of the Madrid Institute for Advanced Studies of Materials (IMDEA Materials) and the University of Leuven (KU Leuven) in Belgium.

www.cordis.europa.eu

Norsk and Spirit to manufacture structural titanium AM components for commercial aerospace industry

Norsk Titanium AS, Norway, and Spirit AeroSystems, Kansas, USA, have entered into a commercial agreement to additively manufacture structural titanium components for the commercial aerospace industry. Norsk Titanium's proprietary plasma arc Rapid Plasma Deposition™ (RPD™) technology will be used to build parts to near-net shape, with the aim of decreasing waste and energy consumption and thus reducing production costs.

Spirit currently builds thousands of titanium parts for customers around the globe and expects that at least 30% of them could be candidates for the RPD process. Tom Gentile, Spirit's President and CEO, stated, "We are pleased to enter into this innovative commercial agreement with Norsk Titanium to fabricate compliant and high-quality parts for our customers. Reducing our material cost and our environmental impact is a win-win for Spirit, our customers and the communities where we do business."

Spirit and Norsk have been collaborating to develop this technology for the aerospace industry since 2008. The companies stated that they have identified parts which can be produced by RPD beginning immediately, thus warranting the extension and solidification of the partnership into a commercial agreement. "As the Spirit and Norsk Titanium relationship approaches its 10th year, we reflect on the value of this partnership and the significant milestones achieved during the transition from R&D to production," commented Warren Boley, CEO of Norsk Titanium. "We recently announced becoming the world's first

Spirit builds thousands of titanium parts for customers around the globe

FAA-approved 3D-printed structural titanium provider and Spirit is the ideal tier-one aerostructures partner to leverage this pioneering capability."

Spirit AeroSystems is one of the largest manufacturers of fabricated parts for the aerospace industry. The company recently announced plans to expand its fabrication business.

www.norsktitanium.com

www.spiritaero.com

3D Systems teams with Airbus Defence and Space to produce metal AM satellite RF filter

3D Systems' Leuven division, Belgium, has partnered with Airbus Defence and Space in Stevenage, UK, to deliver what it states is the first flightworthy metal additively manufactured radio frequency (RF) filter for a telecommunications satellite. According to 3D Systems, the use of metal Additive Manufacturing allowed the companies to achieve a weight reduction of 50% compared to traditionally manufactured RF filters.

Metal RF or waveguide filters have been in use since the introduction of space communication systems nearly fifty years ago. RF filters act as 'wave guides' by allowing frequencies from selected channels to pass through and rejecting frequencies from signals outside those channels. High-capacity telecommunication satellites can sometimes carry as many as 500 RF filters incorporating more than 600 waveguides, many of which are custom-designed to handle specific frequencies.

3D Systems' metal additively manufactured RF filter was developed with funding from the European Space Agency as part of its project on the 'Modelling and design of optimised waveguide components utilising 3D manufacturing techniques.' News of the successful testing and validation of this part follows a trend of increasing metal AM use in the aerospace industry, with the technology rapidly making steps from prototyping to production parts and assemblies ready for flight.

The major goal of this project was to increase the performance, production efficiency and customisation capabilities for RF filters on modern telecommunications satellites, and to produce a part which would pass the rigorous testing imposed by Airbus Defence and Space. Sending a satellite into geo-stationary orbit can cost as much as $20,000 per kilogram of its weight; therefore, every new satellite part designed must also be as light as possible.

3D Systems developed the new RF filter for production in its ProX® DMP 320, a laser powder bed AM system which it refers to as a Direct Metal Printer. As well as achieving a 50% weight reduction, the company was able to consolidate the filter from two parts into one, improve its functionality by incorporating an internal structure not possible to manufacture via traditional means, reduce production time and lower production costs for customised designs.

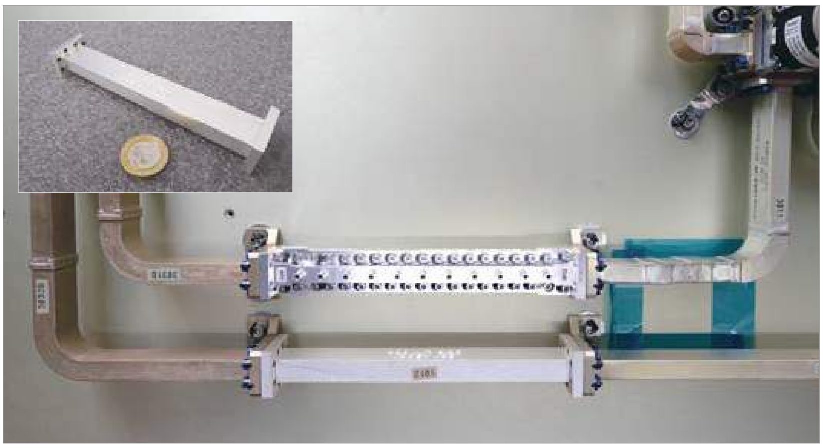
RF filters have traditionally been designed using libraries of standardised elements dictated by the limitations of the manufacturing process, such as rectangular cavities and waveguide cross-sections with perpendicular bends. Using manufacturing processes such as milling and spark eroding, these shapes have traditionally been achieved by machining each RF filter in two halves, which are then bolted together. This increases weight, adds an assembly step to production time and requires additional quality assessment.

In designing the part for AM, 3D Systems and Airbus Defence and Space were able to explore complex geometries at no additional manufacturing cost. The new RF filter design features an internal structure based on a series of depressed super-ellipsoidal cavities. According to 3D Systems, this unique internal structure enables the part to channel and reject RF currents of different wavelengths with the minimum energy loss possible.

In some cases, the difference in surface topology between metal additively manufactured and traditionally manufactured parts may be a concern. While the microscopic topology of machined parts usually includes sharp peaks and troughs, the spherical powders used in metal AM result in a smoother, 'waved' topology, as opposed to steep transitions. However, after X-ray CT scanning by Airbus Defence and Space, the metal AM RF filter was reported to have a good general surface quality for its purpose, with the advantages of its internal structure outweighing any potential disadvantages posed by its surface topology.

During testing to mimic the conditions an RF filter would face during launch and in orbit, including vibration, shock, temperature extremes and vacuum conditions, Airbus Defence and Space reported that all test samples exceeded requirements, with the best performance coming from an RF filter which was silver-plated via an electrolytic process after manufacturing.

www.3dsystems.com
www.airbus.com



The first flight worthy metal AM radio frequency filter for a telecommunications satellite, shown with coin for size comparison (inset) (Courtesy 3D Systems)

Tamper-proof software for Additive Manufacturing files receives patent

A model viewed in Grow's AM software (Courtesy Grow Software Ltd)

Grow Software Ltd, London, UK, has received a US patent for its secure software for Additive Manufacturing files. According to the company, its patented software provides a method for the secure and consistent manufacture of AM designs, in a controlled manner, at a remote location.

During the development and transfer of digital design files for distributed Additive Manufacturing, valuable product data can be vulnerable to security concerns and accidental alterations. The security of product design data is especially important in the aerospace and defence industries, while medical devices are particularly sensitive to the small parameter adjustments which could be made accidentally during file loading.

Using Grow's software, a 3D model and its machine process instructions are combined to create an additive design file containing all of the information needed to manufacture the part. This design file is encrypted prior to transfer to the manufacturing location. Once received, the build location is authorised and model and build instructions transmitted directly to the Additive Manufacturing machine being used, without allowing users access to the design file.

According to Grow, this will allow products to be manufactured exactly to their designers' requirements and could minimise the need for quality assessment. Using Grow's software, no third party will have the opportunity to access any product geometries or intervene with the original design at any stage. In addition, users will be able to verify and trace authorisations by tracking each build, receive automated reports on manufacturing events and access all information necessary to perform Quality Assurance on their final product.

Grow Software Ltd was initially developed at Autodesk subsidiary Within Labs, and its early distributed manufacturing software was integrated with EOS and Arcam. The company believes that the impact of its latest technology on the Additive Manufacturing industry will be significant, as corporations begin to recognise and address the challenges of secure distributed manufacturing.

www.grow.am

Materialise receives first US clearance for metal AM maxillofacial implants

Materialise, Leuven, Belgium, has received US clearance for its additively manufactured titanium maxillofacial implants. The surgical implants will be distributed to the US market by DePuy Synthes, Westchester, Pennsylvania, USA. TRUMATCH® titanium AM implants enable surgeons to provide patient-personalised solutions for orthognathic surgery, also known as corrective jaw surgery, as well as for facial reconstruction. They are produced using Materialise's design software, clinical engineering and metal Additive Manufacturing production facilities and, according to Materialise, are the first AM titanium maxillofacial implants to receive clearance for the US market.

By enabling the production of patient-specific virtual surgical planning, AM surgical guides and implants, Materialise's system is said to help achieve better aesthetic results and minimise surgery time for patients. TRUMATCH has reported positive results in European and Australian markets since its introduction in 2016.

"As the first of our extensive selection of implants to receive clearance for the US markets, the decision is a real milestone for our medical department," stated Brigitte de Vet, Vice President of Materialise Medical. "Thanks to our partnership with DePuy Synthes, our devices will be able to provide better healthcare for as many patients as possible."

Dr Thomas Schouman, who uses TRUMATCH maxillofacial implants as CMF surgeon at Groupe Hospitalier Pitié Salpêtrière, France, commented, "For seven years now I've experienced the benefits of 3D printed implants first hand – they simplify maxillofacial surgery and allow me to perform procedures more accurately, saving time in the OR and improving patient outcomes."

"Moreover, they offer new treatment possibilities, allowing me to perform more complex surgeries or multiple procedures in a single intervention whereas without the implants several interventions would be necessary."

www.materialise.com

The first AM titanium maxillofacial implants to receive clearance for the US market (Courtesy Materialise)

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www.raylase.com

Höganäs appoints Fredrik Emilson as President and CEO following departure of Melker Jernberg

Höganäs AB, Sweden, has appointed Fredrik Emilson as its new President and CEO following an announcement in July that its current CEO, Melker Jernberg, will be leaving the company to join Volvo Group. Emilson joined Höganäs in 2010 and has been responsible for the company's business in Asia since 2012 and prior to that held the same position in Europe. Prior to joining Höganäs he held the positions of CEO at Pergo Europe and CEO at Trelleborg Waterproofing.

"With Fredrik Emilson, Höganäs will have a CEO with a broad knowledge of the company's customer base, products and organisation," stated Staffan Bohman, Chairman of the Höganäs Board of Directors. "He has a documented ability to deliver healthy growth and good results and is a strong leader."

"Fredrik is a highly qualified person to continue the implementation of the different initiatives that have been started during the past couple of years, such as ways of working, strategy and organisation, as well as to develop the company's strong offering and customer relations."

It was announced in July 2017 that Jernberg would be leaving Höganäs to assume the position of President at Volvo Construction Equipment as well as becoming a member of the Volvo Group Executive Board.

www.hoganas.com ■■■

ARC Group Worldwide announces Drew Kelley as new interim CEO

ARC Group Worldwide, Inc, Deland, Florida, USA, a key global provider of Additive Manufacturing solutions through its 3D Material Technologies (3DMT) subsidiary, has announced the appointment of Drew M Kelley to Interim Chief Executive Officer and Board Member. Kelley replaces Jason T Young, who is leaving his position with the company and the board to pursue other interests.

Kelley has served as ARC's CFO since October 2013. Prior to joining the company, he was an investment banker and equity research analyst. "I appreciate the confidence the Board has placed in me and look forward to working with the entire ARC organisation as we establish and implement initiatives designed to improve operational efficiency, increase financial profitability and create a stronger balance sheet," Kelley stated.

www.arcgroupworldwide.com

www.3dmaterialtech.com ■■■

Singapore's A*STAR launches new Industrial Additive Manufacturing Facility

Singapore's Agency for Science, Technology and Research (A*STAR) has launched its Tech Access Initiative and new Industrial Additive Manufacturing Facility (IAMF), reports *OpenGov Asia Singapore*. Both launches are part of the Singapore Government's drive to partner local companies to upgrade their technical capabilities under the Research, Innovation and Enterprise 2020 (RIE 2020) plan, which aims to advance the country's technological capabilities in the domains of advanced engineering and manufacturing.

The new facility is aimed at helping SMEs to take advantage of Additive Manufacturing technologies with the support of A*STAR's equipment, user training and technical advice. Under the Tech Access Initiative, the organisation's Singapore Institute of Manufacturing Technology (SIMTech) will make available nineteen types of AM equipment including inspection tools, robotised 3D scanners and high-pressure cold sprays. Through the IAMF, it is hoped that Singapore's SMEs will be able to identify opportunities to leverage AM processes to improve their offerings and experiment with possible applications, without the high-cost investment of acquiring AM equipment upfront.

The Singapore Government has reportedly identified Additive Manufacturing as one of several technologies which must be embraced to reinforce the competitiveness of the country's manufacturing industry. Under the RIE2020, the government has committed to invest $ 3.2 billion in R&D and innovation, and to support SMEs in overcoming barriers to advanced manufacturing techniques, between 2016-2020.

In a speech given at the launch of the Tech Access Initiative and opening of the IAMF, Dr Koh Poh Koon, Singapore's Senior Minister of State, Ministry of Trade and National Development, stated, "Our manufacturing sector has successfully gone through major shifts, from a labour-intensive sector in the 1960s to one that is innovation-driven and productive today."

"Moving forward, technological trends such as digitalisation, robotics and automation, and Additive Manufacturing are transforming not just shop floor operations and supply chains, but also business models. Against this backdrop, the Committee on the Future Economy has recommended that we continue to sustain a globally competitive manufacturing sector as an anchor for our economy. The government is committed to partnering our companies to upgrade their technological capabilities to ensure that they succeed in the new manufacturing paradigm."

www.a-star.edu.sg ■■■

EPMA launches AM Motion collaboration survey

The European Powder Metallurgy Association (EPMA) has launched a survey related to the collaboration needs of its members as part of the AM-motion H2020 project, launched November 2016.

The overall objective of the AM-Motion CSA is to contribute to a rapid market uptake of AM technologies across Europe by connecting and upscaling existing initiatives and efforts, improving the conditions for large-scale, cross-regional demonstration and market deployment, and by involving a large number of key stakeholders, particularly from industry. According to the EPMA, the survey is aimed at better assessing the needs of the industry, with a particular emphasis on collaboration, in order to address them through its activities – such as a series of 'Match-Making Sessions' scheduled for 2018.

In the framework of the AM Motion project, workshops will also be held with the objective of bringing together key stakeholders to identify barriers to AM business development on both the technological and non-technological side, and search for possible and feasible solutions on selected value chains.

www.epma.com ■■■

New particle size measurement technique uses air permeability for greater precision

Micromeritics Instrument Corporation's Particulate Systems Division, Norcoss, Georgia, USA, has announced a new instrument for the more precise estimation of the average particle size of powders. The new instrument uses an air permeability technique previously popularised by the Fisher Sub-Sieve Sizer, which is no longer available.

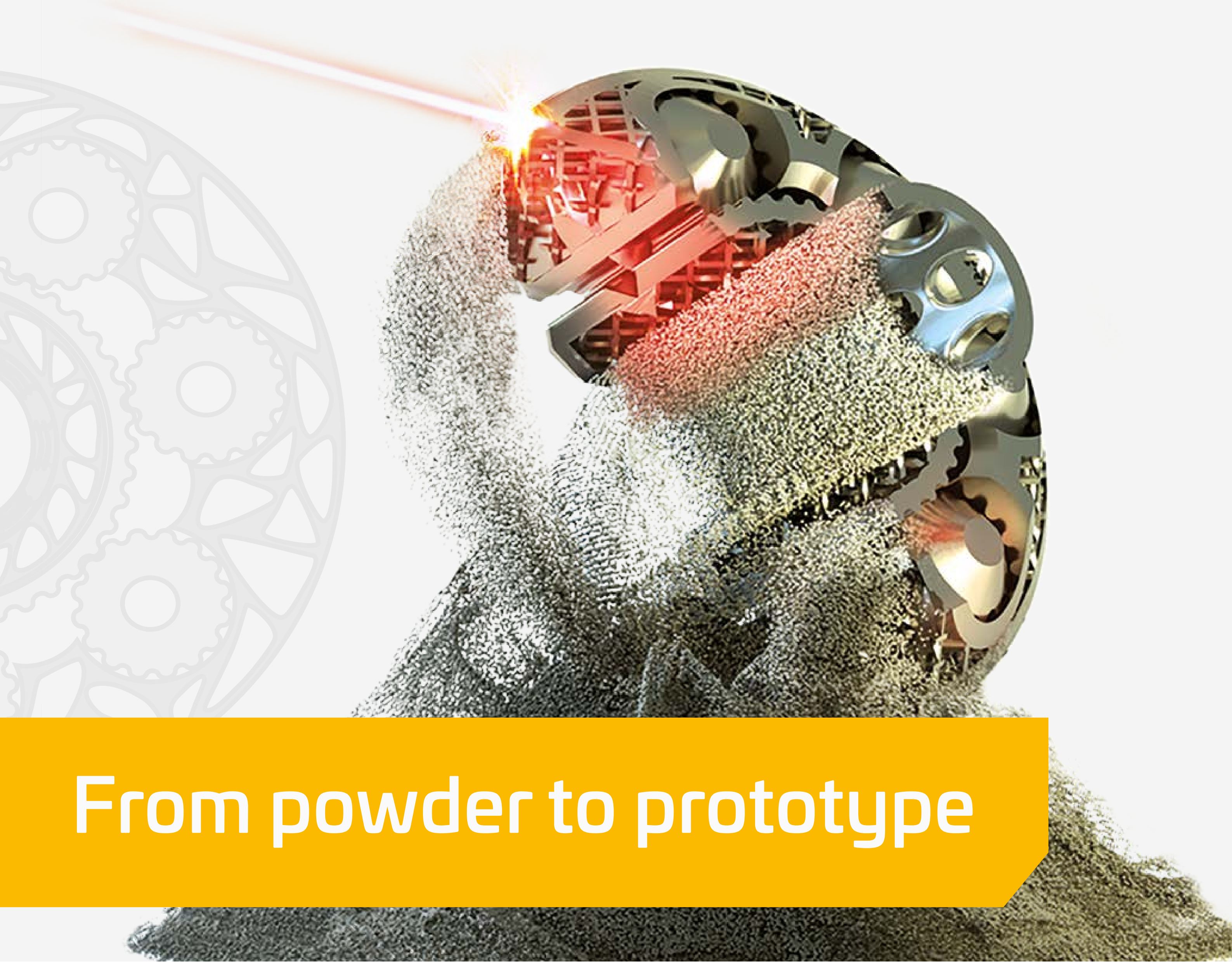
The Subsieve AutoSizer (SAS) measures the specific surface area of a powder by passing air through a packed powder bed and determining the pressure of the transmitted air by means of calibrated and traceable digital pressure transducers (also used for setting the packing force and input pressure) instead of the water-filled manometer standpipe (or bubble-rate pressure estimate, in the case of input pressure) used in older methods. The specific surface area is then easily converted by the instrument to an equivalent spherical particle diameter using geometric and density considerations.

For over fifty years, the refractory metals, ceramics, lighting, other phosphors and pharmaceutical industries have relied on air permeability measurements to estimate the particle size of their materials. Some of these methods offer very imprecise results, leading to a large degree of rework and confusion in those industries. Because of its accurate and precise measurement of pressure by means of pressure transducers, the SAS reportedly provides much greater precision than traditional methods, allowing for appropriate particle size specifications to be set for both process and quality control and for outgoing powder material specifications. The new instrument thus offers a fast and easily-obtained estimate of particle size in order to meet those specifications.

Subsieve AutoSizer (Courtesy Micromeritics Instrument Corp.)

Several international standard test methods have been developed for use with the SAS, including ASTM Standard Test Methods B330 for metals. ISO Standard 10070, a general standard test method for this type of particle size measurement, is currently being revised for use with the SAS.

www.micromeritics.com


From powder to prototype

German researchers receive funding boost for metal AM heart stents

The Bavarian Research Foundation (Bayerische Forschungsstiftung), Germany, has pledged €220,000 toward a research project into the development of heart stents using metal Additive Manufacturing. Led by Germany's OTH Regensburg, University Hospital Regensburg and FIT Production GmbH, the project is part of ongoing global efforts to combat cardiovascular diseases which, according to the World Health Organisation, are the most frequent cause of death worldwide.

A stent is a wire mesh tube which is inserted into a coronary artery to widen it, allowing better blood flow and preventing cardiac failure. The operation is usually carried out when an artery has been narrowed by a build-up of plaque (cholesterol deposits). However, the insertion of a stent into a blood vessel can cause injury by 'stretching' the arterial walls. In addition, most traditionally manufactured stents come in a range of 'off the shelf' sizes, which may not correctly fit every patient's needs. When an ill-fitting stent moves in an artery, it may become blocked, requiring surgical intervention to either reopen or bypass.

The NewGen-Stent project is developing metal additively manufactured stents with a cylindrical geometric structure which are capable of targeted expansion to allow controlled fit and vessel widening, thereby minimising the risk of cardiovascular injury.

www.fit.technology | www.forschungsstiftung.de

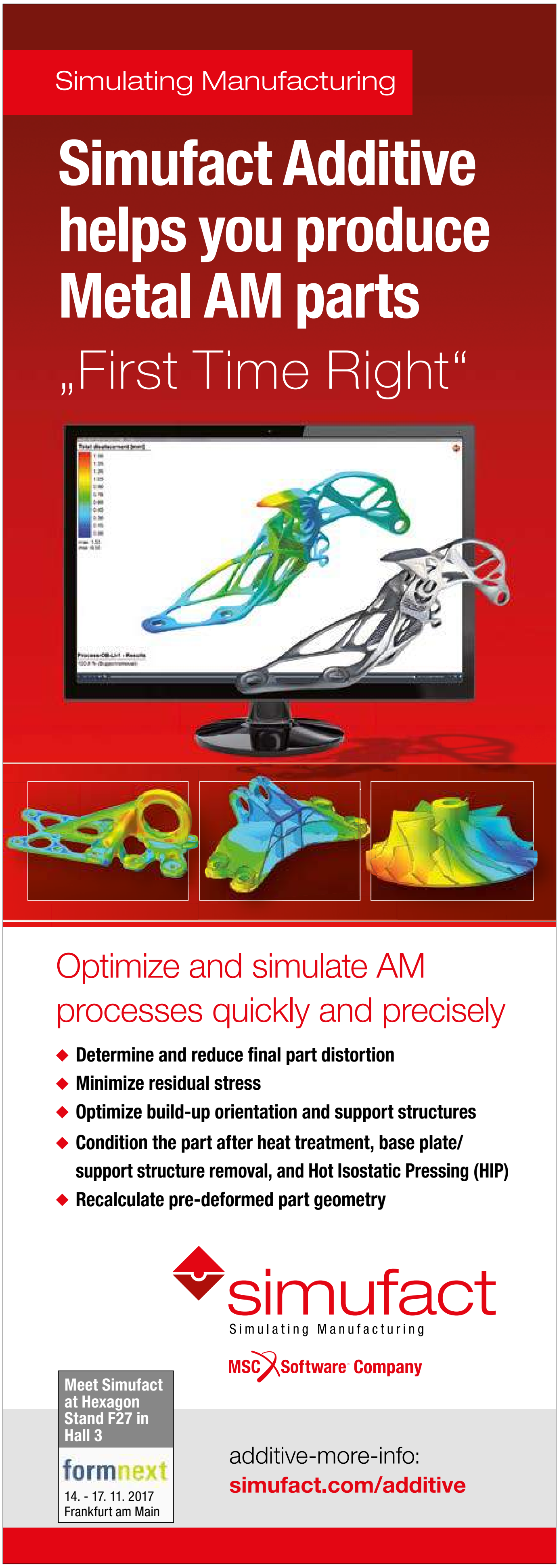
O.R. Laser tailors metal AM systems to universities and SMEs

Germany's Industry Federation of Mechanical Engineers (VDMA) recently interviewed Uri Resnik, CEO of O.R. Lasertechnologie GmbH, Dieburg, Germany. In the interview he explained the company's current target users and applications. Resnik stated that O.R. Laser is currently aiming its AM systems at small to medium-sized businesses (SMEs) and universities, having set itself a price cap of €100,000 per system.

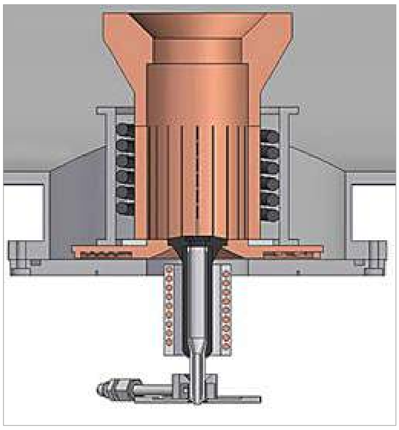
"To [SMEs and universities], the prices of today's powder bed systems pose a high initial hurdle," he stated. "Three years ago, we decided to close this gap... Pricewise, our system is tailored to small and medium-sized businesses and universities."

This comparatively low pricing was made possible by O.R. Laser having its own laser and software development facilities, he stated. "We develop and realise laser systems, mechanics and software in-house. This allows us flexibility when working with our customers' demands."

www.or-laser.com | www.vdma.org



Ames team wins award for development of titanium powder manufacturing process



Schematic of titanium Close-Coupled Gas Atomisation set-up utilising the 'hot shot' composite pour tube

Iver Anderson, Senior Metallurgist at the US Department of Energy's Ames Laboratory, and his team have been announced as winners of a 2017 Excellence in Technology Transfer Award from the Federal Laboratory Consortium (FLC) Mid-Continent Region. The FLC recognised the development of a 'hot-shot' pour tube that, when adapted into a high-efficiency nozzle, can produce titanium powder by a method that is said to be approximately ten times more efficient than traditional powder-making methods.

Titanium powder produced using the hot-shot pour tube is said to have enabled a dramatic shift in manufacturing away from traditional titanium casting/forging methods to net-shape forming. This successful manufacturing technique led to the formation of a multi-award winning start-up company, Iowa Powder Atomization Technologies, which was purchased in 2014 by Praxair Surface Technologies. In 2015, Praxair began international sales of spherical titanium powder for Additive Manufacturing and Metal Injection Moulding for aerospace, medical and industrial parts.

In addition to Anderson, the award is shared by Andy Heidloff and Joel Reiken, formerly of Ames Laboratory and now of Praxair Surface Technologies, Inc.; and David Byrd, Ross Anderson and Emma White of Ames Laboratory. "Our team is very proud to accept this FLC award," stated Anderson. "It helps us keep pushing Ames Laboratory's processing science forward to these ultimate technology transitions involving our people."

In a letter of support for Ames Laboratory in the FLC competition, Dean Hackett, Vice President of Praxair Surface Technologies, Inc., said, "Ames Laboratory is uniquely equipped and staffed with talented researchers who work as a team to develop breakthrough technologies in the production of atomised powders. Praxair Surface Technologies has chosen to commercialise the titanium atomisation technology from Ames and also to hire two of the three investigators (Heidloff and Reiken) that were responsible for this unique titanium atomisation process."

In congratulating Anderson and his team of scientists on the award, Ames Laboratory Director Adam Schwartz said the award demonstrates Ames Laboratory's commitment to the Department of Energy's mission of transferring technologies to the marketplace for the benefit of the American taxpayer. "We are very proud to join Iver and his team in celebrating this technological success," said Schwartz, "And we'll look forward to many anticipated future successes."

www.ameslab.gov

Cummins partners with ORNL on repairs using metal Additive Manufacturing

Cummins diesel engines are used in many heavy-duty truck makes globally (Courtesy ORNL)

Diesel engine maker Cummins, Inc., Columbus, Indiana, USA, is collaborating with Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA, to develop a method and material to repair the cylinder heads on heavy-duty engines by Additive Manufacturing.

Cummins diesel engines are used in many heavy-duty truck makes globally. According to the manufacturer, the cylinder heads on these engines typically wear out after a million miles on the road. Ordinarily, these cast iron parts would have to be replaced with new castings; a costly process in terms of time, energy and money.

Using the new method of repair, the research team 'scoops out' the worn section and uses a Direct Metal Deposition (DMD®) machine by DM3D Technology, Auburn Hills, Michigan, USA, to deposit a high-nickel-containing alloy over the damaged area. This material offers a number of properties which help to avoid cracking of the repaired cylinder head and increase its thermal efficiency

The goal of the new repair process is to save energy at the same time as extending the life and increasing the strength of the engine. "We're decreasing the engine's thermal conductivity, which holds heat in longer, and turning it into increased efficiency," explains Nikhil Doiphode, Parts R&D Engineer at Cummins. "While these are not brand-new engines, we're striving to make them better than new."

www.cumminsengines.com
www.ornl.gov

FAME award presented to Professor Ian Gibson

Professor Ian Gibson, Deakin University, Geelong, Victoria, Australia, has become the first Australian-based academic to receive an international lifetime achievement award recognising his contribution to Additive Manufacturing. The International Freeform and Additive Manufacturing Excellence (FAME) Award is given annually and every year recognises one outstanding researcher in the field. Gibson received the award at the Annual International Solid Freeform Fabrication Symposium in Austin, Texas, USA.

Gibson's research has included a number of metal-focused projects. Speaking to *Metal AM*, he explained, "I started working in metals about twenty years ago when I was a lecturer at Hong Kong University, where my group had purchased one of the first Rapidsteel tooling technologies in the world. This was a technology that used a steel/polymer blend to create a 'green' part using Selective Laser Sintering. The 3D printed part was then transferred to a furnace where the polymer was burnt away and replaced with bronze to create a composite metal part that could then be used as a tool insert."

More recently, Gibson's work on metal AM at Deakin University has developed in two primary areas. "We have generated a lot of traction in research into post-processing of metal powder bed parts," he stated. "This is using our SLM process to create parts that are then studied for machinability, as well as analysing the requirements for heat treatment. This is an area that is of great interest to industrial users of this technology to provide the knowledge to create effective end-use parts."

Professor Ian Gibson (left) received the international FAME Award

The other project is related to Direct Energy Deposition using Deakin University's LENS MR-7 machine. He explains, "This process allows us to control the material and energy flow to create functionally gradient parts. These functional properties can be in terms of mechanical variations, like localised strength and porosity or in terms of blending different metals together for even greater variations throughout a 3D printed metal part. This is in its early stages, but the knowledge gained in this research could be far reaching."

www.deakin.edu.au

Retsch introduces new generation Camsizer X2 for high-res metal powder characterisation

Retsch Technology, Haan, Germany, has released a new dynamic image analysis system for high-resolution metal particle size and shape analysis. The Camsizer X2 offers users comprehensive particle size and shape analysis in the lower micron range and can be used to characterise metal powders used for Powder Metallurgy, Additive Manufacturing and Metal Injection Moulding.

As even the smallest quantity of oversized particles or dust can have a negative impact on the manufacturing process, it is important that the quality control process must ensure that size irregularities in powder samples are reliably detected. According to Retsch, the new Camsizer X2 records all relevant size and shape parameters in less than 2 minutes, including aspect ratio, roundness and symmetry. This makes it possible to quickly and reliably evaluate fresh powders, as well as recycled material which often contains a certain percentage of undesired particles.

During the system's dynamic image analysis process, a sample of metal powder is dispersed to be analysed in an air jet. Two high-speed cameras then capture clear and distortion-free shadow projections of every single particle, enabling the system to carry out an automatic evaluation of more than 300 images per second in real time.

The Camsizer X2's ability to analyse millions of individual particles in real time ensures a high degree of statistical certainty and reproducibility. According to Retsch, particles outside the main size distribution are reliably detected, even if their percentage of the total sample is less than 0.01%, making this technology superior to other methods such as sieve analysis and laser diffraction.

The new Camsizer X2 (Courtesy Retsch)

Retsch will present its Camsizer X2 on Booth #85 at Euro PM2017 Congress and Exhibition, Milan, Italy, October 1-4, 2017, and Booth 3.0-E90 at formnext, Frankfurt, Germany, November 14-17, 2017.

www.retsch.com

Call for papers issued for AMPM2018

The Metal Powder Industries Federation (MPIF) has issued a Call for Papers for its AMPM2018 conference. The event will be co-located with POWDERMET2018, the International Conference on Powder Metallurgy and Particulate Materials, taking place June 17-20, 2018, in San Antonio, Texas, USA.

The three-day conference will feature a number of talks from worldwide industry experts presenting the latest technological developments in the field. All abstracts must be submitted to AMPM's submissions portal by November 3, 2017. The submission of full manuscripts is optional; however, all submitted manuscripts will be considered for the Best AMPM2018 Paper Award. Authors are advised to contact Debby Stab (dstab@mpif.org) for further information.

www.ampm2018.org

Australia to host First Asia-Pacific International Conference on AM

The 1st Asia-Pacific International Conference on Additive Manufacturing (APICAM 2017) is set to take place in Melbourne, Australia, at RMIT University, December 4-6, 2017. The conference is believed to be the first of its kind to be held in the Asia-Pacific region and aims to provide an opportunity for industry professionals and thinkers to come together, share knowledge and engage in the networking vital to the furthering of the Additive Manufacturing industry.

According to Materials Australia, the conference organisers, the programme will include presentations from some of the leading minds in AM on pressing issues facing the industry and the ways in which these challenges can be navigated. AM for the automotive, biomedical, defence and aerospace industries will be covered by experts from each respective field.

As well as a number of expert presentations, APICAM 2017 will include workshops designed to help attendees sharpen their skills and understanding of AM. In addition, the programme 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.

The conference is to be chaired by Jian-Feng Nie of Monash University, Yvonne Durandet of Swinburne University, Ma Qian of RMIT University and Andrey Molotnikov, also from Monash University. The conference will also include contributed presentations and posters, and an award will be given for the best student presentation during the conference.

www.apicam2017.com


Au, Ag, Cu, Sn,
Ni, Fe, Co, Pd...

formnext 2017 reports continued growth

The organisers of formnext powered by tct 2017 have reported a 50% increase in the number of companies set to exhibit at the event compared to the previous year. Taking place November 14-17, 2017, Frankfurt am Main, Germany, this will be the third of formnext's annual Additive Manufacturing industry events. Thanks to its strong international presence, variety of global market leaders and density of innovations from areas along the entire additive process chain, it is considered one of the most important AM events globally.

With 393 exhibitors having registered two months before the trade fair opens its doors, formnext's exhibition floor space has almost doubled – from 15,500 m² in 2016 to around 27,000 m² this year. Sascha F Wenzler, Vice President for formnext at Mesago Messe Frankfurt GmbH, stated, "With this extremely impressive growth, formnext underscores its status as the leading international conference and exhibition for Additive Manufacturing and the next generation of intelligent production solutions. In a highly dynamic market, formnext has its finger right on the industry's pulse and provides the solutions required to meet current and future challenges."

Emphasising formnext's global presence, the organisers stated that around 49.6% of exhibitors at the event will be from outside Germany, with the majority of international visitors being from China (14.7%), the USA (10.2%), France and Great Britain (each with 9.6%), Spain (7.1%), and the Netherlands, Austria, and Russia (each with 6.1%).

In addition to equipment, software and material suppliers, the event will include a focus on measurement technology and post-processing. formnext 2017 will also showcase some of the most sophisticated technology in various other industry sectors. "We are proud of the fact that we have been able to expand into more specialised fields along the process chain," added Wenzler.

formnext.com

The organisers have reported a 50% increase in the number of companies set to exhibit at formnext

Australian team successfully test-fires metal AM rocket engine

A team of designers from Australia's Amaero Engineering and Monash University have designed, manufactured and successfully test-fired a metal additively manufactured rocket engine. The ProjectX engine is built from high-strength nickel based superalloy Hasteloy X on an EOS M280 system and has a design thrust of 4 kN (1000 lb).

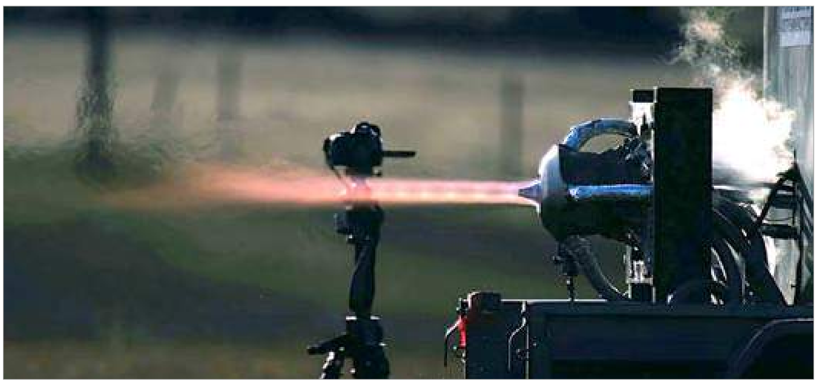
Having successfully manufactured the world's first AM jet engine, Amaero reportedly challenged PhD Engineering students at Monash to design an engine which made full use of the geometric complexity enabled by Additive Manufacturing. Graham Bell, Project Lead, stated, "We were able to focus on the features that boost the engine's performance, including the nozzle geometry and the embedded cooling network. These are normally balanced against the need to consider how on earth someone is going to manufacture such a complex piece of equipment. Not so with Additive Manufacturing."

The resulting rocket engine is a complex multi-chamber aerospike design. According to Martin Jurg, an engineer with Amaero, this geometry offers some unique advantages compared to more conventional designs. "Traditional bell-shaped rockets, as seen on the Space Shuttle, work at peak efficiency at ground level. As they climb the flame spreads out reducing thrust. The aerospike design maintains its efficiency but is very hard to build using traditional technology. Using Additive Manufacturing we can create complex designs, print them, test them, tweak them and reprint them in days instead of months."

The PhD students involved in the project have now created a company, NextAero, to take their concept to the global aerospace industry. The development of the aerospike rocket was supported by Monash University, Amaero Engineering and Woodside Energy through the Woodside Innovation Centre at Monash.

www.amaero.com.au
www.monash.edu

The ProjectX engine is built from high-strength nickel based superalloy Hasteloy X on an EOS M280 system (Courtesy NextAero)



ProjectX engine during a test fire. The shock-cell structure in the rocket plume is visible (Courtesy NextAero)

World's first class-approved metal AM ship propeller nears completion

Rotterdam Additive Manufacturing Lab (RAMLAB) in the Netherlands has produced a full-scale prototype of the world's first class-approved metal additively manufactured ship's propeller. The propeller is being developed by a consortium of companies including Damen Shipyards Group, RAMLAB, Promarin, Autodesk and Bureau Veritas.

The 1,350 mm diameter, 400 kg triple-bladed propeller - named WAAMpeller - is based on a Promarin design used on Damen's Stan Tug 1606. It is produced in a Nickel Aluminium Bronze alloy using wire arc Additive Manufacturing with industrial robotic arms, followed by CNC milling at Autodesk's Advanced Manufacturing Facility in Birmingham, UK.

This first prototype WAAMpeller will be used for display purposes, and planning for a second example is already underway. The consortium reported that it would begin production of a second class-approved propeller prototype late in October 2017, with the aim of installing it on a working tug by the end of the year.

Currently, if a vessel comes into port needing a replacement part such as a propeller, it can take weeks or months to order and deliver, costing companies millions of dollars in lost time. It can also be quite costly for companies to keep large stockpiles of parts in warehouses around the world. Using faster fabrication options such as the metal AM of large ship components and finishing the pieces using traditional CNC milling and grinding methods, replacement parts could be produced within a matter of days, saving time and money without sacrificing precision or performance.

One of the first steps the development team took was to carry out extensive testing of the material properties of the printed material to ensure compliance to Bureau Veritas standards. "This involved printing two straightforward walls of material then using a milling machine to produce samples for lab testing of tensile and static strengths," stated Kees Custers, Project Engineer in Damen's R&D department.

Another key challenge was in redesigning the propeller for AM. "The challenge has been to translate a 3D CAD file on a computer into a physical product. This is made more complex because this propeller is a double-curved, geometric shape with some tricky overhanging sections," Custers explains.

WAAMpeller prototype during production (Courtesy Damen)

"We have to make sure that the material properties meet the needs of the application," states Wei Ya, Postdoctoral Researcher from the University of Twente at RAMLAB. "Material toughness, for example – ensuring that the propeller is able to absorb significant impact without damage. But we have also been working towards optimising the production strategy for 3D metal deposition. This includes bead shape and width, as well as how fast we can deposit the printed material."

www.ramlab.com

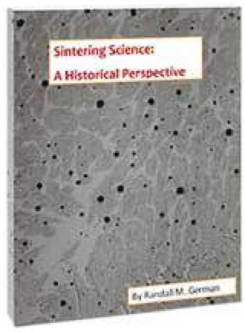
www.damen.com

History of sintering and key players identified in new publication

A new publication from Professor Randall M German, titled '*Sintering Science: A Historical Perspective*', is now available in both print and digital formats. This monograph is an overview on how sintering science evolved, identifying the key actors and the progress that leveraged from advances in atomic theory, materials testing and microstructure quantification. It documents who did what and when critical pieces of the puzzle fell into place.

Sintering is an ancient process, used thousands of years ago for the fabrication of bricks, pottery, crucibles and precious metal jewellery. In modern times, humans apply sintering to the production of precise engineering components, such as automotive transmission gears and artificial knees. Indeed, sintered structures are found in most every aspect of modern life, including cellular telephones, jet engines and laptop computers.

The scientific understanding of sintering is a relatively recent development. Quantitative ideas on particle bonding emerged between 1945 and 1955. Those ideas continue to be refined, now largely in the form of advanced computer simulations.



This historical platform provides a base for looking into the future where research on nanoscale particles and Additive Manufacturing are employing new sintering concepts.

'*Sintering Science: A Historical Perspective*' is available from the MPIF in either print or PDF format.

www.mpif.org

Additive Manufacturing of tungsten metal powder

At the 19th Plansee Seminar held in Reutte, Austria, May 29 - June 2, 2017, Alfred Sidambe and Peter Fox, of the School of Engineering, University of Liverpool, UK, presented the results of their investigation into the challenges of using Selective Laser Melting (SLM) to produce tungsten (W) components from pure W powder (<45 µm).

The authors stated that SLM is not currently used commercially for the processing of refractory metals, such as W, mainly due to the intrinsic problems of processing higher melting point materials. Tungsten has a melting point of 3422°C, as well as a high density (19.2 g/cm^3), and has traditionally been processed using Powder Metallurgy techniques including pressing and sintering, Hot Isostatic Pressing, etc. However, though processing via SLM would be technically challenging, it would lead to a significant advantage in high-value manufacturing sectors.

A Renishaw AM125 system was used to study the effectiveness of SLM processing of pure W. The AM125 system employs a high powered ytterbium fibre laser with a wavelength of 1070 nm, has a maximum laser power of 200 W in continuous wave mode, a maximum laser scanning speed of 2000 mm/s and a laser beam diameter of 43 µm at the powder surface, which was used to melt plasma-densified tungsten powder (W45) under an argon atmosphere. The laser beam has a Gaussian intensity profile, which the researchers stated has sufficient intensity to melt refractory metals such as tungsten when the focus offset is set on the central part of the geometry. A commercially pure titanium substrate was used for the SLM experiments. In addition to identifying some of the technical issues said to limit the effectiveness of SLM processing of pure W, the researchers succeeded in producing four different W components, as well as conducting a study to evaluate the development of W cellular structures for industrial applications.

Fig. 1 Tungsten components manufactured by SLM (Courtesy Plansee)

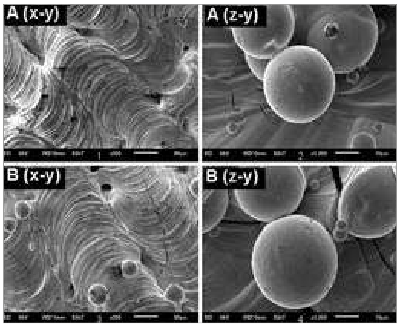


Fig. 2 SEMs of the top surface (left) and side surface (right) of SLM tungsten (A and B) (Courtesy Plansee)

SLM Processing Parameter	Point Distance (µm)	Exposure Time (µs)	Apparent Speed (mm/s)	3D volume energy density (J/mm^3)	Hatch Space (mm)
A	20	200	100	578	0.115
B	20	200	100	434	0.155
C	29	200	145	399	0.115
D	29	200	145	299	0.155

Table 1 Summary of four sets of processing parameters used to manufacture four tungsten components by SLM (Courtesy Plansee)

Table 1 is a summary of the four sets of processing parameters used to manufacture W SLM components with a layer thickness of 30 µm. Processing was carried out in an argon atmosphere to prevent oxidation. The 3D laser energy density was derived from the 3D specific energy input, obtained by combining laser power, laser scan speed, powder layer thickness and hatch spacing. The authors stated that the Renishaw AM125 machine uses a point exposure scan strategy, which implies that the laser does not remain continuously on when incident on powder material. Therefore, the scan speed was derived from the point distance and the exposure time used in the parameters.

Fig. 1 shows tungsten block components (L = 50 mm, W = 10 mm and H = 5 mm) manufactured using the AM125 SLM machine. The samples were successfully fabricated without any visible defects or delamination during the melting process, and a relatively smooth surface was achieved. Fig. 2 shows the SEM images of the top surfaces (left) and side surfaces (right) of SLM tungsten fabricated using the parameters in Table 1.

Optical micrographs confirm the density levels (up to 98%) of the tungsten fabricated by SLM, achieved using the four different processing parameters, which are equivalent to different energy densities used in SLM. The manufacture of a porous lattice structure also demonstrates the suitability and future potential of using SLM to produce lighter weight, geometrically complex W components.

19th Plansee Seminar Proceedings

Proceedings of 19th Plansee Seminar, 2017, are available to purchase directly from Plansee.

www.plansee-seminar.com

Selective laser melting of tungsten and tungsten alloys

Aljaž Iveković, along with research colleagues from Belgium's Katholieke Universiteit Leuven and 3D Systems, has studied the influence of Selective Laser Melting (SLM) processing parameters on the melting and solidification behaviour of both tungsten (W) and W alloys. They presented their results in a paper at the 19th Plansee Seminar, held in Reutte, Austria, May 29-June 2, 2017.

The researchers used a pure W powder and also a W-Ta powder mixture (1, 5, 10 wt.% Ta). Two complementary Additive Manufacturing systems were used to investigate the effect of different equipment on the processing of the W and W-Ta alloy. This included an in-house SLM machine developed by KU Leuven and an industrial ProX® DMP 320 at 3D Systems. The in-house SLM machine is equipped with a 300 W Nd:YAG laser with a wavelength of 1.064 µm and a laser beam diameter of 90 µm. The machine is also equipped with a preheating module, which enables preheating of the baseplate up to 400°C. The ProX DMP 320 machine is equipped with a 500 W laser and has a smaller spot size. All experiments were conducted in a flowing Ar atmosphere with resulting oxygen content of 150-200 ppm for the in-house machine and < 50 ppm in the ProX DMP 320. Samples of 10 x 10 mm^2 and a total height of 10 mm were fabricated with varying processing parameters: laser power, scanning speed, layer thickness, hatch spacing and scanning strategy.

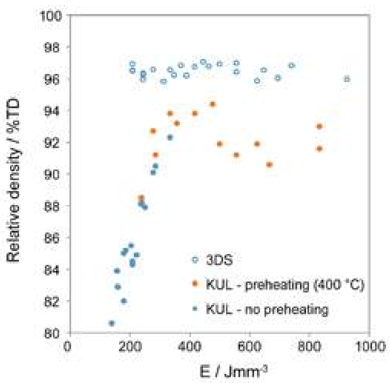


Fig. 1 Relative density of SLM tungsten as a function of the applied energy density (Courtesy Plansee)

The densities of the samples produced at different energy density inputs are plotted in Fig. 1. With increasing laser energy input, the measured density of the W samples increased up to 300 Jmm^{-3}, where a plateau was reached. A maximum density of 94.4%TD was obtained for the materials produced at 475 Jmm^{-3}. Further increase in energy density up to 1000 Jmm^{-3} had a minor effect on increasing densification. Samples produced at 3D Systems (3DS) were characterised by a higher density (95.8-97.1%TD), regardless of the applied energy density above 200 Jmm^{-3}.

For the in-house produced samples with 5 wt.% Ta (W5Ta), the densities ranged from 88 to 94.1%TD with the highest densities obtained at an energy density of 200-250 Jmm^{-3} (Fig. 2a). For the 10 wt.% Ta (W10Ta) grade, the densities ranged between 89.5-97.5%TD, with highest densification at 300-400 Jmm^{-3} (Fig. 2b). A minor beneficial effect of preheating was observed; however, the increase in density was not reproducible. Therefore, it was concluded that no systematic increase in density was observed when preheating was used, similar to the observation with pure W. The researchers attributed the lower density obtained in the in-house built machine, in comparison with the industrial 3D Systems machine, to the higher oxygen level in the chamber of the in-house equipment.

Regardless of the processing parameters used and scanning strategy, cracks were always observed, which was attributed to the thermal stresses arising during rapid solidification or recrystallisation. In pure W, a clear network of cracks was formed. With the addition of tantalum, the grain size was significantly reduced, resulting in a more irregular crack pattern. Baseplate preheating was suggested as a way to prevent crack formation; however, preheating up to 400°C was not sufficient to prevent crack formation in SLM of W or W-Ta. A higher preheating temperature is needed to mitigate thermal stresses during solidification, and lowering the oxygen content is essential to obtain a crack-free high density microstructure in SLM W and W-Ta alloys.

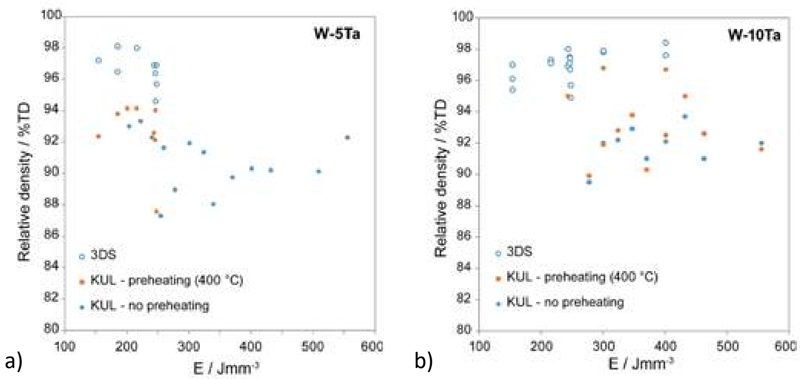


Fig. 2 Relative density of SLM (a) W5Ta and (b) W10Ta as a function of the applied energy density (Courtesy Plansee)

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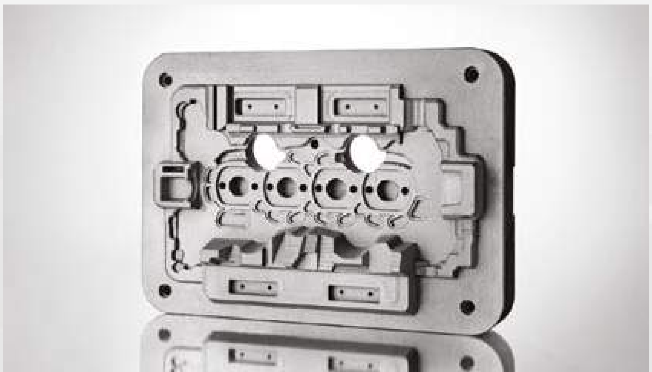

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Effect of process parameters on the selective laser melting of tungsten

In a paper presented at the 19th Plansee Seminar, held in Reutte, Austria, May 29-June 2, 2017, R K Enneti and R Morgan of Global Tungsten and Powders Group in Towanda, Pennsylvania, USA, and S V Atre at the University of Louisville, Kentucky, USA, reported on a study to understand the effect of process parameters such as hatch spacing and scan speed on the densification of tungsten (W) by SLM. It was found that the resulting density of SLM tungsten is inversely proportional to hatch spacing and scan speed.

The researchers used a pure W powder having an average particle size of 30 µm and with morphology shown in Fig. 1. SLM of the W powders was carried out using a Concept Laser Mlab Cusing R machine . Experiments were conducted at hatch spacings of 15 and 30 µm and scan speeds in the range 200–1400 mm/s. A constant laser power of 90W and a powder layer thickness of 30 µm were used. Rectangular cuboids of 7.8 ± 1.4 mm x 10.1 ± 0.1 mm x 10.1 ± 0.04 mm were printed using various process parameters and then analysed for densification. The samples were built on a steel base plate. A maximum density of 75% theoretical was achieved at an energy density of 1000 J/mm^3.

SEM micrographs (Fig. 2) of the W sample processed at a scan speed of 1200 mm/s and a hatch spacing of 15 µm clearly show the balling phenomena of W powders during SLM processing. The balling phenomenon is said to occur primarily due to incomplete wetting and spreading of W melt droplets exposed to the laser. The solidification time of molten tungsten droplets is very short due to the high thermal conductivity of tungsten. The solidification time is much shorter than the spreading time, resulting in molten W droplets solidifying without completing the spreading process. The low power used in the study (90W) is also not sufficient to completely melt the W powder and reduce the viscosity of the partially melted W droplets. The low viscosity of W droplets was also found to inhibit faster spreading of the melt, resulting in low density in the samples.

The researchers stated that SLM processing of the W powder at higher laser powers will increase the temperature, resulting in a lower viscosity melt pool and faster spreading. The faster spreading in turn will assist in increasing the density of the material. They also found that scan speed is the dominant factor in SLM of W, contributing to 75.7% of the variation in densification, while hatch spacing contributed only 7.1%. The high thermal conductivity of W may be the reason for the lack of a significant effect of hatch spacing on densification.

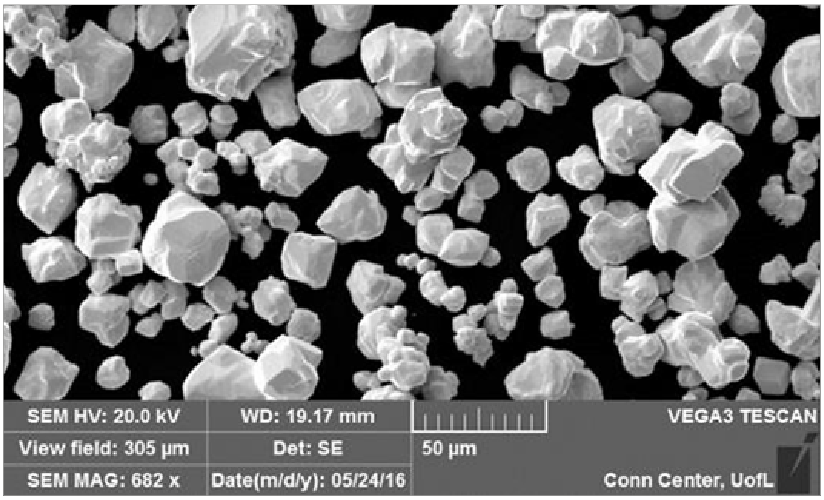

Fig. 1 Morphology of the tungsten powder used in SLM experiments (Courtesy Plansee)

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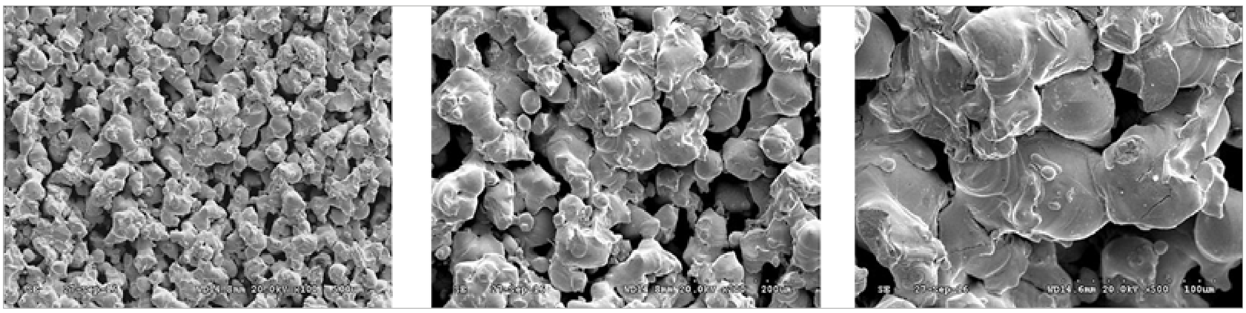
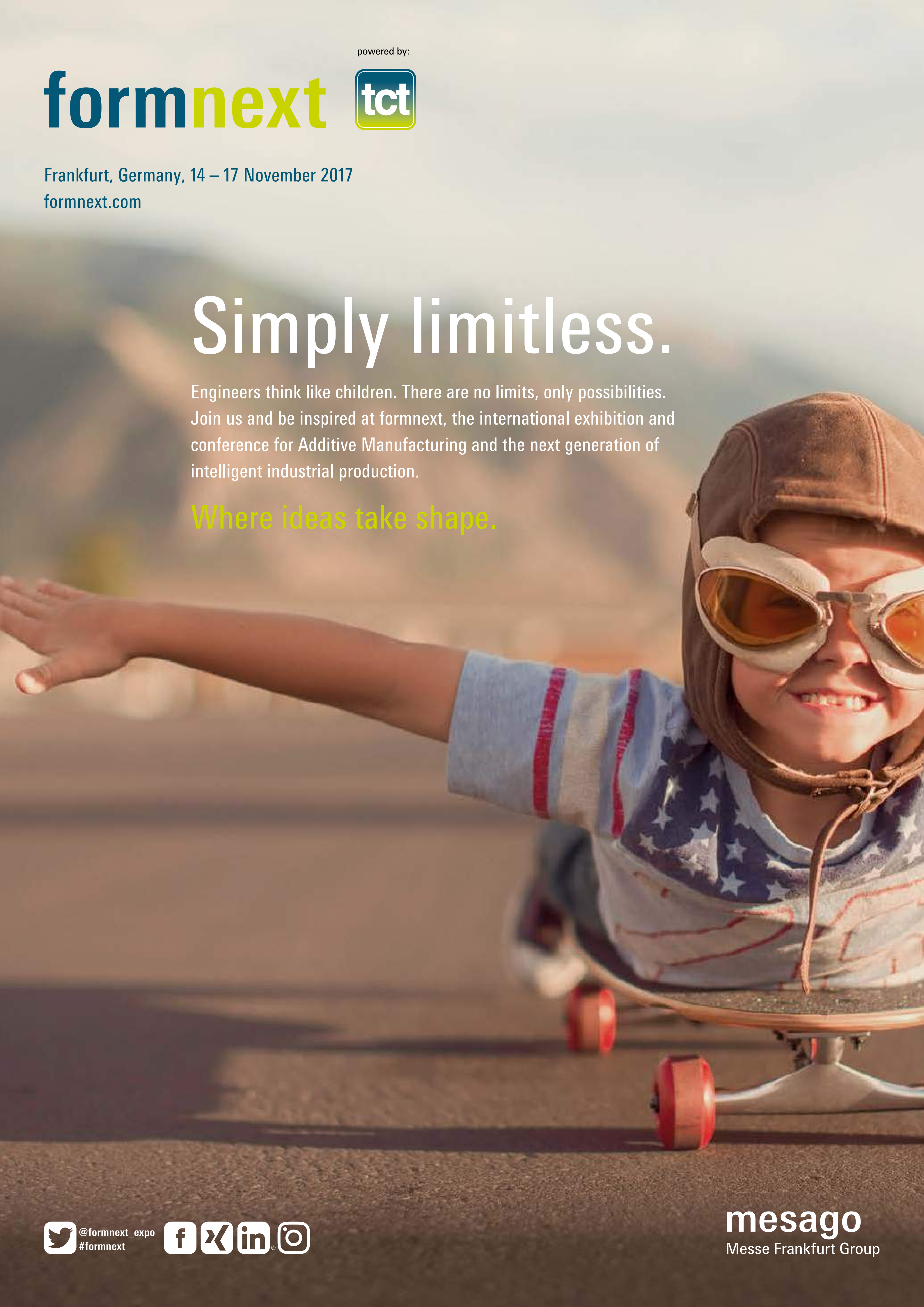


Fig. 2 SEM micrographs of a W sample processed at scan speed of 1200 mm/s and hatch spacing of 15 µm (Courtesy Plansee)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Honeywell: Driving AM application and supply chain development in the aerospace industry

Over the past decade Honeywell has been a leader in accelerating the adoption of metal Additive Manufacturing in the aerospace industry. With dedicated facilities in five countries, the company is at the forefront of the development of new commercial aerospace applications and the supply chain needed to implement series production. Dr Dhruv Bhate, Associate Professor in the Polytechnic School at Arizona State University, visited Honeywell's Phoenix facility on behalf of *Metal AM* magazine and met with Donald Godfrey, an Engineering Fellow at Honeywell and the person most credited with initiating and directing the company's progress in the field of metal AM.

For over a century, Honeywell Aerospace and its legacy companies have been at the forefront of both military and civilian aviation. Today, they are best known as developers of innovative solutions in a wide range of areas, including aircraft engines, cockpit and cabin electronics, wireless connectivity services, logistics and more.

Honeywell Aerospace is a division of the Honeywell International conglomerate and generates approximately $14 billion in annual revenue, about one-third of Honeywell's overall revenue. It is headquartered in Phoenix, Arizona, USA, an area in which aerospace and defence manufacturing is a key industry. Honeywell Aerospace consistently ranks among the top employers in Arizona, with its five facilities in the state employing approximately 8,000. The company has played a key role in driving the aerospace and defence manufacturing sector in the region and has also been instrumental in leading the development of the region's metal Additive Manufacturing expertise.

Honeywell's metal Additive Manufacturing programmes and initiatives are managed out of its Phoenix complex, which is situated next to the Phoenix Sky Harbor International Airport. The largest of the facilities on this complex is tasked with final assembly of the company's propulsion engines for business jets and helicopters, as well as engines for the M1 Abrams battle tank and air turbine starters.

Fig. 1 A Honeywell HTF7000 engine in production at Honeywell's Phoenix facility (Courtesy Honeywell)

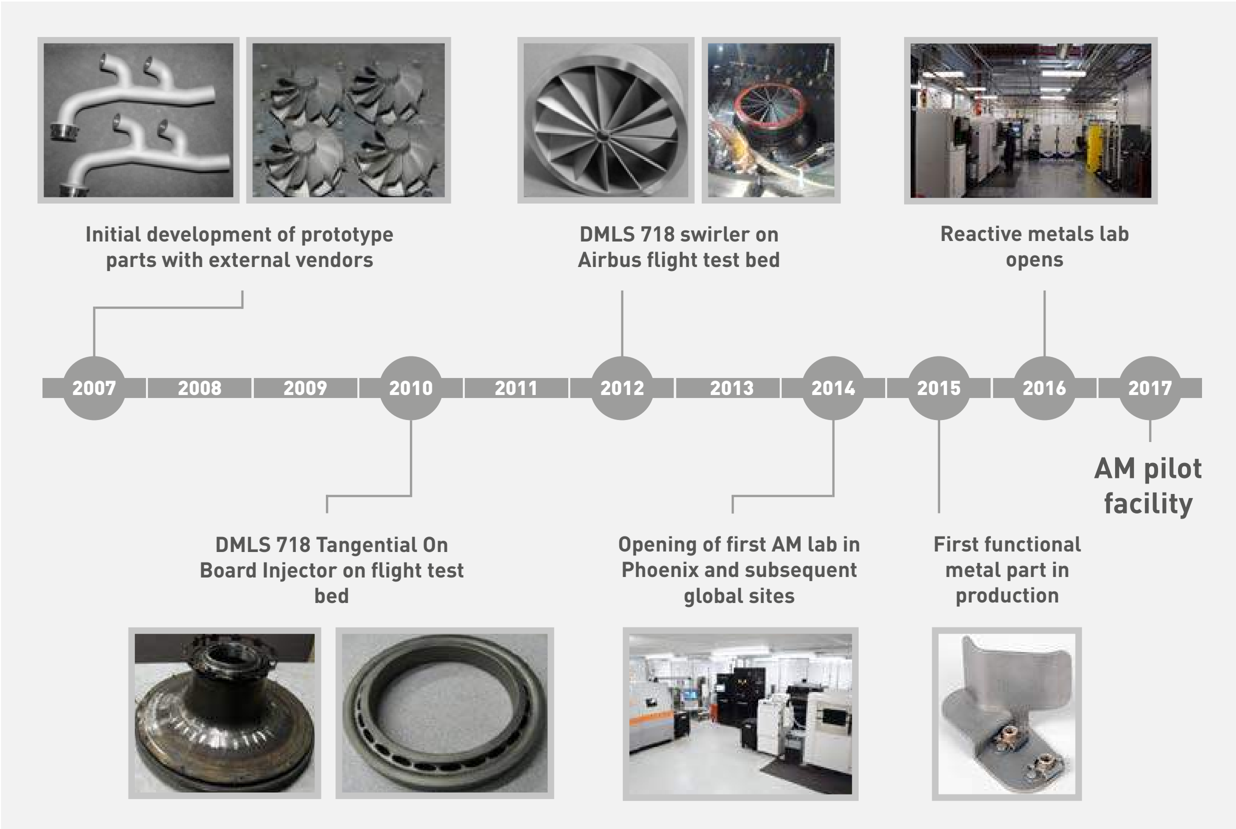

Fig. 2 A timeline of Honeywell's journey in metal Additive Manufacturing over the last decade

Honeywell's metal Additive Manufacturing journey

Honeywell's metal Additive Manufacturing journey began a decade ago with several prototype parts manufactured by external vendors (Fig. 2). Over the following five years, the company continued to evaluate the technology for insertion into applications where there was a need for a rapidly manufactured metal parts, including for test bed components. This coincided with significant consolidation in the metal AM service industry, which had the risk of impacting the company's ability to source metal AM parts.

In 2014, led by the efforts of Engineering Fellow Donald Godfrey, the company opened its first $5 million AM facility in Phoenix, with a focus on Laser Powder Bed Fusion and Electron Beam Melting technologies from a range of different suppliers (Fig. 3). The last three years have been particularly productive, with similar facilities being opened in Bengaluru (India), Brno (Czech Republic), Mexicali (Mexico) and Shanghai (China).

In 2016, Honeywell opened a reactive metal alloy AM facility in Phoenix (Fig. 4). Converted from an old flame spray facility, this now supports the production of AM parts from aluminium and titanium alloys. By the end of 2017, Honeywell is expecting to be in production with Inconel 718 parts at a new large pilot production facility, also in Phoenix (Fig. 5). The company's rapid growth in metal AM has been complemented by over $25 million in procured research funding, a positive endorsement of the progress the company has been making.

This expanding range of facilities is enabling Honeywell to drive forward the development of new AM applications, from concept through to pilot scale production. It is planned that following successful pilot scale production parts will transfer to external vendors.

Metal AM technologies and materials

Over the past three years, the team at Honeywell has focused on Laser Powder Bed Fusion and Electron Beam Melting and is somewhat unique in having real-world experience across these two technologies with four different equipment suppliers, namely Arcam, Concept Laser, EOS and SLM Solutions. This has allowed Godfrey and his team to directly observe the relative merits of the technologies and suppliers first-hand and make informed decisions on production-scale manufacturing.

Honeywell also makes use of indirect metal AM using 3D printed sand casting moulds for short-run metal parts that are best suited to casting but where the timescales and/or costs of traditional methods are not justified or feasible. In a wider discussion about metal AM technologies, Godfrey stated that while other technologies such as Directed Energy Deposition have their merits, their niches do not currently align well with Honeywell's specific needs and applications.

With regards to materials, Honeywell has identified Inconel 718 processed by laser-based Powder Bed Fusion as its leading material and process. This year the team generated a complete 'B-Basis' for this alloy, following requirements specified in the Metallic Materials Property Design and Standardization (MMPDS) handbook used commonly in the aerospace industry. This requires the generation of enough statistically valid data that at least 90% of the sampled population equals or exceeds the value of interest - for example strength - with 95% confidence.

Generating B-Basis data is an essential requirement for the insertion of these materials into critical production parts. In addition to Inconel 718, Honeywell is currently working on titanium and aluminium alloys, stainless steel and a number of proprietary alloys and processes.

Fig. 3 Honeywell's Phoenix Additive Manufacturing Technology Centre, opened in 2014

Fig. 4 The Reactive Metal Alloy Facility in Phoenix, opened in 2016

A spectrum of value: tooling, production parts and design optimisation

Like others in the wider AM industry, Honeywell has recognised the technology's potential beyond prototyping; namely in tooling and for production parts. While there is a temptation to address challenges in production right away, Honeywell has taken an approach that seeks to enable cost and time savings for non-critical applications, while also developing a pathway for moving into the production of parts with increasing criticality and impact. "With regards to production of functional parts, we are currently selecting components that are not life-critical. This is to get ourselves, our customers and the FAA (Federal Aviation Authority) more experience with the technology. There is no sense swinging for the fences when there is so much fruit easily picked," explained Godfrey.

Fig. 5 Honeywell's new metal AM pilot facility in Phoenix is in the process of being commissioned and will be fully operation by the end of 2017

Fig. 6 Some examples of the metal AM tooling currently in use at Honeywell. Left: Carousel for burner rig; top right: Test rake; bottom right, Clamp bracket.

Tooling

The team at Honeywell has made the conscious decision to implement a global effort to additively manufacture production tooling in parallel with the production parts. Godfrey stated, "While the time invested to gain customer and government approvals to print production parts can be long, the printing of tooling is very quick and has immediate impact on financial spreadsheets."

Some examples of functional tooling already in use at Honeywell are shown in Fig. 6. Manufacturing selected tooling with metal AM often results in both cost and time reductions of over 90%. Additionally, operators on the manufacturing floor are able to continuously provide ideas to improve production efficiency, by proposing and designing tools that aid in assembly. In addition to the inspiration for these parts coming directly from manufacturing, Honeywell also used the opportunity to evaluate the process's capability for manufacturing lattice structures by building them into the designs, a good example of the technology's ability to add complexity without incurring additional expense.

"The use of metal AM for production parts has significant benefits for the aerospace industry and is arguably where the largest return-on-investment for the technology lies"

Production parts

The use of metal AM for production parts has significant benefits for the aerospace industry and is arguably where the largest return-on-investment for the technology lies. For a new manufacturing technology to gain acceptance for the production of an engine component for an aircraft, it must be approved at three levels. The first level is internal, which involves all the different groups that are impacted by the change. It is here where risks and benefits are evaluated.

The second level of approval comes from the customer, who has to sign off on the change. Once this is done, the FAA has to certify that all the requisite data necessary for the part in question have been collected and that it meets stipulated criteria. For its first metal AM production part, Honeywell selected a relatively simple and non-critical splash guard used in a gearbox. This part was approved by all three parties and is currently in production.

Fig. 7 Tubular parts are prime candidates for replacement with metal AM. This Inconel 718 part has completed certification at all three levels

Several tubular components were also identified for their ability to enable part consolidation and, in one case, a reduction from eight sheet metal and cast components to one metal AM part was achieved (Fig. 7). This part has recently received approval at all three levels. As previously stated, Honeywell also uses indirect metal AM using 3D printed sand moulds to make metal castings for rapid, low-volume part production or replacement parts. These are deployed on Honeywell's HTF (turbo fan) and 777X turbine engine programmes.

Fig. 8 Two views of another tubular AM part developed by Honeywell

Design optimisation

Several components across different programmes have been identified at Honeywell as candidate parts for production using metal AM. The selection of these parts is often driven by requests from supply chain groups concerned with long lead times or from quality and supplier management groups that are concerned with high rework rates, quality issues and associated costs. Additionally, new product groups are looking at metal AM to improve the performance of their components while reducing weight.

Engineers at Honeywell are actively driving a culture change through the organisation so that metal AM is considered a legitimate option in design and manufacturing discussions. A three-day 'Design for AM' course is currently offered at the Phoenix facility for Honeywell employees and plans are in place to extend this offering worldwide.

Formal training is complemented by proof-of-concept studies such

Fig. 9 A proof-of-concept Inconel 718 engine mount bracket. The original part (top left), topology optimised design (bottom left) and manufactured part using Laser Powder Bed Fusion (right). The process achieved a 56% weight reduction while maintaining desired strength

as the engine mount bracket shown in Fig. 9. The original component was designed for casting and was therefore redesigned using topology optimisation software. It was then manufactured from Inconel 718 using a laser Powder Bed Fusion machine. The finished component was shown to have achieved a weight reduction of 56% while meeting the stated strength requirements.

A key challenge in implementing metal AM for critical applications, such as the above engine mount bracket, is the need to have multiple levels of qualification data. This starts at the material level, in terms of what is commonly called a B-Basis in the MMPDS handbook.

The necessary collection of B-Basis data can be time-consuming and expensive. At this time, Honeywell has established this dataset for Inconel 718 only and, as such, this is the lead alloy being considered for structural applications.

Global presence, local impact

While the majority of Honeywell's metal AM activities are conducted at its Phoenix facility, significant efforts are also underway at its four global sites in Brno, Bengaluru, Shanghai and Mexicali. All these sites have similar equipment to that at Phoenix's first non-reactive alloys lab and are contributing to the overall Honeywell metal AM programme in a number of differing ways, while also looking to improve the company's supply chain responsiveness.

The Brno lab focuses on transportation technology development, reflecting Honeywell's position as a global leader in turbocharger technology. As such, it has developed significant post-processing expertise and capabilities, including machining and inspection. The Bengaluru site has made significant strides in tooling for transportation systems test rigs, among other projects.

Lessons learned in the development of the Phoenix lab have been applied to other facilities. This is perhaps most true for the safety aspects of this technology. Honeywell's laser Powder Bed Fusion reactive alloy facility in Phoenix, supporting both titanium and aluminium alloys, is the only one of its kind in the state and has been established with stringent safety protocols, including implementation of Electro Static Discharge (ESD) prevention methods comparable to those used in the semiconductor industry. These include ESD coatings installed on top of the concrete floor, grounding stations, ESD grounding straps for clothing/shoes, personal protective equipment (PPE) to protect from dust inhalation and ESD mats (Fig. 10).

While the primary driver for establishing a worldwide presence is to have a responsive supply chain, each site has familiarity with problems and opportunities in the areas they work on locally and is thus likely to innovate with regard to using metal AM technology in different ways best suited to their applications. One such example is the remarkable use of metal AM to customise prototype turbochargers, initiated by the Bengaluru site (Fig. 11) by building a custom component on top of a previously built and standard housing.

In addition to a global presence in five countries, Honeywell Phoenix is contributing significantly to the local community and has touched small business and academia in a number of ways. Honeywell has always had a close working relationship with Arizona State University (ASU) and was the largest investor in establishing the university's $2 million Manufacturing Research and Innovation Hub. This hub contains an Additive Manufacturing facility which includes two laser-based metal Powder Bed Fusion machines in addition to a range of polymer technologies. The facility primarily enables students at ASU to gain exposure to this technology and is also used for early-stage research by faculty and students across the university.

Honeywell also works with students from ASU in a number of capacities. One example is the capstone project, a team project involving three to six senior undergraduates who, over a period of nine months, are co-advised by a Honeywell engineer and a faculty member at ASU. Projects that have been completed include the design of an AM heat exchanger, powder alloy development and combustor material development.

"Every project has applicability to real life-production," explained Godfrey, "The projects involve real-world designs within the Honeywell organisation." Honeywell has hired two ASU students at its Phoenix campus this year alone and has supported research at the university through seed funding and teaming on research proposals.

Fig. 10 Honeywell's Shanghai AM facility. An Electro Static Discharge (ESD) surface can be seen on the floor in front of the EOS machine

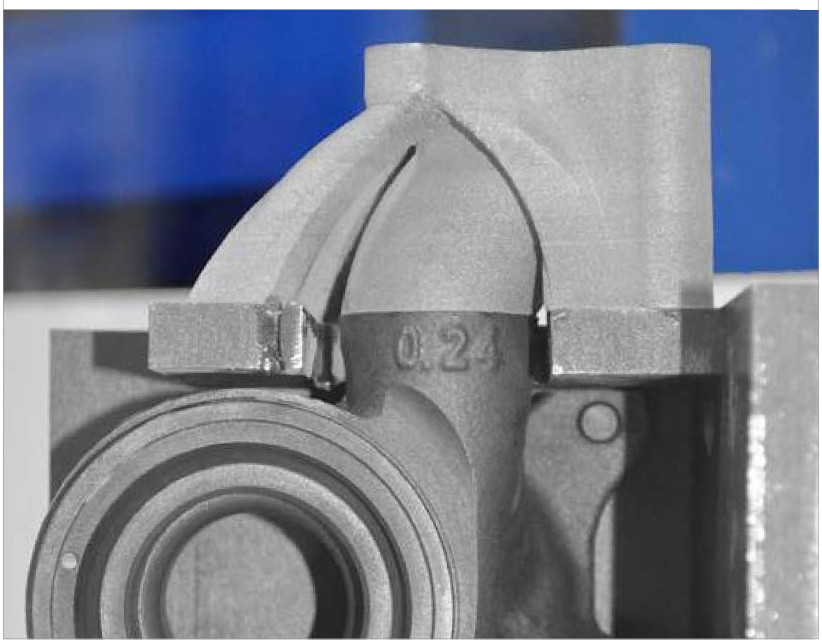

Fig. 11 An innovative feasibility study from Honeywell's Bengaluru facility, which demonstrates a proof-of-concept for rapid customisation of turbocharger prototypes

Fig. 12 Honeywell's new vacuum heat treatment system from Ipsen Industries

Enabling future growth

While Honeywell has already made significant strides in metal AM over the past decade, there is a long road ahead of exciting opportunities and challenges. These broadly fall into three categories: supply chain enabling, workforce development and research and development.

Supply chain

Honeywell's pilot production factory in Phoenix will support AM production using Inconel 718 and stainless steel powders and includes a powder room for storage and sieving, a vacuum furnace, a Hot Isostatic Press (HIP), machining areas and a quality room, as well as engineering offices and training rooms. This is on track to be fully operational by the end of 2017. The purpose of the pilot production factory is to develop processes and get them approved internally, by customers and by the FAA.

"After successful production has been established, Honeywell will look to transfer the process to external vendors by training them on Honeywell's specific requirements..."

After successful production has been established, Honeywell will look to transfer the process to external vendors by training them on Honey-well's specific requirements and working closely with them to ensure all qualification requirements are met during the move toward production at scale. This is currently a major thrust within Honeywell and the company is evaluating both existing metal AM service companies as well as established aerospace manufacturing companies that may only have limited of experience in metal AM. The goal is the building of a robust supply chain.

Commenting on the development of the AM supply chain, Godfrey stated, "Honeywell's approach is to develop Additive Manufacturing to the point where it is a generally accepted manufacturing technology within the aerospace industry. This means a supply chain will have to be developed and managed. Today, engine/airframe OEMs have taken the approach of using a vertically integrated supply chain with respect to AM because a reliable global supply chain does not currently exist. However, it would be unreasonable for a company to expect to vertically integrate all the machining or assembly for its products. The same applies to AM and therefore a supply chain must be developed."

Fig. 13 An operator cleaning an SLM 280 AM machine at Honeywell

"Ultimately, this means that the way Honeywell manages powder, certifies machines, qualifies lasers and many other steps must be integrated into the supply base one vendor at a time. Let us not lose focus on the fact that the FAA still considers AM a new and novel technology and because of this it will be tightly controlled. This work is going to take some time. It will be slow and it will be meticulous but it will be done correctly under the watchful eyes of both internal and external decision makers," stated Godfrey.

Workforce

At the root of Honeywell's investment in ASU is a recognition of the need for engineers who not only have the mechanical aptitude but the know-how to operate and maintain AM machines. In addition to its investment in equipment and support of student projects, Honeywell is also a key member on a recently formed Arizona Additive Manufacturing Committee that seeks to collaboratively address challenges and opportunities in AM for the state. One of the focus areas of the committee is workforce development at senior high school, community college and university levels and engineers from Honeywell are actively informing the direction of the committee with the aim of developing Arizona as a powerhouse for AM talent.

Research and development

Honeywell has obtained over $25 million in federal funding for research in AM since installing its first metal AM facility. Projects have included an Open Manufacturing programme funded by the Defense Advanced Research Projects Agency (DARPA) that combines new alloy development, process monitoring and Integrated Computational Materials Engineering (ICME) software in an effort to accelerate new material qualification and alloy design.

Honeywell has also been part of several teams conducting research as part of the America Makes consortium, working on projects including metal AM heat exchanger manufacturing, lattice modelling and evaluations of in-situ monitoring solutions for laser powder bed fusion. The company has also provided funding for research in dissolvable supports being driven locally out of ASU in collaboration with faculty at Penn State University.

The realisation of a vision

While Honeywell's progress in AM is undoubtedly the result of several team members' efforts, few would argue that Godfrey's vision and drive have been pivotal in ensuring the company is where it stands today. Godfrey first realised the potential of AM for functional parts in 2008 and what started as a solitary project in Honeywell's engines business has now developed into a multi-year, multi-million dollar competitive advantage, which is putting Honeywell at the forefront of metal AM.

Godfrey was recently awarded the Honeywell Aerospace Navigator Award in recognition of his initiative

Fig. 14 At the official launch of ASU's Innovation Hub, January 2017. From left to right, Kyle Squires (ASU), Malcolm Green (ASU), John Murray (GE-Concept Laser), Ann McKenna (ASU), Rich Barlow (Honeywell), Keng Hsu (ASU, currently at the University of Louisville), Don Godfrey (Honeywell), Joyce Yeung (GE–Concept Laser) (Photo Credit Jessica Hochreiter, Ira A Fulton Schools of Engineering, ASU)

and perseverance in bringing the technology to the engines business and beyond. He has also been granted twenty patents, with Honeywell generating additional revenue by licensing its technology.

Godfrey cites several lessons that have emerged from his decade of experience with metal AM technology. Chief among these is an appreciation for working with what is available. "All of us would like to have the ideal situation where we say 'this is needed' and 'that has to occur,' then press an easy button and it happens, but the truth is that is not how businesses operate. It is a fallacy to think a person can say 'let's make production parts with additive' and everyone gets in line and all the pieces fall into place," commented Godfrey.

He also cites the importance of leaders in the growth of AM as a manufacturing option of choice within the company. Finally, Godfrey identifies collaboration with multiple organisations as crucial for success in metal AM, particularly for structural aerospace components. "The key to success with additive technology," Godfrey stated, "is identifying risks and working with organisations to control and minimise them the best we can as an organisation."

> *"All of us would like to have the ideal situation where we say 'this is needed' and 'that has to occur,' then press an easy button and it happens, but the truth is that is not how businesses operate."*

Godfrey has emerged as much a champion of metal AM technology itself as he is a successful member of Honeywell's global AM team. He recently co-authored the book *Additive Manufacturing of Metals: The Technology, Materials, Design and Production* (Springer, 2017). "Machining is a generally accepted manufacturing process," said Godfrey. "My goal is to make Additive Manufacturing a generally accepted manufacturing process." Honeywell's AM team, and its rapid but deliberate progress in the past three years in particular, is evidence of the fact that this goal, as challenging as it may appear to those familiar with the issues the technology has yet to overcome, is well in sight.

Looking ahead

"As of today, the FAA has given approval for three parts to fly in commercial applications," Godfrey stated. "Honeywell has a strong Space and Defense Group and there are AM parts being used for these applications. Honeywell already has one part in space on a satellite launched last year. In rolling out the production of AM components, Honeywell has taken the approach to print non-life-critical engine components. These types of components lower the barrier of acceptance from our customers and the FAA. Honeywell will have at least four components qualified by the end of 2017 but there is a high probability it will most likely be six components. The number qualified for flight should be expected, at a minimum, to double every year for the next few years, meaning that by 2019 we could be looking at twenty-four types of components in production, increasing to nearly one hundred by 2021."

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Dhruv was recently appointed as Associate Professor at the Polytechnic School, Arizona State University. At the time of writing this report he was Senior Technologist at Phoenix Analysis & Design Technologies, Inc. (PADT).

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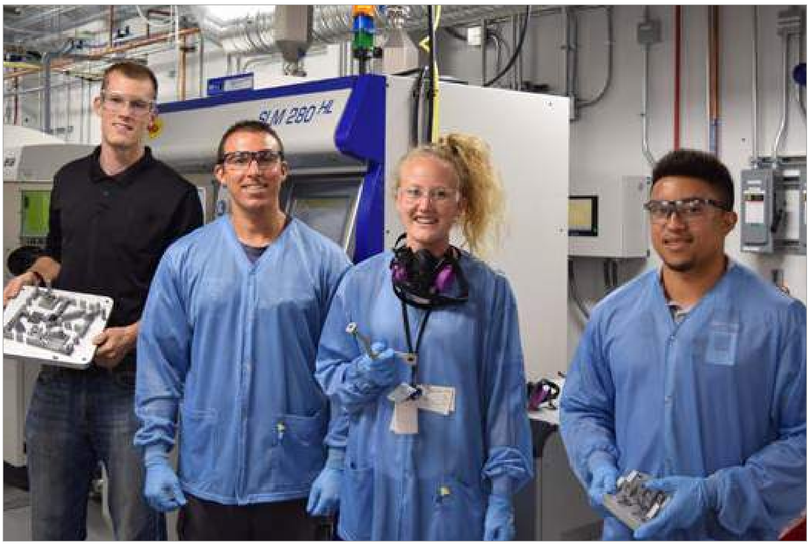

Fig. 15 Honeywell staff in Phoenix presenting recent builds

Fig. 16 A new Quintus HIP system for the final densification of AM parts

Fig. 17 A vacuum heat treatment furnace for the thermal processing of metal AM aerospace components

RapidTech + FabCon 3D: Innovations in binder-based AM and advances in conformal cooling

From June 20-22, 2017, the German city of Erfurt became a centre of gravity for Additive Manufacturing, hosting the annual RapidTech technical conference and its accompanying trade exhibition, FabCon 3D. Dr Georg Schlieper visited the event for *Metal Additive Manufacturing* magazine and highlights a number of innovative trends in metal Additive Manufacturing process technology and applications, including the latest binder-based Additive Manufacturing technologies and innovations in toolmaking.

This year's RapidTech + FabCon 3D event attracted a record attendance of more than 4,800 visitors and over two hundred exhibitors. Now in its 14th year, the organisers also reported a 20% increase in exhibitor numbers over the previous year and an increase in floor space of nearly 25%. The RapidTech conference, held in English and German with simultaneous interpretation, featured nearly a hundred presentations from Europe and further afield, and covered some of the most important sectors of Additive Manufacturing through a series of parallel Trade Forums.

The conference opened with a keynote presentation by Charles 'Chuck' Hull, recognised as the inventor of stereolithography and co-founder of 3D Systems, a leading US producer of AM machines. Hull shared the story of his career and spoke about the many frustrations that each inventor has to go through before a product is created that can be manufactured and marketed economically. Today, Hull is 3D Systems' Chief Technology Officer.

BASF: printing metal like plastics

Several innovative AM technologies were presented in the exhibit hall which will complement, and possibly compete against, established powder bed AM processes such as laser and electron beam Powder Bed Fusion (PBF) and Binder Jetting. BASF SE, Germany, introduced a polymer filament containing a high concentration of 316L metal powder. The filament material is based on the company's Catamold® binder system, which has been used successfully for many years in the Metal Injection Moulding (MIM) industry. In cooperation with

Fig. 1 The modern Exhibition and Congress Centre of Erfurt (Courtesy Messe Erfurt)

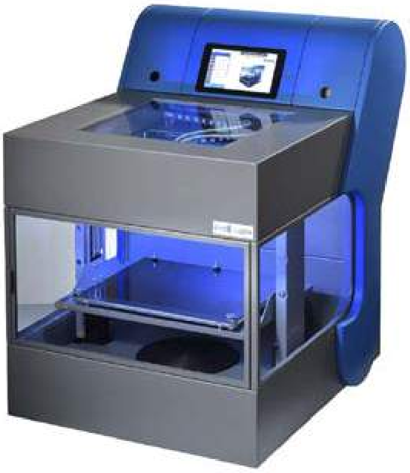

Fig. 2 The desktop-based metal AM system EVO-lizer (left) and printer head with nozzles (right) (Courtesy Evo-tech)

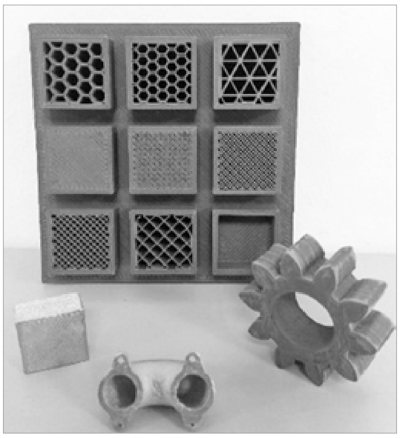

Fig. 3 Demonstration parts in the green state, manufactured on the EVO-lizer (Courtesy Evo-tech)

the Austrian company EVO-tech GmbH, BASF has developed a Fused Deposition Modelling (FDM) process analogous to the printing of polymer filaments and Evo-tech presented a desktop printer for both polymer and metal filaments under the brand name EVO-lizer (Fig. 2).

The EVO-lizer, with external dimensions of 860 x 840 x 540 mm, has a build space of 270 x 200 x 210 mm and is equipped with two high temperature nozzles for melting the filament at up to 330°C. Nozzle diameters between 0.2 and 0.8 mm are available, generating a layer thickness of 0.1–0.75 mm. The EVO-lizer can be plugged into any 230 V household power plug and the power consumption is just 250 W.

Needless to say, the price point for this printer is an order of magnitude less than the price of a PBF-based metal AM system, which could lead to a dramatic reduction in cost for certain types of additively manufactured metal product.

Processing the extruded part

BASF's filament is produced by working metal powder into a polymer binder based on polyoxymethylene (POM), with a metal powder content of 50–60% by volume. It has a diameter of 1.75 mm and can be printed like a polymer filament. The result is what is called a green part (Fig. 3) requiring further processing. The parts created using this method are reportedly characterised by an excellent green strength that allows for the removal of scaffolds and post-processing to be carried out in the green state with little effort and at low cost in order, for example, to improve the surface quality or individual dimensions.

Debinding

The next step is the degradation of the POM binder in an acid environment at temperatures around 120°C. The catalytic debinding process uses highly concentrated nitric acid (HNO_3) with a concentration of at least 98%. The acid vapours rapidly decompose the main binder constituent without damaging the part, thereby creating a network of open porosity in the part. The part shape and size are not changed, nor is there any deformation during the debinding process, since the temperature for catalytic debinding is significantly lower than the softening point of the binder system. A portion of the binder remains in the part after catalytic debinding so that sufficient strength is maintained to hold the part together and allow safe transportation to the sintering furnace.

The speed of binder degradation using this method is relatively high, as compared to other binder removal processes such as solvent or thermal debinding. BASF claims that the main binder constituent, POM, can be completely removed from parts with up to 5 mm wall thickness in less than three hours. The main reaction product is formaldehyde, which is further degraded by the flame of a natural gas burner so that the final products are completely harmless to the environment. Industrial debinding ovens for this process are available from several manufacturers and in various sizes, either batch type or continuous.

Sintering

After the removal of the main binder constituent by catalytic debinding, the parts are sintered at a temperature above 1300°C to create a solid metal structure. The portion of the binder remaining in the component after debinding, the 'backbone binder', is rapidly evaporated through the open pore network while the parts are heated to sintering temperature. As the organic components are removed, the fine powder particles begin to sinter, forming solid material necks at their contact interfaces. This way, the metal powder does not disintegrate and the part shape is maintained throughout the process.

Sintering, the process by which powdered material is transformed from a loose arrangement of powder particles into a solid material without losing the shape of the component, is accomplished by diffusion processes, i.e. atomic displacement and material transport in the solid state. As the temperature increases, so does the part strength, as the internal porosity is reduced until the part is almost fully dense.

The driving force of sintering is the reduction of the free surface energy. Along with the densification goes a shrinkage of the part, amounting to roughly 15% linearly. At the end of the sintering process the material is nearly pore-free and the physical properties are similar to those of wrought materials.

This complete process may sound rather complex to readers who are not familiar with MIM, but it is a well-established industrial process and many millions of parts are produced by this technology every day. MIM parts manufacturers with catalytic debinding ovens and sintering furnaces can easily adopt EVO-lizer technology or similar for rapid prototyping or small series production.

AIM3D: FDM of MIM feedstock granules

Another AM innovation was presented by Germany's AIM3D GmbH. This start-up is a spin-off out of Rostock University. Clemens Lieberwirth, AIM3D's Technical Manager, has invented a micro extruder for use as an AM print head which handles MIM feedstock granules like an injection moulding machine. Integrated in an AM system, it can manufacture metal parts by FDM. As with BASF's new filament, these green parts then undergo a MIM-style debinding and sintering cycle to achieve the required material properties (Fig. 4).

The AIM3D system can handle commercial polymer granules as well as metal and ceramic, making it easier for manufacturers to extend their range of materials using the wide variety of feedstocks commercially available. Lieberwirth told *Metal Additive Manufacturing* magazine that successful tests have been carried out with 17-4 PH, 316 and 304 stainless steels, tungsten carbide and ceramic feedstocks. Even copper has recently been manufactured.

This system is not restricted to a catalytic debinding system and is able to process even feedstocks based on water soluble binders, thereby

Fig. 4 AIM3D's new AM system along with a ratchet and turbine wheel manufactured by the company (Courtesy AIM3D)

Fig. 5 An XJET machine and demonstration parts made from 316L stainless steel (Courtesy XJET)

reducing the required investment for binder removal systems. The system will be commercially available starting in 2018.

These developments mark a significant step towards cost reduction for metal AM components. However, more research and engineering development is required to prove the integrity and reproducibility of materials produced by this technology. Dimensional accuracy and surface quality, critical features of all AM processes, need further improvement. Since the technology is still very young, significant progress in this respect can be expected in the years to come.

XJET: inkjet printing for metal and ceramic powders

A new AM technology for metals and ceramics was promoted by XJET Ltd., Rehovot, Israel. 'Nano Particle Jetting' uses a slurry of sub-micron metal or ceramic powder particles in a carrier liquid as raw material, which is supplied in sealed cartridges. Printer heads are used to deposit an extremely thin layer of particles with each print cycle.

During production, the machine's build space is heated, thereby evaporating the carrier liquid and creating firm contacts between the powder particles. Scaffolding structures can be made of a different material to the product, making them easier to remove than traditional scaffolds and supports. The manufactured green parts are then sintered to almost full density, with a shrinkage between 5 and 10% linearly, depending on the material.

XJET claims to have achieved unprecedented detail, excellent dimensional accuracy and surface quality in parts produced with this technology (Fig. 5). Among the metals available, 316L stainless steel has been processed so far. The speed of manufacture is reported to be similar to that of other AM technologies thanks to a multitude of nozzles in the printer heads.

These examples show that there is still room for substantial innovation in metal AM. It is exciting to see the continued development of such technologies and that new and unconventional ideas are being realised by researchers. This will lead to more competition among the various alternatives in metal AM technology, exert a pricing pressure on the established laser beam systems and further extend the range of applications of metal AM products.

Advances in AM for conformal cooling applications

Since the emergence of metal Additive Manufacturing, the toolmaking industry has adopted this technology for various industrial applications. Many of these have been reported in this magazine; perhaps the most well-known being mould inserts with internal cooling channels, for injection moulding and pressure casting tools. In its Trade Forum on Tool, Mould and Fixture Making, the RapidTech conference covered this topic and the latest broader developments in the sheet metal forming of automotive components and body parts.

Optimising cooling channel design

Gerald R Berger, of the University for Mining, Metallurgy and Materials in Leoben, Austria, presented his research on the optimisation of cooling channel design in injection

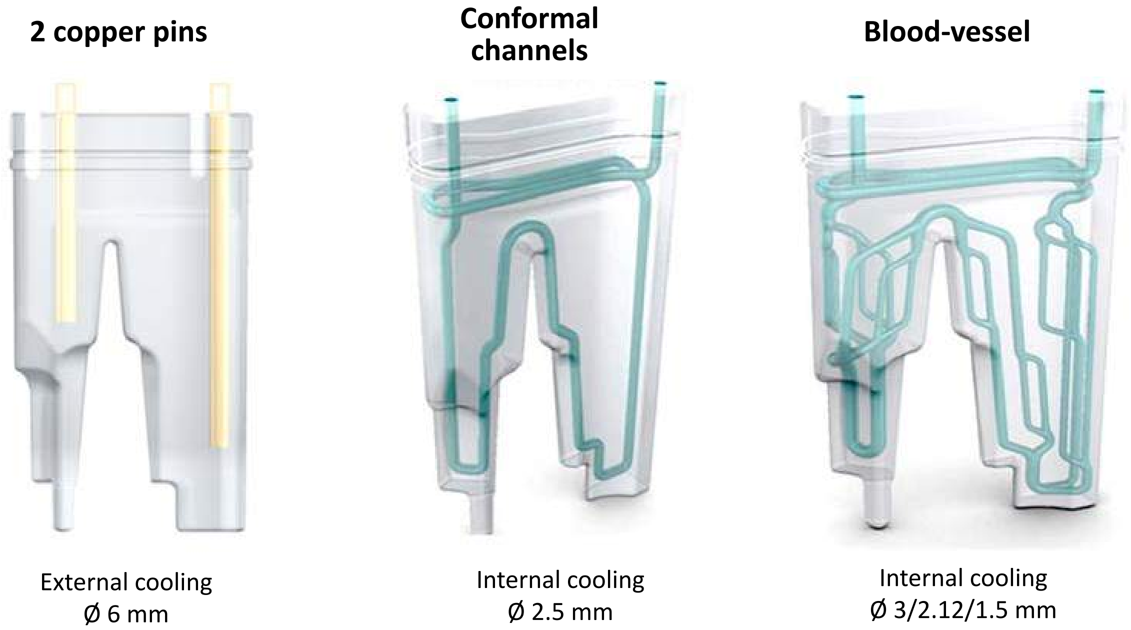

Fig. 6 Possible cooling concepts for an injection moulding tool insert (Courtesy University of Leoben)

moulding tools. The time required for the injection moulding cycle comprises the times required for tool closing, injection, holding the pressure, cooling, tool opening and ejection of the component. To a great extent, productivity is determined by the required cooling time (i.e. pressure hold time plus remaining cooling time). Accelerated cooling is therefore a key approach for increasing productivity. For components with large differences in wall thickness, the installation of tool inserts with internal cooling channels produced by Additive Manufacturing is particularly advantageous.

Berger compared three different injection moulding tool insert designs, one in the traditional design with two copper pins of 6 mm diameter to help remove the heat faster due to the high thermal conductivity of copper and two inserts with internal cooling channels made by metal AM (Fig. 6).

The first AM design presented was a single conformal cooling channel with a constant diameter of 2.5 mm. Conformal cooling means that one or more cooling channels are designed to follow the contour at a constant distance as close underneath the surface of the insert as possible,

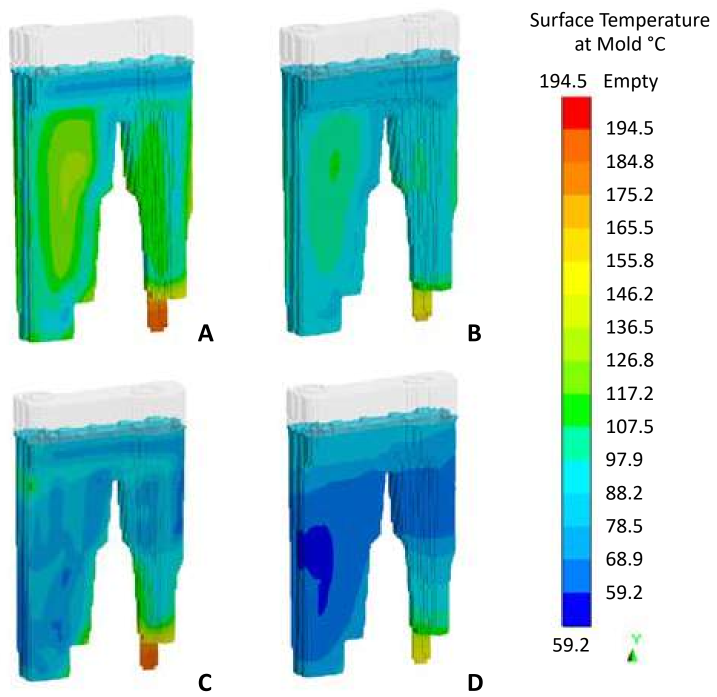

Fig. 7 Surface temperature of the mould insert 3.5 s after the start of the moulding cycle (Courtesy University of Leoben)

without putting the stability of the component at risk.

The second AM design was modelled to mimic the structure of blood vessels, with several branches of channels. The channel diameter was reduced at each branch by the square-root of 2, starting from 3 mm through 2.12 mm to a minimum diameter of 1.5 mm. This ratio derives from the condition of equal volumetric flow rate through each channel.

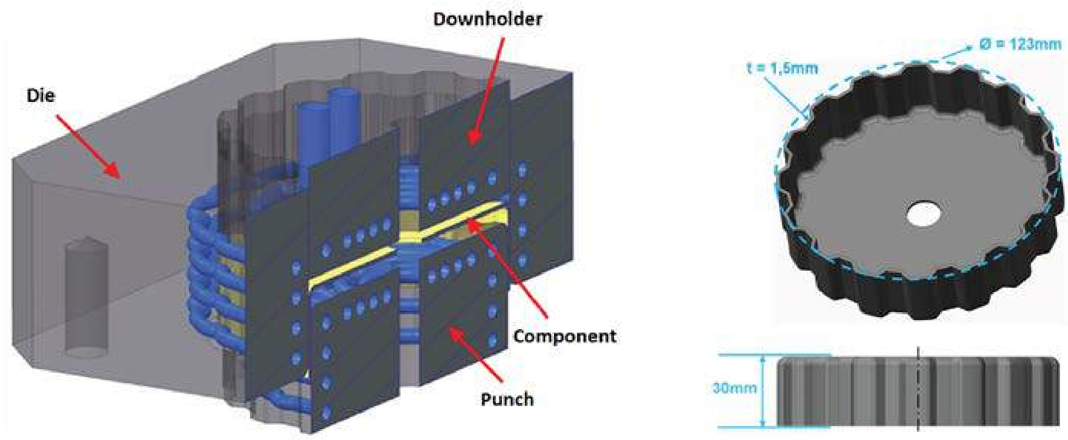

Fig. 8 Forming tool design with conformal cooling (left) and the resulting component (right) (Courtesy Fraunhofer IWU)

A constant flow of the cooling medium and limited pressure differences between the channels were achieved by keeping equal length between the branches as far as possible.

The performance of the investigated cooling concepts was studied in a series of computer models. Fig. 7 shows the calculated surface temperature of the mould insert at 3.5 s after the start of the moulding cycle for the optimised cooling concepts. Images A-D compare two different insert materials, namely steel 1.2343 (A, C) and the copper base alloy AMPCO 83 (B, D) with a higher thermal conductivity than steel, and two cooling concepts, the conformal (A, B) and blood vessel cooling channels (C, D). The higher thermal conductivity of the copper alloy resulted in a marked lowering of the surface temperature, but the effect of the blood vessel cooling compared to the conformal cooling was even more pronounced.

In the discussion that followed the lecture, a listener commented that the blood vessel solution was practically problematic because it would be almost impossible to clean the channels once they were clogged. A practical application would therefore always prefer cooling channels of a uniform diameter over a branched version.

Development of an automotive component forming tool

Although at first sight they may sound almost the same as the injection moulding and pressure casting applications mentioned above, the technical requirements for sheet metal forming are much more demanding. While the temperatures during injection moulding of polymers are usually less than 200°C and temperatures of about 500°C are reached during aluminium pressure casting, sheet metal forming involves temperatures of about 1000°C for austenitising the steel sheet. This is then rapidly cooled to below 200°C in the press to achieve a martensitic hardened structure. Because of the high temperatures involved, the requirements for the mould insert material are much higher than for the other applications mentioned above.

Automotive components made from high strength steels by sheet metal cold forming pose extremely high challenges on the forming process. Alternatively, direct hardening in the forming press offers higher strength and consequently the option to save weight by reducing the sheet thickness. Furthermore, parts can undergo martensitic hardening in sections where high strength and wear resistance is required and left with higher ductility in other sections by cooling less rapidly.

Mathias Gebauer of Fraunhofer Institute for Machine Tools and Forming Technology (IWU) in Chemnitz, Germany, has developed a sheet metal forming tool with conformal cooling channels made by Additive Manufacturing. The three tool elements which make direct contact with the component, i.e. punch, die and downholder, were all equipped with conformal cooling channels (Fig. 8). For economic reasons, a hybrid solution was chosen whereby only the functional geometry with the cooling channels was made by Laser Beam Melting and the main body of the tool elements was made by conventional technologies. With this innovative tool solution, the cooling time required to cool the component from 1000°C to below 200°C and create a martensitic structure could be reduced from ten to three seconds. Here, conformal cooling is crucial to remove the heat fast enough to achieve a martensitic steel.

Car body parts by direct press hardening

Today, car body parts are usually cold formed from steel sheet in several steps on highly automated stamping and press lines. The huge stamping and forming tools used represent a major cost factor in the production of car bodies. Reducing the thickness of the steel sheet offers significant potential for weight reduction; as a result of the trend towards weight reduction in car production, body panels have become ever thinner. In order to achieve sufficient strength and stability, automotive companies have developed a process to harden body parts in the forming press, called press hardening.

Rapid cooling of steel sheet of a reasonable size from 1000°C to below 200°C requires an extremely efficient cooling system. This can only be achieved with conformal cooling channels, as demonstrated by Roland Malek of Volkswagen Slovakia.

Malek reported on the results of manufacturing a demonstrator body part by press hardening. Two mould inserts were compared, one with conventionally drilled cooling channels and one with conformal cooling channels made by Laser Beam Melting. The two solutions are shown in Fig. 9. The upper example has the drilled cooling channels and the lower one has the conformal cooling channels. Temperature profiles of the formed sheet with conventional cooling (top) and conformal cooling (bottom) are also shown. The insert with drilled cooling channels was not capable of cooling the part fast enough for complete martensitic hardening. There was a critical area in the centre where the maximum temperature was still 335°C, whilst the part manufactured with conformal cooling had a maximum temperature of 177°C.

In the discussion following the presentation, an objection was raised that the few tool steels currently available for laser Powder Bed Fusion wear relatively quickly under the high pressures and temperatures they are exposed to during press hardening and thus cannot guarantee a sufficient lifetime. Malek agreed and suggested that it is the responsibility of AM machine developers to enable the production of tool steels with higher carbon contents. This would contribute to further industrialisation of Laser Beam Melting and could be a major advancement for the tool-making industry, growing the demand for AM systems.

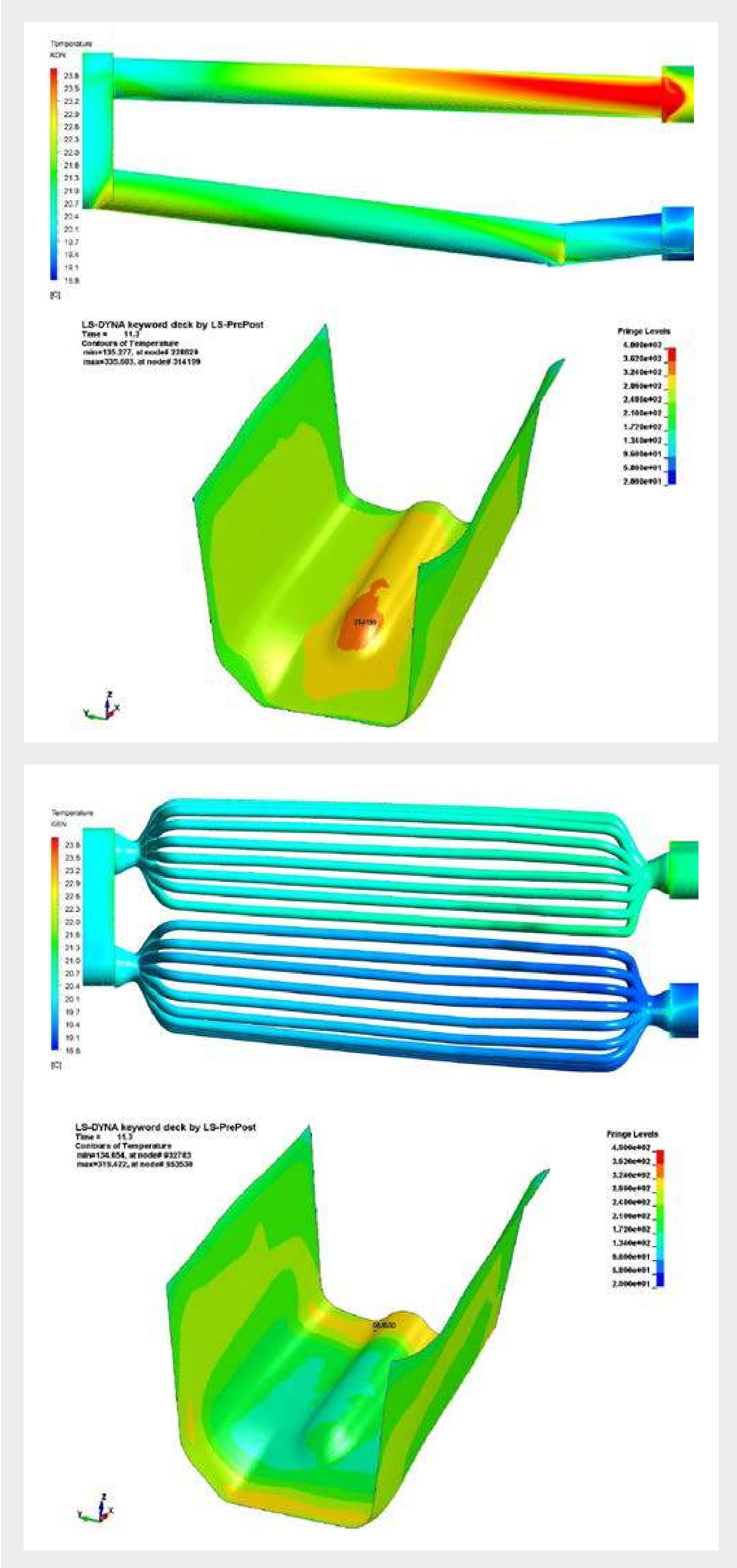

Fig. 9 Demonstrator body part tool cooling designs and sheet temperature profiles for parts made with conventional drilled cooling (top) and conformal cooling channels (bottom) (Courtesy Fraunhofer IWU)

Fig. 10 Stealth keys on a build plate exhibited at RapidTech, along with the finished design (Courtesy UrbanAlps)

Start-up Award: security keys coming out of the powder bed

During the conference, a Start-up Award was given for a particularly innovative business idea relating to AM. All companies that entered the competition presented their business plans to an expert jury, with the winner receiving €3000.

This year, the jury unanimously selected Alejandro Ojeda, Co-Founder and Managing Director of Urban Alps AG, Zurich, Switzerland, for the development of a new type of high-security key. The Stealth Key is similar to conventional high-security keys, but incorporates two flat side covers to hide the key profile – the essential information for unlocking a door – so that it cannot be easily copied, even using the latest 3D scanners. Other geometrical details to prevent copying can be integrated in the design at no extra cost.

The key, manufactured by Laser Powder Bed Fusion, requires no post-processing except separation from the support structure. Fig. 10 shows a batch of stealth keys prior to removal from the build plate of the AM system. According to UrbanAlps, the target price for these keys, when produced at high volumes, is approximately €30.

The jury stated that it was especially impressed by this concept because it demonstrates the feasibility of mass producing consumer products by metal AM. UrbanAlps is now seeking three pilot customers willing to test the innovative key concept in daily practice in order to eradicate any teething problems and prove the usefulness of the stealth key concept.

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Design for Additive Manufacturing: Increasing part value through intelligent optimisation

Paying the right amount of attention to Design for Additive Manufacturing (DfAM) can make the difference between economic success and failure. When considering Additive Manufacturing for production applications, it is important to consider designing, or redesigning, parts that would otherwise be produced using conventional manufacturing. In this case study, Terry Wohlers and Professor Olaf Diegel, both of Wohlers Associates, reveal how industrial mining machine manufacturer Atlas Copco has used DfAM to increase the value of a hydraulic manifold.

Atlas Copco, an industrial tool and equipment manufacturer headquartered in Nacka, Sweden, has been exploring DfAM as it considers the move from traditional manufacturing to AM to add value to its products and production processes. One application example is a hydraulic manifold used on one of its underground drilling rigs (Fig. 1). The company is particularly interested in using AM to substantially reduce the weight of the manifold's parts while improving its functionality. Because the manifold is mounted at the end of the rig's extendable boom arm, reducing its weight could add substantial value to the rig's functionality. A project to redesign this manifold for AM was carried out by Fredrik Andersson, Magnus Karlberg and Sima Valizadeh of Atlas Copco, together with Lund University Master of Engineering student Henrik Nilsson, who led development.

The hydraulic manifold, currently manufactured by CNC machining, consists of a block of stainless steel into which a large number of connecting holes are drilled. They form a number of interconnecting channels through which hydraulic fluid flows to the proper ports. Valves and sensors can also be attached to measure pressures. When using conventional manufacturing, the only way to produce connecting channels inside the block is to drill holes from the outside of the block and then plug them so that the internal channels remain.

Support structures as a key consideration

One of the most important goals of designing for metal AM is to reduce the amount of support material used when printing the part. With metal AM, support material is used to anchor the parts to the build plate

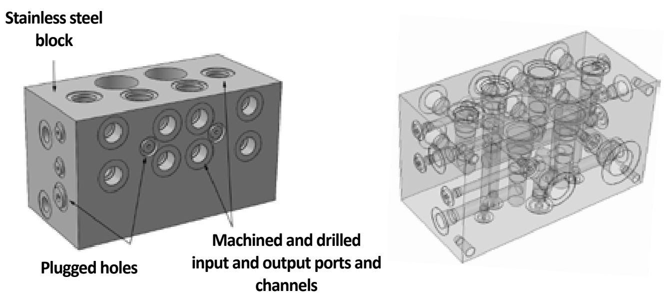

Fig. 1 Top, an Atlas Copco underground drilling rig and bottom, the company's original manifold block design

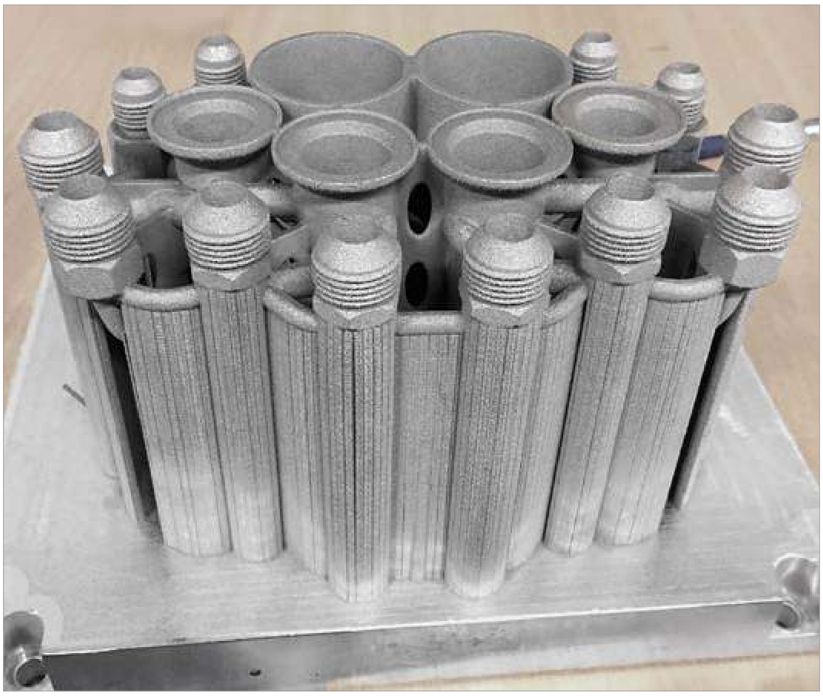

Fig. 2 The hydraulic manifold designed for metal AM with support structures attached

Fig. 3 The hydraulic manifold designed for metal AM with support structures removed

during printing and to transfer heat away from the parts. This approach reduces the possibility of distortion of the parts from the extreme heat. In particular, it is important to avoid support material in any internal features, such as the channels of the manifold, as this can be difficult or impossible to remove. Typically, any feature that is more than a certain angle from vertical, such as 45° (the exact angle varies depending on the material being printed), will require support material. A wall can be used as a feature of the design to avoid support material while also improving the strength and rigidity of the part.

The functionality of the manifold was also improved using the DfAM process. On the original design, the positions of the inlet and outlet ports were determined by the easiest direction from which the holes could be drilled, rather than where they would be most suitable for use or assembly. On the redesigned version, the outlet ports were moved to the top surface and only the inlet remained at the bottom surface. This greatly reduced the overall volume required to install the manifold in the machine. Fig. 2 shows the redesigned manifold before support removal, Fig. 3 shows the manifold after support removal and Fig. 4 shows the completed manifold.

Atlas Copco's redesigned manifold required minimal amounts of support material (Fig. 5). Also, the required support material was in easy-to-access locations, making it relatively straightforward to remove. After being redesigned for metal AM, the manifold's weight dropped from 14.6 kg to 1.3 kg - a weight reduction of more than 90%.

Understanding the thought processes used through a simplified design

It is important to consider the overall thought process employed in the redesign of this manifold. One way to examine it is through the step-by-step design of a simple generic manifold made from a 100 mm^3 block of steel (Fig. 6).

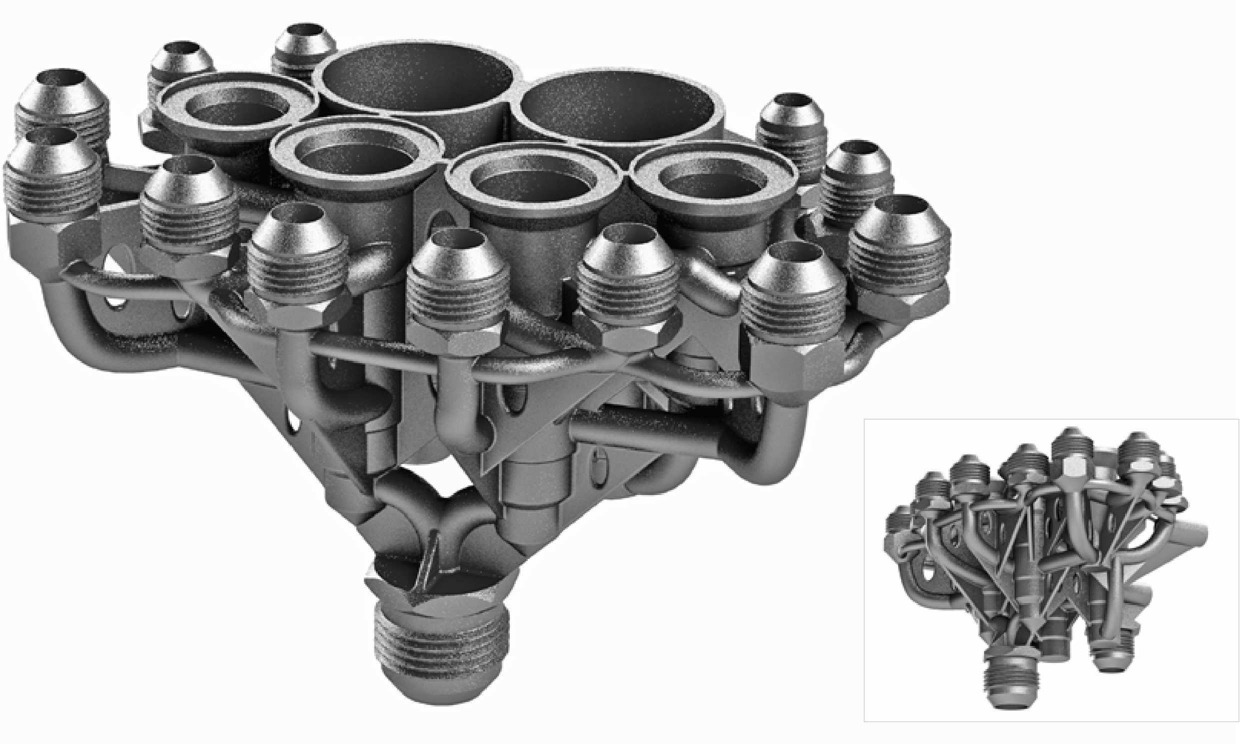

Fig. 4 Top and bottom views of the finished optimised stainless steel AM hydraulic manifold

The process begins with simplifying the original block design by eliminating all drilled holes that are normally blocked by plugs. These holes serve no functional purpose other than to allow the creation of internal channels. The goal is to produce the simplest representation of the block manifold with the actual channels for transporting hydraulic fluid. It can also be useful, at this stage, to add fillets to smooth the flow of fluid, compared to the original straight holes.

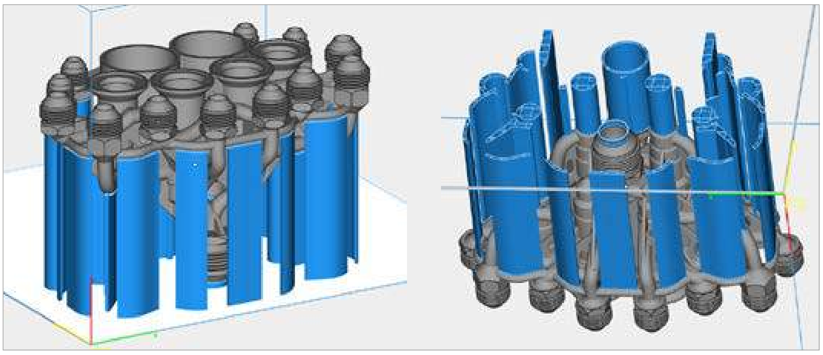

Fig. 5 The support material required for the optimised manifold design

Reducing material usage

Once the block design has been suitably simplified, the next step is to remove the excess material of the cube to leave only the pipes that form the manifold channels. Most CAD software products have a shell function that removes everything except for a shell of specified wall thickness; in this case, the six outer faces of the cube were selected to be removed, leaving only the internal channel structure, with a wall thickness of 2 mm (Fig. 7).

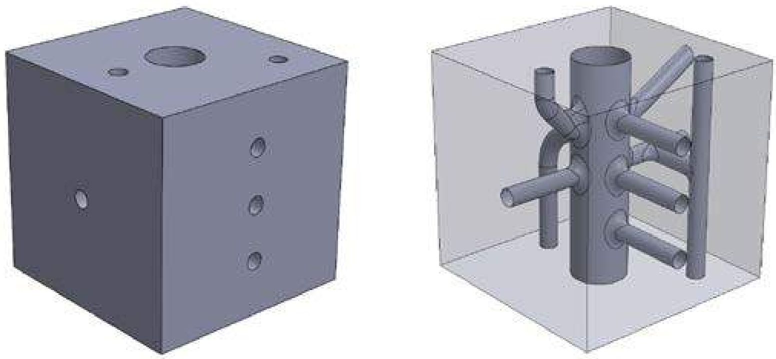

Fig. 6 Simplified block design manifold showing only the required in and out channels

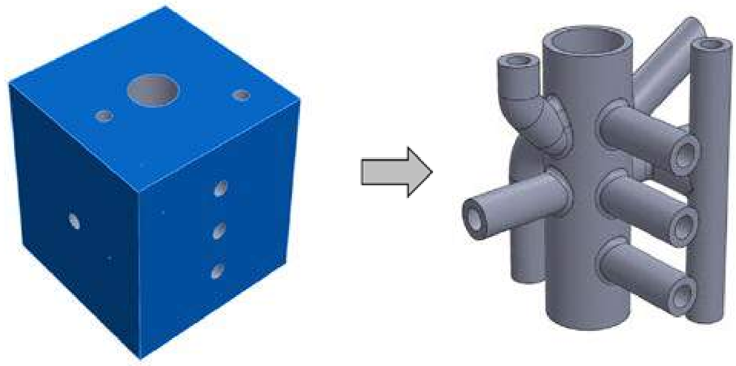

Fig. 7 Manifold design before and after the shell operation on the manifold block design

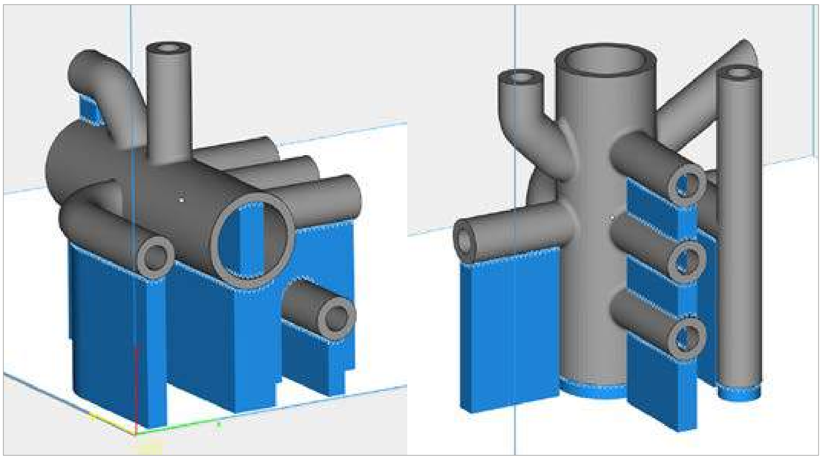

Fig. 8 Support material required by the shelled block design in two different print orientations

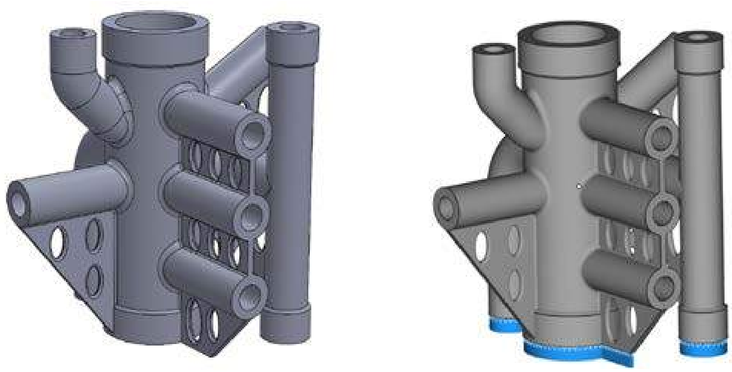

Fig. 9 The optimised design on the left requires minimal support material, as can be seen on the right

Using the shelled version, it is much easier to visualise the overall manifold design. This in turn makes it easier to determine whether, and how, the part's functionality could be improved. In this case, one improvement might be to modify the horizontal channels to include an upwards vertical bend. If so, the easiest option may be to return to and modify the original block design, then redo the shell function. Alternatively, supposing the design is as functionally sound as possible, the next step would be to examine the design from the point of view of AM optimisation. Note also that if the sole purpose of this exercise were to achieve maximum weight reduction, the design would now be complete, because it uses a minimum amount of material.

Part orientation on the build plate

An important factor to consider at this stage of the design is the print orientation, as it will affect most other design decisions. When designing for metal AM, one should always design around the specific orientation in which the part will be printed. This is because part orientation impacts the direction of anisotropy, surface finish, roundness of holes and support material. In this case, one could make the decision to print the part with the large diameter pipe in the vertical orientation. If it were printed with the larger pipe in the horizontal orientation, the larger diameter pipe would become filled with support material, which would be difficult to reach and require additional post-processing, increasing the build time and amount of material used (Fig. 8).

When running the design through software used to generate support structures, such as Magics, we can see that support material is generated between all the horizontal pipes. In the orientation at which the larger diameter pipe is horizontal, support material is generated inside this pipe.

Both print orientations necessitate the removal of support material after printing and both will require surface treatment to improve the finish at the points where the support material makes contact with the part. The print orientation at which the large diameter pipe is horizontal would make it difficult to remove the support from inside the pipe. The better print orientation, therefore, is with the large pipe positioned vertically.

Alternatives to support structures

A design option worth considering is to add a thin wall under each of the horizontal channels to entirely eliminate the need for support material. The idea is that the added wall becomes the support, as well as a permanent feature of the part. In Fig. 9, the bottom walls are chamfered at 45° to eliminate the need for support material. Oval holes in the walls are instead used to reduce weight and eliminate the need for support material inside the holes. The result is a design in which support material is only necessary to attach the bottom of the part to the build plate.

The support walls also provide the functional benefit of added rigidity. These walls will counteract some of the forces generated when fastening the pipes to the manifold and thus help to minimise the risk of damage.

Compared to alternatives, the design in Fig. 9 would require minimal work to remove support material. After using wire EDM or sawing to remove the part from the build plate, a quick shot-peening operation may be sufficient to finish the surfaces. The part may also require the tapping of screw threads, so material can be added to accommodate this (Fig. 10).

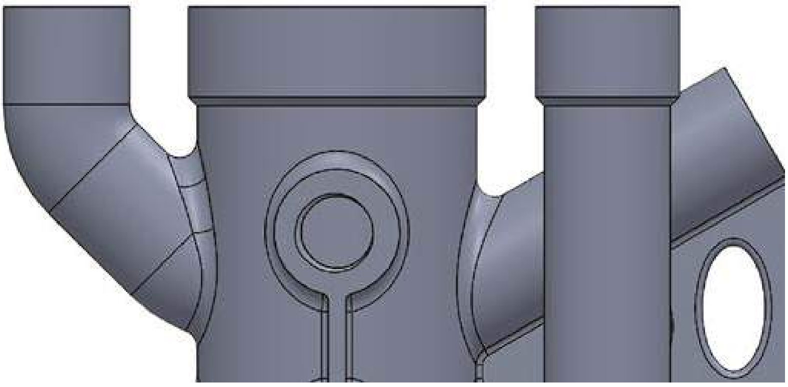

Fig. 10 Material was added to the pipes for subsequent tapping of screw threads, with a 45° chamfer to eliminate the need for support material

"A design option worth considering is to add a thin wall under each of the horizontal channels to entirely eliminate the need for support material."

Conclusion

With DfAM, it is important to consider a number of design rules and guidelines. Among them are minimum wall thicknesses, hole diameters above which support material is required, and the angle beyond which support material is required.

In this example, the horizontal pipes have been carefully sized to include an inner diameter which eliminates the need for support material. This is usually 6-8 mm, depending on the AM system being used. Material has been added where pipes will be tapped for screw threads as a post processing operation. A 45° angle for chamfers has been used to eliminate the need for support material. The weight of the original 100 mm^3 block manifold design in steel is 7.1 kg. In contrast, the optimised design weighs only 600 g - a weight reduction of nearly 92%.

It is important that approaches to DfAM must be taken consciously. The results are only as good as the decisions made about the strategies used to minimise the need for post-processing. This is clearly demonstrated in the Atlas Copco manifold example. By reducing its weight, making it easier to manufacture and improving its functionality through the use of DfAM, the value of the part was substantially increased.

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Design for Additive Manufacturing: Transforming RF antennas through intelligent optimisation

Additive Manufacturing presents the opportunity to completely rethink a product's design, transforming its functionality and reducing manufacturing complexity. With the right application and the right approach, the results really can live up to industry buzzwords such as 'disruptive' and 'transformational'. In the following article, Optisys LLC reveals how, through intelligent design optimisation, the company has used Additive Manufacturing to develop the next generation of RF antenna systems for aerospace and defence.

Optisys, based in West Jordan, Utah, USA, is a specialist producer of innovative radio frequency (RF) antenna systems using Additive Manufacturing. By applying the principles of Design for Additive Manufacturing (DfAM), the company's engineering team can take an antenna assembly that has a hundred parts and consolidate them into just one. Optisys' CEO Clinton Cathey calls the results of this extreme parts consolidation 'single-piece assemblies.' The result is a dramatic reduction in size, weight, lead time and cost while boosting RF performance. Fig. 1 shows an aircraft antenna with an AM antenna feed running horizontally through its centre and an AM Ortho Mode Transducer protruding through the rear; these two components were optimised through DfAM.

"There are not many companies like us that are designing products to take full advantage of AM," stated Cathey. "Designing antennas for Additive Manufacturing requires a new way of thinking about structures. The early adopters of AM made just prototypes and tooling and that mindset is still pretty widespread. But we formed our company by identifying a niche market where Additive Manufacturing is the production method from the start. We're solving end-use challenges with it."

Earlier this year Optisys revealed the savings possible in weight, time and costs through parts consolidation in a Ka-band monopulse tracking array. Today the company is developing a full line of customisable antenna feeds and other antenna products and delivered its first commercial products to a customer this summer (Fig. 2).

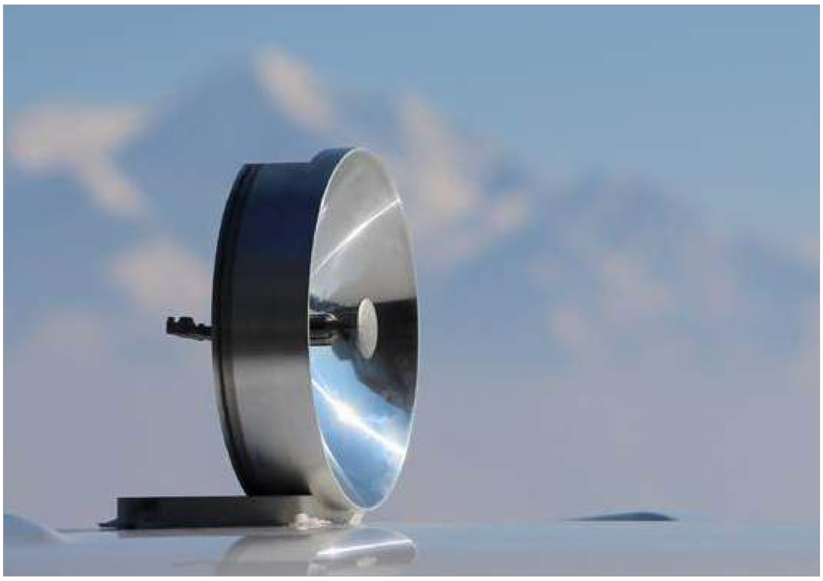

Fig. 1 Extreme parts consolidation of antenna systems enables reduced size, weight, lead time and cost while boosting RF performance

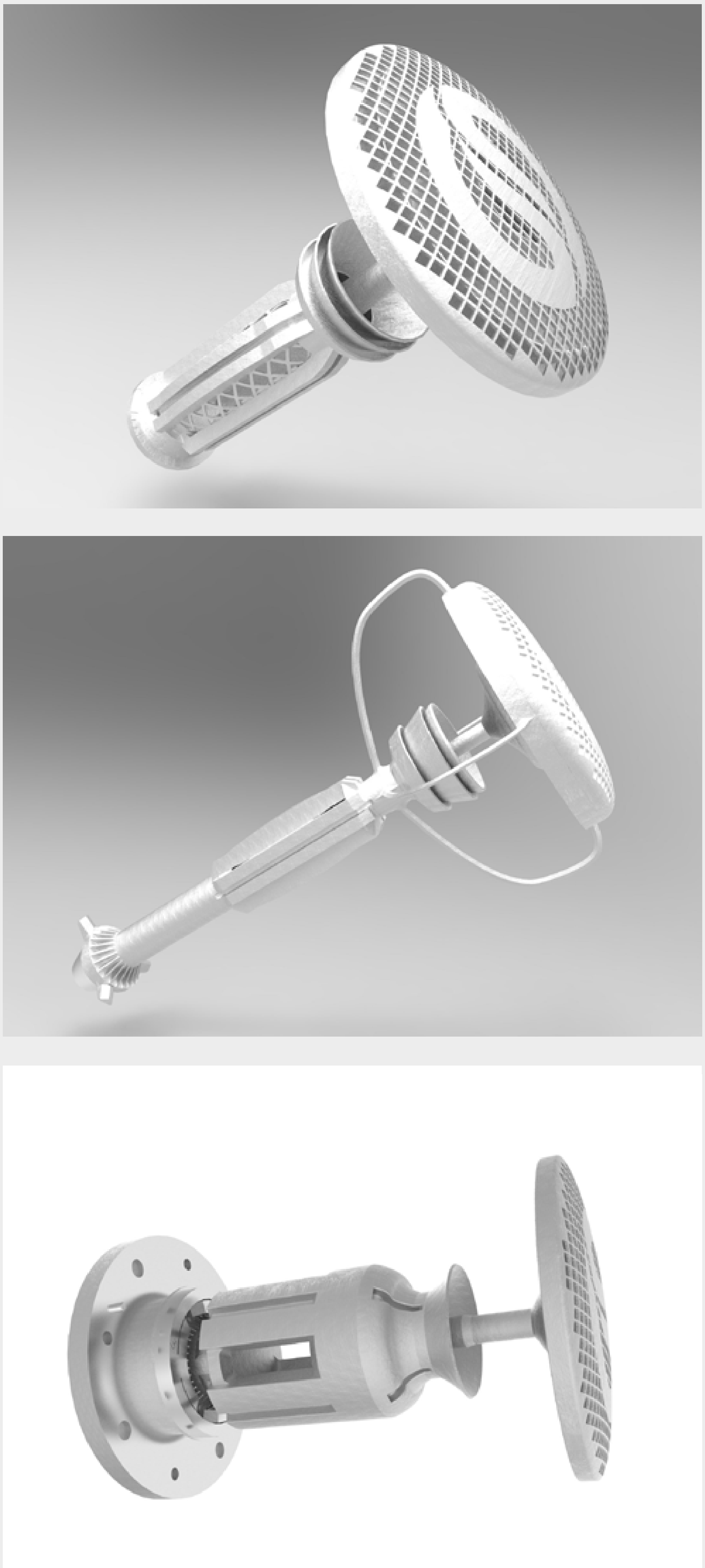

Fig. 2 Examples of additively manufactured metal antenna feeds customised by Optisys and produced in its Concept Laser AM machine

An opportunity to fill an industry void

Cathey and COO Rob Smith came together to form Optisys with a like-minded group of colleagues who share a combined sixty years' experience in the aerospace systems world which includes RF design, satellite communications (SATCOM), mechanical engineering and Additive Manufacturing.

"We had the total package for generating full antenna systems and, with our experience in AM, we saw the potential to put everything together to fill a void in this niche market," states Smith. The team felt that the AM industry as a whole had a weakness in terms of value-added engineering. "We realised we could be the turnkey provider that adds pre- and post-processing to meet exact customer specifications," Smith explained.

Cathey agreed, stating, "There are certainly plenty of companies that know how to do design, that know how to additively manufacture, but there's a lot of throwing things over the wall between them. You end up with parts that are intended to be machined, or designed for traditional manufacturing methods, that don't take full advantage of Additive Manufacturing."

The ability to consolidate parts with AM was what sparked the idea to form Optisys, stated Smith. "We had a high degree of intuition that Additive Manufacturing would solve many of the problems we'd been fighting in our past experiences with antenna manufacturing" (Fig. 3).

AM overcomes the challenges of conventional production

The challenges faced by an antenna producer when using conventional manufacturing technologies are numerous, adding both time and money. There is often a huge number of parts in a conventional design, typically a daunting array of a hundred or more individual metal components (Fig. 4). These include the hollow,

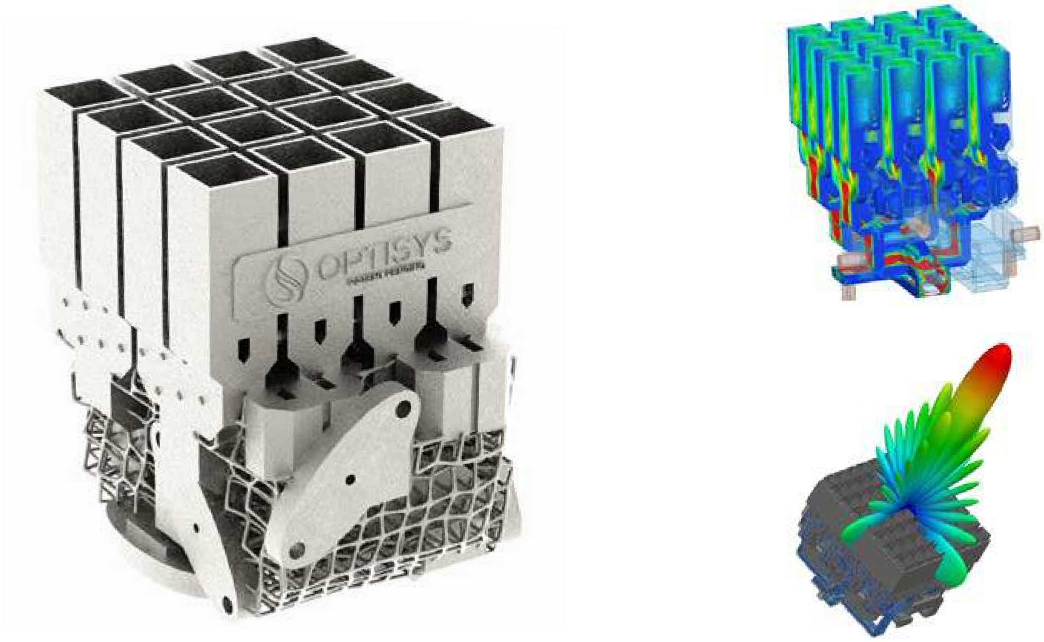

Fig. 3 Optisys designed and manufactured the one-piece, functional assembly antenna shown on the left by optimising a 100-piece design for AM. As shown on the right, high-frequency electromagnetic field simulations are used to analyse and optimise AM antenna designs for maximum RF performance

rectangular waveguides so critical for channelling the electromagnetic energy carrying the data; these are joined together via brazing, plunge EDM and/or multiple bolted joints.

Such assemblies can be large and long with unique shapes creating internal geometric hazards that can interfere with the flow of the very data the antenna is supposed to convey. "Every single joint, seam or fastener creates the potential for a discontinuity that can result in RF losses as the signal travels through the antenna," stated Smith. "Even how tight you make the screws can add a lot of variability to this insertion loss - if you don't do it exactly right you can end up with an inadvertent antenna at each of your seams."

Tolerances can also be an issue when a hundred or more parts are joined together, Smith pointed out. "When you have the kind of complicated system you get with a traditionally manufactured antenna assembly, you have to inspect each piece part independently, then put them all together and hope it translates to better overall RF performance. The tolerances of each part have to be very, very exact and by the time you integrate so many pieces together you can have significant tolerance stack-up and be completely off target."

Additive Manufacturing, by contrast, supported the type of systems-engineering approach that Optisys' founders envisioned for building their business. By viewing an antenna assembly as an integrated structure in which all the parts are combined into a single functional one, they realised they would be able to reduce lead times from months to weeks, cut size and weight dramatically and improve costs to their customers.

"Of course, we did testing to validate our assumptions and took parts to customers to get their responses and then tested for answers to their questions. But we

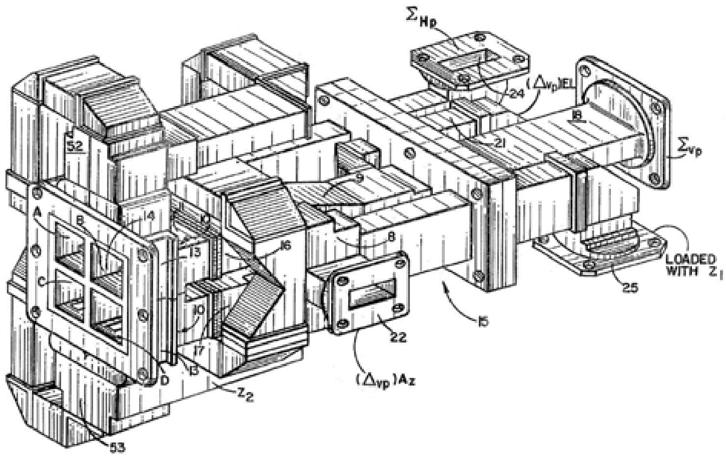

Fig. 4 Complexity that can affect RF: a drawing of a metal antenna system to be manufactured according to traditional methods. The antenna horn is represented by the four square holes at left

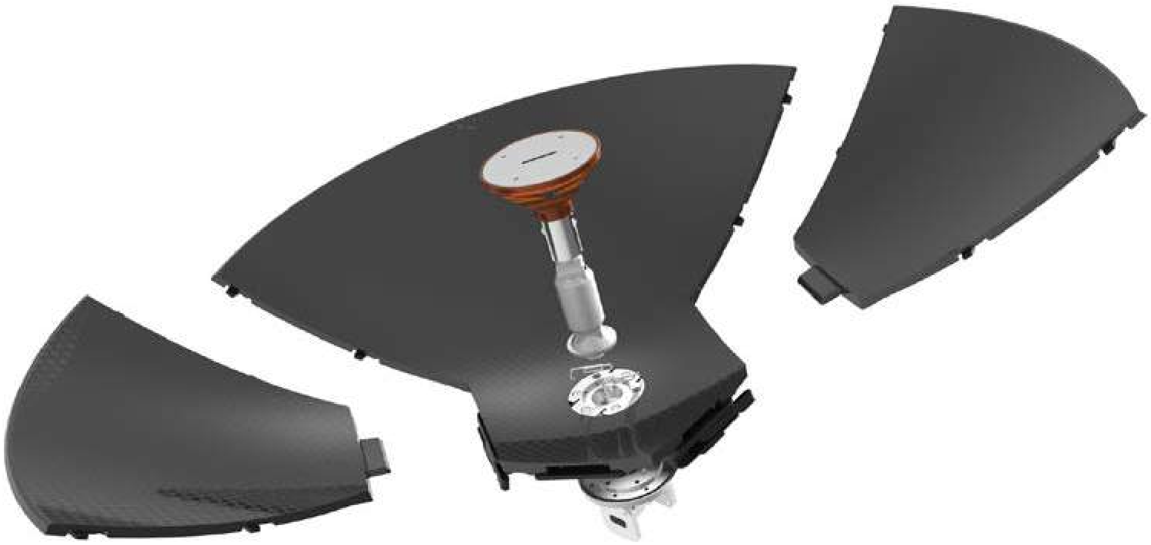

Fig. 5 Optisys makes antenna feeds such as the one in the centre of this segmented antenna. The black reflector shown, made by a partner company out of composites, completes this lightweight antenna intended to disassemble and fit into a soldier's backpack. This feed (long structure in the middle) includes an AM polariser that is both cost effective and lightweight

had already done enough internal testing to convince ourselves that we were onto something," stated Cathey.

The biggest discovery during early evaluations, and the one that delivered the most convincing value proposition to potential customers, was that the smaller size of their additively manufactured products greatly shortened the overall distance that an RF signal had to travel within the system, a huge benefit to antenna performance.

Extreme accuracy is not necessary for, say, a car antenna, which picks up signals from 360° around the vehicle. But the directional, microwave antennae used for most satellite and line-of-sight communications, aircraft and UAVs operate in the 1-100 GHz frequency band. In those industries, light weight is highly desirable.

"We found a sweet spot for Additive Manufacturing where the technology provides many benefits and is also economically advantageous," stated Cathey. "With our Ka-band monopulse tracking array we tested RF frequencies to 30 GHz, which is much higher than anyone else was doing; other companies have only reached 5-15 GHz." As with all Optisys products, the Ka-band array was evaluated for both bench and outdoor RF range performance. Similar designs have passed rigorous vibration testing for 'military ruggedness.' Subsequent Optisys designs have reached up to 50 GHz in RF capacity.

Designing for AM

The Concept Laser metal AM machine used by Optisys provides the build quality to achieve such results, Smith stated. "I've been very happy with its fine resolution, nice surface finish and the superior 'human factor' element of working with these machines. We felt confident that we can meet the type of feature resolutions that we need with them."

Aluminium is the material of preference for a build; it stands up better than plastics to environmental stresses, from ground level to outer space, and has essentially the same properties as a solid piece of the same material.

It could be said that the final AM process is the easiest stage of Optisys' systems-engineering approach to antenna production; however, the company stresses that it is critical to design for AM from the start. "This lets us take advantage of all the best aspects of Additive Manufacturing, while recognising its challenges and designing around those," stated Smith.

Rather than start from a preconceived geometry, Optisys begins with the RF requirements desired for the finished product. "Because AM promotes parts consolidation, we have the freedom to work towards the goal of optimum RF output rather than derived requirements such as individual part tolerances," explained Smith. "Your typical Additive Manufacturing service bureau doesn't have the RF expertise to achieve these requirements, so passing inspection is a challenge because the critical geometry is internal and can't be measured directly. Using AM, we can avoid internal geometry issues and deliver the lowest insertion loss and the highest RF possible for each design."

For the next step in Optisys' process the group's RF expert, Mike Hollenbeck, develops a microwave simulation using Ansys HFSS software to model the high-frequency electromagnetic field inside the air cavity of the proposed array. Smith explained, "Mike and I go back and forth a bit to identify the air-cavity design that best meets our requirements, then I import that file into SolidWorks to figure out the optimum wall thickness for the aluminium walls that I'll 'wrap around' that air cavity in order to create a design that can be additively manufactured as a single metal assembly."

At this point Smith uses his experience and intuition to create the ideal topology of the design, adding just enough extra material where needed to create an integrated unit which will manufacture consistently. He also adds support structures for those features that merit them, using Autodesk Within and merging the result using SolidWorks and Magics. "These integrated support structures stabilise the geometry throughout the build, drawing the heat away so we don't get stress concentrations in shrinkage locations, and then provide the entire system with support when it's in operation," stated Smith. "They also happen to look pretty cool!"

Fig. 6 Optisys CEO Clinton Cathey examines a microwave waveguide 'single-piece assembly' manufactured in the company's Concept Laser machine

Fig. 7 Optisys CBO Janos Opra (left) and COO Rob Smith (right) with antenna components produced by AM

Benefits beyond the build

The final design is transferred into Concept Laser's proprietary manufacturing software, which drives what Concept Laser calls the LaserCUSING® process in the AM machine. The advantages of Additive Manufacturing carry forward, Smith pointed out. "By consolidating parts, you've already designed out assembly and rework. You can easily tweak an existing design with new features, and components with fewer parts require less maintenance and service over time."

With a number of patents pending and discussions progressing with leading aerospace companies and academic institutions about expanding their portfolio of antenna-product lines, Optisys is optimistic about business growth. "Our competitive advantage is the integration of systems engineering, design and Additive Manufacturing, all customised for this niche application," stated Cathey. "We haven't even pushed the RF boundaries as far as they can go yet so metal Additive Manufacturing will continue to be pivotal in getting us there."

Cathey has some advice for others looking to capitalise on AM technology; "I highly encourage people to look closely at Additive Manufacturing and find other niche markets in which to apply it from the very beginning. There's still a lot to be achieved there."

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AMPM2017: Understanding the impact of powder reuse in metal Additive Manufacturing

An issue of significant current interest to the AM world, which can potentially impact both the quality and cost-effectiveness of built parts, is whether there is a limit on the number of times that metal powders can be cycled around an AM process. In this article, Dr David Whittaker reviews three presentations on the topic from AMPM2017, the fourth annual Additive Manufacturing with Powder Metallurgy Conference, held in Las Vegas, USA, June 13-15, 2017.

Understanding the effects of metal powder reuse in laser Powder Bed Fusion

The first reviewed presentation on this subject was given by Lucy Grainger (Renishaw plc, UK) and further supported by reference to a relevant Renishaw White Paper on the subject. The presentation began by underlining that the properties of the powder, and the machine parameters that are used to process it, are closely related. The chemical and physical properties of the powder are therefore critical.

Only a small proportion of the powder that is laid down in a build process is actually melted into a component, with most being left unmelted and therefore available for reuse. If unmelted powder was to be considered as contaminated and, therefore, unfit for reuse, then the cost of additively manufactured parts would likely be prohibitive for the vast majority of applications.

Renishaw AM systems use an inert argon atmosphere, which is generated by first creating a vacuum and then backfilling with the inert gas. Builds generally start at a low oxygen content of <1000 ppm, with the possibility of a starting atmosphere of <100 ppm if required. The oxygen content in the chamber drops to approximately <10 ppm after the first few layers. For the main reported study, builds began at <1000 ppm oxygen content. For titanium powder,

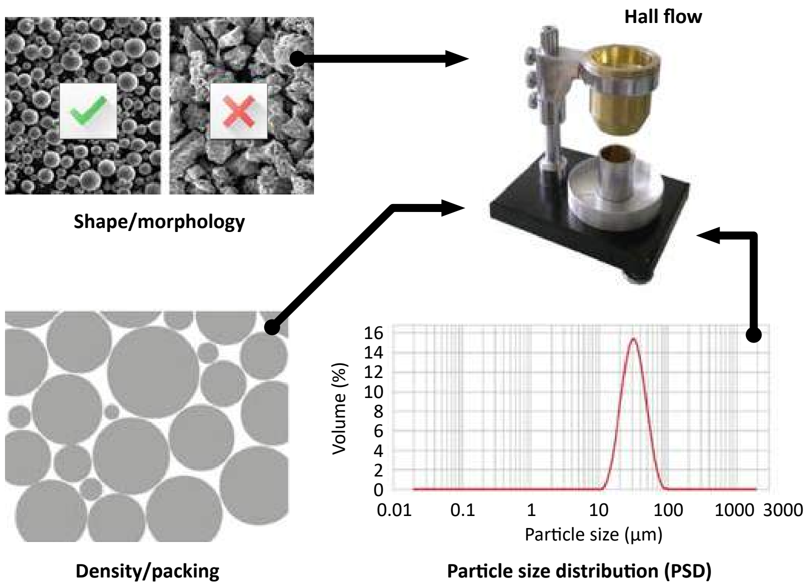


Fig. 1 Important physical properties of metal powders for AM include shape/morphology, particle size distribution (PSD), density/packing and flow [1]

Element type	Element	Ti6Al4V grade maximum / %	
		Grade 5	Grade 23 (ELI)
Interstitial	Oxygen (O)	0.20	0.13
	Nitrogen (N)	0.05	0.05*
	Carbon (C)	0.08	0.08
	Hydrogen (H)	0.0125	0.0125
Alloying	Aluminium (Al)	5.5-6.75	5.5-6.5
	Vanadium (V)	3.5-4.5	3.5-4.5

Some specifications state 0.03%

Table 1 Ti6Al4V grade specifications for interstitial and alloying elements [1]

Fig. 2 The Renishaw AM250 system [1]

it is important to have a low oxygen (and nitrogen) atmosphere due to the material's propensity to absorb these gases. The question therefore arises as to whether, if reused many times, the cumulative effect might cause the powders to become out of specification in terms of these elements.

In terms of physical characteristics, the powder can be affected in a variety of ways, with the majority of effects due to powder particles being either near the weld pool or being ejected from the weld pool. Physical properties which will have an effect on the way a metal powder behaves within the AM system include:

- Shape; a spherical morphology is preferable compared to angular or spongy
- Packing/density
- Particle size distribution (PSD)
- Flow

Powder flow is very important when dosing from the silo and for creating consistent layers across the bed and this is directly affected by shape, density/packing and PSD. If PSD is too wide or bimodal, the smaller particles will sit in the spaces between the larger particles, increasing packing and inhibiting flow. If the PSD is too narrow, this could lead to insufficient packing and pores in the melted part (Fig. 1). In the study, powder flow was measured using the Hall funnel method.

The reported study focused solely on the reuse/recycling of a titanium alloy, Ti6Al4V, which is specified in two main grades; 23, also known as ELI or extra low interstitial, and 5. Maximum allowable levels of some elements are highlighted in Table 1.

In the Renishaw AM250 machine (Fig. 2) used for the reported trials, the powder silo is located at the top of the machine. The advantages of this arrangement are that sieved powder from a previous build can be

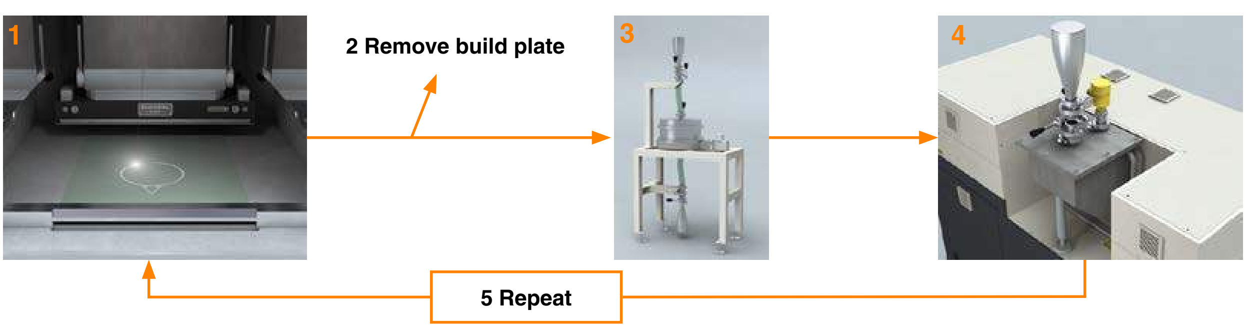


Fig. 3 A reuse cycle: 1) build, 2) remove build plate, 3) sieve unmelted powder, 4) replace sieved powder into silo at the top of the machine [1]

placed directly on top of the remaining powder in the silo. It can also be topped up during a build with virgin or used powder, although for this study only used powder was added.

The way that the argon atmosphere is generated is unique to Renishaw systems. Firstly, a vacuum is created in the chamber to remove any air and moisture. The chamber is then backfilled with argon, creating an inert atmosphere for the build with <1000 ppm O_2. This process takes approximately 10 min and requires 600 l of argon.

After the build, all unmelted material is directed into overflow bottles, using the integrated glove box located in the door of the build chamber. Overflow bottles are then sealed ready for removal from the system. Overflow bottles filled with unmelted powder from the build are directly connected to the sieve, which is kept under an inert argon atmosphere. An argon-filled overflow bottle catches the powder as it is sieved and is then used to replace the powder directly back into the silo.

The basis of the experimental study was to start with a single batch of virgin powder to fill the silo, to use the same AM250 system throughout, to carry out routine builds reusing the powder until there was not enough left to build to the full test sample height, to not add any virgin or other powder to the batch at any point, to build standard test samples to analyse both powder and tensile properties over the period of reuse and to sieve unmelted powder to remove oversized material from each build before replacing into the silo. In total, thirty-eight AM builds were carried out over a period of three months.

This was an extreme analysis of powder reuse, as usually the silo would be topped up regularly with virgin powder, essentially refreshing the used powder; this study looked at the most extreme case of never refreshing the used powder. After the silo had been filled with virgin metal powder, the following stages (Fig. 3) contributed to a reuse cycle: AM build, removal of the build plate, sieving of the unmelted powder under argon, replacement of the sieved powder into the silo located at the top of the machine and repeating of the cycle

Fig. 4 shows the oxygen content results from this and an earlier study, starting from a slightly lower oxygen level of 800 ppm and comprising twenty builds. Compared to the first study, the oxygen levels from the second study were generally higher, but the oxygen pick-up rate was similar. A few of the builds crept out of the ELI maximum range (builds 15, 25, 26, 27 and 33), but all others were within the boundary of grade 23 ELI and well within the grade 5 boundary. Results from the first study showed all of the powder was within ELI limits for oxygen over 20 builds.

In studies 1 and 2, it was observed that, when starting with <1000 ppm oxygen in the chamber, oxygen pick-up over 20 build cycles was 320-360 ppm. In a third study with zero oxygen in the chamber, there was still an oxygen pick-up of around 230 ppm (Table 2). It seems likely that the source of this oxygen was H_2O from moisture in the powder

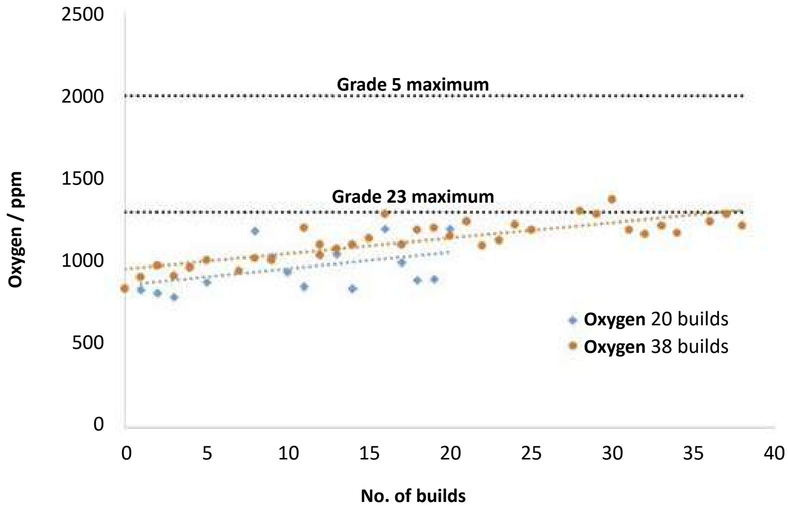


Fig. 4 Oxygen analysis over two separate reuse studies shows a gradual increase in concentration [1]

> "This was an extreme analysis of powder reuse, as usually the silo would be topped up regularly with virgin powder, essentially refreshing the used powder"

	Starting atmosphere O_2 level	Δ oxygen pick up after 20 builds
Study 1	< 1000 ppm	365 ppm
Study 2	< 1000 ppm	321 ppm
Study 3	< 30 ppm	238 ppm

Table 2 Oxygen pick-up in the three studies [1]

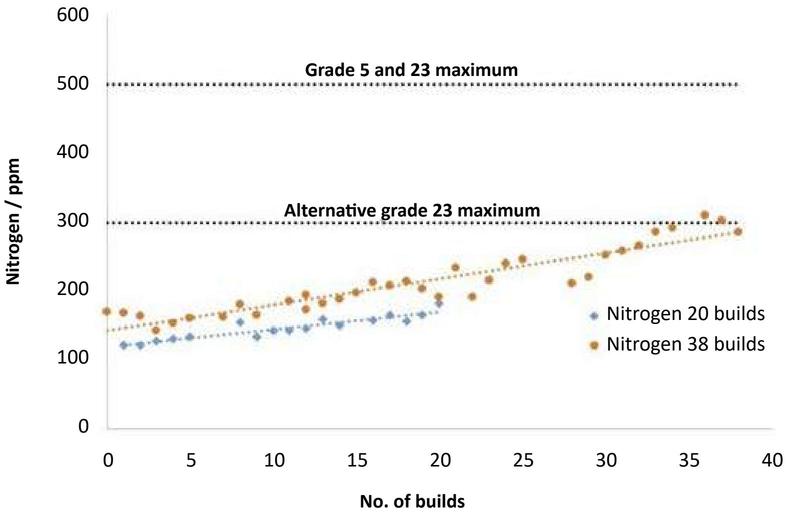


Fig. 5 Nitrogen analysis over two separate reuse studies shows a gradual increase in concentration [1]

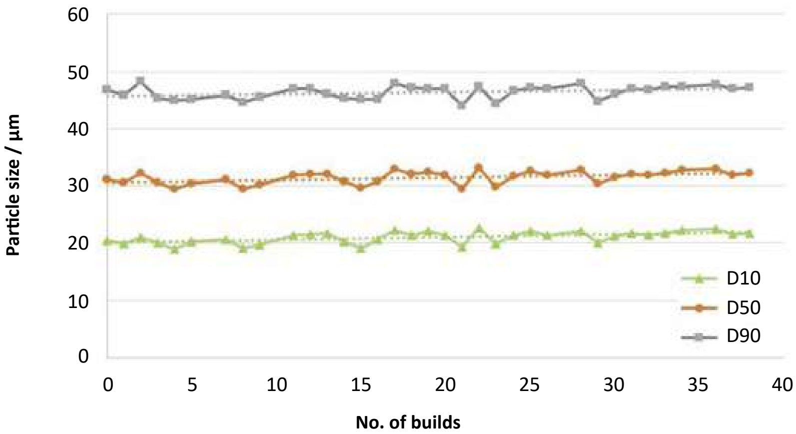


Fig. 6 D10, D50 and D90 values for the metal powder over the period of the reuse study [1]

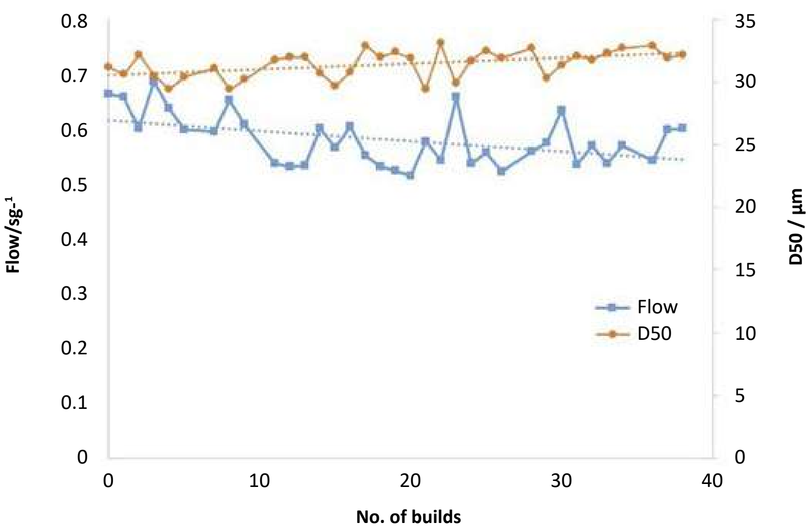


Fig. 7 Powder flow generally increases in speed over the reuse study. As D50 increases, so does the flow due to loss of smaller particles [1]

or chamber; this issue is currently under investigation at Renishaw. Nitrogen levels (Fig. 5) also showed a gradual increase, staying well within the 500 ppm maximum specification and coming above the 300 ppm maximum specification within the last few builds.

PSD was measured using a wet laser diffraction method. Very little change was observed in the particle size distribution of the powder (Fig. 6). The difference between the 1st virgin and 38th build powder samples was most significant in the D10 value, where a very small change of +1.30 µm was recorded. D50 and D90 values increased by +1.0 µm and + 0.4 µm respectively. There was a general tightening in PSD over the reuse cycles, with smaller particles being slowly removed - probably by sintering to larger particles. This resulted in an increase in the Hall flow of the powder. The virgin powder required a single tap to flow through the Hall funnel, while all subsequent powder samples flowed freely.

There was a general increase in Hall flow speed over the period of the reuse. This was probably due to a reduction in the number of smaller particles. D50 is compared with Hall flow speed in Fig. 7. It is clear that, as D50 increases, so does flow speed, highlighting the relationship between the two powder properties. However, these changes did not appear to be significant in terms of material parameters or layer spreading.

Powder density was measured using a helium pycnometer. There was little change found in the powder from virgin to 38 builds, all values being within 99.397-99.158%.

All tensile bars were heat treated in a vacuum furnace. Bars from builds 1, 12, 18, 24, 31 and 38 were tested. In order to investigate as-built surface and machined surface tensile properties, three of the test bars from every build were designed with an extra 1 mm diameter to allow for machining, meaning that all six bars conformed to the E8 ASTM standard diameter of 3 mm.

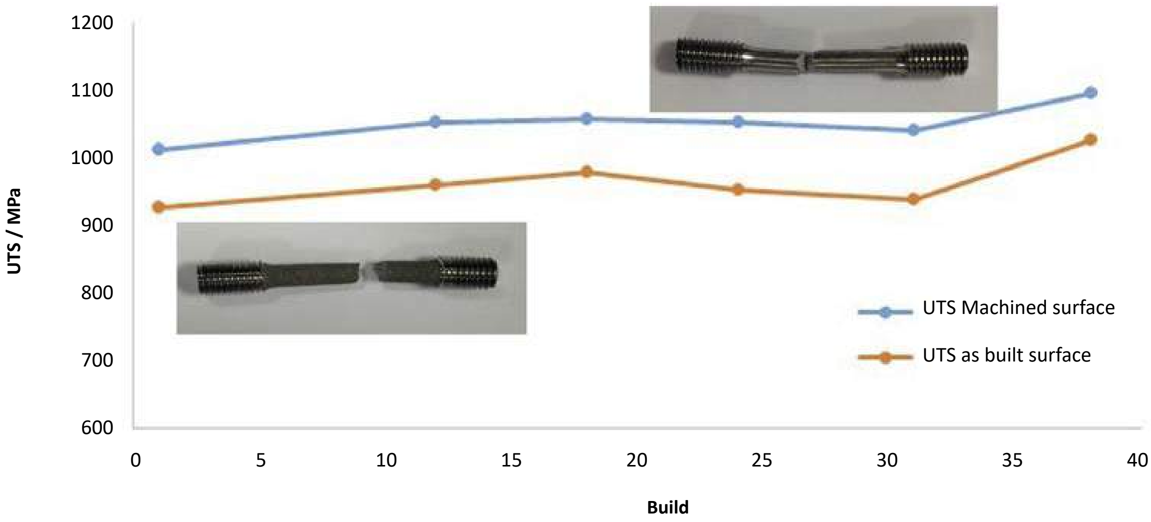


Fig. 8 Ultimate tensile strength values for the 'as built' and machined tensile bars from builds 1, 12, 18, 24, 31 and 38 showing an example of each type of pulled bar [1]

Ultimate Tensile Strength (UTS) values did not change significantly. An increase in 100 MPa from virgin to build 38 can be attributed to the increase in oxygen and nitrogen levels. A comparison between the 'as built' and machined tensile test bars is shown in Fig. 8. The machined bars gave higher UTS values, which can be attributed to their smoother surfaces, with fewer crack initiation points compared to the rougher 'as built' samples. However, an alternative explanation could be that the values for the two different surface finishes are a result of measurement error in the cross-sectional area for the rougher surface.

Qualitative analysis of powder morphology was carried out by scanning electron microscopy. The virgin powder was highly spherical, with a moderate level of satellites and small particles. It was clear from the PSD data that smaller particles had been removed over the period of the builds and this was also observed in the SEM analyses. Other than the loss of smaller particles, the powder changed very little, staying spherical, with the occasional misshapen particle, most likely ejected from the melt pool or agglomerated next to the weld pool.

The observations from this study suggest that there is no requirement to dispose of unmelted Ti6Al4V after it has been cycled around the AM250 system a limited number of times. This does, however, depend on the specific requirements of the component material properties, in which case a stringent blending regime may be required for traceability.

The effects of powder reuse may potentially be different for other materials, in terms of physical property effects. However, because titanium has a high propensity to pick up interstitial impurities, the pick-up rates observed can be thought of as a 'worst case' for commonly used metal AM powders.

Investigation of the effects of recycling 316L powder on consistency and properties of parts made by Selective Laser Melting

A further reported study also used a Renishaw AM250 system but focused on Type 316L austenitic stainless steel powder. This presentation came from Martin Kearns (Sandvik Osprey, UK) and was co-authored by his Sandvik Osprey colleagues Keith Murray and Mary-Kate Johnston, and Nick Lavery (MACH1 Centre, Swansea University, UK).

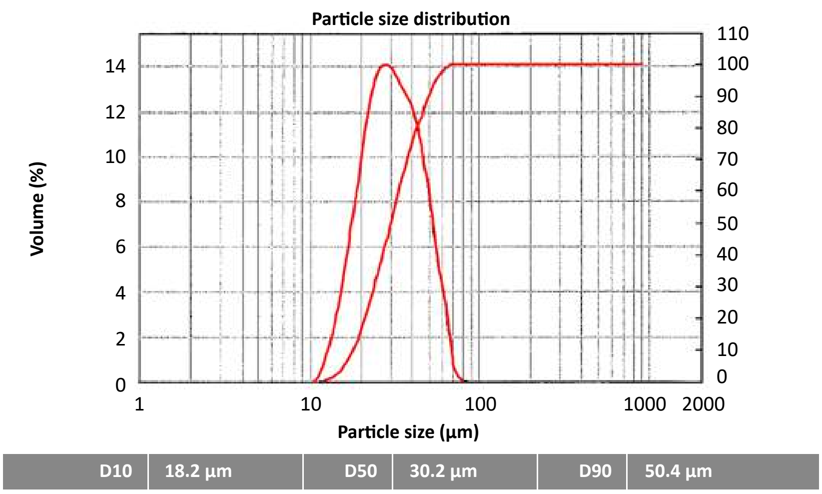
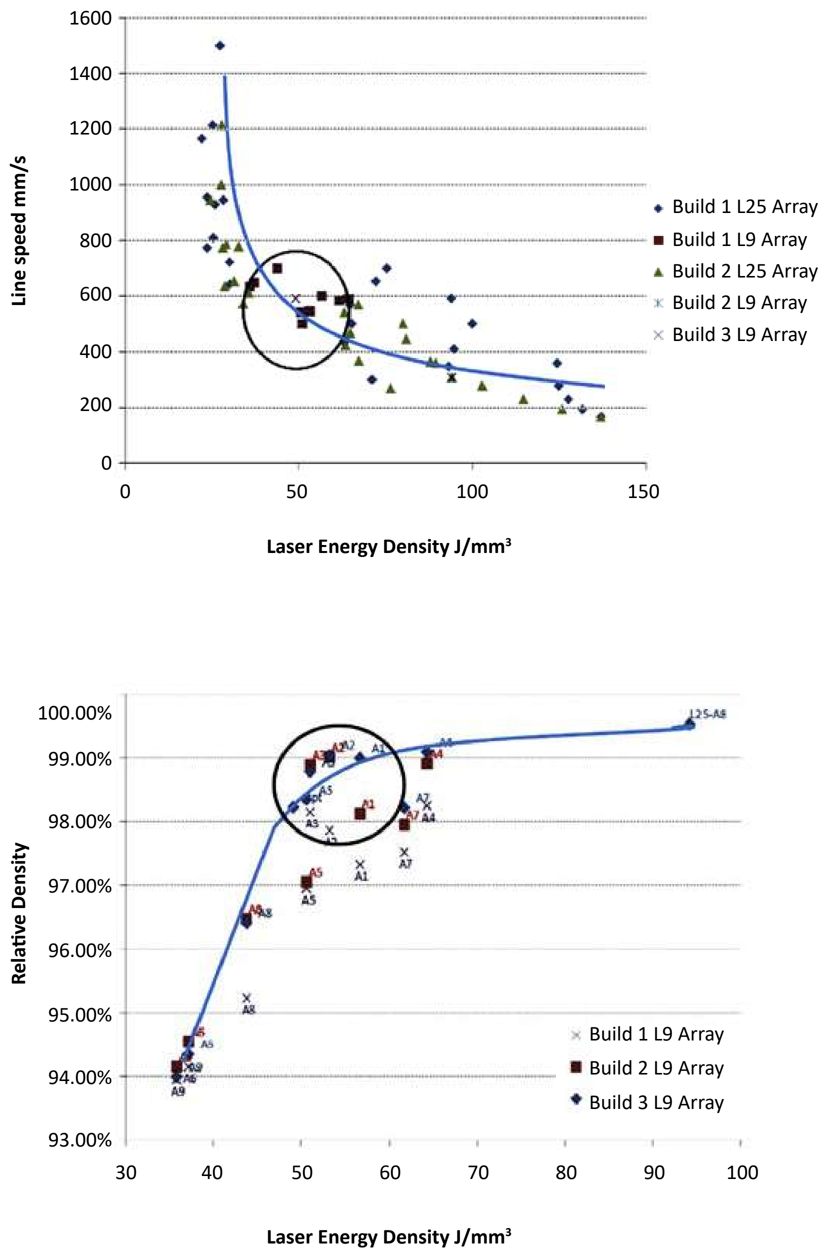


Fig. 9 Particle size distribution data for the original virgin powder [2]

Parameter	Range
Laser Power (PW)	160-200 (W)
Point Distance (PD)	25-105 (µm)
Hatch Spacing (HS)	70-175 (µm)
Exposure Time (ET)	70-150 (µs)

Table 3 Parameters investigated in builds 1-3 [2]



Density measurements by Archimedes Method

Fig. 10 Comparative data for builds 1-3 [2]

The virgin 316L powder had the composition Fe-16.8%Cr-12.4%Ni-2.3%Mo-0.7%Si-0.7%Mn-0.02%C-0.02%P-0.01%S and was processed to the -45+15 µm size range by sieving and air classification. Particle size distribution was as shown in Fig. 9.

The powder was processed through over 30 AM test builds, producing a range of density cubes and tensile test pieces for evaluation. After each test build, the remaining powder was sieved using a 63 µm mesh in preparation for the next build. Powder samples were taken after each build for the characterisation of particle size distribution, rheology and chemical analysis.

In builds 1-3, L25 and L9 arrays were designed to determine the influence of AM machine parameters on build densities and to identify the optimum settings. The investigated machine parameters are shown in Table 3. In Fig. 10, the circle on the lower graph shows an inflection, where the plateau high density achieved in the L9 array corresponded to a laser energy density of 56-60 J/mm^3. This was selected as the set of conditions to be run repeatedly as a reference to monitor the effects of recycling on density in the array.

For builds 4-31, the schedule of samples built was as defined in Table 4. For builds 1-14, the powder used was that remaining from the initial virgin batch (Batch A). For builds 15-24, the remaining powder was supplemented with an addition of 66.7% fresh powder from the original virgin batch (Batch B). For builds 25-31, the remaining used material was supplemented with an addition of 31% fresh powder from the original virgin batch (Batch C).

Powder sampling was carried out at various machine locations, including from the freshly dosed powder prior to the build, in front of the overflow after the build, at the argon gas outlet after the build and from the machine's sieve after the build. Fig. 11 shows the particle size distribution data measured on the powder prior to each build and

Build	Description	Build	Description
4	Single line plates	18	L9 Reference array + vertical & horizontal tensile bars
5	Build failed due to insufficient powder dosing	19	L9 Reference array + vertical test bars
6	L9 Reference array + vertical & horizontal tensile bars	20	Crucibles
7	L9 Reference array + horizontal tensile bars	21	L9 Reference array + vertical test bars
8	90 density cubes at optimal parameter settings	22	L9 Reference array + prototypes
9	L9 Reference array + horizontal tensile bars	23	Prototypes
10	90 density cubes at optimal parameter settings	24	Crucibles
11	90 density cubes at optimal parameter settings	25	L9 Reference array + vertical & horizontal tensile bars
12	L9 Reference array + prototypes	26	Prototypes
13	Crucibles	27	L9 Reference array + vertical & horizontal tensile bars
14	L9 Reference array + horizontal tensile bars	28	Prototypes
15	90 density cubes at optimal parameter settings	29	L9 Reference array + vertical & horizontal tensile bars
16	L9 Reference array + vertical test bars	30	L9 Reference array + vertical & horizontal tensile bars
17	L9 Reference array + vertical test bars	31	L9 Reference array + horizontal tensile bars

Table 4 Samples built in Builds 4-31 [2]

Fig. 12 the data for the samples taken from the overflow after each build. Fig. 12 shows more variability in the D90 values, reflecting the presence of small amounts of splats formed under the laser actions, but these splats were removed each time by the sieving to restore effectively a standard starting PSD. No systematic trends to a coarser or finer distribution were observed.

Fig. 13 indicates a very gradual increase in nitrogen and oxygen levels throughout the build series. However, the levels of all major alloying elements were reported as being consistent throughout the build series. Fig. 14 shows results of assessing powder rheology of samples taken from the freshly doped powder prior to a number of builds, in terms of the basic flow energy (BFE) parameter from tests using a Freeman FT4 Torque Rheometer. Received wisdom would suggest that this parameter should tend to rise after powder reuse, as flow is compromised. Although the presented dataset is incomplete, it does not support this view and in fact shows a wide range of values that is difficult to interpret.

Initial evaluations of spatial variations in the density of built parts were in tests where the laser focus was not optimised. However, once this focusing issue was addressed, a much more uniform and higher density was achieved.

The tensile strength data from samples built with an optimal laser power input of 60-70 J/mm^3, shown

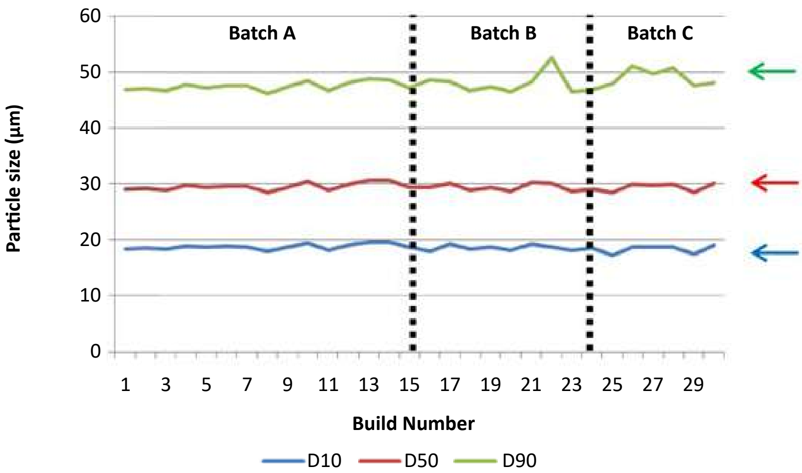


Fig. 11 Variation in particle size – Position 1 [2]

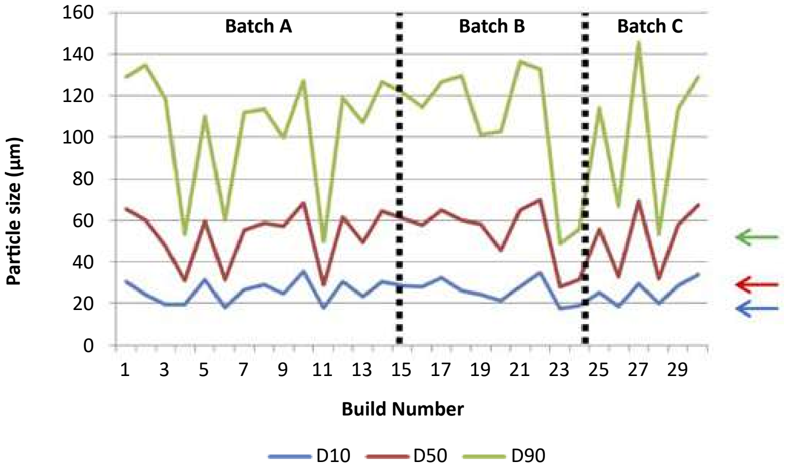


Fig. 12 Variation in particle size – Position 2 [2]

in Fig. 15, indicate very consistent strength levels throughout the build series. The built sample surface roughness data (Fig. 16) shows a significant scatter, but the regressed trend lines show no systematic trend over the 31 build cycles. The roughness values were similar to those seen in other studies. The authors drew the following overall conclusions:

1. 316L stainless steel gas atomised powders can be used effectively in Additive Manufacturing to produce parts with densities exceeding 99%
2. Multiple powder reuse (in up to 30 builds) with periodic rejuvenation of the powder does not appear to have a significant effect on powder characteristics, machine performance and the quality of built parts
3. There is some evidence of a gradual increase in O and N levels
4. Sieving after each build appears effective in reconditioning the powders to remove processing artefacts.

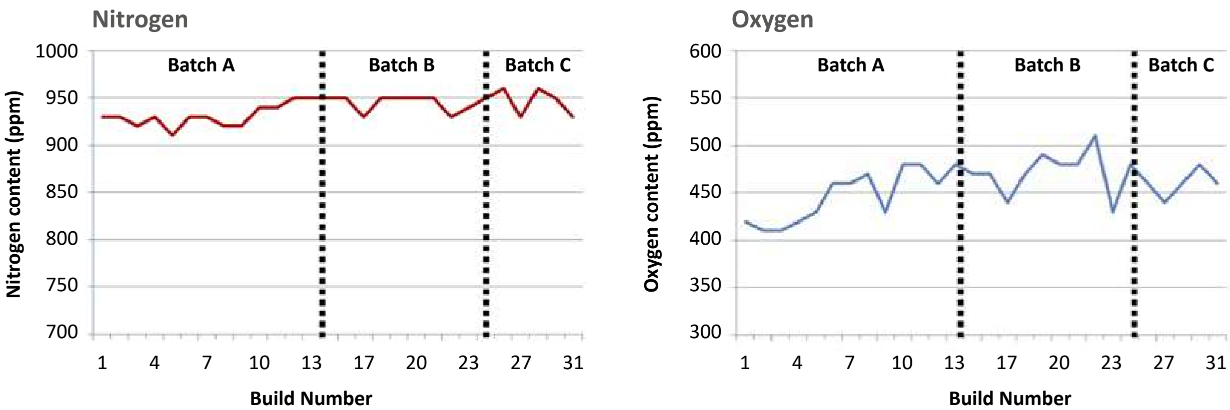


Fig. 13 Variation in nitrogen and oxygen levels in powder samples from position 1 [2]

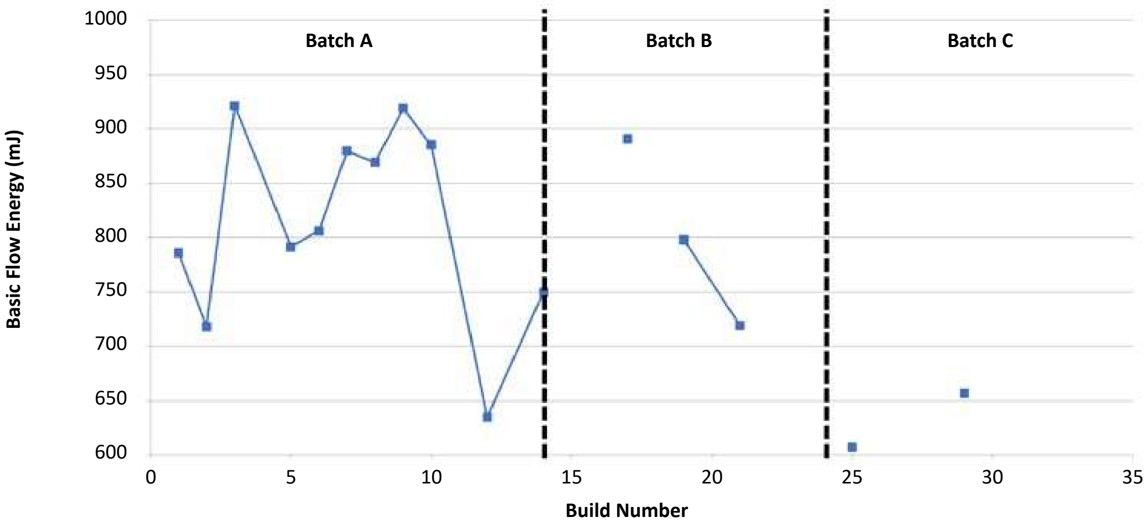


Fig. 14 Variation in rheology of powder samples from position 1 [2]

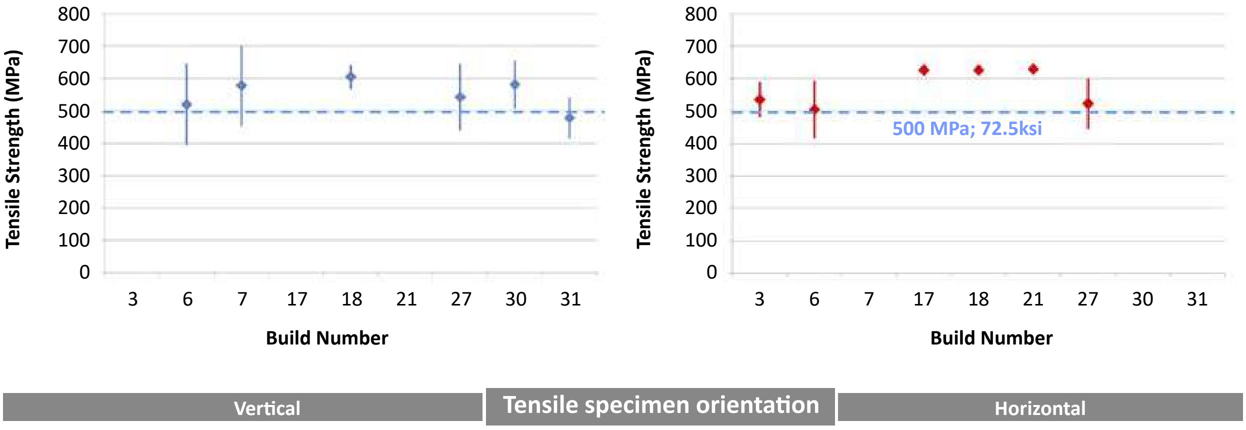


Fig. 15 Tensile strength data throughout the build series [2]

Comparing powder characterisation, mechanical properties and microstructures of virgin and highly recycled 304L for the EOS M280

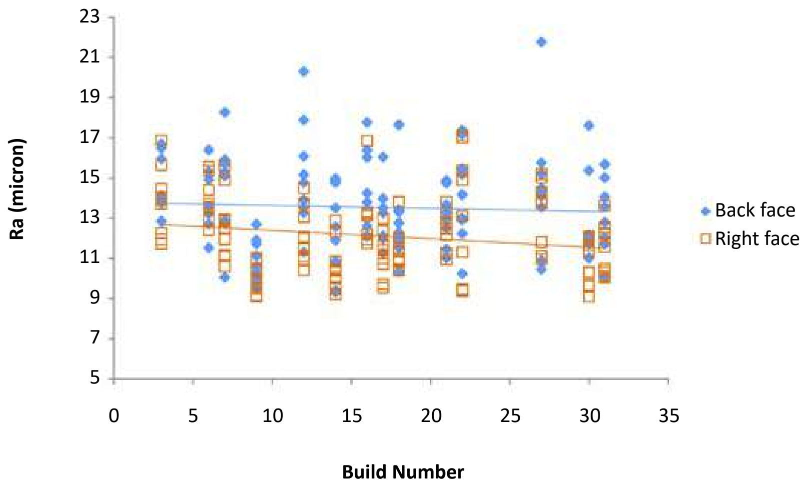


Fig. 16 Surface roughness data throughout the build series [2]

Finally, a presentation from Robin Pacheco (Los Alamos National Laboratory, USA) focused on an alternative austenitic stainless steel, Type 304L, this time processed in an EOS M280 system.

As an alternative to the use of a relatively expensive powder reconditioning technology such as plasma spheroidisation, this study was aimed at determining the number of reuse cycles that are feasible until powder characteristics and composition, built part mechanical properties and overall functionality are compromised. In this context, the highly recycled (HR) powder had been in use for around two years.

The virgin 304L powder used was sieved and classified to the -44+16 µm size range. The AM process used a build temperature of 100°C, a nitrogen atmosphere, a layer height of 40 µm with a 67° rotation between layers, a contour speed of 1400 mm/s, a contour power of 140 W and a total build time of 85 hours.

Chemical analyses of the virgin and highly recycled powder are given in Table 5. The increases in C and O in the highly recycled powder suggest that more oxides are present in the deposited layers. The increase in O should cause an increase in oxide layer thickness and a consequent increase in absorptivity of the laser during building. On the basis of the measured low P and S contents, solidification cracking would not be expected.

	C	Cr	Cu	Fe	Mn	Mo	N	Ni	O	P	S	Si
Virgin	0.011	18.41	0.010	69.8	1.52	0.004	0.055	9.56	0.038	<.005	.002	0.58
Highly Recycled	0.015	18.39	0.012	69.8	1.51	0.004	0.053	9.58	0.046	<.005	0.006	0.58
% Diff.	36.36 ↑	0.11 ↓	20.00 ↑	0.00	0.66 ↓	0.00	3.77 ↓	0.21 ↑	21.05 ↑	-	200 ↑	0.00

Table 5 Chemical analyses of virgin and HR powders (wt.%) [3]

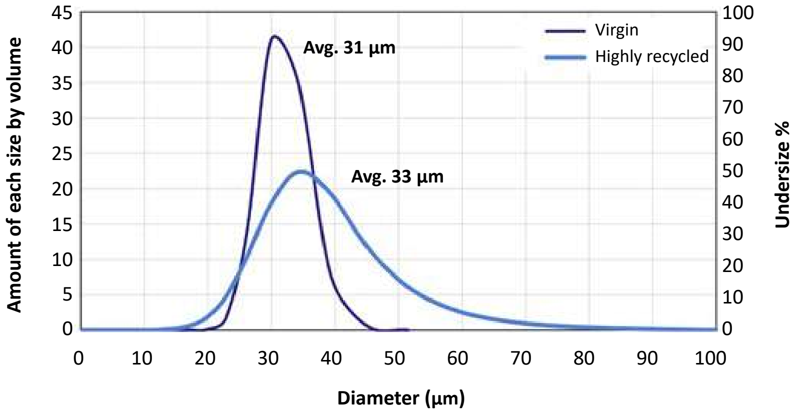


Fig. 17 Particle size distributions of powder samples from storage containers [3]

The PSD of the virgin and HR powder samples, taken from storage containers, are compared in Fig. 17. The HR powder had a wider PSD, possibly caused by agglomerated powders in previous builds being broken by the recoater blade. This seemed a very likely hypothesis, as the HR powder had a smoother exterior than the virgin powder. Pores within the powder particles were observed in both virgin and HR powders.

The comparative flow rates and apparent densities of the powder types and the as-built part densities are shown in Table 6. Particle layer packing could be more efficient for the HR powder due to the smaller, broken-off particles, yet the agglomerated particles can impede flow and increase inter-particle friction during recoating.

Mechanical properties in compression for parts built from the two powder types are given in Table 7.

304L	Powder		As Deposited
	Flow Rate (ASTM B213 Hall Flow)	Apparent Density (ASTM B212)	Part Density
Virgin	13.9 s	4.39 g/cc	7.63 g/cc
Highly Recycled	13.2 s	4.46 g/cc	7.51 g/cc
Difference	5.04%	1.6% (HR inc.)	1.57%

Table 6 Comparative flow rates, apparent densities and as-deposited part densities for the two powder types [3]

Average Max Values				
304L	Displacement (Std Dev)	Load (Std Dev)	True Strain (Std Dev)	True Stress (Std Dev)
Virgin	0.52 mm (0.07)	18.77 kN (1.31)	0.15 (0.02)	795.79 MPa (38.67)
Highly Recycled	0.62 mm (0.09)	19.94 kN (0.45)	0.19 (0.03)	829.16 MPa (11.02)

Table 7 Mechanical properties in compression for parts built from the two powder types [3]

Oxides, pores and oxides in pores are seen in both powder types, with a typical size of 5 to 10 µm. These oxides seemed to be composed mainly of Si, Al, Ca and O, with their numbers being slightly higher in the HR samples (Table 8). However, there was less than 0.1% oxide/pore area in both powder types, with almost no oxides/pores being observable in both virgin and HR builds.

In tensile testing, the parts built from virgin and HR powders, tested to failure, showed virtually identical results (Table 9). Dimpling, oxides, pores and unfused particles were seen in the fracture faces of both virgin and HR builds.

Very similar microstructures were observed in virgin and HR builds, with a 'fish scale' dual primary solidification mode (ferrite growing along the austenite). EBSD showed that the grains were not strongly textured.

In conclusion, the differences observed between HR and virgin powders and built samples were as follows:

1. Particle size and distribution due to partial fusion, agglomerate formation and the breaking of satellites by the recoater blade
2. A slightly higher number of oxides, pores and oxygen/silicon inclusions in deposited HR
3. A higher oxygen content in the HR powder.

On the other hand, there were no significant differences in the two powder types, in terms of:

1. Microstructures
2. Particle morphology – the virgin and HR surface roughness difference was only 1 to 2 µm
3. Mechanical properties, with similar average maximum stress and strain to failures, in both compression and tension.

Based on the reported results, it was proposed that highly recycled powder can be used over the range of two years without compromising the AM product.

Sample	Total Area (µm²)	Total Area (µm²)	Area (%)
HR - Before MTS	16,943,010	8434.1132	0.0498
V – Before MTS	17,039,882	4714.0815	0.0277
HR – Post MTS	15,464,585	5474.7622	0.0354
V – Post MTS	15,434,536	3727.0242	0.0242

Table 8 Oxide and pore levels in parts built from the two powder types [3]

	Average Max Values			
304L	Displacement (Std Dev)	Load (Std Dev)	True Strain (Std Dev)	True Stress (Std Dev)
Virgin	17.34 mm (0.93)	12.71 kN (146.19)	0.51 (0.02)	906.35 MPa (2.60)
Highly Recycled	16.89 mm (0.85)	12.80 kN (130.31)	0.50 (0.02)	900.03 MPa (6.17)

Table 9 Tensile properties for parts built from the two powder types [3]

References

[1] Understanding the effects of metal powder reuse in laser Powder Bed Fusion, Granger, L. As presented at the AMPM2017, the Fourth Annual Additive Manufacturing with Powder Metallurgy Conference, Las Vegas, USA, June 13-16, 2017, and published in the Conference Presentations PDF by the Metal Powder Industries Federation (MPIF).

[2] Investigation of the effects of recycling 316L powder on consistency and properties of parts made by Selective Laser Melting, Kearns, M *et al.* As presented at the AMPM2017, the Fourth Annual Additive Manufacturing with Powder Metallurgy Conference, Las Vegas, USA, June 13-16, 2017, and published in the Conference Presentations PDF by the Metal Powder Industries Federation (MPIF).

[3] Comparing powder characterisation, mechanical properties, and microstructures of virgin and highly recycled 304L for the EOS M280, Pacheco, R. As presented at the AMPM2017, the Fourth Annual Additive Manufacturing with Powder Metallurgy Conference, Las Vegas, USA, June 13-16, 2017, and published in the Conference Presentations PDF by the Metal Powder Industries Federation (MPIF).

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AMPM2017 Conference Presentations

A PDF compilation of presentations from AMPM2017, the fourth annual conference focused on Additive Manufacturing with Powder Metallurgy is available from the MPIF. The PDF features 59 technical presentations and 12 technical manuscripts presented by worldwide industry experts. It is available for $150 (MPIF members $120).
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- ✓ Access to mobile app
- ✓ All meals and beverages

Registration Opens
October 1, 2017
Register at www.amug.com

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industry events

2017

CONVERGE 2017 Europe
October 17, Essen, Germany
event.converge2017.com/europe

Additive Aerospace Summit
October 18-20, Los Angels, United States
www.infocastinc.com/event/additive-aerospace/

DEVELOP3D Live
October 23-24, Boston, United States
www.d3dliveusa.com

formnext powered by TCT
November 14-17, Frankfurt, Germany
www.formnext.com

Asia-Pacific International Conference on Additive Manufacturing
December 4-6, Melbourne, Australia
www.apicam2017.com.au

Additive Manufacturing Americas 2017
December 6-8, Pasadena, United States
www.amshow-americas.com

2018

MAPP First International Conference
January 30-31, Sheffield, United Kingdom
mapp.ac.uk/events/mapp-1st-international-conference

SAE 2018 Hybrid & Electric Vehicle Technologies
February 20-22, San Diego, United States
www.sae.org/events/hybridev

Additive Manufacturing Forum
March 5-6, Berlin, Germany
www.additivemanufacturingforum.com

PM China 2018
March 25-27, Shanghai, China
www.cn-pmexpo.com/en/

AMUG
April 8-12, St. Louis, United States
www.additivemanufacturingusersgroup.com

Rapid + TCT
April 23-26, Fort Worth, United States
www.rapid3devent.com

AKL'18 - Int. Laser Tech. Congress
May 2-4, Aachen, Germany
www.lasercongress.org

AMPM2018
June 17-19, San Antonio, United States
www.ampm2018.org

Additive Manufacturing Europe 2018
June 26-28, Amsterdam, Netherlands
www.amshow-europe.com/welcome-additive-manufacturing-europe

World PM2018
September 16-20, Beijing, China
www.worldpm2018.com

Euro PM2018 Congress & Exhibition
October 14-18, Bilbao, Spain
www.europm2018.com

Event listings and Media Partners

If you would like to see your metal Additive Manufacturing related event listed in this magazine and on our websites, please contact Paul Whittaker:
email: paul@inovar-communications.com

We welcome enquiries regarding media partnerships and are always interested to discuss opportunities to cooperate with event organisers and associations worldwide.

Pick up your free copy!

Metal AM magazine is exhibiting at and/or being distributed at events highlighted with the Metal AM cover image

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