Vol. 1 No. 2 SUMMER 2015

THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

ADDITIVE INDUSTRIES / ADDLAB

MTU AEROSPACE DEVELOPMENTS

CONFERENCE REPORT: AMPM2015

Published by Inovar Communications Ltd

www.metal-am.com

Publisher & Editorial Offices
Inovar Communications Ltd
2 The Rural Enterprise Centre
Battlefield Enterprise Park
Shrewsbury SY1 3FE, United Kingdom
Tel: +44 1743 454990
Fax: +44 1743 469909
Email: info@inovar-communications.com
www.metal-am.com

Managing Director, Features Editor
Nick Williams
Tel: +44 1743 454991
Email: nick@inovar-communications.com

Publishing Director, News Editor
Paul Whittaker
Tel: +44 1743 454992
Email: paul@inovar-communications.com

Advertising
Jon Craxford, Advertising Sales Director
Tel: +44 207 1939749
Fax: +44 1743 469909
Email: jon@inovar-communications.com

Production
Hugo Ribeiro, Production Manager
Tel: +44 (0)1743 454990
Fax: +44 (0)1743 469909
Email: hugo@inovar-communications.com

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

Printed by
Cambrian Printers, Aberystwyth, UK

ISSN 2057-3014 (print edition)
ISSN 2055-7183 (digital edition)

Vol. 1. No. 2 Summer 2015

METAL ADDITIVE MANUFACTURING

New challenges as series production comes of age

Following the launch issue of *Metal Additive Manufacturing* magazine earlier this year, we have been delighted with the enthusiastic response and support that the publication has received from the various industries involved in this dynamic technology.

In addition to the many thousands of downloads of our digital edition, our print edition saw extensive distribution worldwide at key industry events including Rapid 2015 (Long Beach, USA), AMPM2015 (San Diego, USA), Rapid.Tech (Erfurt, Germany), China PM Summit (Tianjin, China) and the Additive Manufacturing European Conference, held at the European Parliament (Brussels, Belgium), to name just a few.

What became clear from these events is that the metal AM industry is moving rapidly towards the successful commercial production of series components for critical applications in the aerospace, automotive and medical sectors. Such developments are bringing new technical and commercial challenges to the industry, particularly in terms of production speeds and efficiency, material supply and re-use, and quality control.

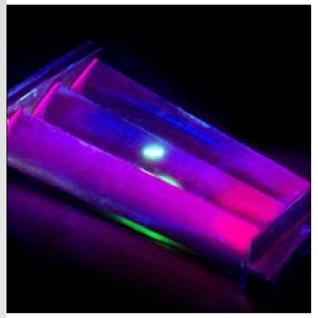
Many of these themes are addressed in the articles and technical reports featured in this issue of *Metal AM* and they will no doubt continue to be a key aspect of our industry coverage in future issues.

This autumn our team will once again be out on the event circuit. We will be exhibiting at numerous events, starting with Euromold at its new home in Dusseldorf in September. Please visit us on booth C123, we hope to see you soon!

Nick Williams
Managing Director

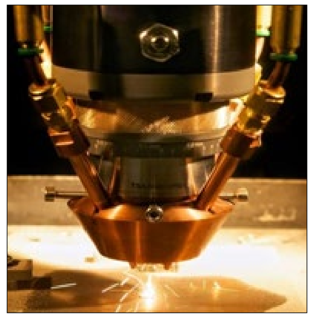
Cover image
A water pump wheel manufactured by BMW using Selective Laser Melting (SLM) technology and used in the German Touring Car Masters (DTM) series. The 500th light alloy part was recently celebrated as a milestone for the company. (Courtesy BMW)

METAL ADDITIVE MANUFACTURING


18


38


43


46


69

Contents

industry news

BMW installs 500th metal AM racing car water pump wheel

BMW uses metal AM to produce this water pump wheel for DTM race cars and its Z4 GT3 customer vehicles

The current season of the German Touring Car Masters (DTM) began with a small celebration for BMW, as one of the powertrains is fitted with its 500th water pump wheel made by metal Additive Manufacturing. The precision component, which is subject to high stresses, is created from an aluminium alloy and is proving its worth in the tough environment of motorsports.

In a race, the high-performance powertrains run up to 70% of the time under full load. In addition, the moving parts in particular have to handle extreme conditions. In 2010, in order to address these issues, the BMW engineering team developed a one-piece, light-metal water pump wheel to replace the previously used polymer part.

Based on BMW's long-standing experience in Additive Manufacturing, the engineers decided from the outset to apply Selective Laser Melting (SLM) in the production of the small series.

Additive Manufacturing as a production method has turned out to be the ideal procedure for the small batch, stated BMW. Firstly, it allows for the inclusion of design refinements in the six-bladed centrifugal pump wheel, whose implementation would require much greater effort with other production methods.

With AM, it was possible to achieve ideal aerodynamics of the component for the DTM race series. Secondly, no complex tools or moulds are needed, which makes demand oriented production more cost effective. Additionally, AM ensures the dimensional accuracy of the water pump wheel over the entire production time. BMW uses the high-precision part both in its DTM race cars and in the Z4 GT3 customer vehicles.

The BMW Group has applied additive production technologies in concept prototyping since 1991 and has continued to develop the process. The Rapid Technologies Centre at BMW Group's Research and Innovation Centre (FIZ) in Munich works on close to 25,000 prototype requests annually, producing around 100,000 components a year for in-house customers. Depending on the procedure and the size of the component, sample parts can be produced in only a few days.

www.bmwgroup.com

EOS and GF Machining Solutions enter strategic cooperation

EOS has entered into a strategic cooperation with Swiss based GF Machining Solutions to offer innovative solutions, combining both companies' technologies, to the mould and die sector. The two companies will develop exclusive solutions for mould makers, a market in which GF holds a leading position thanks to its EDM, high speed milling and automation technologies.

The Additive Manufacturing technology offers for such customers the possibility to generate metal inserts featuring cooling close to the surface, allowing a shorter mould cooling sequence and therefore a much faster plastic injection cycle.

GF and EOS will undertake the integration of the AM machines into the production process of mould inserts, including the necessary software and automation link with downstream machine tools and measuring devices.

"The cooperation allows us to increase the value for customers by integrating conventional and additive technologies. This is a large step towards seamless production and we join forces with a strong and experienced partner," stated EOS founder and CEO, Dr Hans J Langer.

"We welcome very much this strategic partnership. GF and EOS complement each other very well to offer the large customer base of GF Machining Solutions a unique set of technologies," added GF CEO, Yves Serra.

www.georgfischer.com
www.eos.info

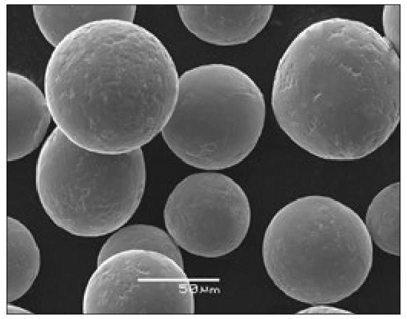
Hoeganaes Corporation introduces metal powders for Additive Manufacturing

Hoeganaes Corporation, based in Cinnaminson, New Jersey, USA, has launched AncorAM™, a new product line of metal powders engineered for Additive Manufacturing. The first offering in this series includes AncorTi™ titanium powder. Available in Ti6Al4V alloy and commercially pure grades, AncorTi is a spherical powder for applications in Additive Manufacturing, Metal Injection Moulding and Hot Isostatic Pressing.

Ti6Al4V alloys exhibit a high strength to weight ratio with excellent corrosion resistance and biocompatibility. This range of properties makes the alloy a perfect candidate to manufacture parts for aerospace, medical, chemical and marine applications. AncorTi is available in particle sizes optimised for Electron Beam Melting (EBM) and Selective Laser Melting (SLM) manufacturing.

"As a new technology, Additive Manufacturing requires a supplier whose knowledge base is exceptional in metal powder manufacturing, has a true understanding of metal powder properties suitable for the AM processes and a history of meeting exacting requirements for quality, supply, and certification of PM materials," stated Richard Kallee, Director of Business Development for Powder and AM at Hoeganaes Corporation. "Hoeganaes has put the resources in place to become a long-term market leader in this emerging sector."

The Advanced Powders Development Facility at Hoeganaes



AncorTi is a spherical powder for applications in Additive Manufacturing

Hoeganaes has taken this step into the AM market in conjunction with a multi-million dollar expansion of its Innovation Center in Cinnaminson. Additions to the research and development facility include a new Advanced PM Machining Lab and 3D printer. Chief among the technological upgrades is a pilot atomising facility dedicated to the development of AM powders and scalable production of advanced metal powders.

A leader in the development and production of ferrous powders primarily for automotive and industrial applications, Hoeganaes stated that its investment in new AM technology provides the basis for long-term growth in new arenas, including the aerospace and medical industries.

For over 65 years Hoeganaes has been a major part of the global landscape in conventional Powder Metallurgy. The company is a leading contributor to the approximately one million metric tons of iron powder used to produce press-and-sinter parts worldwide.

Hoeganaes is already collaborating with new customers to supply AncorTi for aerospace applications using Additive Manufacturing. For more information on AncorAM solutions, contact Paul Taylor, paul.taylor@hoeganaes.com.

www.hoeganaes.com

New members join 3MF Consortium

Four new members have joined the recently launched 3MF Consortium, an industry association set up to develop and promote a new full-fidelity file format for Additive Manufacturing systems. 3D Systems, Materialise, Siemens PLM Software and Stratasys will join the seven founding members of the consortium, Dassault Systemes S.A., FIT AG/netfabb GmbH, Microsoft Corporation, HP, Shapeways Inc., SLM Solutions Group AG and Autodesk Inc.

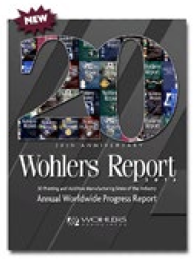
"The addition of 3D Systems, Materialise, Siemens PLM Software and Stratasys to our membership ranks further demonstrates the significant industry momentum behind the adoption of 3MF," stated Adrian Lannin, 3MF Consortium Executive Director. "By participating in the 3MF Consortium, our new members will ensure that their customers get all the advanced capabilities and productivity benefits of the 3MF specification. We welcome them and look forward to their contributions."

The 3MF Consortium was formed to close the gap between the capabilities of modern 3D printers and outdated file formats. The 3MF specification eliminates the problems associated with currently available file formats, resolving interoperability and functionality issues, enabling companies to focus on innovation.

"Our partnership with Microsoft and the interoperability of the 3MF format will help our customers harness all the key features of our 3D printers from the Windows platform," stated Chuck Hull, Chief Technology Officer and Founder, 3D Systems. "As the inventors of 3D printing and the widely used STL file format, we're pleased to join the 3MF Consortium and bring our expertise to help shape the future of interoperability and print integration."

www.3mf.io

Latest Wohlers Report claims AM market was worth $4.1 billion in 2014



Wohlers Associates, Inc., a leading consultancy and respected authority on Additive Manufacturing and 3D printing, has announced the publication of its Wohlers Report 2015. Now in its 20th year, the annual publication provides an in-depth review and analysis of the global industry. It includes growth, competitive products and services and the future outlook for this growing sector.

The report states that the market for Additive Manufacturing, consisting of all AM products and services worldwide, grew at a compound annual growth rate (CAGR) of 35.2% to $4.1 billion in 2014. The industry expanded by more than $1 billion in 2014, with 49 manufacturers producing and selling industrial-grade AM machines. The CAGR over the past three years (2012–2014) was 33.8%.

The comprehensive study covers all aspects of AM and 3D printing, including its history, applications, processes, materials and equipment manufacturers. It covers developments in R&D, investment and collaborative activities in government, academia and industry, and summarizes the state of the AM industry around the world.

Wohlers Associates reports that growth occurred in all segments of the diverse industry, including the low-cost desktop 3D printer segment. The use of industrial metal AM systems for demanding production applications in the aerospace and medical markets also grew strongly. The report thoroughly documents the increasingly rich range of technologies, markets and business models that are emerging within the industry.

"The first Wohlers Report was published in April 1996," stated Terry Wohlers, Principal Consultant and President of Wohlers Associates. "It was 40 pages in length and represented the first-ever published analysis of the industry worldwide. The AM industry represented a mere $295 million in 1995. A lot has changed in 20 years, and we've worked hard to document this change. I am proud to say that no other publication comes close to matching the depth and breadth of data and market analysis that is found in our annual report."

The 314 page Wohlers Report 2015 includes 39 charts and graphs, 63 tables and 279 images. The report, which sells for US$495, was developed with support from 87 service providers, 40 system manufacturers and the contributions of 78 co-authors in 31 countries.

www.wohlersassociates.com

Powder Metallurgy Day at Ceramitec to focus on Additive Manufacturing

Ceramitec 2015, the international trade show for the entire ceramics industry, ranging from conventional ceramics and raw materials to Powder Metallurgy and technical ceramics, will take place at Messe München, in Munich, Germany, from October 20-23, 2015.

The Supporting Programme will provide a platform for the transfer of knowledge and expertise in research and development. Attendance at the specialist lectures and panel discussions will be free of charge and simultaneous translation in German and English will be offered for all lectures.

This year's programme will begin with a panel discussion themed "Ceramitec goes digital" on the opening day, Tuesday 20 October 2015. Experts from ceramics and Powder Metallurgy will report on progress in Additive Manufacturing with regard to industrial realisation and further needs for research and development.

The theme continues during the afternoon of the first day with the Powder Metallurgy Day programme, organised by the Fachverband Pulvermetallurgie, including presentations on dynamic developments in metal and ceramic Additive Manufacturing.

www.ceramitec.de

World's first hybrid grinding machine with integrated AM technology

The world's first hybrid grinding machine, integrating surface and profile grinding with Additive Manufacturing in a single setup, has been developed by Elb-Schliff WZM GmbH, Germany, in collaboration with Hybrid Manufacturing Technologies, UK.

The new system, named millGrind, is a continuous-dress creep-feed grinding machine equipped with Ambit™ laser cladding and milling capabilities. "This millGrind machine offers a new level of flexibility by reducing the number of setups needed to get to finished parts. We believe that our customers will benefit from both the ability to add metal and mill features together with precision grinding surfaces and profiles. This multi-tasking machine breaks new ground for time and cost savings and is aimed squarely at aerospace applications," stated Dr Markus Stanik, ELB's Managing Director.

MillGrind is the first AM product from ELB and was developed in collaboration with Hybrid Manufacturing Technologies. Dr Jason Jones, CEO of Hybrid stated, "It has been a privilege to join with ELB to produce the world's first hybrid grinding machine. The ability to automatically change between precision grinding, milling and AMBIT™ metal deposition sets this machine apart in a class of its own. Perhaps most exciting is that precision ground surface finishes are now achievable in-process on parts made by Additive Manufacturing."

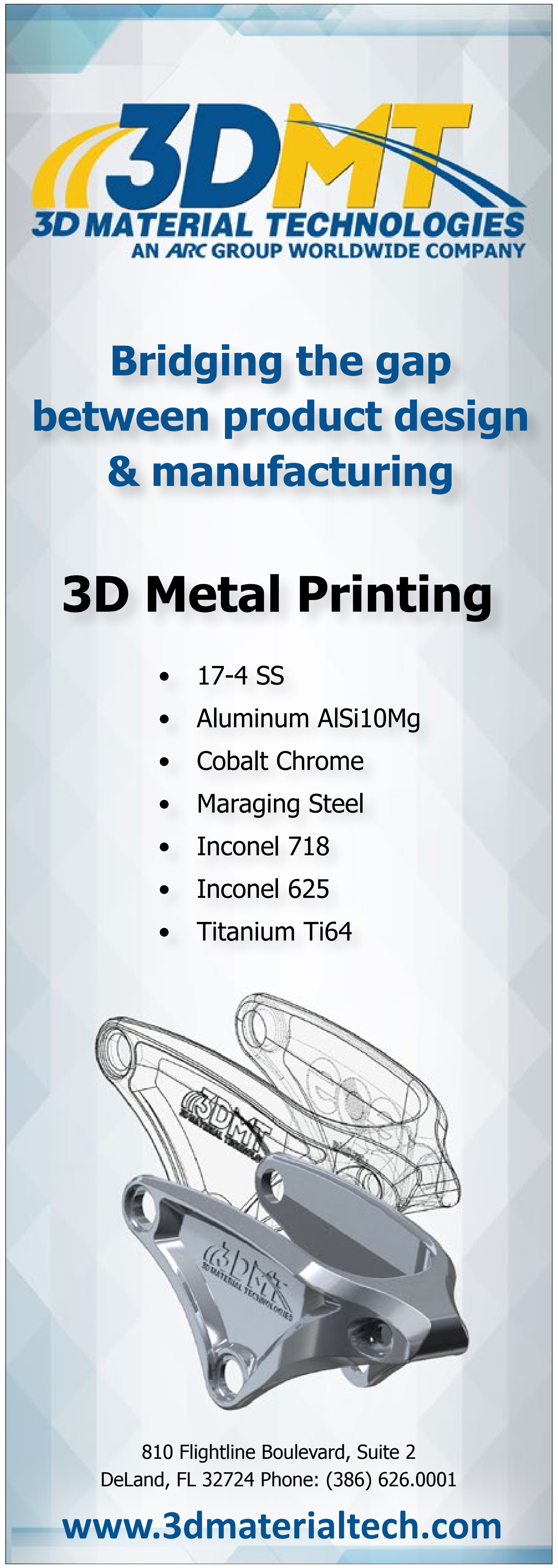
Although the perceived cost of grinding is often higher than milling, when used appropriately it can provide dramatically more cost-effective material removal as well as a superior surface finish, often an order of magnitude improvement over milling. Grinding particularly excels in cost-effectiveness for

The new millGrind creep-feed grinding machine with integrated laser metal deposition and milling

processing materials that are difficult to machine, such as nickel-based superalloys.

The system runs conventional abrasives (corundum) with superabrasive capability and has an XYZ resolution of 1/10th of a micron (0.0001 mm). Changeover between grinding wheels can be done in a matter of seconds. In addition, the 8,000 RPM spindle can be automatically loaded with milling cutters for drilling, tapping and other milling operations as needed.

www.autania-grinding.de
www.hybridmanutech.com



Euromold expecting 420 exhibitors at its 22nd event

Demat GmbH, the founder and host of Euromold, is reporting that this year's event is expecting to attract around 420 exhibitors. The event is taking place from September 22-25, 2015, in Düsseldorf, Germany.

"We are very pleased with the current number of registrations for the coming Euromold 2015. To date a total of 328 companies already registered. Within the next few days we will release a list of exhibitors on our website. The registrations we received until now are a clear resemblance of our efforts to jointly develop the exhibition with our exhibitors. Euromold remains the largest international platform for 3D-Printing, Product Development and Mouldmaking & Tooling," stated Diana Schnabel, CEO of Demat GmbH.

According to Schnabel, some 420 exhibitors can be expected at the upcoming Euromold when taking into consideration the course of registrations of previous years. The exhibition currently lists 53% of all registered companies coming from outside Germany, with 23% of those from Western Europe, 20% from the Far East, 6% from Eastern Europe and another 4% from North America.

"In line with of our sharpened concept, we slightly adjusted the product division at Euromold in order to put more focus on the process chain and the prospective developments in all participating sectors," added Schnabel. Additive Manufacturing & 3D Printing is currently the strongest sector with 36%, followed by Mouldmaking & Tooling (30%) and Production and Suppliers (24%).

www.euromold2015.com

H.C. Starck acquires stake in Metasphere Technology

H.C. Starck has acquired a minority stake in Swedish start-up, Metasphere Technology, which has developed an innovative technology for the production of spherical metal powders suited to Additive Manufacturing.

H.C. Starck and Metasphere Technology plan to build a new production line for the spherical metal powders in Lulea, Sweden. The agreement secures H.C. Starck exclusive sales rights of the materials produced. Both partners have agreed not to disclose further details of the agreement.

"With our many years of experience in the processing of technology metals and technical ceramics, we see great growth potential for our company in Additive Manufacturing," stated Andreas Meier, CEO of the H.C. Starck Group.

www.hcstarck.com | www.metasphere.se

ATI to expand nickel-based superalloy powder capabilities for the Additive Manufacturing sector

Allegheny Technologies Incorporated (ATI) is investing around $70 million to expand its nickel-based superalloy powder production to satisfy strong demand from the aerospace jet engine market and growing demand from the Additive Manufacturing industry. The development is expected to take two years to complete and will be located at its Specialty Materials business unit near Monroe, North Carolina, USA.

Nickel-based superalloy powders provide extreme alloy compositions and a refined microstructure that offer increased performance and longer useful lives in high-temperature and highly corrosive environments. "This strategic growth project will strengthen ATI's position in the production of technically demanding superalloy powders used to produce advanced mill products and forgings, primarily for next-generation jet engines," stated Rich Harshman, ATI's Chairman, President and CEO.

"A significant portion of the powders to be produced from this expansion are needed to meet requirements of existing long-term agreements with jet engine OEMs that run well into the next decade. The expansion also better positions ATI to continue as a leading innovator supplying advanced powders to the new and rapidly growing Additive Manufacturing industry," added Harshman.

The expansion builds on ATI's existing powder capabilities located at facilities in Oakdale, Pennsylvania, USA, which, the company states, are currently operating near capacity.

www.atimetals.com

MatterFab to develop affordable metal AM system

MatterFab, based in San Francisco, USA, has announced it has raised a total of $5.75 million in funding, including investments from GE Ventures and the Innovate Indiana Fund. The company will use the money to complete the design and development of the its first commercial industrial 3D metal printer.

"Our vision is not just to solve today's biggest challenges with metal 3D printing, but to revolutionise the capabilities of metal printing," stated Matt Burris, CEO at MatterFab.

The investment from GE is seen as further validation for MatterFab's printer, which the company claims will be the first affordable, scalable 3D metal printer using next generation laser technology to print solid metal parts.

www.matterfab.com

Safran orders new BeAM Additive Manufacturing system

Aerospace and defence systems manufacturer Safran is adding a new BeAM Additive Manufacturing machine to its research and technology department. The metal powder deposition system from BeAM can be used for the production of components as well as performing repairs to existing structures.

The purchase follows an 'Open-Innovation' collaboration between the two companies where the first series of tests were carried out in 2014 to allow the validation of BeAM's technology to be used in several of Safran's subsidiaries.

"We have proved the feasibility during the test series since 2014 and we are now industrialising the process. Additive Manufacturing is the future of manufacturing industry and that is why the Safran group would like to be a leading actor," stated Thierry Thomas, Safran's Additive Manufacturing VP.

"The work done with the Safran's Open Innovation team allowed us to spare precious time to get fast industrial results for the benefit of both Safran and BeAM, thus making the adoption of this technology a lot faster as many barriers have been eliminated. This purchase by an important industrial group like Safran is, for BeAM, a proof of confidence that demonstrates the industrial quality of our machines and their innovative potential," added Emmanuel Laubriat, BeAM's CEO and co-founder.

www.beam-machines.fr
www.safran-group.com

The CLAD MAGIC is a range of machines for AM of metal parts in three and five axis for the aerospace industry

The BeAM Additive Manufacturing machine has been used to repair this worn labyrinth seal

Airbus A320neo passenger jet takes off with Additive Manufactured parts in LEAP jet engines

A next-generation A320neo Airbus passenger jet, powered by twin LEAP jet engines with Additive Manufactured parts, is reported to have completed its maiden flight on May 19, 2015, in Toulouse, France.

The LEAP is the first engine equipped with 19 3D-printed fuel nozzles, as well as parts made from high performance ceramics that make it 15% more fuel efficient than comparable engines built by CFM International, the 50/50 joint-venture between GE Aviation and France's Safran (Snecma) that designed the engine.

"Today, we are celebrating the next step in our very successful journey with Airbus, a journey that goes back nearly 35 years to the very launch of the A320 programme," stated Jean-Paul Ebanga, President and CEO of CFM.

The two engines used for the four and a half hour flight were the LEAP-1A, developed specifically for the Airbus jet. Airbus picked the LEAP for the A320neo in 2010. Since then, CFM has received more than 2,500 orders and commitments for the LEAP-1A engine, representing 55% of A320neo orders to date.

CFM International also designed the LEAP-1B for Boeing's 737 MAX aircraft and LEAP-1C for Comac's C919 planes. With a running tally of 8,900 orders, valued around $115 billion (US list price), the LEAP is the bestselling engine in GE Aviation's history.

CFM has said it was "on track" to receive joint US Federal Aviation Administration and European Aviation Safety Agency certification. The first LEAP is scheduled to enter service in 2016.

The A320neo Airbus passenger jet is powered by twin LEAP jet engines, each with 19 AM fuel nozzles

There are currently more than 30 LEAP engines (all three models) in final assembly or going through tests at GE and Snecma testing facilities in Peebles, Ohio, Victorville, Cal. and elsewhere in Europe and around the world. The testing program has logged a total of more than 3,660 certification test hours and 5,460 test cycles.

The FAA recently certified the first 3D printed part for a GE jet engine - a casing that houses the compressor inlet temperature sensor inside the GE90 jet engine.

www.ge.com

Sigma Labs and Arete Innovative Solutions form joint venture company

Sigma Labs, Inc., has entered into a definitive agreement to form a joint venture company with Arete Innovative Solutions LLC. The new entity, Arete-Sigma LLC, will be a comprehensive metal solutions provider for the AM market and offer a full suite of services from design through prototyping and manufacturing of high precision metal components.

"This is an exciting development for Sigma Labs, which I believe will accelerate the company's growth prospects going forward," stated Mark Cola, President and CEO of Sigma Labs. "The joint venture will bring unique manufacturing competencies and capabilities within the metal AM space together under one roof - giving us the ability to offer clients design, process control and quality assurance solutions not found anywhere else."

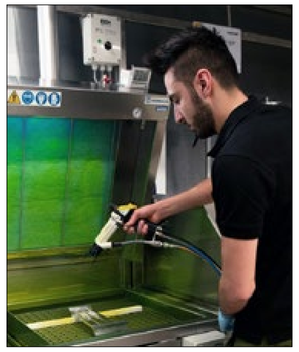
"We're thrilled to be working with a leader in AM quality assurance such as Sigma Labs," stated Bill Herman, President of Arete Innovative Solutions.

www.sigmalabsinc.com

www.areteisllc.com

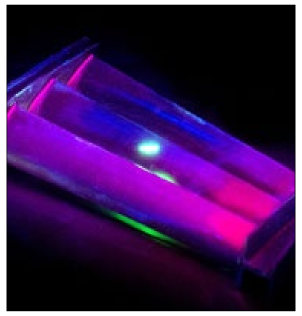
Non-destructive surface testing of AM components at Toolcraft

A process for the non-destructive testing of components produced via metal Additive Manufacturing is now being used by German engineering company Toolcraft. The system offers the opportunity to check components, using a non-destructive method, for cracks, overlaps, folds, pores and binding errors in the surface.



Components are wetted with a fluorescent penetrant

Precision parts and high-tech components are wetted with a fluorescent penetrant, thereby making even the smallest cracks visible under UVA light. The process is predominantly used on metallic materials, although it can also be applied to other materials such as ceramics, assuming the surface is suitable for testing with penetrants.



Microscopically small cracks are revealed in the evaluation cabin

Each testing process starts with preliminary cleaning of the components in an alkaline bath. Following this, the alkali is washed off in a three-stage bath cascade using demineralised water. To protect the environment, an activated charcoal filter continuously filters the process water and prepares it for further cleaning processes. Toolcraft has also installed an additional water treatment plant that filters the water required for the process so that it can be reused in further test procedures.

Once the fluorescent penetrant has been applied by an electrostatic method, the component undergoes intermediate cleaning. Following this, it is immersed in an emulsifier bath in order to partially dissolve the penetrant. Immersion in the water stop bath is used for finishing the process.

The testers apply a dry developer before assessing the component. This picks up the penetrant remaining in the defects and shows it up under UVA light.

Even microscopically small cracks, which can have a decisive effect in aerospace applications, are revealed in the evaluation cabin.

www.toolcraft

Additive Manufacturing with microscopically small metal droplets

A team of researchers from the University of Twente, The Netherlands, has established a process to additively manufacture structures of copper and gold by stacking microscopically small metal droplets. The droplets are made by melting a thin metal film using a pulsed laser.

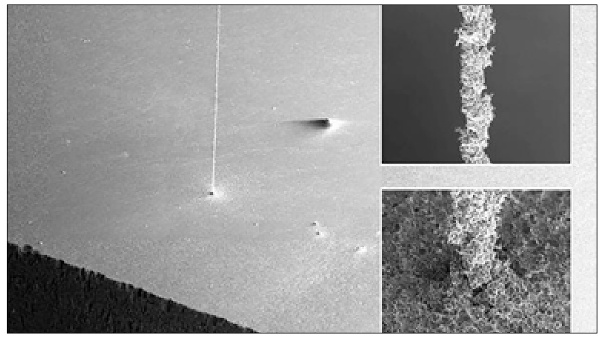
In this method, a pulsed laser is focused on a thin metal film that locally melts and deforms into a flying drop. The researchers then carefully position this drop onto a substrate. By repeating the process, a 3D structure is made. As an example, the researchers stacked thousands of drops to form micro-pillars with a height of 2 mm and a diameter of 5 μm. They also printed vertical electrodes in a cavity, as well as lines of copper. In effect, virtually any shape can be printed by smartly choosing the location of the drop impact.

In this study, the researchers used a surprisingly high laser energy, in comparison to earlier work, to increase the impact velocity of the metal droplets. When these fast droplets impact onto the substrate, they deform into a disk shape and solidify in that form. The disk shape is essential for a sturdy 3D print: it allows the researchers to firmly stack the droplets on top of each other. In previous attempts, physicists used low laser energies. This allowed them to print smaller drops, but the drops stayed spherical, which meant that a stack of solidified droplets was less stable.

In their article, the researchers explain which speed is required to achieve the desired drop shape. They had previously predicted this speed for different laser energies and materials. This means that the results can also be readily translated to other metals.

One remaining problem is that the high laser energy also results in droplets landing on the substrate next to the desired location. At present this cannot be prevented. In future work, the team will investigate this effect to enable clean printing with metals, gels, pastes or extremely thick fluids.

www.utwente.nl



High energy lasers are used to create fast-flowing metal droplets (Courtesy University of Twente)

Aero Kinetics and SLM Solutions to bring metal Additive Manufacturing to commercial unmanned aircraft

Aero Kinetics, Fort Worth, Texas, USA, has partnered with SLM Solutions NA to bring advanced Additive Manufacturing technology to Aero Kinetics' latest generation multi-rotor Unmanned Aircraft Systems (UAS).

The use of additive technology for manufacturing aluminium and titanium prototypes and production parts allows Aero Kinetics to rapidly produce complex, fully optimised, aerospace-grade components. By integrating these components into unmanned aircraft, Aero Kinetics improves component life cycle and mitigates the obsolescence commonly associated with the hobbyist systems on the market.

Serving as the North American subsidiary of SLM Solutions Group AG, SLM Solutions NA, Inc. is a leading provider of metal-based Additive Manufacturing technology. "We are thrilled to have SLM on board with our programme," stated W Hulsey Smith, Chairman and Chief Executive Officer of Aero Kinetics.

"The safety, speed and quality of SLM's machines are well suited to produce ultra-lightweight structural components for unmanned aircraft. When coupled with Aero Kinetics' subject matter expertise in design for additive metal manufacturing, we will reduce weight in our critical structural components. SLM and their technology help us deliver unmanned aircraft to our clients with the most advanced 3D printing technology," added Smith.

Aero Kinetics was the first company to file for FAA Type Certification for multi-rotor unmanned aircraft and has developed a range of UAS solutions for its international customer base in the critical infrastructure, disaster/emergency response, border security, ranching and electronic newsgathering industries.

James Fendrick, SLM's Vice President of Sales & Marketing – NA, stated, "We are excited about the opportunity to work with a leading innovator in the VTOL segment like Aero Kinetics, in attaining FAA certification for parts built on SLM Solutions products. We believe there is true value in proving that our products are capable of manufacturing parts that are flight worthy and able to pass strict FAA requirements."

www.aerokinetics.com

Development of customised total hip replacement using Additive Manufacturing

A cost effective method of producing customised total hip replacement implants has been developed using Additive Manufacturing technology at Malaysia's Advanced Materials Research Centre, SIRIM Berhad, reports Dr Mohd Afian Omar.

The medical devices market in Malaysia is highly reliant on imports and was reported to be at US$ 1.2 billion in 2011 and is estimated to reach US$ 1.8 billion in 2016. This is mainly due to the lack of local manufacturers producing medical devices in Malaysia, where, for example, only two companies currently produce orthopaedic prostheses.

Expensive imported products are currently used in Malaysia's hospitals, which can cause a financial burden to many patients. Furthermore, the designs of the prostheses are not necessarily tailored to the Malaysian population, which is made up of various ethnic communities.

A team of experts in precision manufacturing, orthopaedic surgeons and materials scientists from SIRIM Berhad, Kolej Kemahiran Tinggi Mara Kuantan, the Medical Faculty of International Islamic University Malaysia and Cyberjaya University College of Medical Science Malaysia has worked together to address these problems. The team has now successfully developed a customised total hip replacement implant using Additive Manufacturing technology. The prototype from this research will be further evaluated in terms of bio-corrosion, fatigue and biocompatibility assessment.

The current techniques for production of total hip replacement include traditional methods such as investment casting, forging and machining. Each of these methods requires finishing enhancement to achieve the final desired properties. Additive Manufacturing in metal represents a transformational option for production of orthopaedic implants, producing a customised net shape product. Using just-in-time manufacturing and delivery, each implant can also be designed, produced and shipped to the surgeon just before the procedure, therefore eliminating the need for hospitals to store multiple implants in inventory.

Hip replacement implants have been developed using AM technology at Malaysia's Advanced Materials Research Centre

afian@sirim.my

Bulk Additive Manufacturing available at UK's Nuclear Advanced Manufacturing Research Centre

The system incorporates a six-axis Kuka robot arm

The Nuclear Advanced Manufacturing Research Centre has completed the installation of a £1 million automated bulk Additive Manufacturing cell at its facility in South Yorkshire, UK. Built by Kuka Systems UK, the system can build high-integrity near-net shape parts from the ground up and add metal features to large forgings such as pressure vessels.

The ten by five metre cell features a six-axis Kuka robot arm, mounted on a three-axis nine metre gantry, plus a two-axis manipulator with 3.5 metre diameter turntable. The robot initially carries a 'toptig' welding system, which integrates the wire feed into the welding torch, and has been developed by Air Liquide specifically for robotic welding applications.

The robot will work directly from a CAD model to lay down weld material to create three-dimensional geometries. As well as creating near-net shape parts, the cell can also add non-critical structural features to large pump and valve casings or pressure vessels, reducing the initial size and complexity of expensive forgings or castings.

"We're looking at the whole system of Additive Manufacturing with this cell – both the technical process development and the business side," stated Udi Woy, Nuclear AMRC technology lead for Additive Manufacturing. "Manufacturers aren't so concerned about developing the process, they just want to build something that meets customer requirements in a more cost-effective way."

The technology builds on previous research at the Nuclear AMRC and its sister centre, the AMRC with Boeing, into the shaped metal deposition technique, which builds large near-net shape parts from welded wire.

The new robot is able to carry a selection of end effectors, allowing the Nuclear AMRC team and partners to investigate a range of arc and power beam welding technologies using metal powder and wire and to inspect and finish parts in a single set-up. The design of the cell helps avoid contamination problems that can arise in traditional powder-bed additive machines.

www.namrc.co.uk

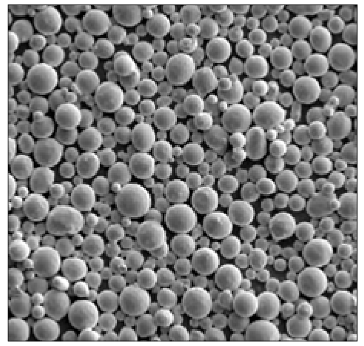
Optimised superalloy powders now available from Oerlikon Metco

Oerlikon Metco, Winterthur, Switzerland, has expanded its materials portfolio with novel superalloy powders optimised for new applications in laser-based and electron beam Additive Manufacturing processes that, states the company, save customers development time and resources.

For key applications, superalloy materials are preferred for their strength and corrosion resistance at high temperatures. Oerlikon Metco has been involved in multiple projects to correlate materials, manufacturing processes and metallurgical mechanisms to create tailored materials for Additive Manufacturing processes.

The company is equipped to custom-design materials and currently markets optimised alloys such as MetcoClad 718, MetcoClad 625, MetcoClad 625F. Aiding these activities is Oerlikon Metco's ability to offer clients high-end testing and characterisation services that ensure materials meet customers' requirements.

"Additive Manufacturing has created an increased interest for developing metals and alloys materials," stated Materials Product Line Manager Thomas Glynn. "The boost in process-specific powder development activities prepared us to meet this market trend through innovations that reinforce our knowledge in the relationship between powder characteristics and resulting component quality."



The company currently markets a range of optimised alloys such as MetcoClad 718, MetcoClad 625, MetcoClad 625F

Oerlikon Metco has over fifty years of experience in developing powder products for challenging industries with critical material requirements. Current powder manufacturing activities include initial prototype quantities, pilot production lots and scale-up to produce and deliver many tens of tons of materials per year suitable for laser-based and electron beam Additive Manufacturing applications.

www.oerlikon.com/metco

AP&C increases production capacity of titanium powder

Sweden's Arcam AB has announced that a third atomisation reactor is now operational at the company's powder manufacturing subsidiary, AP&C, in Montreal, Canada.

AP&C uses proprietary plasma atomisation technology and has designed and manufactured its third atomisation reactor with a new state-of-the-art process control system. With this new investment, AP&C now has two production lines, encompassing reactors and related sieving and mixing equipment, fully dedicated to titanium products. A third reactor is dedicated to Inconel and other alloys. After the expansion, AP&C has an atomisation capacity of over 150 tons of titanium alloys per year.

"The need for high end titanium powder is driven by the fast growth and adoption of Additive Manufacturing. Arcam is determined to serve the industry through cost efficient solutions, thus converting traditional manufacturing into Additive Manufacturing. A requisite is to offer the highest quality powder for production at competitive cost," stated Magnus René, CEO of Arcam.

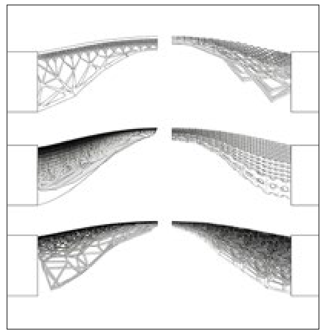
"With this investment in capacity, we continue to drive AP&C's mission to be the reference for high quality titanium and other high-melting point alloy powders for the Aerospace and Medical industries," added Jacques Mallette, President of AP&C.

www.arcam.com

Additive Manufacturing to build bridges in Amsterdam

MX3D, a Dutch company focussed on the research and development of robotic Additive Manufacturing technology, plans to build a steel bridge in place over water in the centre of Amsterdam.

The company equips multi-axis industrial robots with 3D printing tools and develops software so that the robots print metals, plastics and combinations of materials in virtually any format. MX3D state that this technique can build strong, complex structures from durable materials, while being cost-effective and scalable.



Sketches of the bridge design

"What distinguishes our technology from traditional 3D printing methods is that we work according to the 'Printing Outside the box' principle. By printing with six-axis industrial robots, we are no longer limited to a square box in which everything happens. Printing a functional, life-size bridge is, of course, the ideal way to showcase the endless possibilities of this technique," stated Tim Geurtjens, the company's CTO.

The bridge will be built in-situ in the centre of Amsterdam

Building an intricate, ornate metal bridge for a special location is the ultimate test for robots and software, engineers, craftsmen and designers, stated MX3D. The bridge, by designer Joris Laarman, will be ready in 2017.

"I strongly believe in the future of digital production and local production, in 'the new craft'. This bridge will show how 3D printing finally enters the world of large-scale, functional objects and sustainable materials while allowing unprecedented freedom of form. The symbolism of the bridge is a beautiful metaphor to connect the technology of the future with the old city, in a way that brings out the best of both worlds," stated Laarman.

www.mx3d.com

AMT unveils new 3D metal printing centre

Advanced Materials Technologies Pte Ltd (AMT), Singapore, has announced that it is now offering metal Additive Manufacturing services to complement its existing range of mass manufacturing processes. The company specialises in the high volume manufacture of complex precision components via Metal Injection Moulding (MIM) and Ceramic Injection Moulding (CIM).

In addition to prototyping parts, AMT stated that it is also leveraging Additive Manufacturing technology to meet demands for small volume batch production. One of the main advantages of 3D metal printing for small volume production is the potential elimination of tooling. This leads to direct production being possible without costly and time-consuming tooling.

Having established a 3D Metal Printing Centre, AMT is able to offer a complete solution to customers seeking to accelerate their development of ideas and translation into final product.

www.amt-mat.com

Serial production of titanium suppressors at Norway's Tronrud Engineering

Gunsmith Didrik Sorlie with the new suppressor

Tronrud Engineering, in Eggemoen, was the first company in Norway to start commercial production in metal Additive Manufacturing. Now, with five years of experience in the field, the company has developed a new titanium firearm suppressor that, it hopes, will lead to rapid growth.

The new titanium suppressor is already on sale in the hunting and sports market, having been tested by several agencies in the hunting, sport shooting and defence sectors. When the military model is approved, the company is looking expand its production capacity.

Gunsmith Didrik Sorlie at Tronrud Engineering is in charge of the 3D-printer and worked on the development of the new suppressor. "Just minor technical adjustments remain before the military model is approved and then we believe the market will be open for us," stated Sorlie. "To start with, we do not have the capacity to meet the market demands with our present 3D-Printer, so we will have to invest in new technology in order to be able to deliver to the market."

The company's current machine is running at capacity, producing over 1000 suppressors units per year. "If we get orders from the Norwegian military, or other defence customers, we will immediately need to invest in new 3D–technology that is significantly faster and able to produce more and bigger parts than what we are presently able to do," added Sorlie.

Sorlie demonstrated the suppressor and explained how he developed it. "Here you can see how I have built up the geometry of the suppressor to get the best strength while using the least possible amount of material. The suppressor is therefore very light without losing robustness."

If the company succeeds with this suppressor on the global market, it will have to establish a separate building with many more machines in order to handle the demand.

www.tronrud.no

Our thanks to Joppe N Christensen of Norway's Maskinregisteret for supplying this report.

Cooksongold wins UK retail jewellery award

Cooksongold, Birmingham, UK, received an award for Innovation at the UK Retail Jewellery Awards, June 17, 2015, for its precious metal Additive Manufacturing technology. The award highlights the jewellery supplier's work to continually develop technology to a commercial standard, enabling the creation of complex jewellery designs.

With 18 categories, the awards cover every aspect of the jewellery industry. Competition this year was reported as being extremely tough with a record number of entries received. Cooksongold won the Innovation category for its Direct Precious Metal 3D Printing technology and was also highly commended in the Supplier of the Year category.

David Fletcher, Business Development Manager at Cooksongold, stated, "It truly is an honour to have been nominated in both the Supplier of the Year and the Innovation Award categories at the 2015 UK Retail Jewellery Awards. The UK jewellery industry is at the forefront of both innovation and creative design in a global market. So, to be recognised by our peers in the Innovation category for our Direct Precious Metal 3D Printing technology is really fantastic."

www.cooksongold-emanufacturing.com

AUSTECH 2015: Metal Additive Manufacturing on the rise in Australia

The AUSTECH 2015 exhibition took place in Melbourne, Australia, from May 26-29, 2015. As Stefan Ritt, Head of Global Marketing and Communications at SLM Solutions GmbH explains, Australia finds itself at a crossroads in terms of its manufacturing base, with traditional industries closing down and new technologies, including Additive Manufacturing, moving to the fore.

Australia is very much in fashion these days, attracting visitors who range from international travellers and students on exchange programs to film stars and international celebrities. However, not all international visitors know that Australia also has a significant manufacturing industry and, even more importantly, natural resources that many industries rely upon. The country is, for example, one of the largest producers of titanium and precious metals.

Given the size of the country, which comfortably matches the US or the whole of Europe, it can easily be underestimated as the population of less than 24 million people is mainly gathered around the coastal areas in a handful of big cities.

After the dominant mining industry, the automotive industry is the most significant industrial sector, consisting of the three big automobile manufacturers, Ford, Holden-GM, and Toyota, as well as the associated sub suppliers. A fourth one, Mitsubishi, closed down some time ago. Aerospace is also of some importance and is well connected to international development programs such as the F-35 joint strike fighter project.

The automobile industry is, however, the big "coming threat" as all three manufacturers will cease car production in Australia by the summer of 2017. The effect of this decision can only be estimated but will surely be severe. The early closing of the aluminium smelter in Geelong, outside Melbourne, which has already cost 1,500 jobs, is only the beginning. In the light of these dark clouds coming up on the horizon, the AUSTECH exhibition was a very interesting mirror of the present state of industrial technology and its use on the continent.

In the Melbourne Exhibition Centre, one of the most beautiful in the world, AUSTECH was jointly held with Australian Manufacturing Week and the Inside 3D Printing conference. This conference featured Terry Wohlers, the widely known expert in Additive Manufacturing, who just so happened to be on the same flight from Los Angeles with me and his colleague Tim Caffrey after we finished the RAPID show there. The AM community is still like a big family after all!

Of note is that visitors had free access passes to the exhibition floor. This is an interesting concept that should be considered for other international events as well. After all, we, the manufacturers and vendors, want customers to visit us, right?




During the four day show a total of 11,490 visitors came to the Melbourne Exhibition Centre to visit around 150 exhibitors

During the four day show a total of 11,490 visitors came to the Melbourne Exhibition Centre to visit around 150 exhibitors. Kim Warren and the whole team were very helpful and did a great job in organising the event. These visitor numbers are very good in relation to the size of population and industry. The scope of exhibitors was very international and I could even speak to people from the German government in Stuttgart as well as a Danish company based not far from my hometown of Lübeck in northern Germany.

Machine tools were a major display area and working equipment was a focus for visitors. One exhibitor had placed a very old truck from the 1920s with a turning and grinding machine on it next to the latest laser cutting equipment. However, as if the writing was already on the wall, the next generation of technologies such as 3D printing with the associated design bureaus, RP-services and universities were also a big part of the exhibition. All major manufacturers of Additive Manufacturing equipment and materials had a booth at the show.

It came as a pleasant surprise to all of us that, on day two of the show, the government in Canberra announced that within the Innovative Manufacturing Cooperative Research Centre (IMCRC) program, funds of a total of AUS$40 million were to be allocated over the next few years to boost future industrial applications in Australia. Clearly, this is an initiative to compensate for anticipated losses that are expected from the closing of the automotive industry. It was delayed by more than a year from the initial plan, but, as everyone commented, "better late than never".

What this will mean is that a large number of funded projects will create a new manufacturing and R&D structure in the country. Working in the metal AM industry myself, I would expect an interesting and logical development here to use the continent's natural resources to manufacture metal powders for use by the metal 3D printing industry internationally.

I was also involved in many of the frequently repeated discussions at the show which revolved around the fear that the 3D printing of metals will kill traditional milling and machining applications. Fortunately, we could clear up these misunderstandings through discussions with universities and early technology adopters who were also attending the show. More than 25 metal AM machines are now installed in Australia and New Zealand and the IMCRC funds will boost this number in the future.

In a separate section of the event, technical presentations from various experts, again freely accessible for the visitors, gave in-depth insight into the industrial status and future developments in metal AM. The outstanding, catching and often funny introduction to the presentations by the hired professional speaker Warwick Merry, who made the event sometimes sound like a big boxing match, brought a brilliant unique flavour to the event - only in Australia!

The use of lasers is now starting to dominate the machine tool industry as well as the AM-industry and this to me is a common link that we all should grasp to join forces. We are asked to restructure and rebuild Australia's industrial infrastructure and everyone who can bring a positive contribution should try to be part of it. We were able to sell our display machine at the show to a startup company which will now produce medical implants with it.

Although I am not Australian, I have visited frequently for more than 17 years and am privileged to call some Australians personal friends. Always positive, refreshing and good fun, I can only encourage everyone to join in the journey. It will be an interesting five or so years and the connections made will be global. Finally, as a German, I cannot refuse the comment that there are also a whole lot of great beers around here and that makes it even easier to come next time, "No worries Mate, we´ll be back!"

Dipl.eng. Stefan Ritt has worked for today's SLM Solutions group since 1998 where he is Head of Global Marketing and Communications. In parallel to his main role, he is Global Ambassador of the Additive Manufacturing User Group (AMUG) as well as international adviser to the SME (Society of Manufacturing Engineers). Email Stefan.ritt@slm-solutions.com

Additive Industries: Moving towards automation and integration in metal Additive Manufacturing

Additive Industries b.v., based in Eindhoven, The Netherlands, announced at the RAPID 2015 event in Long Beach, USA, that its new metal Additive Manufacturing system, MetalFAB1, will be launched later this year. Dr Georg Schlieper visited the company for *Metal Additive Manufacturing* magazine and reports on the vision behind the development of its new machine, as well as the AddLab 'open innovation' consortium that has proved to be so successful in The Netherlands.

Eindhoven is widely known as an important seat of industry and home of the technology headquarters of the global electronics company Philips. Some fifteen years ago, blocks of Philips factory buildings in the city centre were abandoned as the company moved its activities to the southern outskirts of the city. In the past, these empty buildings were protected by security fences as a measure against industrial espionage, with only Philips employees allowed to enter. As Daan Kersten, CEO and one of the shareholders of Additive Industries b.v. commented, the area has been described as "the Forbidden City of Philips."

After being empty for more than a decade, the fences have been removed and the surrounding areas have been cleared up and modernised. The buildings are now gradually being brought back to life by new start-up companies. The area is an ideal environment for young high-technology, IT and design companies, with an excellent infrastructure and close proximity to the city centre.

Fig. 1 The old Philips factory buildings in Eindhoven are now being revitalised

It is here that Additive Industries b.v. moved to in October 2013 following the company's formation in December 2012. The two co-founders, Jonas Wintermans, COO, and Daan Kersten, CEO, had recognised the immense potential of metal Additive Manufacturing technology and decided to create a new start-up company. As a first step they identified the design opportunities for metal AM in the high-tech production equipment industry and they quickly came to the conclusion that the AM machines that were available on the market were good for research and prototyping purposes, but not for serial production on an industrial scale. They therefore decided to become involved in the development of advanced Additive Manufacturing equipment for metals.

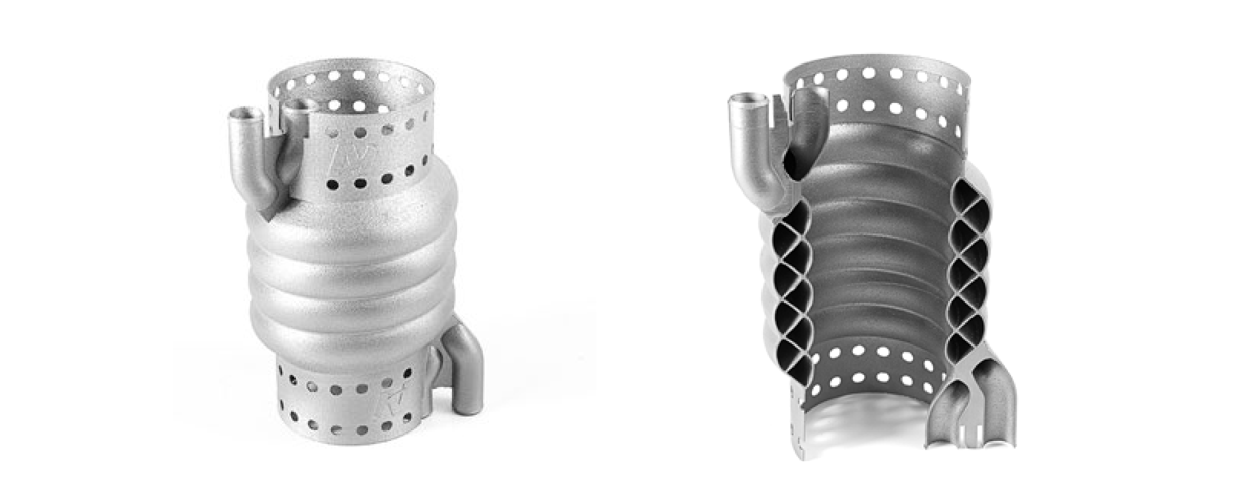


Fig. 2 Heat exchanger (left) with two independent inlets and outlets, and cross-section (right) (Courtesy Additive Industries/AddLab)

"When we started," stated Kersten, "we looked at all metal Additive Manufacturing technologies in order to determine which one was the most promising for manufacturing industry and we found that the laser based powder bed fusion process was the most advanced and closest to standardisation, which is a very important consideration. We therefore decided to focus on the Selective Laser Melting (SLM) technology. When standardisation is in place, and we as an industry think we are very close, it will allow manufacturers to embrace the technology and really put it to work."

A good example of what Selective Laser Melting can achieve is the heat exchanger shown in Fig. 2. This component has two independent channels for liquids that exchange their heat in counterflow, and the whole component can be placed in an environment that can both absorb or provide heat.

Most of the capital for the company came from the family-owned business of co-founder Jonas Wintermans, an industrial holding company based on the fortune of one of the world's largest cigar manufacturers. This holding company has specific experience in the development and production of high-tech equipment. The second shareholder, Daan Kersten, told *Metal AM* magazine that further investment capital had been received as an innovation loan from the Dutch government. "All this gives a solid and stable capital base that can sustain the company through the difficult start-up phase until revenues cover costs," he stated.

Additive Industries currently has two distinct activities, the development of what it states is the next generation of metal AM production equipment, and AddLab, an 'open innovation' pilot facility for metal AM production where parts are designed and manufactured on a daily basis.

Metal AM machine development at Additive Industries

The ambition of Additive Industries is to become a leading supplier of production equipment for industrial metal Additive Manufacturing. The company's mission has therefore been to develop a highly integrated, automated metal Additive Manufacturing system that is specifically designed to be used by manufacturing industry. The launch of the company's new system, named MetalFAB1, is scheduled for the fourth quarter of 2015, with the first delivery to a customer being envisaged in the first quarter of 2016. Kersten stated that this comprehensive system embodies the ambition of Additive Industries to take 3D metal printing beyond the current laboratory and prototyping use to series manufacturing on the factory floor. "Our system will bring a substantial improvement in reproducibility, productivity and flexibility as a result of our quest to design an industrial grade metal printing process," commented Kersten. The first target market after Europe is the United States because, stated the company, the North American AM industry is already very well developed.

According to Kersten, feedback from potential customers indicates that the future success of metal Additive Manufacturing in industrial environments will be down to the degree of automation and user friendliness. The first model will therefore have multiple build chambers, up to four lasers, automated build plate handling, fully automated powder removal and an integrated heat treatment module.

"Additive Industries believes in an integrated process flow for industrial Additive Manufacturing, therefore multiple process steps are incorporated in one machine for the first time. Fully automated handling connects all process steps, reduces manual labour and improves product consistency and quality, while also increasing operator safety," stated Mark Vaes, Technology Manager at Additive Industries.

"Our modular architecture offers maximum flexibility, allowing the user to start with a basic machine configuration with the possibility to enlarge the scope of the process, enabling substantially increased productivity. Moreover, modules can be added to allow the use of multiple materials in one machine without having to clean the powder system and running the risk of cross-contamination. We are on schedule to launch the machine in the fourth quarter of this year."

During development, Additive Industries identified the main 'building blocks' for its new metal AM machine, designed the architecture in-house and then looked for experts in specific fields to work for it either as employees or as subcontractors developing certain modules. These modules include optics, motion control, thermal control, highly precise positioning, electronics and software development. The philosophy was that much of the technology required for 3D printing was readily available in the Eindhoven region and proven in other very demanding contexts such as the semiconductor and medical imaging industries. This technology, believes Additive Industries, only had to be identified and integrated into the system. Besides its own staff of 22, around 25 further experts work for Additive Industries.

"One of the reasons why we are in a position to develop this kind of equipment is that we did not have to start from scratch," stated Kersten. "We have built on the experience of other companies in this region. In our machines we use the knowledge about functional building blocks that has been developed for other applications and has proven successful there. We want to achieve predictability, stability and productivity and, in order to ensure these three requirements, we try to avoid completely new solutions that might exhibit growing pains, instead using only proven building blocks."

As an example, the knowledge about the laser optics required in an AM machine has been taken from applications developed for medical scanning technologies, scanning electron microscopy and lithography technology. Additive Industries hires the experts that are experienced in these technologies to develop its own optical modules.

Fig. 3 The AddLab team in a technical discussion on part design (Courtesy Additive Industries/AddLab)

Whilst few details have been released regarding the exact specifications of MetalFAB1, it is believed that the system will feature advanced technologies for quality assurance in metal AM component production. In December last year Additive Industries announced an agreement with Sigma Labs, based in Santa Fe, New Mexico, USA, a developer of advanced, in process, non-destructive quality inspection systems for metal-based additive manufacturing.

At the time of the announcement Mark Cola, President and CEO of Sigma Labs, stated, "Teaming with Additive Industries will bring Sigma Labs closer to other companies working towards the goal of improved, reliable, high-volume additive manufacturing. The technology agreement serves to increase collaboration around shared objectives in the 3D printing space, and our PrintRite3D® quality assurance software will be tested with equipment currently being developed by Additive Industries."

"Cooperating with Sigma Labs allows Additive Industries to improve the predictability of the 3D print process, which is critical to advanced applications in markets like aerospace, medical technology and high-tech equipment," stated Kersten.

AddLab: An open innovation initiative for metal Additive Manufacturing

The Eindhoven area is not only known for its industrial heritage, but also for a tradition of 'open innovation'. Open innovation means that a consortium of industrial companies shares the cost and outcome of a joint development project. Among the many business units and spin-offs of Philips in the Eindhoven area there is great confidence in the future of AM technology. Many of these companies have joined an open innovation initiative, named AddLab, for the design and manufacture of metal AM products.

AddLab has nine industrial partners and the initiative is now in the second year of a three year programme. The cooperation is so successful that the partners are already exploring the opportunities to extend the cooperation after the initial three years. It was suggested that there is the possibility that a new company may emerge that continues to design and manufacture metal AM components for high-end industrial applications. The team that now runs AddLab (Fig. 3) will become the support team for Additive Industries'

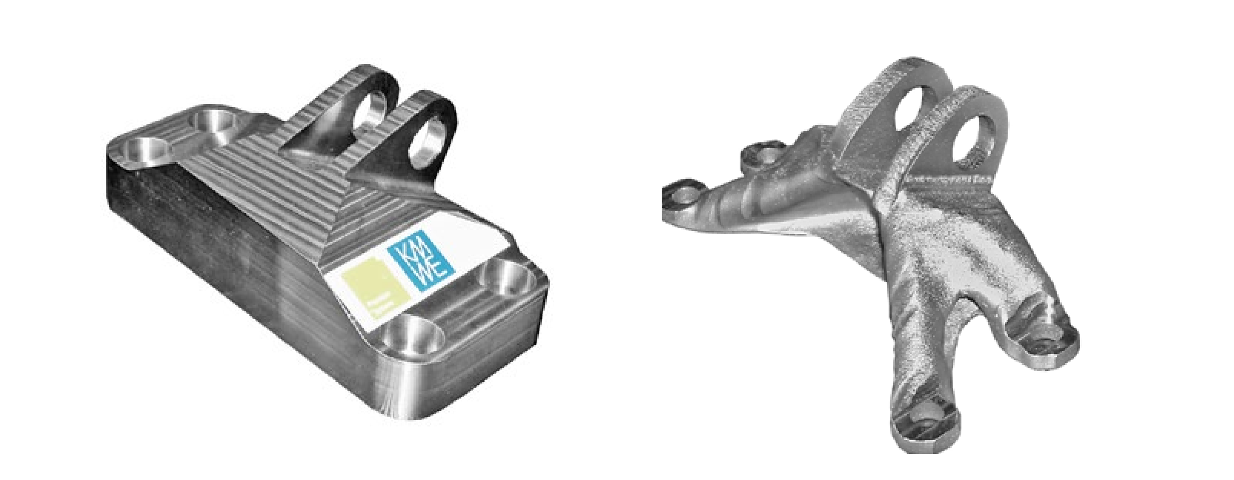


Fig. 4 A stainless steel fixture produced as a machined part (left) and optimised for Additve Manufacturing (right)

new industry-focused Additive Manufacturing equipment.

Some of the AddLab partners, the majority of which are located in the Eindhoven area, see AM as a technology that allows them to redesign parts of their products and improve their equipment. As an example, suppliers to ASML, a leading manufacturer of high-tech equipment for the semiconductor industry with more than 14,000 employees worldwide, can redesign machine components with integrated cooling channels. This reduces the thermal expansion in their products and thus increases the dimensional accuracy that they can achieve with their machines.

Other AddLab partners use the network to keep in touch with developments at the cutting edge of innovation in this field, as well as to participate in the development of the next generation of AM technology. Further AddLab partners plan to launch their own AM component production operations and see the partnership as a way to get a head-start on the learning curve with regards to the design and application of components prior to making a major investment.

In the AddLab open innovation initiative, Additive Industries shares the cost of AddLab, as well as the learning curve, with its partners. AddLab's function as a shared pilot facility for metal Additive Manufacturing is supported by the installation of three AM machines of various build volumes and with different laser power. The systems, from SLM Solutions and Phenix Systems (currently part of 3D Systems), all use Selective Laser Melting technology. All the information and knowledge acquired through the design, 3D printing and application of new parts is open to, and shared with, all partners in AddLab. The cooperation between the partners accelerates the learning curve because each partner contributes with their own experience.

> *"If we fully utilise the design freedom of AM as much as possible, we can make products that are really different from parts made with other manufacturing technologies."*

AddLab is currently testing a wide range of process parameters in order to establish how optimum part quality, in terms of mechanical properties, dimensional accuracy and surface quality, can be achieved. The powder bed is held under a constant flow of inert gas which sweeps away dust and smoke arising from the laser impact whilst at the same time improving the heat dissipation during the process. Layer thickness is clearly an important parameter affecting not only shape accuracy, but also the productivity of the process. A new layer of fresh powder may be applied with either a metal strip or a roller, with the latter offering the advantage of pre-compacting the powder bed which can allow for thinner layers and improve the surface quality.

AM part design considerations at AddLab

The results of AM design are often surprising and clear weight reductions are regularly achieved. Fig. 4 shows an example of a fixture made from stainless steel, a typical aerospace component. The design for AM on the right resembles a bionic structure, however it fulfils the same functions as the machined part but with only a quarter of the weight.

The development of a new AM component at AddLab starts with a first assessment of the feasibility for Additive Manufacturing. The feasibility assessment is based on past experience as well as technical and economic considerations. When the feasibility has been confirmed, the design phase follows. "Design is the key to Additive Manufacturing," stated

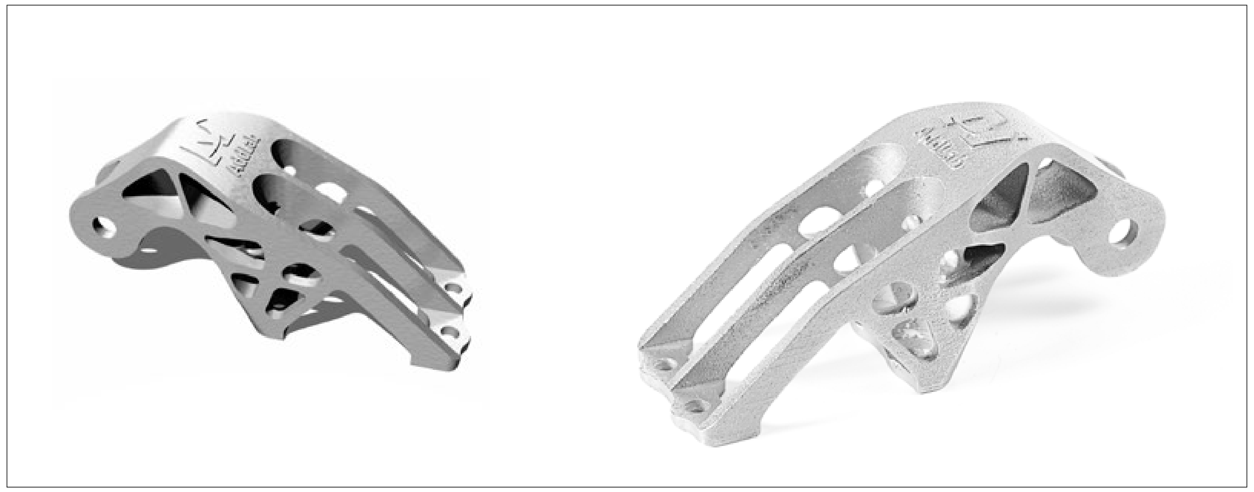


Fig. 5 Computer designed AM part (left) and manufactured part (right) (Courtesy Additive Industries/AddLab)

Kersten. "If we fully utilise the design freedom of AM as much as possible, we can make products that are really different from parts made with other manufacturing technologies." A learning phase is required until the benefits of Additive Manufacturing, in contrast to subtractive manufacturing technologies such as turning and milling, are fully understood.

The AddLab team starts with a functional model that simply specifies the loads acting on the component, the boundary dimensions and the interfaces with other parts. Topology optimisation software is then used to create a part design with a minimum of material usage and weight. This topology optimised part is not yet ready for production, but serves as an initial guide showing where material is needed and where it can be removed. In the next step the computer design model undergoes an engineering review. Corrections may be required for aesthetic or functional reasons and the surface is smoothened in order to make the part look like an industrial product rather than a bionic structure (Fig. 5). Another critical decision relates to the orientation of the product in the build chamber. Supporting structures are necessary to print the majority of parts and these have to be added to the design. The material and process details are then defined before the data file can be loaded into the 3D printer.

Metal AM processing

Three materials are currently considered by Additive Industries as the primary metals for Additive Manufacturing; 316L stainless steel, titanium alloy Ti6Al4V and aluminium. The raw materials are generally gas atomised powders consisting of spherical particles that range from 20 to 45 µm in size. Typical layer thicknesses for laser melting are between 30 and 50 µm, so the maximum particle size of the powder should be somewhat smaller than the layer thickness.

Metal powder is handled in a clean room environment with access through a double door system. This helps to avoid contamination of powders and materials with non-metallic substances. Workers protect themselves with respirator masks against inhaling powder particles.

Parts are printed on a build plate, as can be seen in Fig. 6, for two reasons. Firstly, the initial layer of the part must be securely fixed to the build plate, otherwise it would be swept away when fresh powder is spread over the powder bed. For the same reason support structures are required for the horizontal portions of a component. Secondly, the laser beam induces extremely high

Fig. 6 An AM part on the build plate being removed from a 3D printer (Courtesy Additive Industries/AddLab)

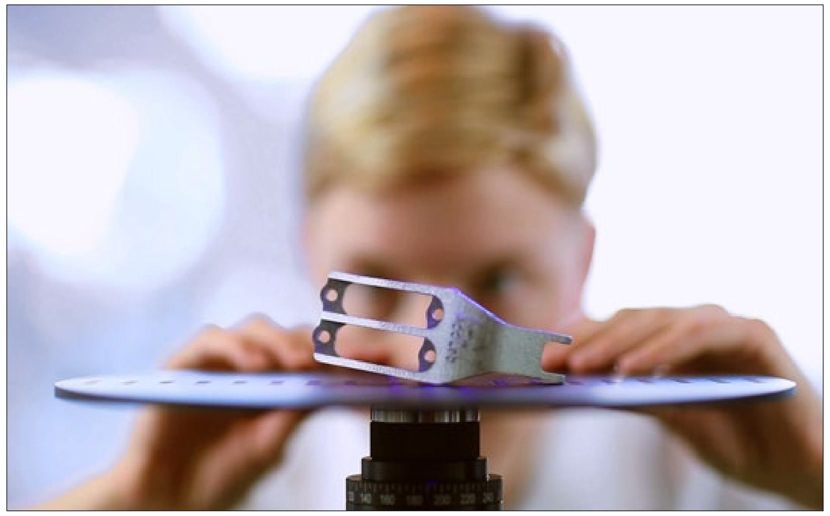


Fig. 7 AM part being aligned on a 3D scanner stage for dimensional control (Photo Additive Industries/AddLab)

temperatures in very small areas where it melts the powder. As the heat is dissipated, the metal cools quickly from melting temperature. This extreme heating and cooling cycle is repeated with each layer of the component. The permanent heating and cooling is associated with repeated thermal expansion and contraction and as a result high stresses are induced in the material that can negatively affect the dimensional accuracy of the products. The build plate therefore fixes the part and reduces deformation due to thermal stress.

The first prototype of a component produced by AM technology is thoroughly analysed and the design and parameters are optimised as required. When all details are fixed and approved, the part can be reproduced as often as necessary. Post-processing after printing includes a heat treatment in a furnace for stress relief. Shot peening is also frequently applied to improve surface quality. Finally the parts are separated from the build plate and final machining or surface treatment is performed as needed.

Quality control at AddLab

AddLab has a Phenom World tabletop scanning electron microscope to control the quality of the powders used. Particle size has a major influence on the flowability, tap density and layer thickness when printing. As is widely recognised, quality control of parts is a major challenge in Additive Manufacturing. Since there is still little standardisation, manufacturers rely on their own experience with regards to how to best inspect metal AM parts. Additively manufactured components are often of such complex shape that conventional methods such as 3D (tactile) coordinate measuring machines are ineffective in completely characterising the geometry of a part.

AddLab therefore uses a 3D scanner to measure the dimensions of a component and compare it with a 3D CAD model by superimposing the two datasets (Fig. 7). Further regular quality inspection procedures include microstructural analysis and surface roughness testing, as well as X-ray inspection. A tensile test piece and a cube are often printed with parts so that the density and tensile properties can be evaluated with each production run. For more in-depth material investigations, AddLab can rely on the extensive facilities of its partners such as the Philips materials laboratory.

Looking ahead

Besides the development of manufacturing technology for metal AM components, Additive Industries states that it will also offer support in application development and for design optimisation according to the requirements of the process.

In the meantime, the company continues to focus on AddLab where existing technologies are applied to the design and manufacture of AM components. This enables the company to fully understand what kind of applications are the most promising for metal AM technology and what kind of designs really make a difference to existing manufacturing technologies. Kersten is confident that the company will play an important part in the future of industrialising metal Additive Manufacturing.

Contact

Additive Industries b.v.
ir. Daan A.J. Kersten, CEO
Leidingstraat 27
NL-5617 AJ Eindhoven
The Netherlands
Tel: +31 40 21 80 660
Email: team@additiveindustries.com
www.additiveindustries.com

Author

Dr Georg Schlieper
Gammatec Engineering GmbH
Mermbacher Strasse 28
D-42477 Radevormwald
Germany
Tel: +49 2191 6889274
Email: info@gammatec.com

Advances in aerospace applications: MTU produces Airbus A320neo borescope bosses with Additive Manufacturing

Additive Manufacturing technology is rapidly making gains in the aerospace sector, particularly in the field of aero engine construction. Munich-based MTU Aero Engines is the first company to use this technology for the serial production of borescope bosses used in the new PurePower® PW1100G-JM engine from Pratt & Whitney and fitted to the Airbus A320neo aircraft. In this report *Metal AM* magazine reviews the development of the technology at MTU and the close collaboration with EOS that helped to ensure the success of the project.

When it comes to new technologies, the aerospace sector is one of the most innovative yet cautious industries in the world. New materials and technologies that are suitable for series production have an important role to play, with the primary drivers being cost, weight and function. Because of this, both aerospace manufacturers and suppliers have been testing the performance capabilities of metal Additive Manufacturing (AM) processes for many years.

Whilst Additive Manufacturing was originally used in the manufacture of prototypes, thanks to its many advantages the technology has since established itself as a staple in series production. The advantages associated with metal AM include increased design freedom as well the ability to use a wide range of raw materials that are extremely difficult to process using conventional technologies.

Fig. 1 The Airbus A320neo aircraft features the Pratt & Whitney PurePower PW1100G-JM engine (Courtesy Airbus)

With its A320neo (new engine option), a new short and medium haul aircraft, Airbus' key objective was to offer global airlines a significant reduction in fuel consumption. Achieving this goal required, above all, much more efficient engines. Airbus selected the award-winning Pratt & Whitney geared turbofan™ engine as the launch engine on the A320neo aircraft family (Fig. 1). The ultra-efficient PurePower PW1100G-JM engine, described by Pratt & Whitney as the greenest engine option on the A320neo, delivers double-digit improvements in fuel efficiency, reduces noise by 50% and cuts CO_2 and NO_x emissions (Fig. 2).

The low-pressure turbine for the PW1100G-JM geared turbofan (GTF) engine is the first turbine ever to come equipped with borescope bosses produced by AM (Fig. 3).

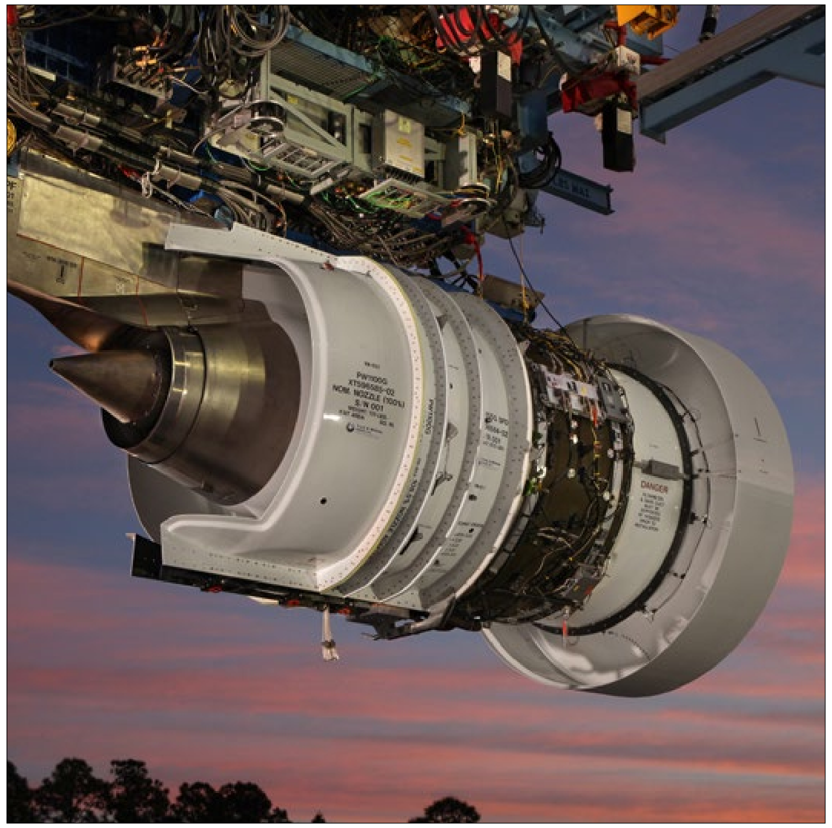


Fig. 2 The first PW1100G-JM engine for the Airbus A320neo during testing on the sea-level outdoor test stand at Pratt & Whitney's West Palm Beach, Florida, facility (Courtesy Pratt & Whitney)

The application of metal AM at MTU

MTU Aero Engines, based in Munich, is Germany's leading aero engine manufacturer. The company, which has around 9000 employees worldwide and annual sales of €3.9 billion, is a primary supplier to Pratt & Whitney and played a key role in Airbus reaching its objectives.

MTU began looking into options to use metal Additive Manufacturing around ten years ago, describing the benefits as "too compelling to ignore." The company has taken a strategic step-by-step approach towards the technology's use. "About ten years ago, we began with the manufacture of tools and development components," stated Dr Karl-Heinz Dusel, Director of Rapid Technologies at MTU. "In order to optimise capacity utilisation and implement our phased plan, we went in search of further areas where we could apply the technology" [1]. The principal challenge consisted of cost and safety considerations on the one hand, and the pursuit of strategic innovation on the other.

Metal Additive Manufacturing processes allow complex components that are extremely difficult, if not impossible, to manufacture using conventional methods to be produced with minimal amounts of material. The technology opens the door to entirely new designs, appreciably cuts development, production and lead times and brings down production costs. "Additive Manufacturing is particularly suitable for producing parts in materials that are difficult to machine, as, for example, nickel alloys," stated Dusel.

MTU started off making tools and development parts with a simple geometry. In a second phase, parts were produced by metal Additive Manufacturing as substitutes for existing ones, such as spray nozzles and grinding wheels for use on the shop floor. At around the same time, work on the engine borescope bosses began to pick up speed [2].

"At the beginning of the second phase we started to produce raw components, which replaced existing parts. The borescope bosses for the low-pressure turbines of the A320neo-GTFs fell into this category," explained Dusel.

MTU currently uses seven laser sintering machines from EOS, also based in Munich (Fig. 4). "EOS technology is characterised by its virtually unlimited design freedom and the significantly shortened development, production and delivery times. In addition, development and production costs are drastically reduced. Components of lighter weight and greater complexity can be made a reality and production requires less material and minimal tools," stated Dusel.

The Additive Manufacturing of borescope bosses

Borescope bosses are small add-on components that allow technicians to check the condition of turbine blades inside the engine using endoscopes. The parts are riveted to the turbine housing to create an opening for the endoscope, which in the aerospace sector is termed a borescope. In the past, the borescope bosses were cast, or milled from a solid, but the low-pressure turbines for the A320neo's geared turbofan are the first turbines to be serially equipped with borescope bosses produced by Additive Manufacturing.

The key characteristics of the nickel-based alloy used in this application are heat resistance and durability. This high-quality material achieves the highest results demanded by the component, but it is very difficult to machine. Fortunately a problem such as this is easily overcome with Additive Manufacturing. MTU is also a producer of raw materials and the company was able to develop a new process chain, which has been approved and integrated into the manufacturing system.

Series production of the borescope bosses has now begun. Sixteen parts per job are required, totalling up to

2,000 parts per year. The savings in percentage terms, compared to previously established processes, are expected to be in double figures and quality is already at a very high level. The borescope bosses are manufactured using the EOS laser sintering machines installed at MTU. EOS is working with MTU to further optimise the finishing for the component, especially the smooth surfaces, with the aim of achieving perfection in the structural mechanics.

EOS stated that cost advantages of its technology were a decisive factor both in the successful serial production of the component and in the development stages.

MTU & EOS: A strategic partnership for quality control in Metal AM

The entire manufacturing process for the borescope bosses is underpinned by a quality control system specifically developed by MTU. Online monitoring captures each individual production step and layer. In addition, new quality assurance procedures have been introduced such as optical tomography. The German Federal Aviation Authority even certified the EOS machines.

As previously reported in *Metal AM* magazine (Vol. 1 No. 1, p. 9), EOS and MTU have closely cooperated on improving quality assurance for metal engine components produced using Additive Manufacturing. The two companies signed a framework agreement earlier in the year for the joint strategic development of their technology [3].

The first result of these joint endeavours is the Optical Tomography (OT) developed by MTU, a powerful complement to the modular EOS monitoring portfolio. In addition to several sensors that monitor the general system status, the camera-based OT technology controls the exposure process and melting characteristics of the material at all times to ensure the optimum coating and exposure quality.

Fig. 3 Additive Manufactured borescope bosses from MTU Aero Engines for the high speed, low pressure turbine of the Geared Turbo Fan engine PurePower® PW1100G-JM, which will power the A320neo (Courtesy MTU Aero Engines)

Fig. 4 Manufacturing at MTU: One of the seven EOS systems that produces series components for engine construction (Courtesy MTU Aero Engines)

Dr Adrian Keppler, Head of Sales and Marketing (CMO) at EOS, stated at the time of the announcement, "MTU and EOS have been working intensively for several years and this collaboration is now about to develop into an even closer, partner-based technological cooperation, centred on the above quality assurance tool. The OT solution enables us to perform an even more holistic quality control of the metal Additive Manufacturing process – layer by layer and part by part. A very large proportion of the quality control process that previously took place downstream can now be performed during the manufacturing process, with a considerable saving

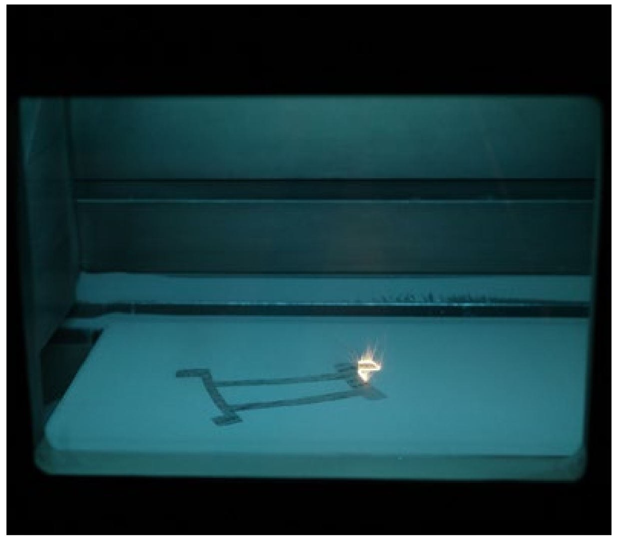


Fig. 5 MTU produces components by Selective Laser Melting (SLM) (Courtesy MTU Aero Engines)

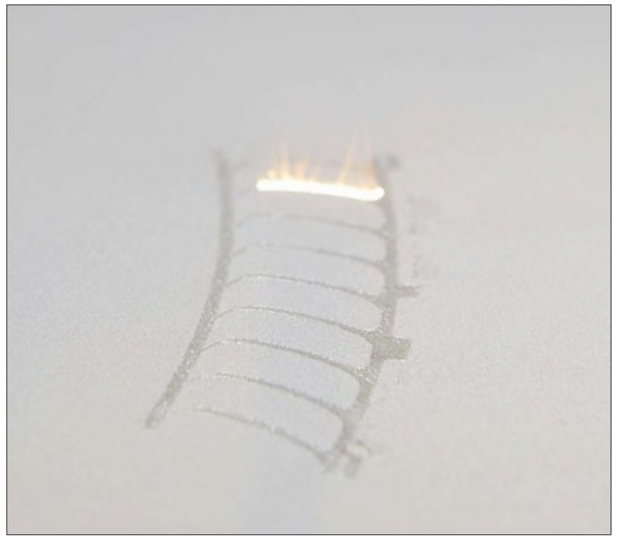


Fig. 6 Additive Manufacturing of a vane cluster at MTU in Munich (Courtesy MTU Aero Engines)

in quality assurance costs. This also allows us to satisfy a central customer requirement in the area of serial production."

"By employing the quality assurance system developed by us for use in serial production, EOS is backing an industrially proven solution for its Direct Metal Laser Sintering (DMLS) process. It has proven itself in practical testing and we now intend to make it available to other customers too," stated Thomas Dautl, Head of Production Technologies at MTU.

MTU has been amassing its experience over several years by deploying the system on EOS machines. Not only does this ensure comprehensive transparency, but it also provides a quality analysis method for the entire manufacturing process and supports its full documentation. Dautl stated that, in this way, EOS and MTU are jointly furthering the qualified use of Additive Manufacturing in aerospace engineering while also reducing costs. "The monitoring solution represents a value enhancement not only for the EOS technology, but also for each and every customer."

Quality assurance is especially important in serial production because it is vital for ensuring repeatable high component quality and for continually reducing the quality control costs of components made using the technology, which ultimately serves to reduce unit costs. The system settings and process parameters are constantly monitored in the ongoing manufacturing process to ensure that system and manufacturing process conditions are ideal for maximum component quality.

Looking to the future

MTU sees significant opportunities for the manufacture of further series components for aero engine manufacture, including bearing housings and turbine blades, both of which need to meet the highest demands in terms of safety and reliability. MTU's aim, it is stated, is that a significant proportion of components should be manufactured using industrial 3D printing within fifteen years.

Commenting on the development of the metal AM borescope bosses when the application was first announced in May 2014, Dr Rainer Martens, MTU Aero Engines' Chief Operating Officer, stated, "With this move, MTU has reaffirmed its leadership in delivering innovation; for we are using one of the most advanced technologies there is to produce parts for one of the most advanced engines in the world, the geared turbofan."

What is clear is that the aerospace sector shows little sign of slowing down, with growth supported in particular by the Asian and Middle East markets. During the 2015 Paris Air Show alone, Airbus reports that it won $57 billion worth of business for a total of 421 aircraft. The deals comprise firm orders for 124 aircraft worth $16.3 billion and commitments for 297 aircraft worth $40.7 billion. The A320neo aircraft accounted for 323 of the above, taking total orders and commitments for the A320neo family beyond 4,000 since launch in December 2010.

References

[1] "Aerospace: MTU manufactures Engine Components for the Airbus A320neo with EOS Technology," Case Study as published on www.eos.info

[2] "Trailblazing technology: MTU Aero Engines produces parts by additive manufacturing," Press Release, March 13, 2014, www.mtu.de

[3] "EOS and MTU: strategic partnership for quality control in metal-based additive manufacturing," Press Release, January 20, 2015, www.mtu.de

AMPM2015 conference report: Innovative materials, powder characterisation and metallographic testing

The AMPM conference series, sponsored by the Metal Powder Industries Federation (MPIF), was initiated in 2014 and ran in parallel with the PM2014 World Congress in Orlando, Florida. The second conference in the series was held in San Diego, California, from May 17-20, 2015. In this exclusive report for *Metal AM* magazine Dr David Whittaker reviews a number of key papers from the conference, ranging from a presentation on the activities of America Makes to developments in the production and characterisation of metal powders for AM.

Metal AM at America Makes

In his opening presentation at AMPM Howard A Kuhn, The ExOne Company, USA, and Technical Adviser to America Makes, provided a summary of the Powder Metallurgy for Additive Manufacturing projects that have been funded through the America Makes programme [1].

America Makes was established in Youngstown, Ohio, by the Obama administration as the USA's first manufacturing innovation institute. It is a multi-agency collaboration and public-private partnership with a mission to pursue the widespread adoption of Additive Manufacturing. It was launched in August 2012 by the Air Force Research Laboratory and is led by the National Center for Defense Manufacturing and Machining (NCDMM), a non-profit company. The aim was to work on developments in the Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs) 4 to 7. Federal investment of $50 million was pledged to fund applied research projects and to support the development and management of the institute over a five-year period. Ultimately, it was envisaged that America Makes would be self-sustaining by August 2017.

America Makes has established an Innovation Factory containing 'entrusted' equipment covering the full gamut of AM technologies, including Selective Laser Melting, Binder Jetting, Selective Laser

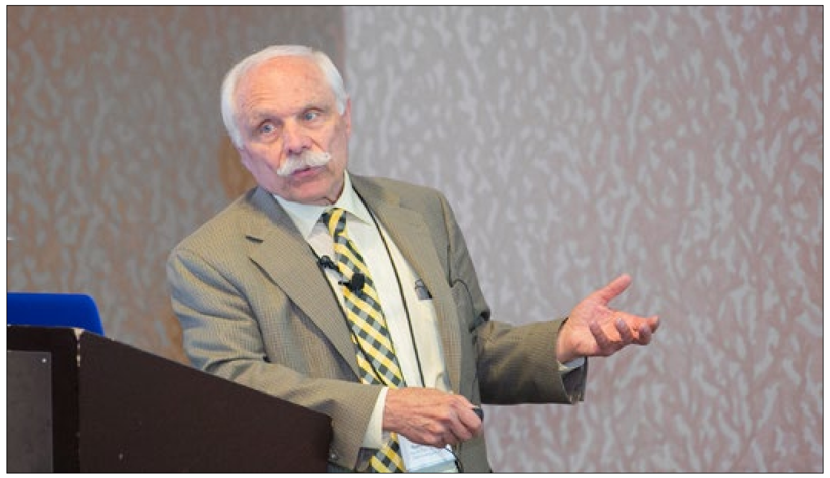


Fig. 1 Howard A Kuhn, The ExOne Company, USA, and Technical Adviser to America Makes, provided a summary of projects that have been funded through the America Makes programme (Photo courtesy MPIF)

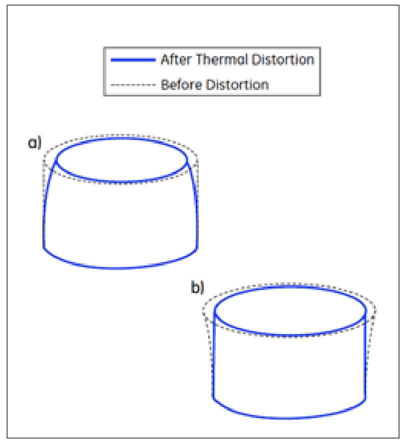


Fig. 2 Modelling of distortions in metal powder bed AM [1]

Sintering, material extrusion and direct metal deposition as well as specialist support activities such as plunge/dry EDM and metrology by laser scanning.

At the outset, the challenges to the full realisation of AM were identified and these have defined the technical agenda for project calls:

- Design: the need to think differently, to develop novel material combinations and geometries and to provide the tools to enable AM designs
- Repeatability, process qualification and certification: real push button repeatability incorporating acceptance and control
- Material characterisation: complete material properties, traceability to input materials
- Manufacturability and throughput: increased speed and size of AM equipment
- Production and life cycle cost: validated cost models.

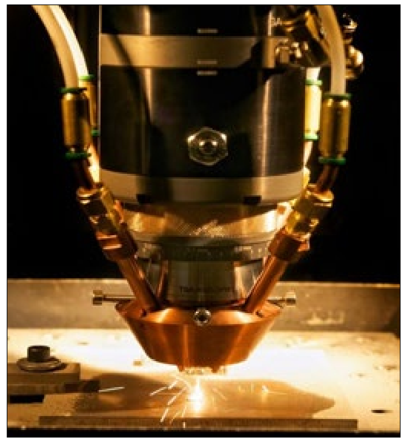


Fig. 4 LENS Engine system in preparation for America Makes Open House [1]

To-date there have been three separate calls for project proposals. In the first call, which had an April 2013 start, six projects were awarded. These projects addressed both metals and polymers and covered the topics of materials characterisation, process capability and characterisation and quality control. The six projects involved a total of $9.5 million technical investment ($4.5 million Government funds + $5 million cost share) and each project included technology transition, advanced manufacturing enterprise development and workforce education. Thirty five participants were involved, including eight universities.

The second call awarded fifteen projects in January 2014. These involved the awarding $9 million of America Makes funding with $10.3 million matching cost share from awarded project teams.

The third call had a submission deadline of May 1, 2015 and is therefore still at the proposal evaluation stage. $8 million of government funding is earmarked for this call, with a stipulated maximum of $1 million support for each awarded project. The projects will run for a maximum period of 18 months and a 1:1 cost share is required. The stipulated technology areas will cover:

- Design: product and process design aides/apps
- Materials: Additive Manufacturing technical data packages, material property characterisation, next-generation materials
- Process: multi-material delivery and deposition systems, next-generation machines, process temperature gradient control
- Value Chain: advanced sensing and detection methods, intelligent machine control methods
- AM Genome: benchmark validation use cases, model-assisted property prediction, physics-based modelling and simulation.

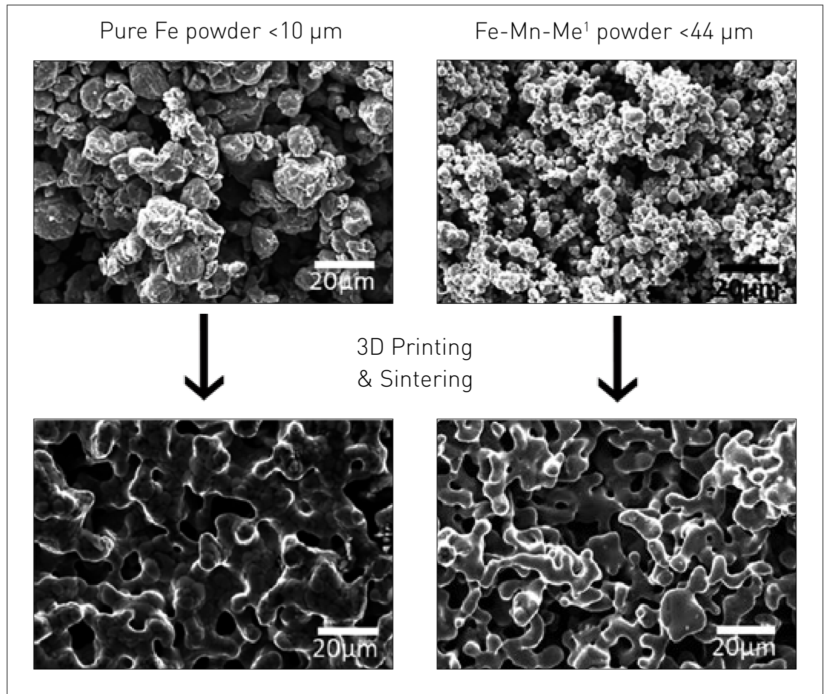


Fig. 3 Porous scaffolds in iron-based alloys [1]

Highlights from the first two project calls

A project on rapid qualification methods for powder bed direct metal AM processes has generated a process mapping methodology that can use knowledge on the influence of processing conditions on microstructure and consequent properties to predict product performance/life. Alternatively, the mapping can be used 'in reverse' to optimise process parameters for a desired outcome.

A project on the development of distortion prediction and compensation methods for metal powder bed AM has identified that intensive localised heating and extremely fast cooling in powder-bed processes lead to substantial residual stresses, distortion and cracking and that support structures restrain parts from moving, leading to lengthy post-processing and limits on complex geometries. Extensive modelling has been carried out to mitigate and predict distortion (Fig. 2).

A project on the Additive Manufacturing of biomedical devices from bioresorbable metallic alloys has demonstrated the building of complex implants from CT scan data and the 3D-printing of porous scaffolds from iron-based alloys (Fig. 3) and magnesium-based alloys.

A low cost Optomec LENS® Print Engine™ has been developed that will enable metal laser deposition equipment to be installed as an accessory on a machine tool base (Fig. 4). Finally, the efficient design of Additive Manufactured cellular structures (Fig. 5) has been explored, using a methodology that comprises homogenisation, topology optimisation and topology reconstruction.

The presentation concluded with a description of America Makes' current expansion concept. This will involve the establishment of a network of regional satellite centres with links to the central institute. These satellite centres will provide a regional footprint and will be charged with pursuing technology development, technology transition, the establishment of "advanced manufacturing enterprises" and workforce education and training.

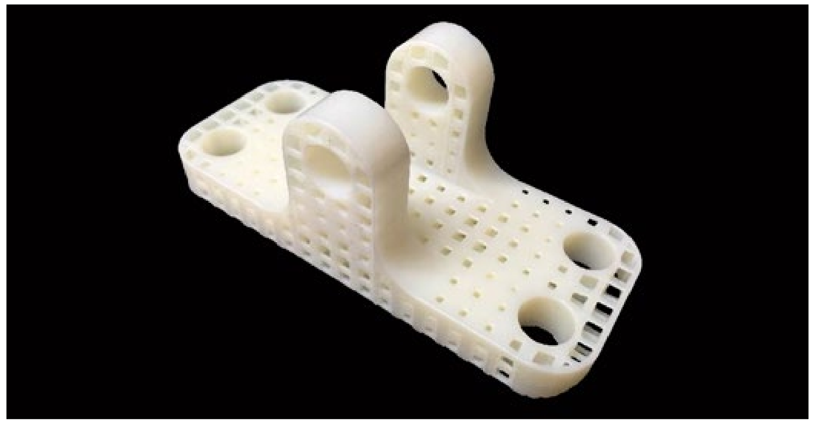


Fig. 5 Designed AM cellular structure [1]

Novel materials for metal Additive Manufacturing

Two papers for review from AMPM2015 addressed the topic of unique materials for Additive Manufacturing.

Magnesium alloys by AM

Rajiv Tandon, Magnesium Elektron Powders, USA, and Todd Palmer, Pennsylvania State University, USA, described an investigation into process development and mechanical properties related to the Additive Manufacturing of a rare earth containing magnesium alloy, Elektron®43, using directed laser energy deposition [2].

Magnesium based alloys are used in various applications such as the aerospace, automotive and 3C (computer, communication and consumer electronics) industries. These applications are driven largely by a necessity for weight savings due to the low density and high specific stiffness of magnesium. More recently, magnesium alloys have also been investigated as promising materials for biomedical implants due to their biocompatibility, biodegradability and an elastic modulus that is closer to human bone than those of conventional implantable materials such as cobalt and titanium based alloys.

AM offers the potential for topology optimisation and component integration, both of which are essential for achieving weight reduction beyond what is possible by other traditional manufacturing routes. AM can also be used to custom design magnesium

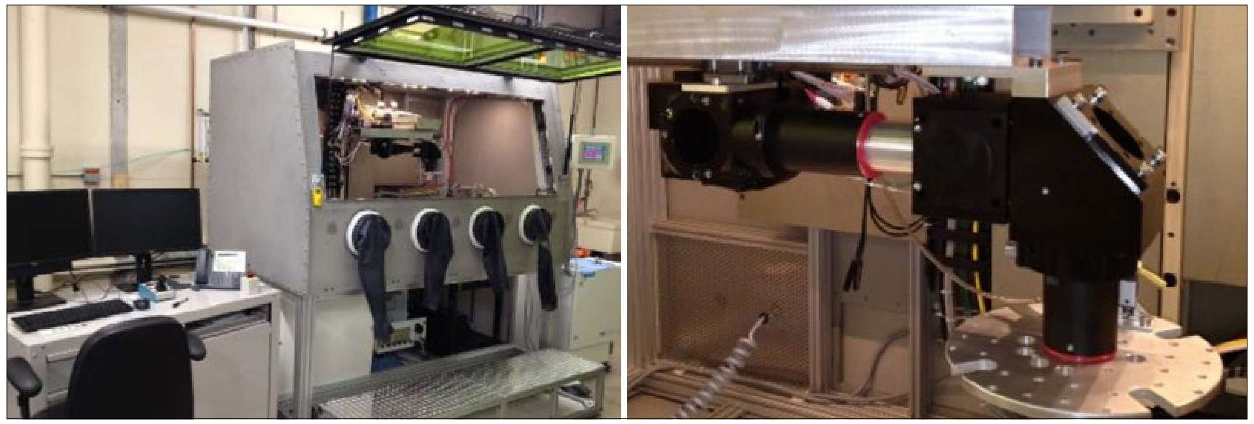


Fig. 6 The High Productivity High Deposition System used in the investigation [2]

Laser Power (W)	Travel Speed (in/min)	Powder Flow Rate (g/min)	Oxygen Level (ppm)	Center Nozzle Gas Flow (CFH)	Layer Height Step Size (in)
1750	20	5	100	50	0.04
1750	20	5	80	50	0.04
1750	20	5	90-110	100	0.04
2250	20	5	90-110	100	0.04
2250	25	5	90-110	100	0.025
2250	30	5	90-110	100	0.015

Table 1 Processing Parameters Investigated in Directed Energy Deposition [2]

Laser Power (W)	Travel Speed (in/min)	Micro-Hardness (VHN)	Grain Size (µm)	Pore Volume (%)
1750	20	77	9.57 ± 0.69	1.26 ± 0.86
1750	20	76	9.48 ± 0.69	0.99 ± 0.60
1750	20	77	8.99 ± 0.47	0.93 ± 0.36
2250	20	79	8.40 ± 0.69	0.60 ± 0.40
2250	25	81	8.00 ± 0.57	0.70 ± 0.40
2250	30	77	8.03 ± 0.25	0.89 ± 0.39

Table 2 Microhardness, grains size and pore volume of the window study [2]

Condition	Yield (MPa)	UTS (MPa)	Elongation (%)
As-Deposited	143 ± 3.5	195 ± 9.7	3.8 ± 1.2
As-Deposited+T5	140 ± 1.4	189 ± 2.4	3.4 ± 0.3
As-Deposited+T6	167 ± 2.7	231 ± 7.2	4.3 ± 1.0
As-Deposited+T6 (horizontal)	166 ± 2.1	234 ± 1.7	6.2 ± 0.7
HIP	142 ± 2.6	213 ± 4.2	6.8 ± 0.5
HIP+T5	134 ± 2.1	204 ± 6.1	6.2 ± 1.0
HIP+T6	170 ± 6.1	246 ± 7.8	6.3 ± 1.7
HIP+T6 (horizontal)	167 ± 2.9	255 ± 6.7	7.9 ± 1.6
As-Cast WE43B+T6 (typical)	180	250	6

Table 3 Mechanical properties of the directed energy deposited sample under various condition [2]

based implants with defined cellular structures such as scaffolds, which could allow full vascularisation of implants.

There are relatively few published studies on the AM of magnesium and the most commonly investigated AM process for magnesium is the laser powder bed process. There have been no published studies investigating the use of Directed Energy Deposition (DED), also known as blown powder AM or laser cladding, using magnesium alloy powders.

The rare earth containing alloy Elektron®43, with a nominal composition of Mg-4%Y-2%Nd-0.5%Zr, is widely used in applications where a combination of high strength, high temperature creep resistance and good general corrosion resistance is desired. In addition, variants of this alloy have been used for biomedical research as resorbable implants.

Therefore, the aim of the reported investigation was to study the DED process using the Elektron®MAP+43 powder and to develop a basic understanding of its processing behaviour.

Gas atomised spherical Elektron®MAP+43 powder (100/325 mesh) with a mean particle size of 90 µm, a powder specially developed for AM processing, was used for this investigation. The Directed Energy Deposition (DED) experiments were performed in a custom-fabricated deposition system, shown in Fig. 6. This system has a customisable build volume and can handle rectilinear builds, up to 1000 mm long, 300 mm wide and 450 mm high, and utilises an open architecture for easy synchronisation and control of all system variables.

During processing, the chamber was purged with ultra-high purity argon to attempt to maintain oxygen levels between 60 and 110 ppm in the chamber. The laser power was delivered from an ytterbium fibre laser and powder was delivered using a custom designed four nozzle powder delivery system. The substrate was placed at a location approximately 10 mm from the nozzles, which corresponds to the focus point for the powder flow. At this location, the laser beam is in a defocussed position and has a measured beam diameter of approximately 4 mm.

A series of process development builds was fabricated to examine the role that changes in laser power, travel speed and powder flow rate have on the properties of the Mg deposits. A summary of the processing parameters used in the development is given in Table 1. The individual builds were characterised by extracting a cross section from the linear build and analysing the changes in micro-hardness levels, grain size and pore volume.

It was found that high laser power, in the range from 1750 to 2250 W, was necessary to achieve good quality deposits with densities exceeding 99%. The results of the process development window study are shown in Table 2. These results showed that some grain coarsening occurred as a result of re-melting and solidification of the powder (for reference, the grain size of the starting powder was measured to be approximately 2 µm). The pore volume data showed that a high deposited relative density of > 99% of theoretical could be achieved. The micro-hardness of the deposited layer ranged from 76 Hv to 81 Hv, which was slightly lower than the micro-hardness of the starting powder, measured to be 96 Hv.

| contents page | news | events | advertisers' index | contact |
AMPM2015 Report

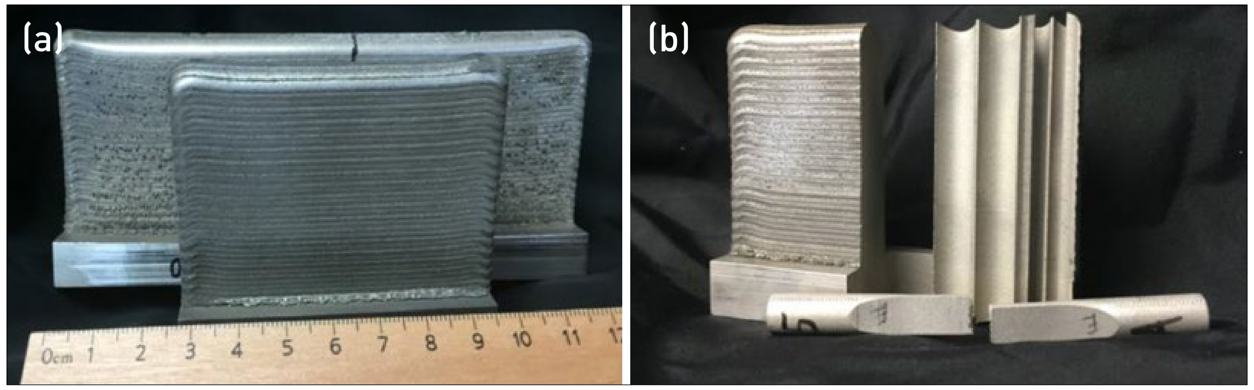


Fig. 7 Laser directed energy deposited samples (a) and machined to extract tensile specimen in a vertical orientation (b) [2]

Based on these results, a laser power of 2250 W, a travel speed of 63.5 cm/min, with an overlap of 2.032 mm and a z-height offset of 1.27 mm was selected for further evaluation. These parameters were used to fabricate wall structures on an Elektron®43 substrate of 15.2 cm x 15.2 cm x 1.27 cm as shown in Fig. 7. A series of rectangular build geometries 7.6 cm (L) x 5.08 cm (H) x 1.27 cm (W) and 15.2 cm (L) x 5.08 cm (H) x 1.27 cm (W) were fabricated, from which tensile and metallographic samples were extracted and tested from selected orientations.

After the DED process, some of the samples were Hot Isostatically Pressed (HIPed) using a cycle which was specifically designed to minimise grain growth while achieving 100% densification. Two different types of heat treatment were also investigated. The first involved an artificial aging or T-5 at 250°C for 16 hours while the second involved a T-6 (a solutionising step at 525°C for 2 hours followed by aging at 250°C for 16 hours). Both the as-deposited and HIP samples were subjected to the T-5 and T-6 treatments.

Metallographic examination of the deposited material showed that pores were present as clusters rather than being randomly distributed and a closer inspection showed that these pore clusters were aligned with the overlapping regions of the deposit, where re-melting and re-solidification of the previously deposited layer had occurred. The microstructure also showed the presence of features, described as 'skin clusters'. These were identified using scanning electron microscopy and are shown in Fig. 8(a). These clusters were randomly present throughout the microstructure including in the HIPed and heat treated samples. However, the pores were eliminated by Hot Isostatic Pressing and the fully dense microstructure of a HIPed part is shown in Fig. 8(b). The 'skin clusters' were identified as being features that were rich in Y and Zr. On the other hand, Nd appeared to be well distributed in the matrix and no Nd segregation was observed. There were also no oxide rich phases in these zones, despite the presence of a thin oxide passive film on the starting powder surface. At this point, the reasons for the segregation of Y and Zr into these 'skin clusters' are still under investigation.

The mechanical properties of the as-deposited, HIPed and heat treated samples are listed in Table 3.

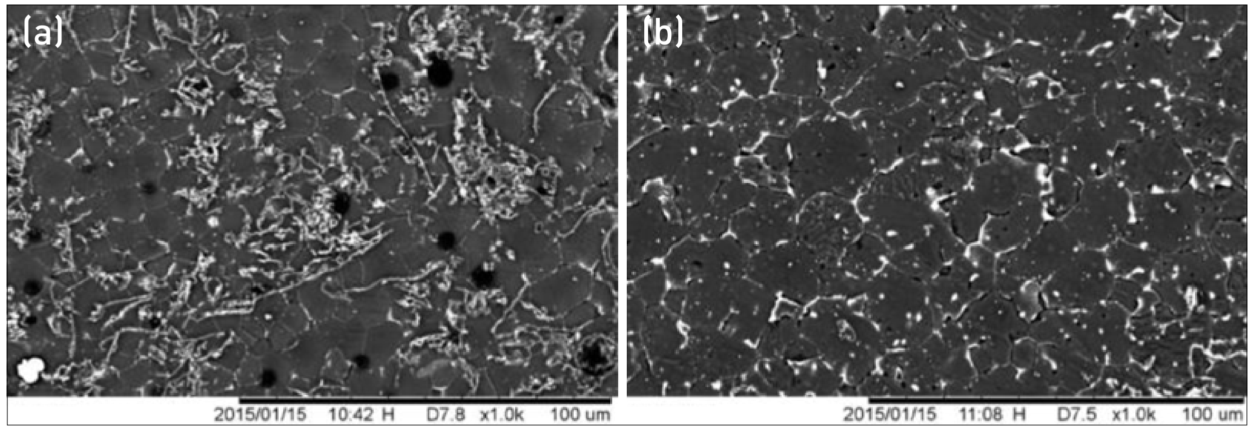


Fig. 8 SEM micrographs showing (a) "skin clusters" in as-deposited sample and (b) fully dense microstructure of a HIPed sample [2]

These results show that the artificial age (T-5 cycle) did not result in any changes to the as-deposited properties, implying that the cooling rate in the deposition process was slower than the critical cooling rate that is required to produce this effect. Similarly, a T-5 treatment after HIP did not result in any change. By comparison, the T-6 treatment restored the aging response and improved yield strength, UTS and elongation. This resulted from the dissolution of the Y and Nd-rich precipitates into solid solution and re-precipitation within the grains during the aging cycle. However, some regions of the T-6 microstructure showed the evidence of isolated grain coarsening.

The mechanical test results also showed that the samples extracted and tested from a horizontal orientation resulted in higher elongation than those machined and tested from a vertical orientation, although the yield strength and UTS remained essentially unchanged. The overall mechanical properties obtained compared very favourably with those of typical cast WE43B alloy used in aerospace applications.

The results of this study have shown that a DED setup, which is similar to commercially available systems, can be used to deposit magnesium alloy powders. The basic steps and methodology that were taken into consideration can be used as a platform to develop more elaborate protocols for scaling up. Further refinement of the processing parameters may be necessary to mitigate the porosity clusters that were observed in the overlapping regions of the deposit. It is believed that the elimination or reduction of these pores and skins can lead to further improvement of the mechanical properties.

Development of a maraging steel powder for AM

Simon Hoeges, GKN Sinter Metals GmbH, Germany, and Christopher Schade and Robert Causton, Hoeganaes Corporation, USA, described the development of a maraging steel powder for AM [3].

To extend the possible range of AM applications to small series production for instance, the cost of the technology needs to be reduced by increasing productivity. A further limitation is the availability and cost of materials for AM. The focus of research to-date has been on the use of gas atomised high alloy powders, which are generally preferred because of the spherical nature of the powder. However, water atomisation is the most common and economical production technique for metal powders and, if a low water to metal ratio is used in water atomisation along with a high pressure, a spherical powder with a particle size distribution optimised for Additive Manufacturing can be produced. To ensure uniform and consistent part build, powders must also have consistent flow and high packing density.

One alloy that has seen considerable interest is a maraging steel (Table 4). This steel, which uses nickel as the primary strengthening element rather than carbon, is known for its superior strength and toughness. Despite its high strength, the material can be easily machined or formed and, after these treatments, it can undergo an aging (heat treatment) step that forms intermetallic precipitates involving cobalt, molybdenum and titanium, which aid in increasing the tensile strength. Due to the high nickel content, the alloy has high hardenability and has wear resistance that is suitable for many tooling applications. The material can be heat treated in air at low temperatures and, because of the low thermal coefficient of expansion, has excellent dimensional stability. The low carbon content also helps when used in SLM, since the material is not susceptible to thermal stress cracks during cooling.

1.2709	C	Si	Mn	P	Cr	Mo	Ni	Ti	Co
Specification	Max. 0.03%	Max. 0.10%	Max. 0.15%	Max. 0.01%	Max. 0.025%	4.50 to 5.20%	17 to 19%	0.80 to 1.20%	8.50 to 10.0%

Table 4 Chemistry specification for Maraging Steel (DIN 1.2709) [3]

Type	C (%)	Ni (%)	Co (%)	Mo (%)	Nb (%)	Ti (%)	Si (%)	Cr (%)
Water Atomised	0.010	17.74	9.66	5.00	0.35	---	0.02	0.04
Gas Atomised	0.010	16.69	10.21	4.90	---	0.96	0.02	0.12

Table 5 Chemistry of water atomised versus gas atomised 1.2709 tool steel [3]

Samples	C	S	O	N	AD	FLOW	Sieve Size (mesh)			
							+270	+325	+400	-400
Water Atomised	0.007	0.002	0.04	0.003	3.77	NF	0.0	0.5	10.6	88.9
Gas Atomised	0.010	.002	0.36	0.001	3.84	NF	0.0	0.1	2.4	97.5

Table 6 Chemical and physical properties of maraging steel, gas versus water atomised [3]

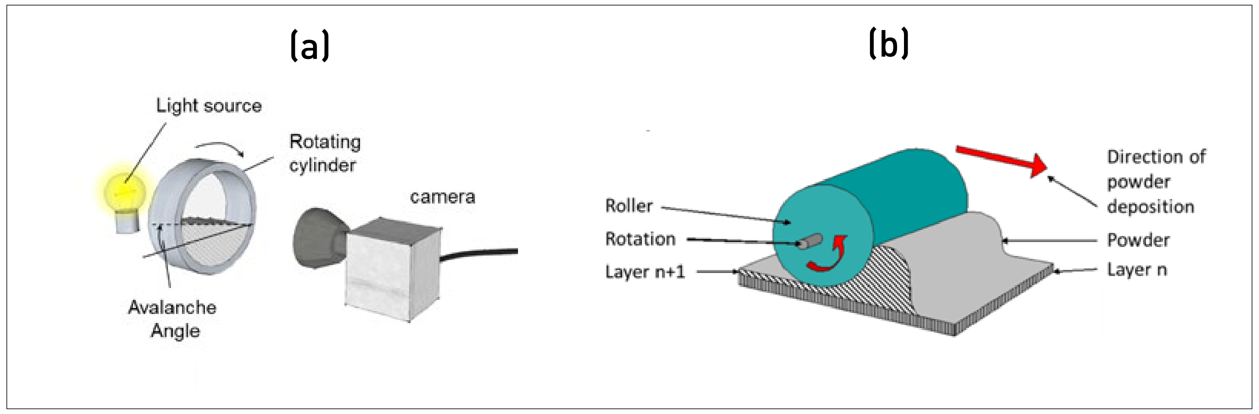


Fig. 9 Schematic of the (a) Revolution Powder Analyser © Mercury Scientific Inc (b) powder deposition process during Additive Manufacturing [3]

The chemistry for the maraging steel, as shown in Table 4, was developed for wrought alloys. A troublesome feature of this chemistry is the use of titanium. Titanium has a high affinity for oxygen and forms stable solid oxides at the melt temperature. A feature of the atomisation process is that the metal must be poured through a nozzle with a fairly small orifice (4-8 mm). The oxides tend to adhere to the pouring nozzle and stop the metal flow. This pour flow can have an impact on the shape and particle size of the powder. This is not such an issue in conventional casting of this alloy as, normally, large ingots or castings are made that have larger flow paths. In order to optimise the flowability of this alloy, an experimental alloy has been made to replace the titanium in the alloy with niobium. Niobium has a lower affinity for oxygen and, in many PM alloys such as 17-4PH and 434Cb, is a standard replacement for titanium. Because of this lower affinity for oxygen, the oxides to do not form on the pour tube and atomisation occurs without slow down or interruption. The lower affinity for oxygen may also lead to lower oxide inclusions during the SLM process.

For this study, a 1.2709 maraging steel was water atomised with pressures around 45 MPa and with niobium replacing titanium. The material was then sieved to closely match the particle size distribution of gas atomised powder. This material was then compared to a commercially available gas atomised 1.2709 with titanium. Additive Manufacturing was carried out using the Selective Laser Melting process in a Renishaw AM 250 machine. Tensile and impact specimens were machined from both as-built and aged specimens.

The chemical composition of the water atomised powder versus the gas atomised powder is shown in Table 5 and the physical properties of the two powder types are shown in Table 6. The water atomised powder had a slightly finer particle size and higher apparent density (Table 6) than the gas atomised powder, but a higher oxygen content. Development work is ongoing to lower the oxygen content.

As shown in Table 6, the flow of the particles could not be measured using conventional Hall Flow testing and a different methodology needed to be used for the characterisation of the particle flow. Therefore, the Powder Revolution Analyser (Fig. 9) has been used, with system settings Rotation Rate = 0.3 U/min, Numbers of Avalanche = 150, Drum size=50.

The avalanche angle is a characteristic parameter when compared with the process of powder deposition (Fig. 9b). The average avalanche angle has been chosen as the preferred parameter to describe powder flow. Fig. 10 shows the results for three measured powders. Water atomised pure iron powder (WA-Fe-Powder) was measured, since the flowability of the powder has been proved to be sufficient to be processed in the AM machine without changes to the powder deposition device. This can be seen as a minimum requirement for processability in SLM. Gas atomised maraging steel has also been measured, as this is the powder most widely used for AM. The avalanche angle differs by

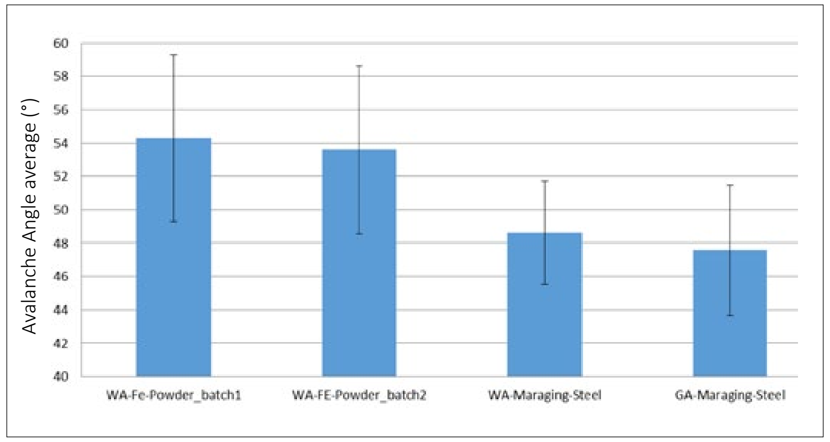


Fig. 10 Average avalanche angle of analysed powders [3]

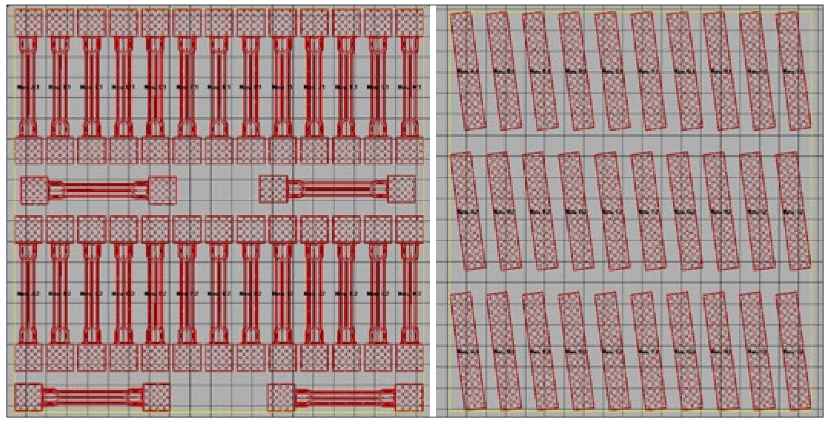


Fig. 11 Overview of build jobs for 30 specimens for tensile test (left) and Charpy V-notch test (right) [3]

only around 1° between the water atomised and gas atomised powders.

For the deposition of layers of the water atomised tool steel powder during powder-bed AM, a flexible silicone device is used. Powder layers generated with water atomised powder showed qualitatively similar characteristics to gas atomised powder during powder deposition. A vibration device was not necessary to achieve a reproducible dense powder layer without defects or disturbance. For the production of parts from a gas atomised maraging steel, a set of process parameters has been developed to achieve high density (99.5% rel. density). The process parameters of exposure time and hatch distance need to be varied to achieve the same results with water atomised powders. Parameters have been chosen for further production of test parts which result in highest density (8.07 g/cm³). The test geometries for tensile test and Charpy V-notch test have then been produced in one production batch, each producing thirty parts. The part distribution on the base plate is shown in Fig. 11.

The mechanical properties of the water and gas atomised powders are shown in Table 7. The test specimens referred to in this table have been aged at 490°C for six hours. The specimens built from water atomised powder had lower ultimate tensile strength and hardness than the specimens built from gas atomised powders. The ductility, as measured by the impact and elongation values, was also lower for the water atomised specimens. However, the niobium level in the 1.2709 water atomised powder was much lower than the titanium in the gas atomised powders (0.35 versus 0.96 wt%), which may have limited the number and size of the precipitates that form.

It has also been found that in water atomised powders utilising precipitation hardening, because of the finer grain size of the powders, the aging time to reach peak strength and hardness is generally lower than that utilised for coarser grained materials such as the gas atomised powder. Currently, aging time studies and TEM (Transmission Electron Microscopy) are being performed to gain a better understanding of the differences in mechanical properties. Additional water atomised powders with refined chemistry will be made after this analysis is complete.

The authors have concluded that although the parameters for SLM of water atomised powders had to be modified, it was shown that water atomised powders can be successfully utilised. The powder size, morphology and flowability showed little difference between water and gas atomised powders. The Revolution Powder Analyser for quantifying the flowability of AM powders has been successfully tested in order to build the foundation for possible standardisation. The behaviour of the powder during AM laser powder bed processing showed no difference between the gas and water atomised powders. Minor changes to the process parameters were necessary to achieve the same high density. In addition, the replacement of titanium with niobium seems to be a viable approach to make the powder more conducive to both atomising and the SLM process. Further refinement of the chemistry, processing parameters and heat treatment are underway to improve the mechanical properties of the water atomised (niobium containing) 1.2709 tool steel powder.

Powder characterisation, re-use and metallographic testing in metal AM

As metal AM moves away from its prototyping origins into serial production, the ability to re-use powder lots that have already previously been in the chamber during a component build run has emerged as an important issue in relation to the cost-effectiveness of the AM process. Two papers at the conference therefore focused on methods suitable for characterising previously used powder lots in order to ascertain their suitability for re-use.

Material	Impact Energy (J)	Apparent Hardness (HRC)	UTS (MPa)	0.20% Offset (MPa)	Total Elongation (%)	Density (g/cm³)
Water Atomised	5	43	1793	1784	1.4	8.04
Gas Atomised	7	52	2006	1793	3.1	8.00

Table 7 Mechanical properties of gas and water atomized 1.2709 in the aged condition (490°C for 6 hrs) [3]

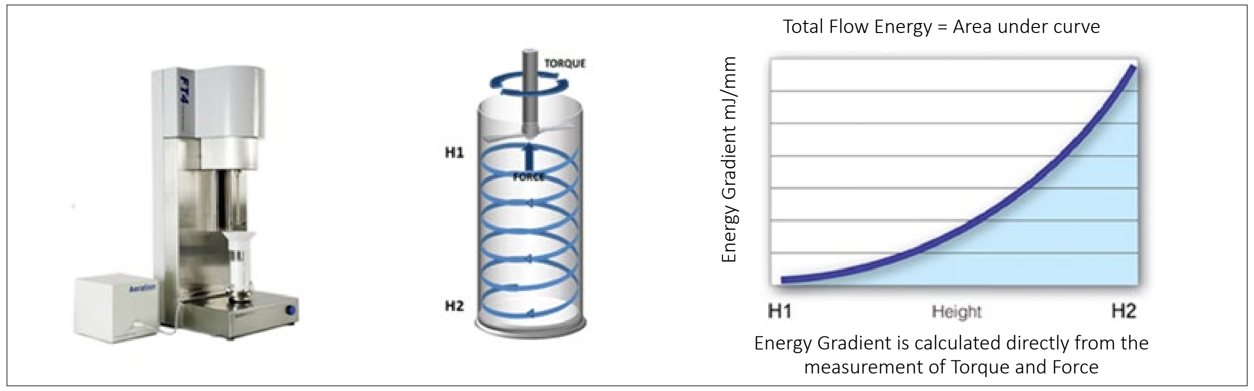


Fig. 12 Measurement of flow energy using the FT4 Powder Rheometer® [4]

The characterisation of powder lots for initial use and re-use in AM

John Yin and Mike Delancy, Freeman Technology Inc., USA, and Tim Freeman, Jamie Clayton, Katrina Brockbank and Doug Millington-Smith, Freeman Technology Ltd., UK, discussed the characterisation of powder lots, both for initial use and re-use in AM [4].

Freeman Technology has recognised that traditional powder characterisation techniques, such as Angle of Repose and Flow through a Funnel tests, are well-documented, but are often incapable of quantifying subtle differences between powders. Similarly, relying on a particle size alone is not always an appropriate way to assess the suitability of a powder. The company has consequently found that powder rheology allows the measurement of dynamic flow and shear properties as well as quantifying bulk properties such as density, compressibility and permeability. These data can be correlated with process experience to improve efficiency and enhance quality. This presented paper was based on two case studies, the first assessing changes in powder supplier and production methods and the second investigating the use of recycled material. The second of these case studies is reviewed here.

To fully understand why materials behave differently in AM processing, it is necessary to study their response to a range of stimuli that represent the stress and flow regimes experienced in the process. To do this, Freeman has developed its own equipment and technology, the

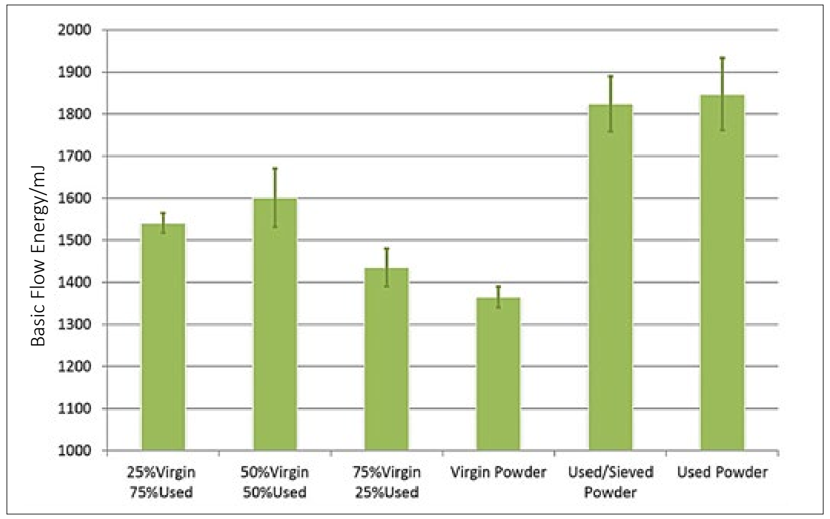


Fig. 13 Using powder rheology to optimise the use of recycled materials [4]

FT4 Powder Rheometer®, shown in Fig. 12 (left), to evaluate powder rheological properties. Fig. 12 centre and right identify how the rheometer results can be used to define total flow energy for the tested material.

In the case study related to the process-relevant differences between fresh and used AM feedstocks, it was recognised that re-use requires an understanding of the extent to which a powder has been altered by the AM process and whether it can be safely re-used without compromising the quality of the finished component.

Feedstocks containing differing proportions of virgin and used powder were evaluated using the powder rheometer to determine whether characteristics of the used powder differed from those of the virgin material. Strategies to return the used powder to a condition that would enable successful re-use were then considered. The results show that AM processing had significantly increased the basic flow energy of the used powder (Fig. 13) suggesting that it is likely to perform differently in the process.

It is recognised that powder scavenged from an AM machine may contain splatter from the melt pool. Experiments were therefore undertaken to determine whether sieving would return the flow energy of the used powder to its previous value. However, this ultimately proved to have little impact. Further experiments were then conducted to ascertain whether a blend of used and virgin powder could replicate the behaviour of the virgin material. It was found that a ratio of 75% virgin to 25% used powder produced a basic flow energy value most similar to that of the virgin powder and this was considered to be a viable re-use scenario.

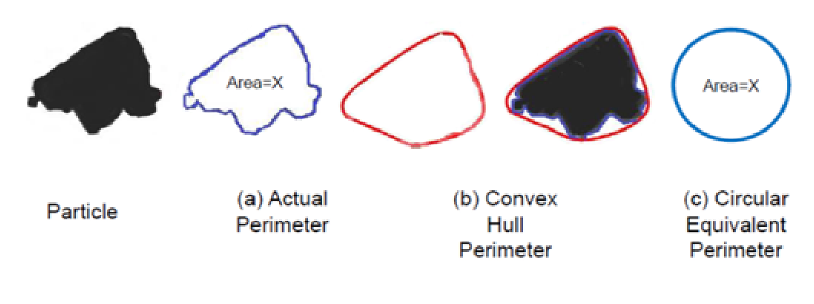


Fig. 14 Parameters relevant to particle shape characterisation [5]

Interestingly, the 50:50 blend had the highest basic flow energy of all the blended samples, demonstrating that flowability does not change linearly with respect to the quantity of virgin powder present. It is therefore not possible to predict performance from knowledge of the blend constituents alone.

Powder characterisation methods

John D Hunter, LPW Technology Inc., USA, defined the company's approach to addressing the powder quality and characterisation issues considered critical to professional Additive Manufacturing [5]. The use of virgin powder and the re-use of powder lots were both considered.

LPW Technology was established in 2007 in the UK by Dr Phil Carroll, who had identified a gap in the market for a specialist supplier of metal powders for the various AM process technologies. LPW strengthened its service offering in North America by opening LPW Technology Inc. in June 2014 and, in 2015, significant investment in capital equipment underscored the company's position as a leading supplier to the AM industry.

The LPW Technology group is involved in powder supply, consultancy and R&D. Its established AM metal powder supply position is strengthened by a focus on the development of new alloys and solutions and of systems to support the management and re-use of powder lots. The presentation proceeded to highlight a number of the company's key powder characterisation methods.

Inert Gas Fusion (using LECO –ONH 836 equipment) is used to quantify levels of interstitial elements (oxygen, nitrogen, hydrogen) in a number of important alloy systems. Powder flow rate is characterised using the Hall Flow method. Flow rate has an impact on the quality of the recoat layer and can cause porosity or build failure. In some cases, poor flowing powder will result in the dosing system's failure to operate.

Particle size distribution (circular equivalent diameter) is measured using a Malvern Mastersizer 3000 dry feed, laser size diffraction system. Particle size distribution directly influences powder flow and packing density and also has an influence on the absorptivity of the target layer to be melted. Particle shape is also characterised, using Malvern Morphologi G3 equipment, through a range of parameters including Aspect Ratio, Convexity and Circularity:

- Aspect Ratio = width/length
- Convexity = Convex Hull Perimeter (b)/Actual Perimeter (a) (Fig. 14)
- Circularity = Actual Perimeter (a)/Circular Equivalent Perimeter (c) (see Fig. 14) .

Particle shape also had a direct influence on powder flow and packing density and on the absorptivity of the target layer.

A number of case studies of powder degradation results were presented to demonstrate how powders change with repeated re-use and to determine how many times a material can be re-used before it is deemed to be out of specification. As the powder particle size distribution changes as it is re-used, occasional screening is done to bring it back into specification. Once this is done, it spreads evenly in the machines enabling additional parts to be manufactured.

After re-use, the chemical composition of powders, particularly in relation to interstitials, can change and this has a potential to create detrimental effects on final mechanical properties. For instance, a continuous increase in the oxygen content of IN-718 nickel superalloy (e.g. from an original 0.016 wt% by an additional 0.0001 wt% per SLM cycle) generates the changes in mechanical properties, shown in Fig. 15. The initial study only covered 14 build cycles due to project funding limits and demonstrated that the oxygen content rose. The second study went much further, with over 40 build cycles, demonstrating that the material would eventually result in poor mechanical properties of the as-built parts. However, it is possible to keep it within specification through the addition of virgin powders and/ or returning the powder to LPW for reprocessing and reduction of the surface oxides.

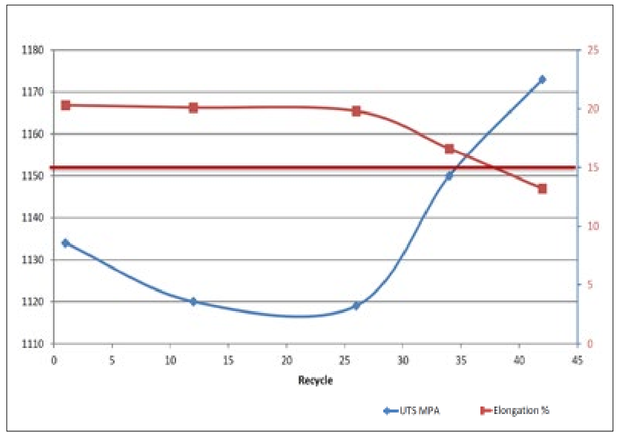


Fig. 15 Influence of repeated re-use cycles on the mechanical properties of SLM processed IN-718 [5]

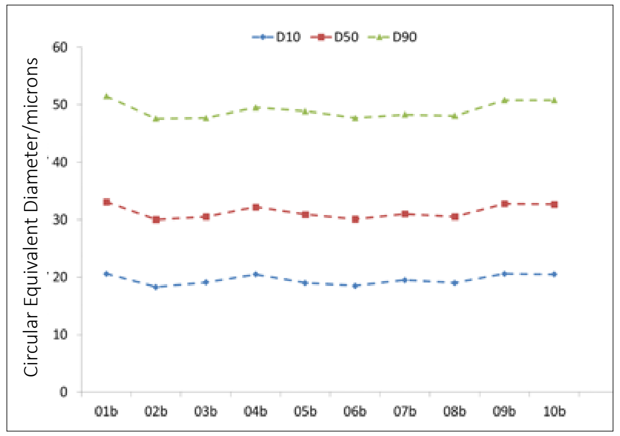


Fig. 16 Control of particle size distribution in the re-use of Ti-6Al-4V powders [5]

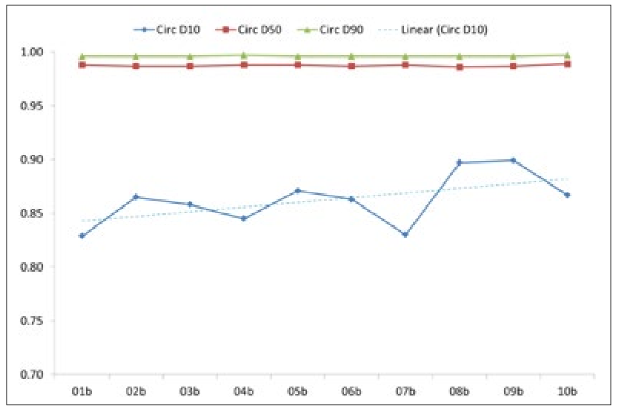


Fig. 17 Increasing circularity of Ti-6Al-4V powder lots through repeated re-uses [5]

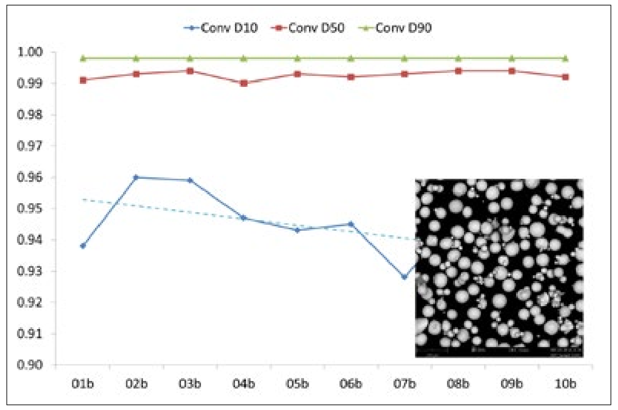


Fig. 18 Decreasing convexity of Ti-6Al-4V powder lots through repeated re-uses [5]

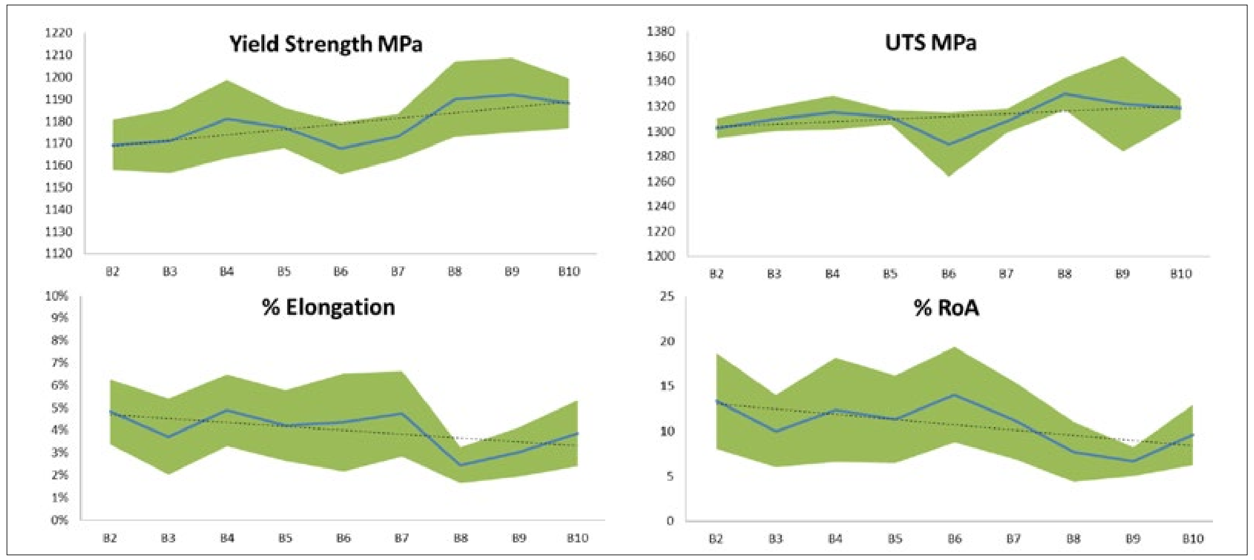


Fig. 19 Influence of repeated re-use cycles on the mechanical properties of Ti-6Al-4V AM specimens [5]

Particle size characterisation has demonstrated a high level of capability for the accurate control of particle size distribution through multiple re-use cycles (Fig. 16). However, particle size distribution is not the only significant factor; particle morphology is also important. Presented results for Ti-6Al-4V (Figs. 17 and 18) showed that, on repeated re-use, the particle shape was becoming more circular and more convex. The consequent changes in mechanical properties are shown in Fig. 19. While the powder was becoming more circular, it also became more convex, i.e. more fissures in the particles. Initially, the greater circularity improves flow, although it implies that, over time, the greater convexity could lead to other issues such as porosity.

LPW stated that its PowderSolve™ software system allows users to track the changes in the powder characteristics, (morphology, flow, chemistry, etc.), resize or correct as possible and when not possible enables the user to change out and recycle the powder. This change is done before making a build, which would result in a failed run, or unacceptable part property.

Metallographic testing methods

Finally, powder characterisation was also the focus of a paper from Tom Murphy, Hoeganaes Corporation, USA, which considered metallographic testing methods for powders intended for use in AM [6].

Metal powders used in AM are required to have a different set of physical particle characteristics compared with the more traditional

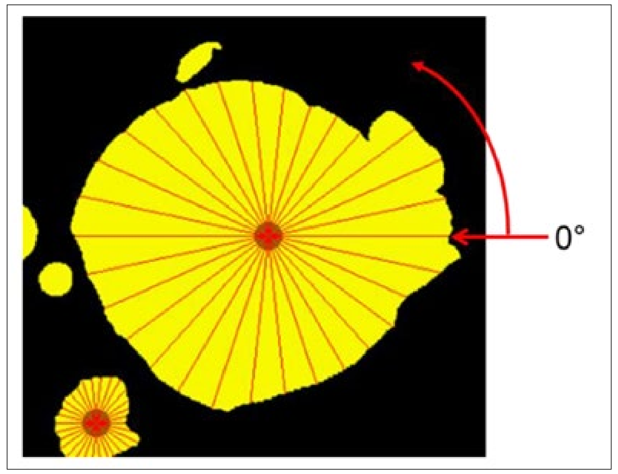


Fig. 20 Example of a defined feature cross-section containing the 30 radii. The 0° radius is located and the angular movement is counter-clockwise [6]

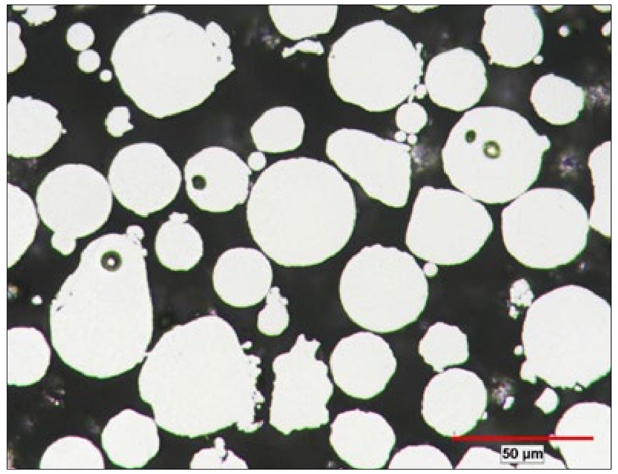


Fig. 21 Cross-sections of a maraging steel powder metallographically prepared and imaged (unetched) [6]

Powder Metallurgy grades. The desired particle size distribution is finer and the shape nearly spherical, in contrast to the PM grade particles that are larger in size and more irregular in shape. The fine, nearly spherical particles are desired since they flow faster, with more uniformity, and fill the AM powder beds more efficiently.

The combination of the small size, spherical shape and minimal particle surface to material volume ratio can often lead to particles being pulled out of the mount during grinding and polishing. This unfavourable situation is compounded when extracted particles become embedded in polishing cloths, thus creating scratches, gouges and deformation on the surface being prepared. Consequently, a new metallographic preparation procedure was developed. The recommended procedure involves the following steps.

Acquisition of a representative powder sample

While many techniques can be used to select a random sample, the best methods conform to accepted standards, such as MPIF Standard 01 or ASTM Standard B215. The selected powder sample must be typical of the powder mass and the sample size should be sufficiently large to allow for preparation and testing of additional samples.

Mounting in a liquid epoxy resin

To make epoxy mounts, the resin should be prepared as normal, then combined with a small amount of the subject metal powder. Care must be taken not to entrap air in the viscous liquid/metal mixture while folding or stirring. Due to the particle size distribution of the metal powders and the high viscosity of the epoxy, segregation of the coarse particles is often not severe, with many of the particles remaining suspended in the viscous epoxy. This helps ensure that a more representative selection of the distribution will remain in the mount for analysis.

Grinding

Grinding is then used to establish the plane for polishing and to expose the particle cross-sections. This should be accomplished using a single fine grinding step, e.g., 600 grit SiC. The use of light pressure is recommended and, in many cases, the grinding would be performed manually.

Polishing

Polishing can then be achieved successfully using a two-step vibratory polishing sequence. This is a combination of a coarser polish on a 'hard' cloth, followed by a final polish on a napped cloth for a short time. Although the time required for the first step is lengthy (often hours are required to remove the evidence from the grinding step), the second step, the final polish, can usually be accomplished in 5 to 15 minutes.

Once metallographic samples have been prepared, the author then recommended the use of automated image analysis techniques to evaluate the shapes and surface textures of the particles. Shape and texture are important factors in the behaviour of the powder mass during the AM process. The shape affects the ability of the particles to fill the powder bed and impacts on the flow, possibly slowing or creating more erratic flow behaviour if the particles deviate from a spherical shape. Surface texture influences inter-particle friction and also may significantly alter powder flow and bed fill.

In the reported work, three approaches to evaluating particle shape and texture were assessed:

- Combining individual measurements, i.e., length, width, area, perimeter, various diameters, etc., into ratios, such as Aspect ratio (length / width) or Roughness (convex perimeter / perimeter)
- Using combinations of areas, perimeters, lengths, etc. in comparison with a geometric shape, in this case, a circle. Relevant parameters here include Circularity (4πA) / perimeter2), Compactness (4πA) / convex perimeter2), Roundness (4 A) / (π max feret diameter2) and Excess Perimeter (perimeter – PAeq x 100 where PAeq = perimeter of an area equivalent circle)
- Reduction of 2D feature data into a 1D graphic and statistical representation by measuring incrementally spaced radii from the feature centroid, plotting the results on an x/y graph and examining the statistical data.

For the examination of the radius function, the feature cross-sections are defined and the centroid of the each is determined. Radii are then drawn from these centroids. In the reported analyses, 30 radii were incrementally spaced at 12° intervals, as seen in Fig. 20, with the 0° location defined. In this way, the shapes of the features were determined by variation in the radius lengths.

In the automated image analysis system used to generate the shape analysis data, procedural decisions were made to determine both the magnification needed to provide images of the small particles and the technique needed to separate particles in the metallographic mount that might be touching due to coincidence of location on the prepared surface.

In deciding on the magnification required to image the small particles, a 50 x objective lens was chosen with a corresponding 0.139 μm/pixel resolution. At this magnification, the particle cross-sections and surface details were visible. Fig. 21 shows a typical field of a metallographically prepared maraging steel powder at this magnification.

A sequence of image transformations was written into the automated analysis software to separate the digital representations of particles that appeared to be touching at a linear distance of <3.75 μm, while multiple particles with more shared surface remained joined. In this way, satellites and protrusions would remain part of the particle, while unattached particles were separated.

The reported results indicated that, although all of shape parameters defined above proved to be effective, some were more useful with specific particle types and, also, some expressions may be more robust than others. It was therefore recommended that multiple criteria should be used in an analysis and that, with an automated system, many measurements can be made without a significant increase in analysis time.

Examples of both successful and less than successful analyses are presented in Figs. 22 and 23. In both of these figures, two different gas atomised 316L stainless steel powder samples were compared. The powders were produced by the same manufacturer at different times and were given the designations 001 and 002. Fig. 22 compares the results of aspect ratio testing. It is clear that this ratio was not applicable to this powder type and, regardless of other shape differences, the length and width measurements were not significantly different within the populations of particles examined in each sample. On the other hand, Fig. 23 shows the results of Circularity and Compactness assessments. It is clear from this figure that the 001 powder sample is rounder when judged by Circularity, with the dashed blue line positioned a significant distance to the right of the dashed red line. The difference in Compactness is only seen with a shape factor value of >0.65, with the two solid lines diverging a measurable amount after that point.

Finally, Fig. 24 shows the usefulness of radius function analysis on four chosen particles (Number 1 was pear-shaped, 2 appeared to have secondary solidification on the lower right side, 3 was nearly round and 4 was roughly triangular). Images of the particles, x/y graphs of the radius length at specific angles and statistics of mean, standard deviation and the coefficient of variation (C.V.) are included in Fig. 24.

The graphs showing the change in radius length appear to be characteristic of the basic shapes. Particle 1 has two high points and dips in the graph as an elongated, pear-shaped particle. The erratic shape of the graph for number 2 is characteristic of the irregular perimeter from the secondary solidification region on the

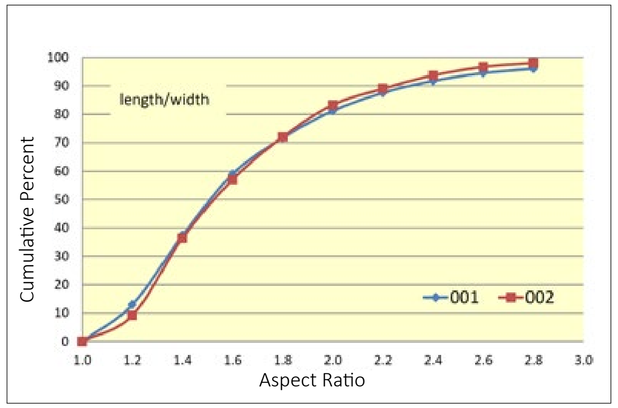


Fig. 22 Aspect ratio results from the testing of gas atomised 316L powder samples 001 and 002. The results are shown as cumulative plots of the frequency distributions [6]

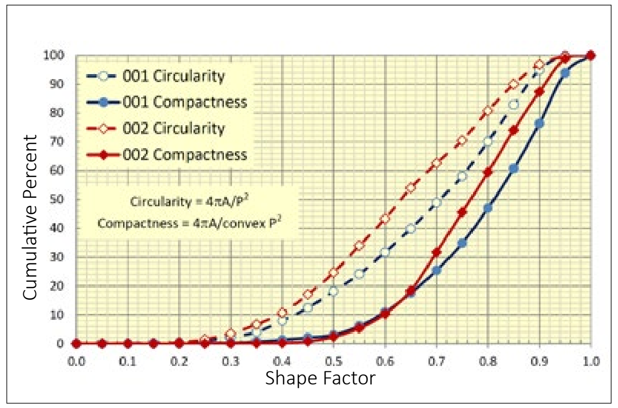


Fig. 23 The results of circularity and compactness testing of gas atomised 316L powder samples 001 and 002. The results are shown as cumulative plots of the frequency distributions [6]

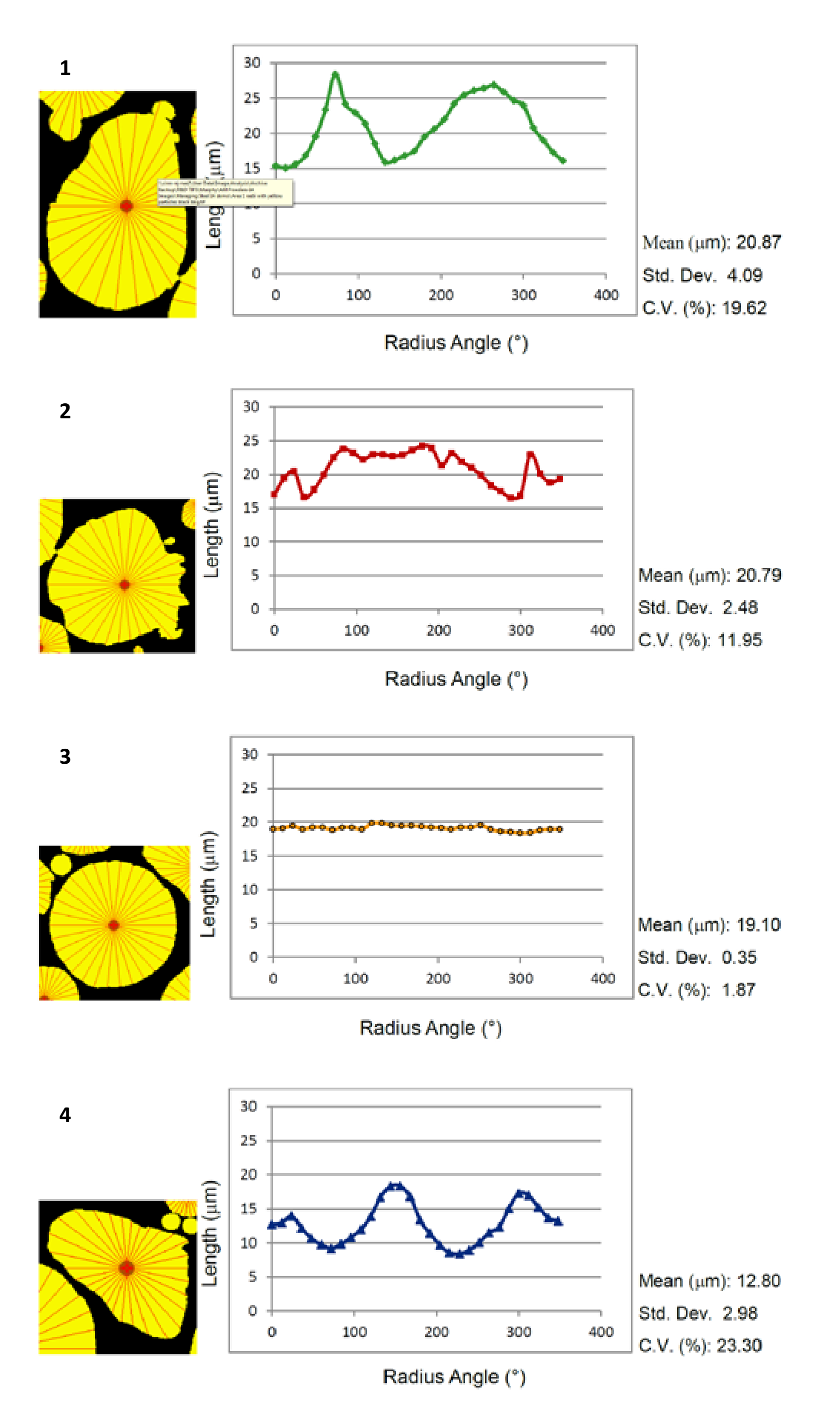


Fig. 24 The four particles chosen as examples of the radius function from an analysis field [6]

lower right edge. Particle 3 is nearly round, with an almost flat graph. As with particle 1, the curve for particle 4 also appears to be cyclic, although with a different period due to the triangular shape. In examining the statistical functions to the right of the graphs, the variation in radius length is reflected in the standard deviations and coefficients of variation. Particle 4 is smaller in size compared with the other three, but the C.V. shows a high variation in the radii lengths. The C.V. is a measure of the dispersion of the frequency distribution and is a valid comparison even though the particles are of different sizes. It can be seen that, as the cross-sections become rounder and smoother, the standard deviation and C.V. have lower values.

Author

Dr David Whittaker
231 Coalway Road
Wolverhampton
WV3 7NG, UK
Tel: 01902 338498
Email: whittakerd4@gmail.com

References

[1] Kuhn, H. America Makes Projects on Powder Metallurgy for Additive Manufacturing, AMPM2015 Conference, May 17-20, 2015, San Diego, California, USA

[2] Tandon, R, et al. Additive Manufacturing of Elektron®43 Alloy Using Directed Laser Energy Deposition: An Investigation into Process Development and Mechanical Properties, AMPM2015 Conference, May 17-20, 2015, San Diego, California, USA

[3] Hoeges, S, et al. Development of a Maraging Steel Powder for Additive Manufacturing, AMPM2015 Conference, May 17-20, 2015, San Diego, California, USA

[4] Freeman, T. Enhancing the Use and Re-Use of Metal Powders for Additive Manufacturing, AMPM2015 Conference, May 17-20, 2015, San Diego, California, USA

[5] Hunter, J. Powder Quality and Characterization Critical to Professional Additive Manufacturing, AMPM2015 Conference, May 17-20, 2015, San Diego, California, USA

[6] Murphy, T. Metallographic Testing of Powders Intended for Use in Additive Manufacturing, AMPM2015 Conference, May 17-20, 2015, San Diego, California, USA

AMPM2016

AMPM2016, the third in the Additive Manufacturing with Powder Metallurgy Conference series, will be co-located with the 2016 International Conference on Powder Metallurgy & Particulate Materials, June 5–8, 2016, in Boston, USA.
www.mpif.org

Rapid.Tech 2015: Germany's conference and exhibition on AM targets an international audience

The Rapid.Tech Conference and Exhibition was first held in Erfurt, Germany, eleven years ago and since then this annual event has attracted ever more visitors. Originally a German language event, the organisers have in recent years worked hard to increase its international appeal and this year the conference was held both in German and English with simultaneous translation. Dr Georg Schlieper reports for *Metal Additive Manufacturing* magazine.

Rapid.Tech

The Rapid.Tech 2015 Conference and Exhibition took place from June 10–11. The technical conference included 79 oral presentations and the event as a whole attracted almost 4,000 visitors from fifteen countries, many of whom are active in research and development. The combination of a technical conference and exhibition is considered by the organisers to be rather unique in this industry as opposed to the larger trade exhibitions.

Rapid.Tech provided a comprehensive overview of the present status of metal Additive Manufacturing in Europe and the diversity of its products. Within the exhibition, a wide variety of metal AM products was on display demonstrating the design possibilities and range of applications. Figs. 2-5 show a number of impressive examples. Besides the high number of equipment manufacturers and research institutions, many AM service providers promoted their expertise to interested visitors.

Selective Laser Melting (SLM) is today by far the most widely used technology for metal AM, followed by Electron Beam Melting (EBM). Other emerging technologies such as inkjet printing are further behind on the route to full commercialisation. At the start of the conference, five keynote presentations under the headline Vision 3D, with two of them covering metal components, highlighted the future of Additive Manufacturing.

The event was held in conjunction with FabCon 3.D, an exhibition for start-ups and semi-professional users of 3D printers with a focus on non-metallic materials. Since the focus of this magazine is on Additive

Fig. 1 Messe Erfurt, home of Rapid.Tech (Courtesy Messe Erfurt)

Fig. 2 A thin walled turbine combustion chamber, produced from EOS Nickel Alloy In718 on an EOSINT 270 machine by Materials Solutions (Photo Georg Schlieper)

Fig. 3 A lightweight ball design manufactured from AlSi10Mg by 3D-Laserdruck GmbH i.G. (Photo Georg Schlieper)

Fig. 4 Additive Manufactured antenna bracket for a Sentinel-1-Satellite, manufactured on an EOS M400 by RUAG Space / Altair (Photo Georg Schlieper)

Fig. 5 Femoral stem with trabecular structures displayed by Arcam AB and manufactured from Ti6Al4V (Photo Georg Schlieper)

Manufacturing with metals, this report does not cover the non-metal side of the conference and exhibition.

Aerospace applications

Peter Sander, Manager, Emerging Technologies & Concepts at Airbus, Hamburg, gave a lecture about the present status and future expectations for Additive Manufacturing in the aerospace industry. Sander reported that the Airbus A350 today contains 80 "flying AM parts". While most of these components are non-metallic lightweight structures, he stated that a trend towards metal components is noticeable.

Sander said that the Ti6Al4V cabin bracket shown in Fig. 6 was the first metal AM component in an Airbus aircraft. It had been designed as a bionic structure, reducing as much material and weight as possible and leaving material only where it is needed for strength. He stated that metal AM allows Airbus to achieve a 30% weight reduction over the carbon fibre reinforced composite (CFC) structures which are currently widely used in aircraft.

Sander also announced that Airbus Operations plans to produce more than 30 tons of AM parts by 2018 and he made clear that Airbus is a key driving force behind the industrialisation of AM technology. His focus was very much on titanium components for aircraft and he expected that the productivity of Additive Manufacturing would increase by a factor of 100 in the near future. However, no definite time scale was given. If this optimistic appraisal should come true, it would mean a fundamental structural change in the industries manufacturing titanium aircraft components.

Jewellery made by AM

The jewellery and watchmaking industries are showing a growing interest in the Additive Manufacturing of precious metals, as was outlined in the keynote presentation by Frank Cooper, Birmingham City University School of Jewellery, UK. It is obvious that the potential for saving material through AM is particularly attractive for high value precious metals. The students of the School of Jewellery explored the design options offered by AM with great excitement and creativity and Cooper demonstrated new solutions for 18 carat gold jewellery manufactured at his institute. Some examples are given in Fig. 7. Watchcases can be designed with unique features that offer protection against product piracy, as shown in Fig. 8.

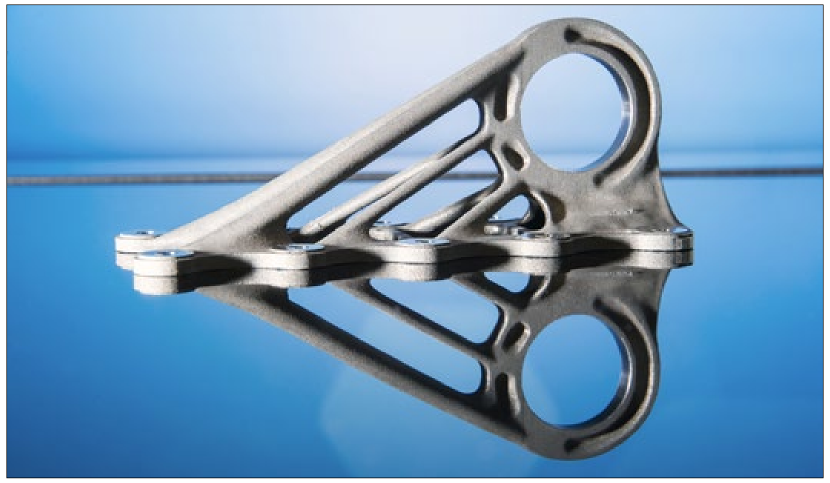


Fig. 6 Cabin bracket made from Ti6Al4V (Courtesy Airbus)

AM in medical technology

Medical technology was a main focus of the technical conference, with five sessions and fourteen presentations reflecting the high standard of recent applications and ongoing research. Topics ranged from surgical instruments, endoprosthetic implants and vascular stents through to innovative biodegradable materials.

The advantages of AM for customised endoprosthetic implants were demonstrated by Maximilian Munsch of Implantcast GmbH, Buxtehude, Germany, with an impressive example as shown in Fig. 9. The custom-made component for partial hip replacement is made from Ti6Al4V by EBM. The part's length is 120 mm and the central section has a diameter of 56 mm. The surface with its EPORE® structure is specifically designed for fast and permanent osseointegration.

Advances in complex maxillofacial surgery were presented by Florian Thieringer, University Clinic Basel, Switzerland. Starting from a data set which had been generated by computer tomography or magnetic resonance imaging of the patient's bone that undergoes surgery - a jaw for example - a virtual 3D model is created and 3D printed in polymer. The model is then used to precisely adapt a titanium plate for osteosynthesis and produce it by SLM. Fig. 10 shows the jaw model and the Ti plate (left) and a virtual simulation of the jaw with the Ti plate in place fixing a fracture (right).

This method is, of course, not restricted to maxillofacial surgery, but can be used for a wide range of surgeries. In medical technology, 3D imaging and 3D software is increasingly used for the simulation of surgical interventions.

Dental technology was notably under-represented at this year's Rapid.Tech exhibition. This was due, stated the organisers, to the proximity to the International Dental Show (IDS) in Cologne, which has a far greater significance for the industry. The technical conference also widely omitted the subject of dental technology.

Software development

3D design software will soon be part of our everyday lives and Adrian Lannin, Microsoft Corporation, USA, announced that the Windows 10 operating system will include a platform that allows users to design in 3D and connect a 3D printer directly to a PC as a plug-and-play device. This underlines the importance that the world's leading software provider for

Fig. 7 Examples of AM jewellery design (Courtesy Birmingham School of Jewellery)

Fig. 8 Golden watchcase with AM design (Courtesy Birmingham School of Jewellery)

Fig. 9 Custom-made partial hip replacement (Courtesy Implantcast GmbH)

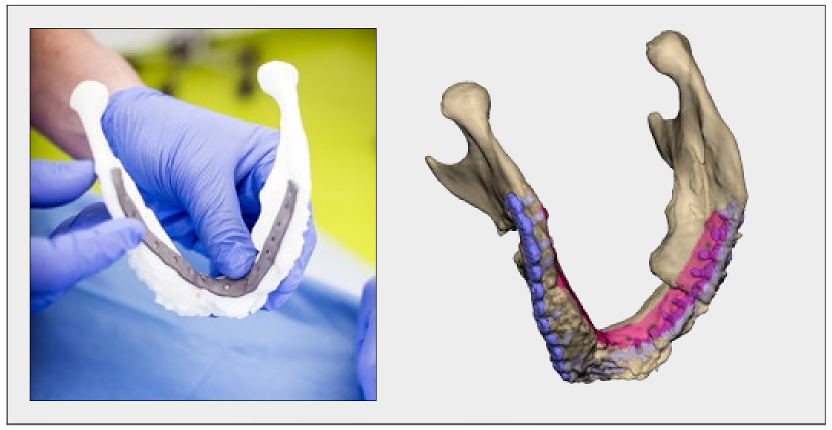


Fig. 10 Jaw model and Ti plate (Courtesy Ralf Schumacher, Fachhochschule Nordwestschweiz and Florian Thieringer, Universitätsspital Basel)

personal computers attributes to AM technology. A new file format, 3MF, has been developed that substantially reduces the size of data files for 3D printing. Lannin assured the audience that the new Windows 10 software would also be compatible with other 3D printer software.

Software developers work hard to improve the user friendliness of 3D design software and Florian Coigny of Mimedis AG, Basel, Switzerland, presented innovative design software for medical implants with improved user guidance and integrated manufacturing guidelines. He stated that the new software is easy to use and intuitive, allowing surgeons to become the designers of their own individual implant solutions, no longer having to rely on design engineers to transfer their ideas into a 3D design.

Tool making industry

The tool making industry is increasingly using SLM for repairs, prototyping and advanced tools with integrated cooling channels. Intelligently designed cooling channels in tools used for die casting and injection moulding can help to reduce cycle times and improve temperature distribution in the tool dramatically. This can reduce the distortion of products due to thermal effects and improve overall quality.

Mathias Gebauer, Fraunhofer Institute for Machine Tools and Forming Technology (IWU), Chemnitz, Germany, reported on the development of inserts for an injection moulding tool by Additive Manufacturing with internal cooling channels as shown in Fig. 11. In addition to the cooling channels, the inserts featured areas with intentional porosity for improved venting of the cavity.

AM research

The number of research groups that are working in the field of metal Additive Manufacturing is rapidly growing and it is hard to keep track with the development. The Fraunhofer-Gesellschaft, a

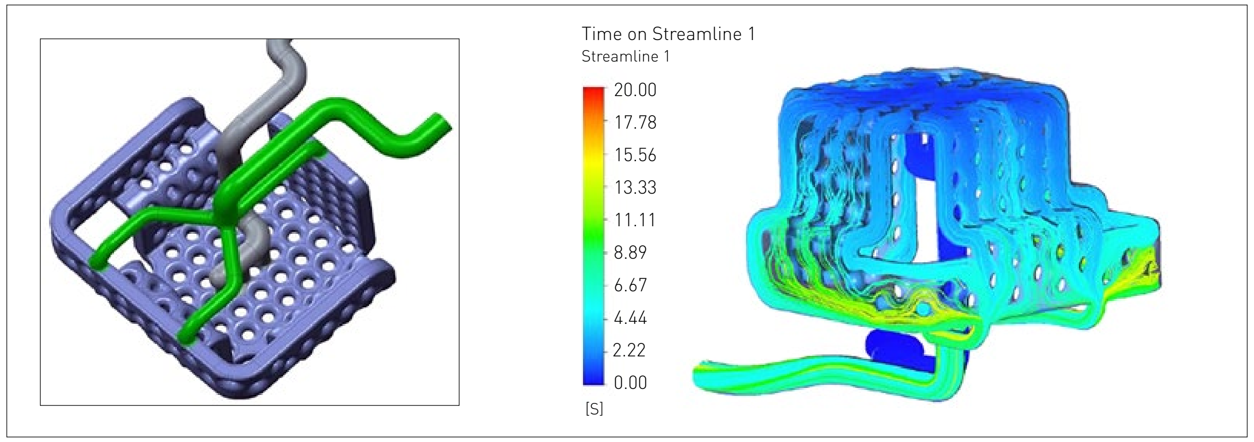


Fig. 11 Cooling channel design (left) and flow analysis (right) (Courtesy Fraunhofer-Institut IWU)

major institution for applied research in Germany, has formed an alliance between several of its institutes in order to cooperate on different areas of AM research. The Fraunhofer-Gesellschaft also held its own expert forum with a number of presentations.

Numerous European universities have also created collaborative research centres for AM. Biodegradable metallic implants from magnesium alloys for applications in osteosynthesis are under development by working groups at the Laser Zentrum Hannover e.V. (LZH) and the University of Hannover. LZH's Matthias Gieseke stated that the high oxygen affinity of magnesium and the formation of magnesium vapours during SLM are the main problems to be solved. The researchers worked with two alloys, MgCa0.8 (0.8% Ca, bal. Mg) and WE43 (4% Y, 2.25% Nd, 0.15% Zr, bal. Mg) and found a slight change in alloy composition due to Mg evaporation during SLM processing. With MgCa0.8 the open cavities of the scaffold were limited to a minimum of 600 µm. However, with WE43 it was possible to produce scaffolds with 400 µm cavities. Both alloys were subjected to a secondary treatment in aqueous nitric acid at room temperature to remove any adhering powder particles and create a smoother surface (Fig. 12). The author stated that the alloy WE43 could be processed more easily than MgCa0.8.

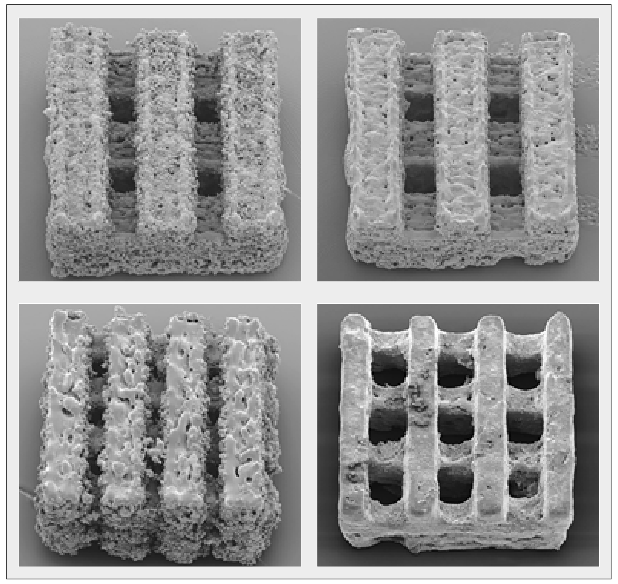


Fig. 12 Magnesium scaffolds approx. 3x3 mm. Top row: MgCa0.8, bottom row: WE43 alloy. Left: as-printed, right: after secondary treatment in aqueous nitric acid (SEM Courtesy Laser Zentrum Hannover)

Outlook

Besides the many success stories that were reported during the conference, there were also critical remarks about the need for further development of AM technology and improvement to processing equipment. Productivity, it was stated, needs to be improved to make the technology attractive for more applications.

The change from one material to another is considered extremely tedious as cleaning a machine can in some cases take two to three days. The limited number of metal alloys that are currently available for 3D printing is another obstacle for further growth of the industry. In medical technology, approval by the US Food & Drug Administration (FDA) is essential. However, this is difficult to obtain and costly. Sophisticated process monitoring systems are also recognised as an essential way to secure higher quality standards.

Based on the success of this year's event, the organisers have announced that Rapid.Tech 2016 will last for three days, taking place in Erfurt from June 21-23.

Author

Dr Georg Schlieper
Gammatec Engineering GmbH
Mermbacher Strasse 28
D-42477 Radevormwald
Germany
Tel: +49 2191 6889274
Email: info@gammatec.com

Concept Laser's QMmeltpool 3D: In-situ quality assurance with real-time monitoring down to the micron level

Concept Laser, based in Lichtenfels, Germany, is a leading provider of manufacturing equipment for metal Additive Manufacturing using its patented LaserCUSING® technology. In this article the company reports on the development of the next generation of its quality assurance monitoring system, QMmeltpool 3D, which will be available on its M1 and M2 cusing machines from 2016. The system, states Concept Laser, promises to make a significant contribution to detecting process defects at an early stage as well being an indispensable tool for process optimisation.

Active quality assurance is one of the most important requirements for producers of critical components by metal Additive Manufacturing and monitoring the key data of a laser melting system, such as oxygen content, temperature, laser output and powder quality, is now commonplace during production. A comprehensive statement regarding the quality of a part cannot, however, simply be made on the basis of machine parameters. With in-situ process monitoring systems based on an on-axis system, it is now possible to obtain information about defects during the build process. Concept Laser has announced the development of a system for position-related, real-time monitoring and three-dimensional visualisation for its LaserCUSING® process. The system, QMmeltpool 3D (Fig. 1), will be available from 2016 onwards for the company's M1 cusing and M2 cusing machines and offers users the next generation of quality assurance tools.

Sources of defects during laser melting

In challenging application sectors such as medical, automotive and aerospace, safety requirements are strict and high quality is a prerequisite. Defects that can occur during laser melting are as the result of an extremely wide range of influencing factors. Examples include scanning speed or laser output. Process defects can, for instance, be caused by scanning speeds that are either too low or too high, having the effect of excessive or inadequate energy input. Inadequate energy input into the powder bed can lead to unmelted

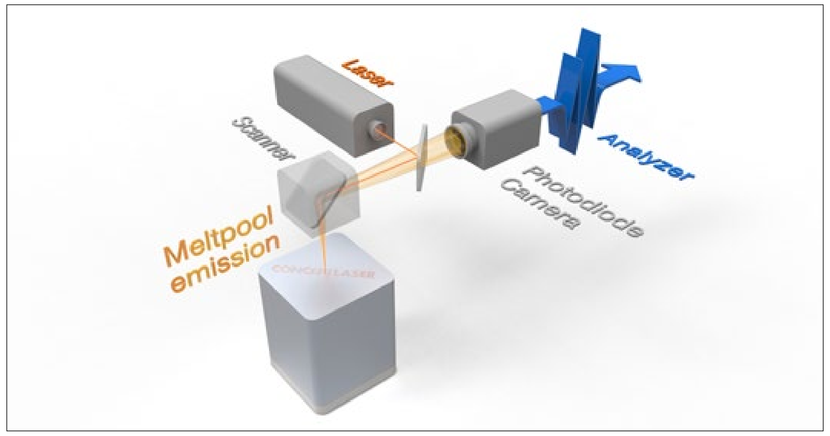


Fig. 1 In-situ monitoring of the melt pool with QMmeltpool 3D: A photo diode and a camera provide coaxial monitoring of the area and intensity of the melt pool through the laser optic with exact positioning

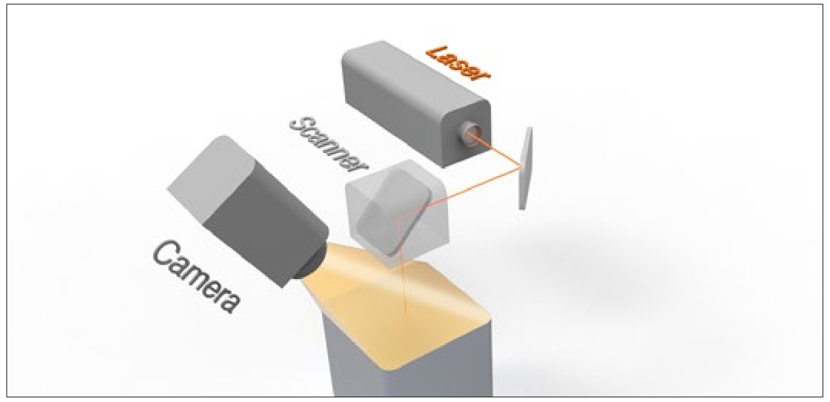


Fig. 2 Conventional ex-situ monitoring by camera

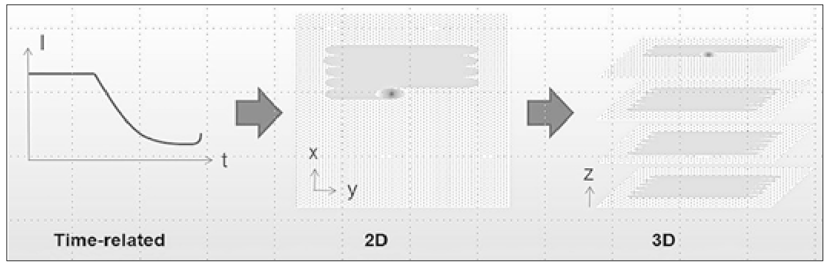


Fig. 3 QMmeltpool becomes QMmeltpool 3D: Position-related analysis of the build process of each part. Local effects are detected during the build process

powder in the form of irregularly shaped pores. If the energy input is too high, on the other hand, gas inclusions can be formed that are revealed in micrographs as regular, round pores. The process gas flow, the material and many other factors can also influence the process and part quality.

QMmeltpool 3D generates quality-relevant data in real time for process monitoring and documentation. The system records position-related characteristics of the melt pool while the component is being built. This data can be visualised in a three-dimensional landscape and analysed by the user. Concept Laser states that the quality of the visualisation is comparable to the HD resolution achieved by Computer Tomography (CT).

Process monitoring in laser melting technologies

The QMmeltpool system uses coaxial sensors to detect melt pool emissions that are created during the fusing process in the form of infrared radiation. The coaxial structure allows restriction to a small region of interest with a high local resolution and rapid scanning rates of up to 50 kHz, depending on the detector type. This melt pool monitoring identifies two characteristic parameters; the melt pool area and melt pool intensity. These characteristic parameters can be allocated to corresponding process errors.

As previously stated, a low melt pool intensity may indicate inadequate laser output or an excessively high scanning speed, resulting in insufficient energy input. Moreover, changes in the area of the melt pool may indicate a variation in the oxygen content within the process chamber. The part geometry also has effects on the thermal conditions in the process, which means that reference samples and a high level of process understanding are required for the variation in data during the process to be interpreted and analysed correctly. In 2D melt pool monitoring, the signals are supplied as average values per component and per layer. This 2D perspective permits a restricted interpretation of localised defects.

Innovations in the QMmeltpool 3D system

The former time-related 2D monitoring of the build process has now become a position-related 3D landscape (Fig. 3). Instead of exclusively time-related data, the system now additionally delivers position-related signals for definitive allocation, comparable to CT. These signals make it possible to generate 3D datasets of the part or its structure. A highly accurate 3D landscape of the part is thus created. In detail, this means identifying characteristic properties of the melt pool. These include the area and intensity of the melt pool that can be investigated using two detectors, a camera and a photodiode, with a high resolution level in terms of location and timing. Following that, these signals are correlated with the corresponding positional data of the laser. This comparison is what makes QMmeltpool 3D so effective: melt pools signals such as melt pool area and melt pool intensity can thus be visualised and evaluated in three-dimensions directly after the build process has finished. The user can trace the process of creating each part in terms of position. Local effects in the part during the build process can now be detected and analysed more effectively.

Coaxial integration: pinpoint accuracy with the on-axis approach

The new approach is based on expanding the 2D inspection into the 3D space, with coordinate-related data acquisition of the melt pool values. It is possible to look at current quality assurance approaches available on the market to assess the new method of QMmeltpool 3D. Traditional off-axis inspections have a lower resolution and lower detection rate. For example, an infrared-sensitive camera is used that is located in a position outside the build chamber (Fig. 2). The advantage of this ex-situ solution is that the system integration of the machine and camera is

Structure of the monitoring	In-situ
Inspection instruments	Camera and photodiode
Dimension	x, y and z
Resolution in 3D	35 µm
Camera sampling rate	> 10 kHz
Camera sampling rate	50 kHz

Table 1 Characteristic data of the QMmeltpool 3D quality module

Fig. 4a A cabin bracket from the Airbus A350 XWB with standard output

Fig. 4b QMmeltpool 3D display of the cabin bracket from the Airbus A350 XWB with standard output

Fig. 5a A cabin bracket from the Airbus A350 XWB with reduced laser output

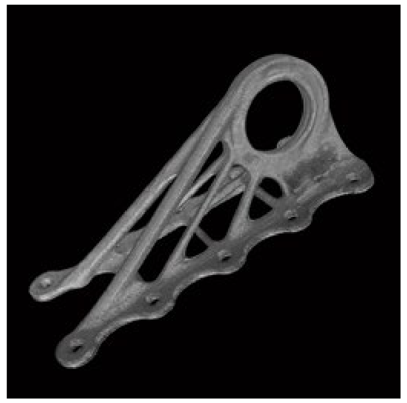


Fig. 5b QMmeltpool 3D display of the cabin bracket from the Airbus A350 XWB with reduced laser output

reasonably straightforward. An off-axis structure enables statements to be made about the overall fusing and cooling behaviour. However, it is not possible to derive a detailed statement about the melt pool.

The on-axis/in-situ structure is based on a two axial arrangement of detectors (Fig. 1). The detectors used are a camera and a photodiode, which use the same optic as the laser. This coaxial integration permits a high coordinate-related 3D resolution of 35 µm. The detection rate results from the scanning speed. If this speed is 1,000 mm/s, the result is 100 µm, i.e. the distance covered by each shot. At 2,000 mm/s, the value is 200 µm. Concept Laser specifies the sampling rate of the camera as > 10 kHz and that of the photodiode as 50kHz. The coaxial arrangement offers the advantage that the melt pool emissions are always focused on one point of the detectors and the frame size is reduced so that the sampling rate can also be increased. As a result, a detailed analysis of the melt pool characteristics is possible.

Possibilities and limitations

QMmeltpool 3D helps to minimise the work involved in quality assurance and to exploit time benefits. The system can supply local indications of defects in the part. As a result, subsequent inspections and tests can be reduced to a minimum. Furthermore, the data is available directly after the build process, resulting in savings in the time taken. The system is unable, however, to rectify defects during the build process. Due to the large number of influencing factors that can cause defects in the build process or on the component itself and the highly dynamic properties of the process, developing a self-correcting control loop represents a significant challenge.

Conclusion and outlook

In-situ monitoring systems can detect process characteristics in real time thanks to their high resolution and sampling rates (every 0.1 mm, depending on the scanning speed) (Figs. 4 and 5). In-situ monitoring systems thus make a significant contribution to detecting process defects at an early stage and avoiding them in future. For the user, this represents a tool for optimising the process.

The practical added value of three-dimensional visualisation is not just that it is an original way of providing active quality assurance. In production and process development, component jobs can be optimised through iterative variation of the parameters. Support structures can be adapted and, above all, the design of the part can be structured in a more efficient and production-friendly manner. Last but not least, new possibilities are opened up in material research and validation of materials.

Contact

Concept Laser GmbH
An der Zeil 8
D-96215 Lichtenfels
Germany
Tel: +49 9571 1679 0
Email: d.hund@concept-laser.de
www.concept-laser.de

industry events

2015

Additive Manufacturing + 3D Printing
August 2-5, Boston, USA
www.asme.org

Ti-2015: The 13th World Conference on Titanium
August 16-20, San Diego, USA
www.tms.org/meetings/2015/Ti2015/

PM Titanium 2015
August 31-September 3, Lüneburg, Germany
www.hzg.de/pmti2015

3rd Annual Additive Manufacturing for Defense and Aerospace
August 31-September 2, Washington D.C., USA
www.additivemanufacturingfordefense.com

3D Printshow
September 10-12, California, USA
3dprintshow.com

3D Printing ASIA
September 15-17, Guangzhou, China
www.asiamold-china.com

Euromold
September 22-25, Dusseldorf, Germany
www.euromold2015.com

TCT Show + Personalize
September 30 - October 1, Birmingham, UK
www.tctshow.com

Euro PM2015
October 4-7, Reims, France
www.epma.com

3D Printshow
October 16-17, Paris, France
3dprintshow.com

3rd Additive/Aerospace
October 26-29, Los Angels CA, USA
www.infocastinc.com/events/add-aero

16th Annual RAPDASA International Conference on Additive Manufacturing
November 4-6, Pretoria, South Africa
rapdasa.org

APMA 2015
November 8-10, Kyoto, Japan
apma.asia

3D Printshow
November 8-12, Dubai,United Arab Emirates
3dprintshow.com

formnext
November 17-20, Frankfurt, Germany
www.mesago.de/en/formnext

2016

Rapid 2016
May 16-19, Orlando, USA
rapid3devent.com

AMPM2016 Additive Manufacturing with Powder Metallurgy
June 5–7, Boston, USA
www.mpif.org

POWDERMET2016 Conference on Powder Metallurgy & Particulate Materials
June 5–8, Boston, USA
www.mpif.org

World PM2016 Congress & Exhibition
October 9-13, Hamburg, Germany
www.epma.com/world-pm2016

Event listings and Media Partners

If you would like to see your metal AM related event listed 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 Additive Manufacturing magazine is exhibiting at and/or being distributed at events highlighted with the Metal AM cover image

Advertisers' Index

Advertising opportunities

***Metal Additive Manufacturing* is the new magazine for the metal Additive Manufacturing industry**

Metal Additive Manufacturing is the new business-to-business magazine that focuses on commercial and technical developments in the metal AM industry. The launch of this new magazine follows the success of the www.metal-am.com website and e-newsletter.

As well as featuring the latest business and applications news, technical developments in the industry will also be highlighted, making the magazine the essential resource for part manufacturers and end-users, along with equipment and material suppliers.

For more information contact Jon Craxford
Advertising Sales Director, Tel: +44 207 1939 749
Email: jon@inovar-communications.com

Industrial-Grade 3D Printing
with Binder Jetting Technology

ExOne® Systems & Services materialize sandcasting cores, molds & functional metal parts with less cost and increased efficiency for prototype or production use.

Select from a variety of build sizes:

S-Max®
1800 x 1000 x 700mm

S-Print™
800 x 500 x 400mm

M-Flex®
400 x 250 x 250mm

innovent™
160 x 65 x 65mm

ExOne™
DIGITAL PART MATERIALIZATION

877 773 9663 • ExOne.com