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METAL AM

in this issue

COMPANY VISIT: FIT AG

ADDITIVE MANUFACTURING AT GE

ALUMINIUM POWDERS FOR AM

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METAL ADDITIVE MANUFACTURING

Acquisitions move the industrialisation of metal AM a step forward

The world of industrial Additive Manufacturing can change at a remarkable pace. Since the last issue of *Metal AM* magazine, GE announced plans to acquire two leading AM machine manufacturers, Arcam AB and SLM Solutions, whilst Siemens confirmed its acquisition of a majority stake in the UK's Materials Solutions.

Both GE and Siemens use metal AM components in high-performance applications, with power generation systems being an important industry sector that both companies have in common. Their moves over the summer must therefore be regarded as a clear vote of confidence in the potential of metal AM technology.

If successful, GE's move would secure additional technical expertise and gives the company a foothold in two areas of the AM supply chain, production machinery and metal powders. This ties in with the company's ambitions of not only developing the use of AM components within its businesses, but of also becoming the leading provider of digital manufacturing solutions on a truly industrial scale.

The interest in AM factory concepts is high on the agenda with a number of companies, including Germany's FIT AG. As one of the most experienced developers and manufacturers of AM components in Europe, FIT has worked hard to develop a 'model AM factory' that starts to address the technical and economic challenges surrounding the commercial production of series AM components (page 49).

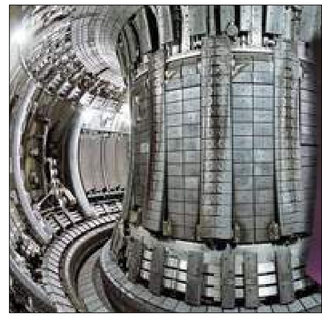
Nick Williams
Managing Director

Cover image
Arcam EBM machines used for the series production of AM titanium components at FIT AG

METAL ADDITIVE MANUFACTURING







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Siemens acquires majority stake in UK-based AM producer Materials Solutions

Siemens has acquired a majority stake in Materials Solutions Ltd., a specialist metal Additive Manufacturing parts maker based in Worcester, UK. Siemens now holds 85% of the shares, with the remaining 15% held by the founder of the company, Carl Brancher. The move follows the announcement in August 2015 that Siemens Venture Capital acquired a minority stake (14%) in the company. Financial details of the deal were not disclosed.

"With the acquisition of Materials Solutions, we are able to secure world-leading expertise in materials and AM process development with focus on high-temperature superalloys. The company's strength is to turn models into high quality components in record time. Clearly Materials Solutions fits perfectly within our vision for growth and application of advanced technologies within our Power & Gas portfolio," stated Willi Meixner, CEO of Siemens Power and Gas Division.

"We are very proud to become a part of Siemens," stated Carl Brancher, CEO of Materials Solutions. "I am sure our know-how and experience will make a significant contribution to Siemens' Additive Manufacturing strategy. Materials Solutions is developing the applications know-how and a supply chain for the world's most advanced engineering companies – delivering processes and precision parts from 3D CAD models, using software, lasers and metal powders," added Brancher.

A specialty of Materials Solutions is making turbomachinery parts, particularly high temperature applications for gas turbines where accuracy, surface finish and the highest quality of the materials is critical to ensure operational performance of the parts in service.

Siemens extensively uses AM technology for rapid prototyping and has introduced serial production solutions for the manufacturing of small fuel mixers and for the rapid repair of burner tips for mid-size gas turbines. Siemens in Finspång, Sweden, began using AM technology in 2009 and opened a production facility for metal AM components in February 2016. The first 3D printed burner component for a Siemens heavy-duty gas turbine is in successful commercial operation in a power plant in Brno, Czech Republic.

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

GE outlines plans to invest $1.4 billion to acquire Arcam and SLM Solutions

On September 6 GE Aviation announced plans to acquire two leading suppliers of Additive Manufacturing equipment, Sweden's Arcam AB and Germany's SLM Solutions Group AG, for $1.4 billion. Arcam invented the Electron Beam Melting machine for metal AM, whilst SLM Solutions is a leading manufacturer of laser-based metal AM machines. Both companies also have interests in metal powder production. Our full report on this and the development of AM at GE can be seen on page 61.

www.geaviation.com

Arcam subsidiary AP&C begins construction of second metal powder plant

Arcam AB has announced that its powder manufacturing subsidiary AP&C in Montreal, Canada, has begun to build its second powder plant in Saint-Eustache, Québec. AP&C, a producer of plasma atomised metal powders for Additive Manufacturing and Metal Injection Moulding, plans to invest up to CAD 31 million in this second powder facility, creating 106 new jobs in addition to the 85 people currently employed within the next three years.

"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 highest quality powder for production at competitive cost," stated Magnus René, CEO of Arcam.

"This investment makes it possible to provide our existing and future clients with superior quality powders to meet the high manufacturing standards of the aerospace and orthopaedic industries," added Alain Dupont, President of AP&C. "With this new powder production facility and advances in atomisation technology, AP&C will significantly increase capacity."

The ground-breaking ceremony for the company's new plant in Saint-Eustache, Québec

AP&C benefited from the support, advice and financial assistance of Canada Economic Development, Montréal International, Investissement Québec and the Québec Ministry of Economy, Science and Innovation in moving its expansion project forward. "Without the involvement from both the federal and provincial governments, our project would have been difficult to carry through at this speed," Dupont added. "Our points of contact were receptive to our needs and showed keen knowledge of the issues and challenges facing our industry."

www.advancedpowders.com | www.arcam.com

LPW moves into metal powder production with £20 million expansion

LPW Technology Ltd, based in Runcorn, UK, has announced plans to invest over £20 million in a new UK based facility to manufacture metal powders for the Additive Manufacturing industry. It was stated that the new facility will create more than 120 new jobs by 2018.

"We have been first to market in this developing industry. With our ambitious growth plans and the support of our amazing staff we now aim to be a truly engineering company," stated LPW's CEO Dr Phil Carroll. "Our new facility will ensure the North West is at the forefront of materials for this new and exciting industry by exporting our products worldwide."

LPW's powders are used to manufacture a wide range of products from aerospace turbine components and engine parts for Formula 1 cars to medical implants such as artificial hips. In addition to developing and supplying metal powders for AM, LPW's PowderLife products include powder handling, testing equipment and quality control software for industrial users of AM systems.

As well as a head office in Runcorn, LPW has a separate R&D facility at STFC Daresbury Labs in Warrington, UK, a fast growing facility in Pittsburgh, USA, an office in Germany and a network of resellers around the world.

www.lpwtechnology.com

Norsk Titanium to build world's first industrial-scale aerospace AM plant

Norsk Titanium AS has announced that the State of New York, USA, in partnership with the State University of New York (SUNY) Polytechnic Institute, has placed an order for twenty of the company's MERKE IV™ Rapid Plasma Deposition™ machines in a deal that will create what is claimed to be the world's first industrial-scale metal Additive Manufacturing plant.

The order is in accordance with an approved state budget allocation that will enable Norsk Titanium's US subsidiary to build and operate the world's first Rapid Plasma Deposition™ factory in Plattsburgh, New York, USA. The new facility is expected to be operational by the end of 2017. A $125 million New York investment in the Norsk Titanium US Plattsburgh factory was approved in the 2016-2017 State budget. Under the terms of the deal, Norsk Titanium US will provide additional investment into the Plattsburgh operation that is anticipated to bring the total program commitment to the $1 billion dollar level over the initial 10-year period of operations.

"We are proud to be a part of the unwavering vision and leadership of Governor Cuomo and are moving forward in support of his efforts to revitalise upstate New York with jobs, technology and community pride," stated Norsk Titanium Chairman of the Board John Andersen, Jr. "Our researchers have spent ten years pioneering the Rapid Plasma Deposition™ process that is now ready to cut millions of dollars in cost from the world's premier commercial and military aircraft, and with the foresight displayed in other sectors, the State of New York is the ideal place to launch this manufacturing revolution."

Norsk Titanium's proprietary RPD™ process works by feeding titanium wire into a set of plasma torches protected by a cool argon environment that has made it possible to replace legacy forged parts, which take months and even years to develop and produce, with precision, additive manufactured components. Norsk Titanium RPD™ components have equivalent strength to forgings, but are delivered inexpensively and efficiently, with unprecedented part cost and design-to-market speeds.

"Today marks the beginning of a new era in the way aircraft, marine vessels, automobiles, spacecraft and many industrial products are designed and built," added Norsk Titanium President & Chief Executive Officer Warren M. Boley, Jr. "Not only are we creating jobs, huge economic impact and great visibility for the wider Plattsburgh community, we are also making history by kicking off a new phase of on-demand, near-net-shape manufacturing that sets a new benchmark of efficiency and customer responsiveness."

www.norsktitanium.com

Certified aerospace quality for metal AM at Airbus APWorks

Airbus APWorks GmbH, Munich, Germany, has announced that it is now certified by TÜV Süd in order to meet the highest security standards required by the aerospace industry. The EN 9100 is a prerequisite for becoming an aerospace supplier. The qualification is also important for customers from the industry sectors such as automotive, robotics, mechanical engineering or medical technology to have documentations and sample inspections as prerequisites for serial production, stated the company.

APWorks, being a certified company, confirms that quality requirements of its own processes and products are fulfilled and are continuously improving. A gapless, traceable documentation of the entire supply chain of a product is required with an integrated document management system. Another essential prerequisite is a risk management system as well as the implementation of standardised company processes.

Certified companies, such as APWorks, are making initial sample inspections for quality assurance. These initial sample inspections include destructive and non-destructive testing on the effective loads of a part. These tests include, but are not limited to, tensile tests, CT Scans and X-rays. APWorks received the certificate for engineering and production of metallic products and sales of metallic powders for Additive Manufacturing.

www.apworks.de

Erasteel achieves EN9100 certification for aerospace AM powders

Erasteel has announced that Metallied, the company's metal powder production facility for Additive Manufacturing powders, located in Irun, Spain, has recently added EN9100 accreditation to its existing ISO 9001 quality standard.

The achievement confirms the company's strong commitment to quality in the aerospace industry which has been a core business of Aubert & Duval, a sister company of Erasteel, for many years. The stringent requirements of this standard will also benefit customers in other markets, the company added.

Erasteel develops and produces its Pearl® Micro metal powders for use in Additive Manufacturing systems. The metal powders offer high flowability in a wide range of standard and customised compositions.

www.erasteel.com
www.aubertduval.com

Sentrol launches new metal Additive Manufacturing machine to compete on global stage

Sentrol Co., Ltd, Korea, has announced the launch of the Sentrol 3D SM350 metal AM system aimed at commercial part production. The company also announced the launch of a new sand based system, the Sentrol 3D SS400(G).

The SM350 is a metal AM machine based on Selective Laser Melting technology and can build metal objects up to 350 mm in diameter and 330 mm in height, at least 30 mm taller than the previous SM150 model. Suitable metal powders include titanium, inconel, cobalt chrome, stainless steel, maraging steel and more.

Seong Hwan Choi, CEO of Sentrol, stated that the launch of these new models would serve as a stepping stone for high-quality Korean AM machines to be noticed internationally and to compete against global players in the market. "With our metal 3D printers we plan to aggressively expand into industry sectors such as aviation, medical device, shipbuilding, construction and electric vehicle," he stated.

www.sentrol.net

InssTek and Z3DLAB to offer materials for aerospace part repair and medical implant markets

South Korea's InssTek and France's Z3DLAB have announced their intention to offer ZTi-Powder® and ZTi-Med® materials on InssTek product lines aimed at the repair of used parts in the aeronautic sector and the medical orthopaedic implant markets.

InssTek is a specialist in Direct Metal Tooling (DMT) technology which has been successfully used to repair parts of the F-15K fighter jets belonging to the South Korean Air Force. Z3DLAB develops and supplies AM materials for advanced engineering applications. The company's flagship ZTi-Powder is an enhanced TA6V powder, developed for additive powder bed SLM and being up to 50% harder and more resistant. It is claimed that Z3DLAB's ZTi-Powder and DMT technology from InssTek will provide a more advanced repair compared to regular TA6V, increasing the life of the repaired parts by up to 30%.

InssTek metal surface coatings applied to orthopaedic implants allow a three-dimensional interconnected array of pores throughout the coating thickness, which in turn helps to promote bone tissue ingrowth and provide long-term stability of the implant.

www.z3dlab.com
www.insstek.com

Hoeganaes to form joint venture with TLS to produce titanium powder for Additive Manufacturing

GKN Hoeganaes has agreed to enter into a joint venture agreement with TLS Technik to manufacture titanium powders in North America for Additive Manufacturing applications. It was stated that the new facility is planned to open in 2017.

TLS is located in Bitterfeld, Germany and has 20 years of experience manufacturing titanium powder. The new joint venture complements GKN's previously announced powder R&D efforts in Cinnaminson, New Jersey, and provides its customers with a North American source for titanium powders especially for the growing aerospace and medical markets.

GKN Hoeganaes, a subsidiary of GKN Powder Metallurgy, is a producer of metal powders for structural components with metal powder manufacturing facilities in the United States, Europe and Asia.

www.hoeganaes.com

Metal AM website re-designed

Metal AM magazine's website has been re-launched with a number of significant visual and technical upgrades. The updated website has been designed around a user-friendly interface, allowing it to fully adapt to the different screen sizes found in mobile and desktop devices.

As well as featuring the latest industry news, an archive of back issues of *Metal AM* offers anyone with an interest in AM technology to download past copies of the magazine in PDF format, free of charge.

There is a section of the site dedicated to providing an introduction to AM technology, as well as an industry events listing. The site also features more flexible advertising banner options, allowing companies to reach their market with a much clearer and more visual campaign.

www.metal-am.com

Renishaw opens dedicated healthcare facility at its South Wales site

Renishaw plc has announced a new Healthcare Centre of Excellence at its Miskin site, located close to Cardiff, South Wales, UK. The centre provides a facility for the manufacture of custom medical devices as well as education and training for the life sciences community. It highlights the company's continuing technology advances for the healthcare sector, including patient-specific implants, dentistry and neurosurgery. There is a mock non-sterile operating theatre and facilities for education, training, workshops and lectures, plus a facility for the manufacture of class 3 custom medical devices produced on Renishaw metal AM machines.

The manufacturing facility within the Healthcare Centre produces custom medical devices under an ISO13485 quality management system. The company's extensive manufacturing knowledge combines with its latest metal AM machines to enable the precision production of dental frameworks, craniomaxillofacial patient specific implants, jigs and guides.

Renishaw's metal AM systems are made at the Miskin site in a production hall adjacent to the Healthcare Centre. Manufacturing of metal components, electronic sub-assemblies and healthcare R&D activities are also undertaken on-site.

A demonstration area within the Centre also showcases Renishaw's full range of metrology and healthcare technologies, including Raman spectroscopy instruments, neurological products and therapies, dental scanners and frameworks, molecular diagnostics and additively manufactured implantable devices.

www.renishaw.com

Altair to reveal new design processes and software tools for Additive Manufacturing

Altair, headquartered in Troy, Michigan, USA, has announced it will showcase the latest versions of its software at this year's formnext powered by TCT, in Frankfurt, Germany, November 15-18. The company will display its simulation software suite HyperWorks® 14.0, concept design and optimisation tools solidThinking Evolve® and Inspire® 2016, highlighting new design processes for the development and manufacturing of innovative products.

In addition, Altair and its customers will also present their projects developed with Altair's software solutions. Highlights at the booth will be Altair's Simulation-driven Innovation™ approach, the development process chain of the Airbus APWorks' Light Rider, the world's first prototype of an additive manufactured electric motorcycle, the 3D printed antenna bracket by RUAG Space and the entire development and manufacturing processes of a cast aluminium component, developed jointly with Altair's partners HBM nCode and voxeljet.

The frame design of the Airbus APWorks' Light Rider that will be displayed at the event is an example of the symbiosis of topology optimisation and Additive Manufacturing. Its structure is based on optimisation results generated with Altair's OptiStruct® technology, supported by HyperMesh® for pre-processing tasks such as meshing and HyperView® for post-processing the analysis results.

The cast aluminium component also to be displayed at the booth was designed and optimised with Inspire, then nCode DesignLife was applied to conduct a fatigue analysis and finally solidThinking's Click2Cast® software was used for a casting simulation. The created design resulted in a casting mould, 3D-printed by voxeljet. This process ensured that the component benefited from all of the positive characteristics that 3D printing and casting offer.

"We are very much looking forward to presenting our solutions, including our Simulation-driven Innovation approach at formnext," stated Mirko Bromberger, Director Marketing and Additive Manufacturing Strategies at Altair Engineering. "Additive manufacturing is making headlines across industry as companies discover and take advantage of the inherent flexibility as well as the potential weight advantages the method offers, when combined with design optimisation techniques. As we will present with the example of the Light Rider, when topology optimisation and Additive Manufacturing are combined, it is possible to produce a structure that is lighter and stiffer than a traditionally manufactured part. The visitors to formnext can expect a very broad and informative program, highlighting solutions for the different production and engineering disciplines."

Visit Altair at formnext, hall 3.1/booth E 50 and at the TCT conference programs in hall 4.2.

www.altair.com

Prodways developing a new metal AM technology

Prodways, Les Mureaux, France, has announced it is developing a new metal Additive Manufacturing process using metal powder combined with organic binders. The company's R&D team has been collaborating on the project for two years with France's CEA-LITEN and the first successful production of titanium parts using this new process has now been announced.

Prodways claims that if it were to be ramped up to series production scale this new technology would offer substantial advantages compared to the highest performance methods currently in use. The technology is said to offer a printing process that is up to five times faster than direct metal Additive Manufacturing and has the ability to work with all types of metals (including titanium, inconel, cobalt-chrome, etc.). "We are still facing numerous challenges in development, but this first successful production, the result of a two year research study, is a major step forward," the company added.

Prodways obtained its first conclusive results in refining the process by using MOVINGLight® technology, a photopolymerization process for producing prototypes or functional parts with very high resolution and at very high speeds, by polymerising the photosensitive resins.

www.prodways.com

Optomec launches metal AM option for CNC platforms

Optomec, based in Albuquerque, New Mexico, USA, has launched a new machine tool series that integrates the company's LENS metal Additive Manufacturing technology into conventional CNC vertical milling platforms. The system is said to offer the industry's first Hybrid VMC controlled-atmosphere system.

Optomec's new LENS machine tool series combines CNC platforms from Fryer Machine Systems with LENS print engine technology. It includes three standard configurations designed to reduce manufacturing process times and costs while enabling improved end product performance and rapid design changes. The first configuration offers a LENS 3D Metal Additive System with open atmosphere processing. The second version is the LENS 3D Metal Hybrid VMC System, combining additive and subtractive operations on the same machine. Thirdly, the LENS 3D Metal Hybrid VMC Inert System provides an atmosphere-controlled environment to extend hybrid manufacturing capabilities for reactive metals and aluminium. The system can maintain oxygen and moisture levels at less than 40 ppm by replacing the upper enclosure of the CNC machine with a proprietary hermitically-sealed chamber and gas purification system.

www.optomec.com

Osaka Titanium to focus on powder for Additive Manufacturing

Osaka Titanium Technologies Co. Ltd., headquartered in Amagasaki, Japan, is expanding its range of titanium powders suited to metal Additive Manufacturing processes. Following external testing and evaluation, the company's TILOP grade of gas atomised spherical titanium powder is now available for AM systems. Osaka Titanium stated that it is also focusing on its TILOP64 grade for AM, a Ti-6Al-4V powder produced using a unique premixed atomisation process.

Osaka Titanium is one of the largest manufacturers of titanium products in the world, having begun commercially manufacturing titanium in Japan in 1952. As well as titanium sponge and titanium ingots, the company has made its TILOP gas atomised titanium powder for the Metal Injection Moulding, Powder Metallurgy and spray forming industries for over 20 years.

Taking advantage of the company's experience and knowledge of titanium sponge and powder manufacturing technologies, Osaka Titanium stated that it aims to proactively develop the market for titanium powder for AM, both at home and abroad, in response to the varied needs of the industry.

AM systems capable of processing titanium powder can vary widely, employing different melting methods, requiring different powder sizes and having different powder supply methods. As well as these differences, consideration has to be given to the shape of the end component and intended end-use sector. As the technological development of Additive Manufacturing systems is progressing rapidly, Osaka Titanium states that it is committed to continue developing its powders to suit future AM requirements.

www.osaka-ti.co.jp

EPMA announces project on quality tests for SLM metal powders

The European Powder Metallurgy Association (EPMA), in partnership with Fraunhofer IFAM, Bremen, Germany, has announced a new version of a Club Project proposal entitled Quality Test for Selective Laser Melting Powder (SLM-POWD).

This project proposes to address three objectives. It will study the applicability of a metal powder for the Selective Laser Melting process, set up a guideline on how to characterise and specify metal powders for SLM and set up a guideline on how to find the right laser parameters to process powder with SLM.

A full description of the project is available at www.epma.com/projects

www.epma.com

Automated sieving technology streamlines metal powder handling for Additive Manufacturing process

Farleygreene, based in Hampshire, UK, is a designer and manufacturer of state of the art sieving equipment and technologies. The company has announced a new metal powder sieving system that it is targeting specifically at the Additive Manufacturing industry. The company's Sievgen unit offers an ultrasonic screening system with inert atmosphere for classifying and recycling of metal powders pre and post build.

Sieving as a process has been around for many years, providing traditional industries with their screening needs. Taking the successes and lessons learned from previous projects, coupled with Farleygreene's 40 years of expertise, Sievgen is said to bring powder handling in-line with the high end AM machines on the market today. "The irony of this high-tech industry is that it requires a great deal of 'hands-on-hours' throughout the process, especially in what's seen as the 'dirty' practice of powder handling. Both production and powder costs are decreasing whilst skilled labour is of course expensive and, for many companies, this is the limiting factor," stated David Buckley, Sievgen Product Manager at Farleygreene. "The way to combat this is to bring the mechanisation of this 'dirty' side of the process up to the advanced level of equipment that exists within AM machines themselves."

With the high costs involved in using different media types this new system gives the user a quality assured powder for first time use, with the added benefit of reclaiming used powders where permitted. This unique product is capable of high-throughputs at very low operational cost due to its ease of use and automation of the process.

Sievgen offers combined sieving and conveying, the former under an inert atmosphere in order to keep the process safe. The working parts of the machine are enclosed within a mobile, stylish and streamlined shell. A touchscreen houses the Siev-Metric control software regulating the amount of powder processed, strength of sieve vibration, and controlling the ultrasonic generator and powder loading pneumatic transfer system. Siev-Metric also logs the amount of powder processed, allowing for batch control by material.

When in normal use the system provides for a completely sealed and dust tight process. The feed hopper is docked into place to feed the sieve unit with a self-sealing interface and the media is introduced through an internal metering device to ensure the optimum screen dwell time to recover as much useable material as possible. Oversize powder is continuously removed and 'good' product falls through the ultrasonically excited mesh.

www.farleygreene.com

Linde launches advanced oxygen measuring technology for AM

Linde Gases, a division of The Linde Group, has announced the launch of its ADDvance™ O2 precision, a measuring and analysis unit which will enable metal additive manufacturers to analyse and control more precisely the level of oxygen and humidity in the build chamber.

The new technology, which has been developed in response to a need identified by aerospace company Airbus Group Innovations, can detect oxygen levels down to 10 parts per million (ppm) in the build chamber and then modify the gas atmosphere by adjusting the level of argon or nitrogen.

The presence of too much oxygen or humidity can pose a challenge as it can negatively impact the quality and performance of the item being manufactured. In addition to ADDvance™ O2 precision allowing for more accurate levels of oxygen and humidity, it does so without cross-sensitivity effects and ensures a constant level of oxygen during the process.

The launch comes on the back of Linde's recent opening of a dedicated industrial gases laboratory for Additive Manufacturing in Unterschleissheim, Munich, Germany. The focus of the laboratory is to research the effect of different atmospheric gases and gas mixtures on the different metal powders used in Additive Manufacturing in order to optimise the various layering processes.

Reproducibility is one of the most important parameters for industries requiring strict consistency in end product, such as the aerospace and automotive industries. ADDvance™ O2 precision is an effective solution to improve reproducibility and through its new research facility Linde states that it will continue to lead research into how oxygen and humidity impact the additive manufacturing process.

"Linde has always played a leading role in developing new technologies for our customers in order to improve the efficiency of their production processes and quality of output," stated Pierre Forêt, responsible for Additive Manufacturing R&D at Linde. "That Airbus Group Innovations selected Linde to work with them to overcome such a challenge in the pioneering area of Additive Manufacturing is testament to Linde's technical competence and innovative spirit." ADDvance™ O2 precision was unveiled at Linde's exhibition stand at the World PM2016 Congress and Exhibition, Hamburg, Germany, earlier in October.

www.linde.com

Simufact to launch process simulation software solution for metal AM

Simufact Engineering GmbH, a MSC Software company based in Hamburg, Germany, has announced the launch of Simufact Additive, a new software solution for the simulation of metal Additive Manufacturing processes. Simufact Additive is said to be a powerful and scalable process simulation environment for 'right first time' optimisation of laser powder bed fusion processes. Features include simulation of all the key AM process steps starting with 'printing' of the part followed by heat treatment, cutting the part off the build plate and removal of support structures, plus heat and pressure combined processes.

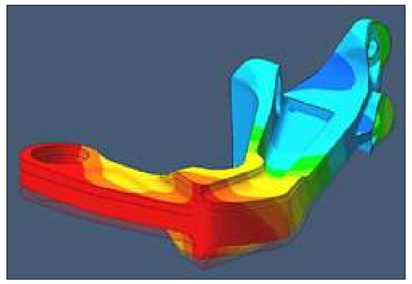
The company stated that initial release of Simufact Additive will predict the final distortion and residual stresses of the metal parts. The modelling is carried out using CAD data in an innovative graphical user interface (GUI) environment aligned with the real process work flow. The software offers an intuitive approach which starts with defining the general process by determining the part and support components. It continues through to definition of manufacturing parameters up to the analysis settings and ultimate results. The software helps to compensate the distortion, minimise residual stresses and optimise the process parameters.

"Today, companies employing AM technology for printing metal parts have to cope with failure in their production processes and the high knock on costs associated with this," stated Michael Wohlmuth, Simufact's CEO. "Simufact Additive is an important tool which will help these companies get it 'right first time', by regularly running simulations prior to production."

The software lays the foundation for a wide variability and scalability through different levels of details. This includes both a fast mechanical method for the prediction of distortion and residual stresses up to a fully thermo-mechanically coupled transient analysis. This will determine the temperature history and derived properties such as the microstructure. The properties of the final part are available for subsequent structural simulations.

The first results of this collaboration will be showcased at formnext 2016, November 15-18, Frankfurt, Germany.

www.simufact.com/additive



Simufact Additive will predict final distortion and residual stresses

Fraunhofer IKTS develops complex hardmetal tools via AM

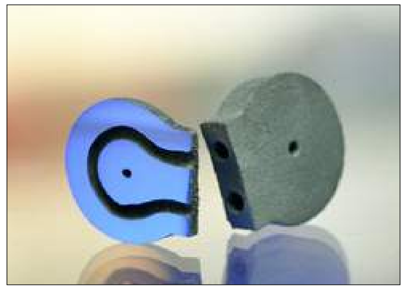
Researchers at the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS), Dresden, Germany, have announced the development of complex hardmetal tools via Additive Manufacturing in a quality that is reported to be in no way inferior to conventionally produced high-performance tools.

High mechanical and chemical performance as well as a high temperature resistance and extreme hardness are required for tools that are used in mechanical and automotive engineering or in the construction and forming industry. Reliable cutting, drilling, pressing and stamping tools made of hardmetals are manufactured by uniaxial or cold isostatic dry pressing, extrusion and injection moulding as well as by green shaping at Fraunhofer IKTS.

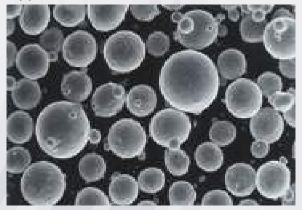
IKTS scientists have now succeeded in producing complex hardmetal tools using a binder jetting Additive Manufacturing method. The starting powders or granules are locally wetted with an organic binder by a print head and bound. The challenge with this process was stated to be achieving 100% dense components, which have a perfect microstructure and thus good mechanical properties.

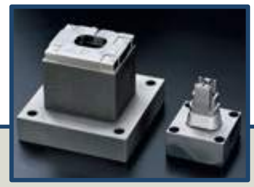
Hardmetals consist of a ceramic hard phase, such as tungsten carbide, and a metallic binder matrix of cobalt, nickel and/or iron. By varying the metallic binder, bending strength, fracture toughness and hardness can be adjusted individually – the lower the amount of binder in the hardmetals, the harder the tool material. The prototypes manufactured at Fraunhofer IKTS have a binder content of 12% and 17% by weight and show a structure comparable to conventional routes. "Through the use of 3D printed complex green bodies which were subsequently sintered under conventional sintering conditions, we achieved components with a typical hardmetal structure and 100% density. Moreover, it is possible to get a homogeneous cobalt distribution, thus achieving a comparable quality to conventionally produced high-performance cemented carbide-based tools," stated Johannes Pötschke, Group Leader (Hardmetals and Cermets) at Fraunhofer IKTS.

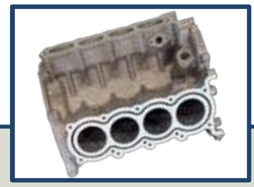
www.ikts.fraunhofer.de



Additive Manufacturing allows the inclusion of integrated cooling channels in complex hardmetal tools







Alcoa opens new metal powder production facility in Pittsburgh

Alcoa has announced the opening of a new metal powder production facility for manufacturing titanium, nickel and aluminium powders optimised for the Additive Manufacturing of aerospace parts. The new plant, located at Alcoa's Technology Center near Pittsburgh, Pennsylvania, USA, is part of a $60 million investment in advanced Additive Manufacturing materials and processes.

In addition to producing powders, Alcoa is focused on advancing a range of additive techniques, including its recently unveiled Ampliforge™ process. The process involves additively manufacturing a near complete part, then treating it using a traditional manufacturing process such as forging to further enhance its properties. Alcoa is piloting the technique in Pittsburgh and Cleveland.

The new facility will form part of Arconic following separation from Alcoa's traditional commodity business in the second half of 2016

www.alcoa.com

Automotive manufacturer uses EBAM to reduce tooling and die costs

It has been reported that Electron Beam Additive Manufacturing (EBAM) technology from Sciaky, Inc., a subsidiary of Phillips Service Industries, Inc. (PSI), in Chicago, Illinois, USA, has helped a major automotive manufacturer cut significant time and costs with the creation and repair of several tooling and stamping dies.

The manufacturer has used EBAM to deposit complicated tooling features, as well as perform customised repairs and cladding operations for several high-volume parts. Following a successful proof of concept stage, the additively manufactured tool has now been brought into service.

"Sciaky's EBAM technology is not limited to titanium parts and aerospace applications," stated Bob Phillips, Vice President of Phillips Service Industries, Inc. "We have provided 3D printed solutions to customers in a variety of industries like automotive, agricultural, defence, nuclear, oil & gas and sea exploration using a wide variety of metals like stainless steel, tantalum, tungsten, Inconel and niobium."

Sciaky's EBAM systems can produce parts ranging from 203 mm to 5.79 meters in length, but can also manufacture smaller and larger parts, depending on the application. EBAM is also the fastest deposition process in the metal additive manufacturing market, with gross deposition rates ranging from 3.18 to 9.07 kg of metal per hour.

www.sciaky.com

Elcan Industries offers screening systems for AM process

Elcan Industries, based in Tuckahoe, New York, USA, has reported that its new Hi-Sifter screening machines, originally developed for the pharmaceutical and food industries, are proving to be well suited to the metal Additive Manufacturing industry.

Elcan has stated that numerous companies have successfully tested products at its facility and have begun purchasing the screeners. Several positive trials on titanium powders and other metal alloys that are used in the Additive Manufacturing process have proven capable of removing 15 micron and below particles, enabling better printing performance.

The entire body and all product contact areas of the machine are polished stainless steel and allow for zero contamination. The high volume of energy being transferred to the screen allows for hard to screen metal alloys to flow seamlessly through the screen. The machine has a strong vertical vibration that allows for high rates of efficiencies and throughputs without any blinding.

Elcan claims that the removal of any potential for contamination within the machine, its explosion proof design and high energy make the machine the precise fit for companies looking to add screening machinery to their Additive Manufacturing plants.

www.elcanindustries.com

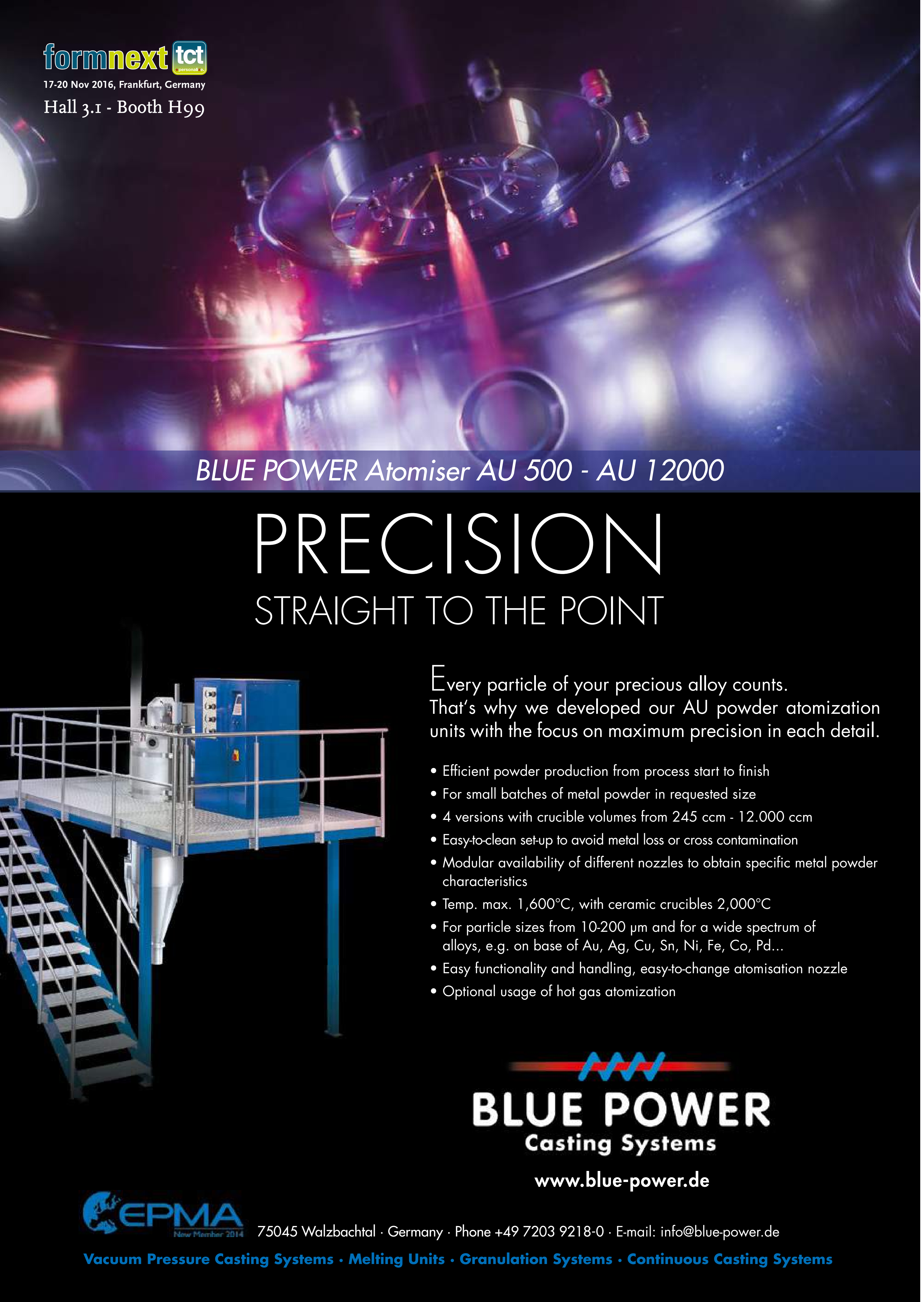
Congress on Welding, AM and NDT heads to Metz

The first International Congress on Welding, Additive Manufacturing and associated Non-Destructive Testing (ICWAM) is to be held in Metz, France, May 17 - 19, 2017. The congress is co-organised by Institut de Soudure and Ecole Centrale Nantes.

The main objective of the conference is to bring together welding technologists, metallurgists, NDT specialists and Additive Manufacturing researchers and end-users. Topics covered will include flexible fabrication, processing, specimen design, developing constitutive relationships, developing feedback loop, process monitoring and control.

A call for papers has been issued and those interested in presenting should submit an abstract no later than November 15, 2016.

www.icwam.com



Concept Laser's new software offers full control of parameter settings

Concept Laser, Lichtenfels, Germany, is now offering advanced users of its AM machines the option to view and freely modify all parameter characteristics through its CL WRX Parameter system. The software is directed towards users from research institutions and industry, in particular from the aerospace and medical technology sectors, where the ability to view and adjust all parameters can help in the qualification of new materials or products.

The CL WRX Parameter software provides the same tools that the development department at Concept Laser uses to develop parameters. The software can be stored on a PC and can thus be edited directly. For all material acquired from Concept Laser the customer optionally receives the speed parameter or quality parameter completely open and for individual adjustment, as far as available. The user can now also obtain further parameters in each case.

"CL WRX Parameter gives us the freedom to optimise our Additive Manufacturing for specific customers and applications and thus exploit the technology to its full potential. This allows us to manufacture products for the medical technology and aviation sectors to the highest quality standards and with qualified processes," stated Eric Wycisk, Technical Director of Bionic Production in Hamburg. Before the user can utilise CL WRX Parameter Concept Laser states that training from the company is absolutely essential. The complex relationships between the parameter options must be explained in order to avoid possible damage caused by incorrect settings in subsequent handling.

www.concept-laser.de

Materialise adds stainless steel

Materialise NV has announced the introduction of stainless steel to its range of materials available for Additive Manufacturing. The metal joins a list of over 30 other materials, including titanium and aluminium, now available for processing at Materialise.

The announcement follows the recent opening of Materialise's new metal AM facility in Bremen, Germany. With a global capacity of more than 130 metal and polymer AM systems and wide variety of available technologies, Materialise has grown into one of the world's largest and most comprehensive providers of AM services. Since its establishment in 1990, the company has been closely involved and actively contributing to the evolution of AM.

www.materialise.com

Titanium Additive Manufacturing used to build spacecraft valve body

SLM Solutions, headquartered in Lübeck, Germany, has announced the completion of a titanium aerospace component that measures 221 x 310 x 219 mm, making it the largest part to date built in an SLM280HL system. The standard build plate size for machines of this class is 250 mm x 250 mm. However the SLM 280, with its increased build plate size at 280 mm x 280 mm, makes larger-sized parts possible. Dual 400 W lasers help make it possible to build a part of this size in a relatively short time frame compared to conventional manufacturing.

"Advancements in Additive Manufacturing using titanium are particularly critical because it is a material that is normally very hard and thus subject to cracking due to high residual stresses, which was the real challenge," explained Mike Hansen, Applications Engineer for SLM Solutions North America. "While the geometry wasn't particularly complex the shear mass of building something that large in titanium with the additive process was challenging." The dual, overlapping laser technology developed and patented by SLM Solutions contributed to the success of this large titanium part. Two lasers working simultaneously on the part in the overlap area enabled not only a faster build but a larger part as well. SLM Solutions carried out tests on these overlap areas showing that there is no difference in quality between the area built exclusively by one laser and the area in the overlap worked on by both lasers interchangeably.

"This part is noteworthy because of its size and the fact that it was built out of titanium in six and a half days with no process interruptions," added Hansen. "The fact that our SLM machine can operate for that period of time, without requiring cleaning or experiencing any interruptions, is in itself extremely significant."

While AM tends to get attention for its ability to build unique geometries, the nature of this component was not particularly complex. However, producing a part of that size in titanium in such a short time was something that could not have been achieved had the part been machined out of a billet. "With Additive Manufacturing you're not restricted to traditional tools and machinery, so you can design in more organic shapes and the entire cycle of designing and engineering a critical part for the aircraft industry is condensed considerably," Hansen comments.

Richard Grylls, head of the applications engineering department/North America Technical Director and a Ph.D metallurgist, stated, "The part's size meant that it would have taken several weeks to machine conventionally, given that it would have required four or five setups it would have been a costly process. Casting the part would have taken even longer given that the tooling would have to be built, which could take as long as six months. And traditional tooling is expensive. We were far faster even though the cost was more. Still, in terms of the total time saved the cost is worth it for a critical part of this size."

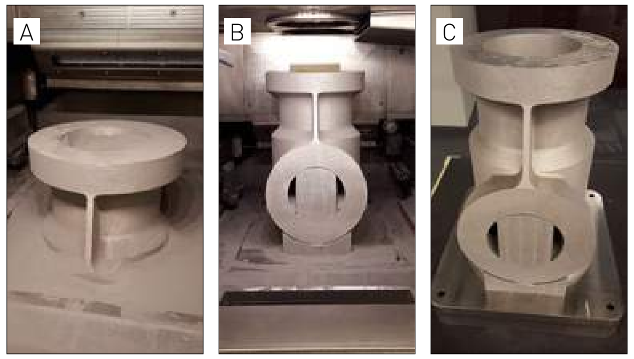
Hansen commented that, "meeting the stringent quality requirements and material specifications with titanium in highly regulated industries like aerospace and automotive involves much testing of the materials and optimising the parameters in order to make sure the customer got what they needed."

In general, aerospace requirements for inspection are quite extensive, usually involving a CT (computed tomography) scan to check for porosity or voids in the part, or the customer may perform destructive testing by cutting up the part. "We used non-destructive testing on this part, then performed a real-world test by mounting it on an engine in its intended use and running it until it failed," Hansen explained.

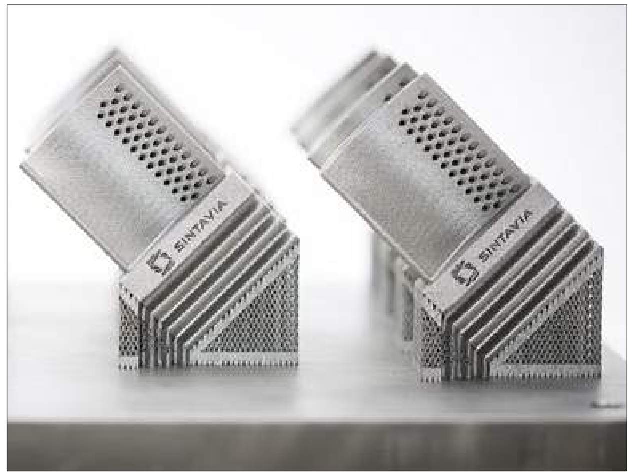
A recent study funded by the U.S. Department of Energy Advanced Manufacturing Office demonstrated that aircraft weight can be reduced by 7% by replacing conventional means of manufacturing with Additive Manufacturing – an impressive number for an industry where most weight efficiency improvements are one or two percentage points. "Within 20 years, there will be a seismic shift in how we manufacture for the aerospace and defence industry," said Brian Neff, Managing Partner of Neff Capital Management who recently established a new company to focus on the AM of production parts for aerospace and defence OEMs around the world. "However, producers who do not understand or are incapable of producing parts with repetitive quality will not play a role in the OEM supply chain."

Neff's newly established company, Sintavia, LLC, is headquartered in Davie, Florida, USA, and produces parts based on the exacting quality control standards required by the aerospace and defence industry. In addition to a serial production capability, the company maintains a state-of-the-art metallurgical and metrology lab. "We are excited to be a part of the coming industrial revolution within the aerospace and defence industry," said Neff. "Over the next few years, as more and more production is shifted to Additive Manufacturing within this industry, serial manufacturers with exceptional quality control, like Sintavia, will be in high demand by the OEMs."

Neff Capital's funding of Sintavia included a $10 million initial capital investment, rolled out as the company grows and develops its capabilities. To support the production of highly complex metal parts, Sintavia added three Selective Laser Melting SLM 280HL systems from SLM Solutions, one with a single 400 W laser and two with twin lasers of the same power. With a 280 x 280 x 350 mm build envelope, the SLM 280HL system offers options to configure a single 400 W or 700 W laser as well as dual (400 + 1000 W), or twin (400 W or 700 W) lasers. Likewise, the system's open software controls, bi-directional loader and closed-loop metal powder handling achieve the speed, safety and flexibility needed to optimise strict production parameters.



[A] Powder Bed: Upon completion of the build the part emerges from the lowered bed of powder to reveal the printed geometry, [B] Build Chamber: Completed part in the 280 x 280 x 365 mm build chamber of the SLM 280HL, [C] Spacecraft Valve Body completed build



Aerospace blades for the aerospace and defence sector from metal AM service provider Sintavia

As the AM industry evolves, SLM Solutions is seeing greater demand for more and more applications. However the materials and the process of producing these parts are advancing so fast that the standards are quickly becoming outdated. "We're being contacted by more companies used to traditional manufacturing that now need to increase speed and throughput while maintaining quality and want to convert conventionally manufactured parts into Additive Manufacturing," added Hansen. "This industry is changing on a day-to-day basis, evolving very quickly, but there is a disconnect between the pace of the evolution in Additive Manufacturing and the ability of some industries to keep pace with approving new materials and processes, particularly the aerospace and automotive industries."

www.slm-solutions.com

www.sintavia.com

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Autodesk launches Netfabb 2017 software for Additive Manufacturing professionals

Autodesk has announced the launch of Netfabb 2017, the latest version of its popular software solution for industrial Additive Manufacturing professionals. Netfabb 2017 integrates design enhancement, manufacturing preparation and build simulation tools in one software system that shares a common installer, common file formats and process definitions.

It was stated that users can access all the software they need to help reduce costs, increase efficiency and improve part performance in industrial Additive Manufacturing production environments.

"Additive manufacturing is having a profound impact on how manufacturers of all sizes look at product design, production, distribution and economies of scale," stated Samir Hanna, Vice President and General Manager of digital manufacturing at Autodesk. "With Netfabb 2017, Autodesk has created a single set of industrial tools that help move from design to finished part quickly and easily."

Since acquiring Netfabb in 2015, Autodesk has added a number of powerful new capabilities to the software package including enhanced simulation, optimisation and advanced toolpath capabilities. These provide engineers and designers with a broad collection of additive design and manufacturing tools.

www.netfabb.com
www.autodesk.com

AMUG conference registration open

The Additive Manufacturing Users Group (AMUG) has announced that online registration is now open for its 2017 Education & Training Conference, to be held in Chicago, Illinois, USA, March 19 - 23, 2017.

The Users Group conference is now in its 29th year and brings together engineers, designers, supervisors, plant managers and educators from around the world to share expertise, best practices, challenges and application developments in Additive Manufacturing.

The AMUG conference will include a technical programme with over 200 presentations as well as hands-on workshops designed to help users get more from their systems. An exhibition will be open during the first two evenings of the event.

www.am-ug.com

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Fully functional additively manufactured automotive cylinder block produced for Volkswagen

Robert Hofmann GmbH, Lichtenfels, Germany, has additively manufactured a fully functional aluminium cylinder block for a Volkswagen VR6 engine. Weighing around 25 kg, the AM cylinder block has undergone and passed a number of tests at Volkswagen, offering significant advantages compared with conventional prototypes.

The cylinder block is virtually the same as Volkswagen's existing series VR6 cylinder block, except for being made from aluminium instead of a cast iron GJL-250 material. CAD data of the existing cast iron cylinder block was used for the prototype which took 300 hours to produce on a Concept Laser X 1000 R system. It was stated that Volkswagen wanted to investigate the potential of Additive Manufacturing technology and convinced the team at Hofmann to take on the project. "When Volkswagen approached us with the idea to build a complete cylinder block in a 3D-printer, we were a bit sceptical in the beginning," stated Michael Dinkel who managed the project at Hofmann.

Following the initial build a number of post-processing operations were necessary, especially with the cleaning and removal of the necessary support structures.

The additively manufactured cylinder block was built in 300 hours on a Concept Laser X 1000 R system

Aluminium powders loosely stuck to the cylinder block after the build had to be removed with close attention given to the difficult to access and narrow areas such as undercuts. Support structures had to be cut out with high precision, even in areas which were hard to reach.

Before the cylinder block could be fully tested at Volkswagen the cylinder liner was coated with an APS-lining. Engineers at Volkswagen then carried out extensive metallurgical and geometric tests. For example, the tests included computer tomography to check internal geometries, such as the cooling jacket around the cylinder tubes, which showed that the AM cylinder block

The AM cylinder block is based on Volkswagen's existing cast cylinder block found in the VR6 engine

has low porosity and significantly smaller distortions and deviations from the desired geometry when compared to cast components. With the successful running of the motor, Robert Hofmann GmbH and Volkswagen proved that it is possible to produced functional cylinder blocks via Additive Manufacturing. This, they stated, could be an important milestone for the future of the car industry.

The cylinder block will on display at formnext, taking place in Frankfurt, Germany, November 15 – 18, hall 3.1, stand E30.

www.hofmann-innovation.com

Seminar to explore the design freedom of AM through simulation

A two day seminar, taking place November 22 – 23, 2016, in Helsinki, Finland, has been organised by NAFEMS Nordic in cooperation with VTT Technical Research Centre of Finland to explore the design freedom of Additive Manufacturing through simulation. In addition to a comprehensive seminar programme, delegates will also have the opportunity to visit the AM facilities at VTT Technical Research Centre of Finland and Aalto University.

The aim of this seminar is to provide an overview of the current state of AM, along with the challenges, risks and opportunities both for simulation engineers and for those within manufacturing. Speakers from industry, research institutes and universities will present on a wide range of topics including AM process simulation, topology optimisation, new design and simulation approaches. There will also be a workshop on the creation of design guidelines for selective laser melting.

NAFEMS is the International Association for the Engineering Modelling, Analysis and Simulation Community. The association provides the engineering analysis community with as many as fifty seminars, courses, workshops and open forums throughout the world each year.

www.nafems.org/am16

Metal Additive Manufacturing helps French cycle team win Olympic medal

Metal Additive Manufacturing technology has been used to help develop custom handlebars for France's cycle team at this year's Olympic Games in Brazil. Erpro & Sprint partnered with the French Cycling Federation and GIE S2A in the development of custom handlebars for seven athletes who competed at the games. The handlebars were produced on a SLM 280HL metal AM machine from SLM Solutions and contributed to the French men's team sprint Bronze medal.

The handlebar designs created by GIE S2A took advantage of the design possibilities Additive Manufacturing offers by incorporating an interior lattice structure, providing strength yet minimising the weight. Additional weight savings were realised through the lightweight material choice, as the handlebars were printed in aluminium on the SLM 280HL system.

In the debut race with the new equipment in Italy earlier this year, French cyclist Thomas Boudat took first place. Leading up to the Olympics, athletes were optimistic about the competitive advantage the additively manufactured handlebars could bring as the UK's Olympic gold medallist Sir Bradley Wiggins had broken records riding with AM handle bars just a few months earlier.

With the largest build chamber in its segment at 280 x 280 x 350 mm, the SLM 280HL offers high throughput technology with multiple laser configurations and a patented bi-directional recoating. Integrated SLM Build Processor and open software architecture offers the freedom of controlling system parameters

The handlebar designs created by GIE S2A incorporate an interior lattice structure, providing strength yet minimising the weight

to optimise for unique requirements, such as Olympic handlebars. Erpro & Sprint became the first French facility to purchase the quad laser SLM 500HL metal Additive Manufacturing system earlier this year to increase their manufacturing capabilities.

www.slm-solutions.com
www.erpro.fr
www.soufflerie2a.com

voestalpine opens research centre for metal Additive Manufacturing

The voestalpine Group has opened a new research and development centre for the Additive Manufacturing of metal parts at its site in Düsseldorf, Germany. The voestalpine Additive Manufacturing Centre will house the group's research activities in AM, harnessing the process for particularly complex and lightweight metal components.

"The new development and test centre will continue to research and develop both metal powders and the design and production of metal components using 3D printing. It therefore represents a significant expansion to our existing material production and processing value chain for the most sophisticated industries," stated Franz Rotter, Member of the Management Board of voestalpine AG and Head of the Special Steel Division.

voestalpine also announced it is investing in new metal powder atomisation facilities at the group's subsidiaries Böhler Edelstahl GmbH & Co KG, Austria and Uddeholms AB, Sweden, to supply the Düsseldorf site. The next step is said to be more cooperative partnerships and locations in North America and China.

"As a result of the intensive research and development work undertaken in the past 15 years, voestalpine has developed from a traditional steel manufacturer to become a global leading technology and capital goods group. We want to consistently strengthen this position and continue to remain at the forefront of developments in new production processes such as Additive Manufacturing," stated Wolfgang Eder, Chairman of the Management Board of voestalpine AG.

www.voestalpine.com

Atomisation for Metal Powders short course

Atomising Systems Ltd and Perdac Ltd (now part of CPFResearch Ltd) have announced that the Atomisation for Metal Powders intensive short course will take place in Manchester, UK, February 23-24, 2017. The course will consist of presentations from John Dunkley (Atomising Systems Ltd), Dirk Aderhold (Atomising Systems Ltd), Doug Millington Smith (Freeman Technology) and Andrew Yule (Manchester University).

Sessions will cover the main methods of atomising metals, the specific requirements for different classes of metal, the design, operation and economics of plant, Additive Manufacturing, measurement methods and modelling techniques.

www.atomising.co.uk
www.perdac.com
www.cpfresearch.com

EOS introduces its largest and fastest system for direct metal laser sintering

The EOS M400-4 has build volume of 400 x 400 x 400 mm

EOS, based in Krailling, Germany, introduced its latest EOS M 400-4 metal Additive Manufacturing system at the recent IMTS show in Chicago, USA. Designed for industrial applications, the quad-laser system expands the company's Direct Metal Laser Sintering (DMLS) range and offers increased productivity, part quality and scalability to meet various manufacturing requirements.

"Following our strategy to establish the Additive Manufacturing technology for production in all industries we have developed this pioneering DMLS system. The EOS M 400-4 is a perfect addition to our industrial systems portfolio. It shatters the boundaries of manufacturing as it meets the most demanding requirements of our industry partners in terms of efficiency, scalability, usability and process monitoring," stated Dr Adrian Keppler, Chief Marketing Officer at EOS.

The EOS M 400-4 expands the company's range of DMLS systems. It offers a large build volume of 400 x 400 x 400 mm and is equipped with four 400 Watt lasers operating independently in 250 x 250 mm squares each including an overlap of 50 mm. The system builds on the well-established and validated process of the EOS M 290 technology. "As the system offers a modular platform designed for industrial 3D Printing, it can easily be integrated into existing production environments and the customer set of future innovations," added Keppler.

As part of the EOS M 400-4 system, the patented EOS ClearFlow process gas management technology ensures optimal and consistent processing conditions. It distributes the process gas in an intelligent way to avoid interference of the lasers with by-products of the melting process. In addition, the integrated industrial-grade, recirculating filter system with its long filter lifetime significantly reduces operating times and expenses.

Initially, EOS NickelAlloy HX and EOS MaragingSteel MS1 will be available for the EOS M 400-4 with other materials to follow. Parameters can be modified to meet individual application requirements using the EOS ParameterEditor.

www.eos.info

TEI reports on use of EOS's EOSTATE MeltPool monitoring

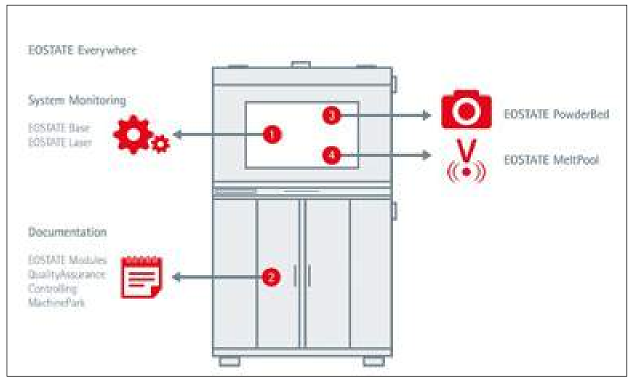
EOS introduced its EOSTATE MeltPool solution as an add-on to the EOS M 290 DMLS system towards the end of 2015. The system was developed to allow complete part trace-ability as well as an automated surveillance and analysis of the melt pool during the build process. An evaluation of the monitoring system has recently been completed at Tusas Engine Industries Inc. (TEI), the leading aviation engine manufacturer in Turkey.

"We consider the EOSTATE Meltpool monitoring system as an initial step for online control and part quality inspection. As such, it was part of our initial technical specifications for the DMLS process and we felt privileged to be one of the first pilot customers to test it," stated Semih Pilatin, Technology Programs Manager at TEI. During the DMLS build process the monitoring system observes the light emitted by the melt pool. Extensive hardware helps to separate the process light from the reflected laser light. The software then offers automatic error correction of the data that is created, as well as process visualisation and evaluation in real time. For the purpose of data analysis, the EOSTATE MeltPool Analysis Toolbox illustrates data in 2D or 3D form, including the ability to analyse discrepancies.

"We are planning to use this tool for aerospace engine parts manufacturing where tight tolerances and high performance are expected. With this tool, we can capture potential part defects online at an early stage and with minimal effort to assess the part quality," added Pilatin.

EOS offers EOSTATE MeltPool as an extension to the EOS M 290 DMLS system for monitoring the manufacturing process. "The decisive factor for customers on the road towards series manufacturing based on AM is reproducible top-quality parts at the lowest costs per part possible. The EOSTATE MeltPool Monitoring allows the movement of part quality assurance from post- to in-process, as such not only supporting a better risk management, but as well reducing time and costs for quality assurance and as a consequence overall costs per part," stated Lukas Fuchs, Application Development Consultant MeltPool for Monitoring Solutions at EOS.

www.tei.com.tr | www.eos.info



A number of process monitoring options are available for EOS systems

FIT AG: Laying the foundations for high-volume metal Additive Manufacturing

There is no doubt that the Additive Manufacturing of series components is quickly becoming a reality. From high-profile applications in the aerospace industry to performance components for the automotive sector, there are now numerous examples of the successful implementation of metal AM. However, the route that a company chooses in order to adopt AM technology could have a significant impact on a component's development time and cost. As Nick Williams reports, Germany's FIT AG sees opportunities in leveraging its expertise to supporting companies with the outsourcing of component development and production. To achieve this, the company has created a model AM factory that it plans to replicate worldwide.

FIT Group, based in Lupburg, Germany, has ambitious plans for metal Additive Manufacturing. The company is one of the world's most experienced in the development and production of AM components thanks in large part to its early involvement in rapid prototyping. It is, however, approaching the goal of creating a state-of-the-art factory for higher volume series metal Additive Manufacturing with an energy and ambition that would put even the most motivated of start-ups to shame.

The force behind the company is its founder and CEO, Carl Fruth. His no-nonsense approach to the industry and his vision for the metal AM factory concept is based on more than twenty years of experience in additive technologies. This experience is balanced with the recognition that metal Additive Manufacturing has to develop into a far more stable, automated and cost-effective process if it is to succeed in series production. Whilst this may sound like an obvious approach, the reality of developing a viable state-of-the-art factory for series metal AM component production is far from straightforward.

The story to-date

In the summer of 2015 FIT AG announced that it was investing €20 million in a new purpose built factory specifically designed for the Additive Manufacturing of high volume components. A year later, when *Metal Additive Manufacturing* magazine visited the company, construction of the first of the new futuristic looking production buildings had been completed and the manufacture of metal and plastic parts was underway (Figs. 1-3).

Fig. 1 The first of FIT's AM factories in Lupburg, Germany

Fig. 2 Interior view of FIT's new AM facility in Lupburg

Reaching this point has in itself been a long journey for the company. Founded in 1995, FIT was a pioneer in the world of commercial rapid prototyping using both metals and plastics. The company started researching paper lamination technology in 1997, followed a year later with trials of Selective Laser Sintering (SLS) technology. By 2003 the company was producing laser sintered rapid tooling for customers and in 2005 the first Electron Beam Melting (EBM) system was in operation for the production of titanium components. Production capacity continued to expand and in 2013 the world's first four-laser machines, SLM Solutions' SLM 500s, were installed. Within a year this had been expanded to seven SLM Solutions machines, including three large frame SLM 500s.

As the business grew so did FIT's expertise in developing the necessary software for AM, culminating in the formation of Netfabb GmbH in 2009. Netfabb's software became one of the most used AM design and manufacturing tools and its success resulted in the acquisition of Netfabb by Autodesk in 2015. FIT's unrivalled reputation in the field of AM software development is further reflected in the company's status as a founding member of the 3MF Consortium alongside international corporations such as GE, HP and Microsoft. The consortium is committed to defining and evolving a 3D printing file format that allows designers to send full-fidelity 3D models between multiple platforms and manufacturing equipment.

At the same time as the acquisition of Netfabb, Autodesk made a strategic investment in FIT AG, acquiring 10% of the company. This development was a natural fit for two businesses that share a vested interest in the increased adoption of AM technology for industrial-scale manufacturing. The investment also provided capital to support Fruth's ambition of creating a state-of-the-art Additive Manufacturing factory.

Today FIT has more than 220 employees, with most of them located at the company's headquarters in Lupburg. The company operates two distinct businesses, FIT Prototyping GmbH and FIT Production GmbH. The group has two further subsidiaries, FIT Nord GmbH near Hamburg, and FIT West Corporation in Boston, Massachusetts, USA. Turnover in 2015 was €17 million, representing an increase of 30% on the previous year.

The business is centred around three main segments; Prototyping, Additive Design and Manufacturing (ADM) and Research and Development. The AM factory concept fits most closely within the ADM segment that specialises in additive engineering as well as high and low volume AM component manufacturing. The Prototyping segment has specific expertise in concept models and functional prototypes, however pre-production runs are also accommodated. The R&D segment specifically addresses system, process and materials development.

Fig. 3 Arcam EBM machines used for the series production of AM titanium components

Creating a metal AM factory template

FIT's primary mission with its facility in Lupburg is the optimisation of a high production volume AM factory template that can be rolled out at other sites around the world. "This factory will serve as a master concept for commissioning industrial Additive Manufacturing close to our customers. By copying the entire production process of an efficiently operating Additive Design and Manufacturing plant, manufacturing costs will be reduced and quality of the parts improved," Fruth told *Metal AM* magazine.

This concept is based on the belief that whilst ever more end-users will recognise AM as a technology that can revolutionise their business, they will chose to collaborate on component development and then outsource production rather than creating their own in-house metal AM facility. Outsourcing could, at the simplest level, involve placing orders for parts to be optimised and manufactured in Lupburg or a future FIT manufacturing site. On a larger scale, a manufacturer could enter an agreement to establish a dedicated metal AM facility near a customer's site using FIT's factory template.

One of the attractions of this route for a company looking to take advantage of metal AM is that it significantly decreases process and component development time. Given that AM requires a completely different approach to conventional manufacturing methods, this can be a significant advantage.

> *"On a larger scale, a manufacturer could enter an agreement to establish a dedicated metal AM facility near a customer's site using FIT's factory template"*

Fruth explained that, in terms of part design alone, the knowledge that an engineer has to possess in order to successfully produce parts by Additive Manufacturing differs fundamentally from conventional manufacturing methods. When the unique challenges of AM production are added, for example system and process stability, materials expertise, materials recycling, post-processing, quality assurance and traceability, the task can appear overwhelming. "People think that metal AM is easy to implement. You have the design freedom, you have a machine that can build complex parts and you believe

Fig. 4 The open-source nature of machines from SLM Solutions and Arcam has been an important factor in enabling FIT's engineers to develop its AM workflows. The company's overhead powder supply systems can be seen in this photo.

that the product comes straight out of this system at the end. This just isn't the case. At FIT our goal is to support you in harnessing the power of Additive Design and Manufacturing."

Fruth added, "There is a belief that to benefit from metal AM you have to set up your own metal AM facility and at the heart of this people see AM machines. But machines are simply machines: they are not the be all and end all. AM machines are just part of a wider process that has to be developed and evolved. Digital manufacturing is disruptive but it is also highly complex. On top of this, the technology is looking to replace processes that in some cases have been refined over many hundreds of years. Put it this way, if you need investment cast parts you probably won't go straight out and buy an investment casting plant. So why buy an AM machine when you can work with us to design, develop and then manufacture your products?"

There is clearly a demand for the company's expertise and to keep up with orders FIT has doubled its production capacity in the last twelve months. Installed equipment within the new facility in Lupburg now includes eighteen Selective Laser Melting machines for aluminium and superalloy parts production. These consist of fifteen SLM Solutions machines plus three EOS machines. This brings the number of lasers, a clearer indicator of production capacity, to sixty. In addition, the facility has four Arcam EBM machines for titanium production. A number of additional machines are on order to be installed within the next twelve months.

"Machines are simply machines: they are not the be all and end all. AM machines are just part of a wider process that has to be developed and evolved"

Fruth explained that as the factory concept evolved it became clear that the flexibility of the open source nature of the machines from SLM Solutions and Arcam was essential for the company. "Developing a metal AM factory demands the customisation and specialist configuration of AM machines, both in terms of hardware and software. Open source machines win here for us" (Fig. 4).

He cautioned, however, about underestimating the wider requirements of a metal AM factory. Machines are an important aspect of the process but they have to be fully integrated into a purpose built, modular and automated AM factory. Customisation and the development of in-house solutions does not therefore stop with the production machines. In addition to sophisticated data networks to monitor and record all operations in the factory, the network concept has been taken a step further when it comes to the handling of metal powders. Metal powder delivery is continuous and fully automated using a network of overhead pipes that feed powder from a central source to each production machine. All materials run in separated pipe feeds under over-pressure to avoid contamination. Manual feeds are only used on a laboratory and prototyping level. The company has also developed its own powder sieving systems to maintain the consistent powder properties that are essential to successful high volume production.

A number of heat treatment operations such as T6 are carried out in-house, however Hot Isostatic Pressing (HIP) operations are outsourced. Fruth stated, "HIP is still done externally as it is unclear for today if this technology will still be needed in 2020. As soon we know about this we are going to decide if this is a useful investment."

Workflow planning

The secret to high volume AM production, stated Fruth, lies in detailed and sophisticated workflow planning, but he cautioned that it is only with experience of volume production that workflows can be fully understood and refined.

Whilst we were standing outside FIT's new AM factory building, Fruth pointed to a McDonalds restaurant sign on the horizon and pressed home the point that just as a fast-food chain can only succeed when process and supply chain are fully optimised, an industrial scale AM operation also has to have every aspect of its workflow and supply chain in place. "The beauty

Fig. 5 EOS machines are used for both metal and plastic AM at FIT

Fig. 6 Pre-processing work includes data conversion, orientation, data modification, support structures, build space management and slicing

Fig. 7 Finishing operations on a titanium medical implant at FIT

Fig. 8 Post-processing of a prototype automotive cylinder at FIT

of McDonalds, of course, is that the business has unlimited scalability. You can also go into any restaurant in the world and because the workflows and supply chain are so sophisticated, you will always get exactly what you expect. This is our mission for metal AM, process and supply chain in harmony, with unlimited scalability."

Reducing costs

With scale and workflow optimisation comes the opportunity to reduce costs and Fruth states that prices will come down significantly in the next five years. The cost of metal AM products will be reduced through a combination of scrap reduction, increased output per machine thanks to faster processing, a reduction in raw material costs and a reduction in the number of operators required per machine. There are, of course, numerous other factors that will also play a role in increasing the efficiency of an industrial-scale process.

Fruth anticipates that with part design, workflow and machine improvements the cost of metal AM parts will drop from a current price of around €3.00 per g for aluminium, titanium and stainless steel alloys to €2.00 in 2017 and €1.00 by 2020.

"We talk to engineers a great deal about metal AM, but the reality is that they cannot facilitate change. We also have to be talking at management and board level"

Getting into the mind-set for the metal AM revolution

Fruth believes that the majority of potential end-users simply are not prepared for digital manufacturing because they have not understood the broadest concepts of how the technology will change manufacturing. "Manufacturing is today based on the traditional linear optimised assembly lines with clearly defined zones, but digital manufacturing and the Industry 4.0 concept turns this on its head."

The challenge is, therefore, far more fundamental than trying to educate designers about the requirements and possibilities of AM. Fruth stated that it is essential that the integration of digital manufacturing into a business happens on multiple levels, with the boardroom being the driving force. "Such a fundamental shift in attitudes needs to be driven at a board level. We talk to engineers a great deal about metal AM, but the reality is that they cannot facilitate change. We also have to be talking at management and board level."

Managing change is a challenge in any organisation, but the aversion to change increases significantly the larger a company is. "There is a natural resistance to change at all levels. The fear of re-qualifying parts, the fear of change that may result in the elimination of your job and the fear of moving from processes that you understand to processes that you do not are just some examples of the effects that such a shift can have in an organisation. It will of course be a bigger challenge for larger companies to make the move to using AM than for operators with less baggage."

Designing for AM is understood by those with knowledge of the technology as being of fundamental importance. It is, however, a message that is still failing to reach many in industry. "Coming to us with an existing part that you just want to make by AM will never work. In order for AM to succeed a part has to be designed for the process and this takes experience and knowledge. There also has to be a reason to use AM, be it advanced functionality, the need for customisation or certain production volumes. We can help with this, but anything else will simply make no financial sense."

Fig. 9 An exhaust manifold manufactured by Selective Laser Melting at FIT

Unrealistic expectations are, however, not limited to design considerations. "Companies have to learn to understand the nature of the process. When we are making a single component for a customer they have to appreciate, for example, that a build plate is shared with other components from other companies and they have to understand that in AM powder has to be recycled. This is a part of the process and needs to be more widely understood."

ADM solutions tailored to specific requirements

During the evaluation of a component for AM at FIT a number of criteria are considered to establish which of the company's ADM programmes the part most closely relates to. For single or limited part production the ADM-Quality (ADM-Q) programme focuses on the development of a component to a level where it can be manufactured to specification and within a fixed budget. Quality certificates accompany the part in line with the respective part's requirements.

Whilst the quality of single parts and small batch series is assured by the ADM-Q programme, ADM Volume Manufacturing (ADM-V) focuses on establishing a thorough and consistent process control for larger series production. A full audit trail of every job, part variations and the tracking of material batches is, states the company, the foundation for ADM-V to meet the necessary level of quality control. In addition, parts for higher volume production are subjected to a far more intensive process of design optimisation with the evaluation and testing of a number of design variants where necessary.

Whilst ADM-V development takes longer than for an ADM-Q component, the results typically include reduced final component weight and, of course, significantly reduced unit costs. As an extension of ADM-V, customised volume manufacturing enables the efficient production of a large number of individualised single parts in one production cycle to achieve genuine mass customisation.

Quality management at FIT

The quality requirements of metal AM parts are application and market specific and as such FIT is ISO 9001 and EN 9100 certified (the European equivalent of AS 9100 for aerospace) and the company's medical devices and implants are FDA compliant and fulfil the requirements of the EN ISO 13485. The company is also certified to the automotive industry supply chain standard ISO/TS16949.

Traceability is offered at all stages of AM part production, from the starting powder to testing of the final product. The company has also recently confirmed the purchase of a CT scanner that will provide customers with certification that their critical components do not contain defects such as cracks or voids.

Fig. 10 This concept F1 Cylinder Head is manufactured on a SLM 500 machine using AlMg10Si powder by FIT. By applying Additive Design and Manufacturing, FIT used AM technology to significantly increase the surface cooling area while achieving reduced vibration and great weight reduction of the part

Fruth stated that a realistic approach to metal AM needed to be taken from a quality assurance perspective. "The aerospace industry was an early adopter of AM technology and new applications in this sector attract considerable attention. This is the sector, however, that demands the highest levels of quality assurance because of the critical nature of the components used. This puts a lot of pressure on a young technology. It has to be remembered that all parts fail at the highest level and such extreme levels of quality assurance come at a very high price. Growth for the industry will therefore come from more mainstream applications where the quality assurance and qualification requirements are less cost-prohibitive."

> *"Growth for the industry will come from more mainstream applications where the quality assurance and qualification requirements are less cost-prohibitive"*

Markets

FIT's most important markets for its Additive Design and Manufacturing business are motorsport, medical, defence, aerospace and advanced engineering. Motorsport has long been an adopter of AM technologies as the process can achieve the highest requirements in terms of component performance and flexibility. The technology can also offer very short development times. By applying Additive Design and Manufacturing to a prototype F1 cylinder head, FIT used Selective Laser Melting to significantly increase surface cooling area while achieving reduced vibration and part weight (Fig. 10).

The metal AM industry has also enjoyed considerable success with the production of medical implants and FIT specialises in the manufacture of implants made from Grade 2 and Grade 5 titanium alloys by Electron Beam Melting (Figs. 11 and 12). These bone replacing implants are used when a section of bone is missing and the gap needs to be filled, for example following an accident or after the removal of a tumour. AM's main advantages lie in the extremely short lead times that average one to two weeks instead of six to eight weeks by conventional

technology. AM can also generate a rough and deliberately porous surface that allows for improved bone ingrowth, or osseointegration, helping to avoid common problems such as loose and unstable implants and to shorten rehabilitation time. With AM, of course, implants are produced to a size and shape specifically to meet a patient's requirements.

In terms of the wider markets for metal AM, design innovations at OEMs will, believes FIT, lead to a much wider adoption of the technology, particularly when combined with a fundamental shift in the approach to manufacturing. In order to facilitate this the company offers "Additive Design and Manufacturing" workshops that cover all aspects of the component development and production process.

Fig. 11 Spinal implant cages manufactured by EBM at FIT

Innovation: People: training and education

Those studying for engineering related degrees at university generally recognise Additive Manufacturing as a high profile and attractive industry from a career perspective. There are, however, widespread concerns in the industry about the number of people with the necessary skillsets to sustain growth. FIT's workforce is continually expanding as the company grows and, to help meet the challenge of securing a skilled workforce, the company runs a number of highly sought-after apprenticeships.
In September this year eighteen apprentices started their training at FIT, a record number for the company. These apprenticeships cover all aspects of AM including process mechanics, mechatronics, modelling, product design and IT.

"Access to capable young talent is very important to us. Our trainees learn in a very high-tech industry and contribute from the outset to growth of the company. Again and again they are also among the best of their peers. We are very proud of what we achieve with these apprenticeships," stated Lorenz Barth, Personnel Manager at the FIT AG. The company

Fig. 12 A HIP replacement manufactured by EBM at FIT

Fig. 13 Quality inspections at FIT

employs a high proportion of women, at around 40%, and it has made efforts to successfully integrate disabled workers into the business.

Outlook

Given the rapid pace of metal AM's growth it is impossible to predict with any certainty how trends in part manufacture will play out. For the major aerospace manufacturers there will always be the funds and skills available to develop systems and workflows in-house whilst additionally retaining a level of technology independence and security in terms of production capacity. There will, however, also be companies that have the desire to take advantage of all that metal AM can offer for series part production whilst working with an experienced industrial partner to facilitate this.

FIT's commitment to the development of a model production facility dedicated to higher volume AM part production has without doubt put it in a leading position to be able to capitalise on the rapidly increasing demand for metal AM parts. "We believe this is what qualifies us as the industrial partner to implement new manufacturing concepts with customers worldwide," stated Fruth. He cautioned, however, that the technology still has a long way to go in terms of industrialisation. "We only know 5% of what there is to know about commercial AM production. The industry has only touched on the surface of the challenge and potential of metal AM."

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The evolution of AM at GE: On the acquisition trail as the focus turns to technology supply

With the announcement of GE's planned acquisitions of metal AM machine producers Arcam and SLM Solutions, the company is making a bold move to not only enhance its already significant AM expertise but also to position itself as a leading supplier of AM technology to the wider industry. This ties in closely with GE's ambitions to evolve into the world's leading 'digital industrial company.' *Metal AM* magazine's Nick Williams reports on the recent developments at GE and the milestones that led to this point.

On September 6, 2016, GE announced plans to acquire two leading suppliers of Additive Manufacturing equipment, Sweden's Arcam AB and Germany's SLM Solutions Group AG, for $1.4 billion. This news came as a surprise to the majority of those in the AM industry and served to boldy reinforce GE's previously stated ambitions in the Additive Manufacturing sector. The planned acquisition of Arcam and SLM Solutions would significantly bolster GE's already impressive material science and Additive Manufacturing capabilities. The company had invested approximately $1.5 billion in manufacturing and additive technologies since 2010, enabling it to develop additive applications across six of its business areas, create new services applications across the company and earn more than 300 patents in the area of powder metals alone.

Jeff Immelt, Chairman and CEO of GE, stated when announcing the proposed Arcam/SLM acquisition, "Additive Manufacturing is a key part of GE's evolution into a digital industrial company. We are creating a more productive world with our innovative world-class machines, materials and software. We are poised to not only benefit from this movement as a customer, but spearhead it as a leading supplier. Additive Manufacturing will drive new levels of productivity for GE, our customers, including a wide array of Additive Manufacturing customers, and for the industrial world." Should the deals go through, GE expects to grow the new additive business to $1 billion by 2020 at attractive returns and also expects $3 to $5 billion of product cost-out across the company over the next ten years [1]. At the time of publishing, the acceptance deadlines for the SLM Solutions and Arcam acquisitions were October 24 and November 1 respectively.

Fig. 1 AM components with an SLM Solutions machine at GE Power's Advanced Manufacturing Works in Greenville, South Carolina (Image: GE Power) [2]

Fig. 2 An Arcam Q20 Additive Manufacturing machine (Courtesy Arcam AB)

Should the deals go ahead, both Arcam and SLM Solutions would report to David Joyce, President and CEO of GE Aviation, who would lead the growth of these businesses in the AM equipment and services industry, as well as leading the integration effort and the GE Store initiative to drive Additive Manufacturing applications across GE.

In addition to supporting the growing use of AM components within GE's businesses and positioning GE as a major supplier of AM production technologies, the planned acquisitions would also allow GE to leverage its Predix platform for the industrial internet. Any AM equipment portfolio that can be acquired would form part of GE's Brilliant Factory initiative, which aims to help manufacturers increase production efficiency, execution and optimisation through advanced real-time analytics. This technology, it was stated, will enable all manufacturers to realise GE's Brilliant Factory vision.

"We chose these two companies for a reason," explained Joyce. "We love the technologies and leadership of Arcam AB and SLM Solutions. They each bring two different, complementary additive technology modalities as individual anchors for a new GE additive equipment business to be plugged into GE's resources and experience as leading practitioners of Additive Manufacturing. Over time, we plan to extend the line of Additive Manufacturing equipment and products."

The additive effort will utilise GE's global ecosystem but will be centred in Europe. GE will maintain the headquarters locations and key operating locations of Arcam and SLM Solutions, as well as retain their management teams and employees. These locations, it was stated, will collaborate with the broader GE additive ecosystem including the manufacturing and materials research centre in Niskayuna, New York, and the additive design and production lab in Pittsburgh, Pennsylvania.

GE's initial targets

Arcam AB

Arcam AB, based in Mölndal, Sweden, invented the Electron Beam Melting (EBM) machine for metal Additive Manufacturing. Its customers are predominantly in the aerospace and healthcare industries and in 2015 the company generated $68 million in revenues with approximately 285 employees. The company's most widely used machines are the Q10 and the Q20 (Fig. 2), with the current generations of both of these machines marketed with the 'plus' designation. The systems are targeted at the orthopaedic and aerospace sectors respectively, with the Q20plus offering a larger build area that is better suited to turbine blades and structural airframe components, for example.

Arcam stated that its Board of Directors had unanimously recommended that the company's shareholders accept the offer made by GE. The initial offer valued Arcam's ordinary shares at SEK 285 per share, corresponding to a total offer value of SEK 5,855,776,725 (US $686,322,797). In terms of Arcam's long-term prospects, the company believes that the demand for its technology for the AM of aerospace and orthopaedic implants will increase dramatically. However, in assessing the merits of GE's offer, the board stated that the company had limited resources and that it operated in a demanding and highly regulated environment with long lead times. Furthermore, Arcam's board commented that the market for AM was still 'rather immature' and could be subject to technological leaps that would require substantial investments in order to deliver on its business plan [3].

GE stated that Arcam's strategy and products aligned closely to its vision of building its own expertise and capabilities in AM to serve customers in the global industrial community. GE added that it had the resources needed in order to implement and take advantage of Arcam's growth and business opportunities and that it would provide the know-

Fig. 3 SLM Solutions' flagship SLM®500HL can be fitted with up to 4 x 400 W lasers (Courtesy SLM Solutions Group)

how and expertise to further leverage the company's technology 'to forcefully go to market with Arcam's products and services' [3].

Advanced Powders and Coatings, Inc. (AP&C)

In addition to EBM machine production, Arcam also operates Advanced Powders and Coatings, Inc., a specialist metal powder producer based in Montreal, Canada, as well as DiSanto Technology, a medical Additive Manufacturing firm in Connecticut, USA.

AP&C is of particular interest as it would give GE specific expertise in metal powder production for AM and related powder-based part production technologies such as Metal Injection Moulding. AP&C, which was acquired by Arcam in February 2014 [4], uses proprietary plasma atomisation technology to produce highly spherical powders of reactive and high melting point materials such as titanium, nickel, zirconium, molybdenum, niobium, tantalum, tungsten and their alloys. Since the announcement of the proposed acquisition of Arcam by GE, AP&C has revealed that it is planning to invest up to CAD $31 million in a second metal powder production facility that will see the creation of more than 100 new jobs, more than doubling the firm's workforce over the next three years.

Alain Dupont, President of AP&C, stated at the time of the new plant's ground-breaking ceremony, "This investment makes it possible to provide our existing and future clients with superior quality powders to meet the high manufacturing standards of the aerospace and orthopaedic industries. With this new powder production facility and advances in atomisation technology, AP&C will significantly increase capacity" [5].

SLM Solutions Group AG

SLM Solutions Group, based in Lübeck, Germany, produces laser-based machines for metal Additive Manufacturing with customers in the aerospace, energy, healthcare and automotive industries. The company generated $74 million in revenues in 2015 with 260 employees. In addition to its operations in Germany, SLM has sales and application sites worldwide. Should the proposed acquisition go ahead, GE stated that it would maintain the headquarters and key operating locations of SLM Solutions, as well as retaining the management team and employees.

Hans-Joachim Ihde, founder and Chairman of the Supervisory Board of SLM Solutions Group AG at the time of the announcement of the proposed acquisition, stated, "General Electric has already accompanied us as a user and customer since our inception. They assumed a pioneering role in aerospace technology and were early to identify the benefits of Selective Laser Melting, for example in terms of savings in the weight of components. They are entirely familiar with SLM Solutions' multi-laser technology and its advantages vis-a-vis our competitors" [6].

Fig. 4 AM allows engineers to manufacture objects with complex internal geometries that would be otherwise very difficult or expensive to achieve, such as this fuel nozzle (Images: GE Reports/Chris New)

SLM Solutions' flagship system is the SLM®500HL (Fig. 3), which provides a large build envelope of 500 x 280 x 365 mm and features the company's patented multi-beam technology. In the high-performance SLM®500HL machine, four fibre lasers (4 x 400 W) operate simultaneously, increasing the build-up rate by up to 90% compared with a twin laser configuration (2 x 400 W). The system has fully automated powder management located between the SLM system and the sieving station in which the metal powder is continually sieved and fed to the building process. This eliminates the time-consuming manual filling of the system. Tasks such as the cleaning of the cylinder and the removal of components are performed in a separate unpacking unit, enabling the next build job to be started in parallel using a second construction cylinder.

As with Arcam, SLM Solutions Group also has interests in metal powder production for Additive Manufacturing. In February 2016 the company entered into a cooperation venture with PKM Future Holding GmbH to manufacture AM-grade metal powders. PKM is the main shareholder of TLS Technik GmbH & Co Spezialpulver KG, a manufacturer of gas atomised metal powders in Bitterfeld, Germany [7].

"As with Arcam, SLM Solutions Group also has interests in metal powder production for Additive Manufacturing"

The venture, in which SLM Solutions is reported to have a 51% stake, focuses on the development, production and distribution of aluminium alloys for AM systems. At the time of the announcement it was estimated that more than 100 tonnes of aluminium powder would be produced annually for Additive Manufacturing purposes. It was also stated that the production of further materials may commence at a later point. The expansion of SLM Solutions' metal powder business was seen as helping to overcome the 'strong seasonality' of the company's machine system business whilst also recognising that extremely attractive margins can be achieved through developing and marketing metal powders.

GE's key previous AM related acquisitions

Morris Technologies

In November 2012 GE Aviation acquired the assets of Morris Technologies and its sister company Rapid Quality Manufacturing (RQM), both based in Cincinnati, Ohio, USA. With these acquisitions, GE sent the international community a clear signal of intent with regards to its ambitions for AM technology [8].

Founded by Greg Morris, Wendell Morris and Bill Noack in 1994, Morris Technologies and RQM had supplied parts to GE Aviation for a number of years, as well as to GE Power Systems and GE's Global Research Center. Early commercial applications included lightweight parts for unmanned aerial vehicles (UAVs) for the US military as well as medical applications. The companies were also contracted by GE Aviation to produce components for the best-selling LEAP jet engine.

Whilst the acquisition of Morris Technologies was regarded as an effective route to secure AM capacity and expertise, the planned acquisitions of Arcam and SLM Solutions can been seen as more strategic in nature, not

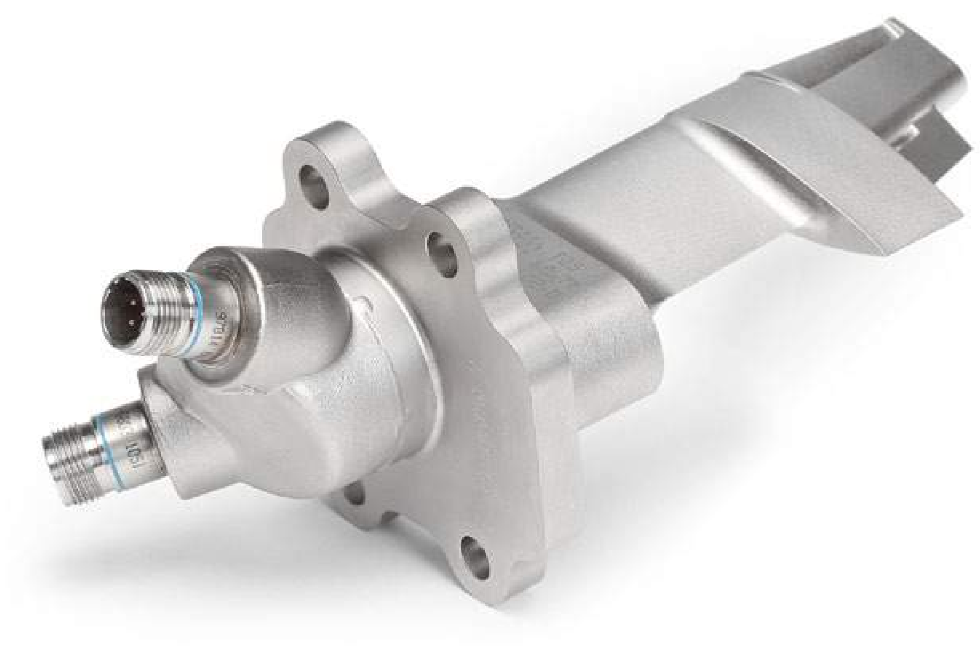

Fig. 5 The AM housing for the T25 sensor. Located in the inlet to the high-pressure compressor, the sensor provides pressure and temperature measurements for the GE90 engine's control system (Image GE Aviation) [11]

only bolstering GE's capability for the in-house development of AM applications, but also placing the company at the forefront of the development and supply of AM equipment, expertise and materials to industrial markets worldwide.

Avio Aero

In August 2013 GE completed the acquisition of the aviation business of Avio S.p.A., a leading Italian provider of civil and military aviation components and systems. The purchase price of $4.3 billion did not include Avio's space unit. Avio's aviation business was renamed Avio Aero, a GE Aviation business [9].

This acquisition furthered GE's participation and expertise in the areas of mechanical transmission systems, low-pressure turbines, combustion technology and automation systems. Avio Aero was also a leading manufacturer of AM aerospace components using both EBM and laser-based powder bed technologies and it has specific expertise in applications such as turbine blades. The company also developed metal powders specifically for its AM processes. Today Avio Aero has more than 4,600 employees worldwide, around 4,000 of whom are based in Italy.

In December 2015 Avio Aero ordered ten Arcam EBM systems for the production of state of the art turbine blades, doubling the company's EBM machine capacity [10]. At the time of the purchase, Giacomo Vessia, Plant Leader at Avio Aero, stated, "These machines will be vital to move to series production of turbine blades. Arcam is the leading supplier of titanium alloy Additive Manufacturing systems and we again turned to them with confidence, having used their products for years." This was the largest single order for Arcam EBM systems to-date, confirming the value to GE of Arcam's EBM technology as a volume production system for the aerospace industry.

GE's AM application milestones in the aviation industry

It is widely recognised that applications for AM in the aviation sector offer huge potential in terms of weight saving, enhanced component functionality through previously unimaginable design complexity, as well as the ability to simplify production by merging what would have been an assembly of multiple components into a single item. Furthermore, the use of AM in this sector, where the technology is applied to critical high performance components, has caught the public's imagination and GE has been extremely successful in maximising its much deserved exposure in the media - exposure from which the industry as a whole has benefitted.

T25 sensor housing

In February 2015 GE received FAA Certification for its T25 sensor housing, GE Aviation's first AM part

Fig, 6 An AM fuel nozzle manufactured by GE for the LEAP engine (Image: GE Reports/Adam Senatori) [13]

and one that is used in the GE90 engine (Fig. 5). The part was first used in flight in April 2015. The upgraded T25 sensor, located in the inlet to the high pressure compressor, was retrofitted into more than 400 GE90-94B engines in service. The T25 sensor provides pressure and temperature measurements for the engine's control system [11].

"Additive Manufacturing has allowed GE engineers to quickly change the geometry through rapid prototyping and producing production parts, saving months of traditional cycle time for the T25 sensor housing without impacting the sensor's capabilities," stated Bill Millhaem, General Manager of the GE90/GE9X engine program at GE Aviation at the time of the announcement.

It would normally take GE several years to design and prototype such a part, but the GE team was able to shave as much as a year from the process. "The 3D printer allowed us to rapidly prototype the part, find the best design and move it quickly to production," added Millhaem. "We could never do this using the traditional casting process, which is how the housing is typically made."

"Additive Manufacturing has allowed GE engineers to quickly change the geometry through rapid prototyping and producing production parts, saving months of traditional cycle time"

Fuel nozzles for the LEAP engine

In July this year GE Aviation introduced into airline service its first additively manufactured jet engine component, a fuel nozzle with extremely complex interior features, for the LEAP engine (Fig. 6). The LEAP engine is the new, best-selling engine from CFM International, a 50/50 joint company of GE and Safran Aircraft Engines of France.

Turkey's Pegasus Airlines was the first airline to take delivery of the Airbus A320neo powered by CFM International's LEAP-1A engines. Airbus had selected the LEAP-1A as an option for the A320neo in 2010 and the engine flew for the first time on the A320neo on May 19, 2015. The LEAP-powered A320neo received its Type Certification from the European Aviation Safety Agency (EASA) and the US Federal Aviation Administration (FAA) on May 31, 2016 [12, 13].

In addition to featuring a combustor that uses the new AM fuel nozzles, the LEAP-1A, which powers the Airbus A319neo, A320neo and the A321neo aircraft, features some of the industry's most advanced technologies. These include 3D woven carbon fibre composite fan blades and fan case, a unique debris rejection system, 4th generation three dimensional aerodynamic designs, ceramic matrix composite shrouds in the high-pressure turbine and titanium aluminide (Ti-Al) blades in the low-pressure turbine. The engine will provide operators with double-digit improvements in fuel consumption and CO_2 emissions.

More than 11,000 LEAP engines are on order with up to 20 fuel nozzles in each engine. This, states GE, sets the stage for sustainably high and long-term additive production at GE Aviation's Auburn, Alabama, manufacturing plant. Production will ramp up to more than 40,000 fuel nozzles using Additive Manufacturing by 2020.

Commenting on the LEAP project in July 2014, Greg Morris, General Manager, Additive Technologies at GE stated, "We spent years proving out this technology for a critical component in the heart of the engine, the combustion chamber. Now we are well positioned to apply this technology to other components in the same harsh environment which could prove to be game changing for future engine programs and designs" [14].

CATA: GE's new $39 million AM centre

In April 2016 GE opened its new Center for Additive Technology Advancement (CATA) near Pittsburgh, Pennsylvania, USA, with the aim to drive innovation and the implementation of Additive Manufacturing across the company (Figs. 7-9) [15]. The centre will focus on developing and implementing industrial Additive Manufacturing applications from which all GE businesses and customers will benefit.

The new facility represents a $39 million investment over three years and will initially result in the creation of fifty engineering jobs in disciplines ranging from mechanical and electrical to systems and software

Fig. 7 An AM machine at CATA is vacuumed to salvage unused metal powder and prevent cross-contamination (Image: GE Reports/Chris New) [15]

Fig. 8 An Ipsen heat treatment furnace at GE's CATA facility for the thermal processing of additively manufactured parts (Image: GE Reports/Chris New) [15]

Fig. 9 A CATA worker using an electric discharge machine to separate AM parts from the support plate (Image: GE Reports/Chris New) [15]

engineering. The site is designed as an innovation hub, offering training and development in both design and applications.

Commenting at the time of the centre's opening, Philippe Cochet, GE's Chief Productivity Officer, stated, "Today's opening is strong evidence that GE is leading the digital transformation of industry, starting with a hub for the advancement of Additive Manufacturing techniques. The application of insights from digital connectivity in collaboration with intelligent devices will elevate the skills of our workforce, streamline productivity and enhance product development overall. This represents a new era of manufacturing."

The new facility reflects GE's belief that the intersection of technology and manufacturing – marrying hardware with software – will change the way industry creates, iterates and services products. In line with GE's Brilliant Factory concept, CATA will combine lean manufacturing and optimal productivity with advanced software analytics to improve capabilities and usage of Additive Manufacturing across GE while advancing materials sciences and inspection technologies.

GE stated that CATA will contribute to the global exchange of knowledge, technology and tools across the company and, as a multimodal facility, will contribute advances to a number of our industrial businesses including aviation, transportation, power and oil and gas.

AM beyond aerospace: GE's oil and gas plant in Talamona

Whilst the aerospace industry has to some extent become a flag bearer for the capabilities of Additive Manufacturing, the technology is succeeding in finding commercial applications in a wide range of other industries, including many in which GE has business activities. The oil and gas sector is one notable example and in May 2016 GE inaugurated a new AM component production line at the GE Oil & Gas plant in Talamona, Italy [16]. The line uses laser-based systems to additively manufacture end burners for gas turbine combustion chambers.

GE Oil & Gas states that it is pioneering the industry's foray into Additive Manufacturing, which offers increased speed and accuracy in component production. The company commented that AM technology 'represents the next frontier' for energy manufacturing. After extensive validation of AM during prototyping of the NovaLT16 gas turbine, GE decided to move the technology into full production, leveraging the design enhancement capabilities, cycle time reduction and improved product quality.

GE Oil & Gas opened an Additive Manufacturing laboratory in Florence, Italy, in 2013 with the installation of a laser-based powder bed AM machine. Since then, the laboratory has increased its capabilities thanks to the addition of two further machines for the development of turbomachinery components and special alloys. Collaborations with GE Aviation and GE Global Research Centre have significantly accelerated the development of the technology within GE.

"The opportunities for the application of Additive Manufacturing and 3D printing in the oil and gas industry are only just starting to be explored and it will require an ongoing rethink of component design and production approach," stated Massimiliano Cecconi, GE Oil & Gas Materials & Manufacturing Technologies Executive at the time of the plant's inauguration. "GE Oil & Gas is fostering the development of this technology to produce complex components for gas turbines, while cutting costs, boosting performance and reducing emissions."

Outlook

Whilst this overview presents some of GE's activities in metal AM, it by no means presents the complete picture of how deeply the technology is being integrated into the company's businesses. GE has of course been investing and growing its work in Additive Manufacturing for many years at R&D sites across Asia, North America and Europe. What is clear, however, is that GE sees AM as far more than a technology with which to simply produce cutting edge components for its own business groups. The planned acquisitions of leading AM machine manufacturers, be it SLM Solutions and Arcam as initially planned or alternative firms, would position GE to become a leading supplier of AM production technologies and ties in closely with its ambitions to evolve into a 'digital industrial company.'

As Immelt stated at the time of the Arcam and SLM Solutions announcement, "GE's aspirations in additive fits our long-term business model. We have world-class industrial businesses that leverage systems integration, material sciences, services and Predix. We want all of our businesses to leverage the GE Store, promote digital differentiation and drive productivity for GE and our customers. We are excited about the opportunity" [1].

From Arcam, SLM Solutions and AP&C there has also been a clear message since the proposed acquisition that chimes with the message from GE - it will be business as usual in terms of the supply of production machines and materials for AM should the deals go ahead. It remains to be seen if last minute obstacles can be overcome, but as GE's CFO Jeff Bornstein stated recently, the company does have options and alternatives.

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Selecting atomised aluminium alloy powders for the metal Additive Manufacturing process

As the metal Additive Manufacturing industry continues to grow at a rapid pace, aluminium and aluminium alloy powders are gaining ever more attention. Component and equipment manufacturers are deploying immense efforts in exploring advanced aluminium alloys in order to target more complex applications that demand higher mechanical performance. As they move forward, the selection and optimisation of powders is becoming increasingly important. In this article, Jessu Joys and colleagues from United States Metal Powders, Inc. (USMP), identify the most popular aluminium alloy grades for AM technology and discuss the unique properties of each powder.

Today a wide range of aluminium alloy powders are commercially available. However, only a small number of these are proving popular in industry, with the majority being based on cast alloys. As there are no established standards, these powder grades have been sub-categorised into several customised grades, predominantly based on particle size distribution with slight variations in chemistry. This article will review the particle size distribution, morphology, flow properties, oxide content and specific surface area of the most popular aluminium alloy grades for AM technology. It will also look at optimising particle size characteristics, a challenging task in AM due to the various processes that are used in the industry. Aluminium powder characteristics and properties of existing metal powder part manufacturing technologies, namely Powder Metallurgy (PM) and Metal Injection Moulding (MIM), will also be compared to AM technology.

Metal powders used in the AM process

In metal AM parts are typically produced from a feedstock in the form of powder or wire using a layer by layer process. Metal Additive Manufacturing is further classified into sub-categories such as Powder Bed Fusion (SLM/SLS/DMLS, EBM etc), Direct Energy Deposition, Binder Jetting and Sheet Lamination. Both Powder Bed Fusion and the Direct Energy Deposition methods use metal powder grades with a particle size distribution ranging anywhere from 10 µm to around 150 µm. Laser-based Powder Bed Fusion processes are

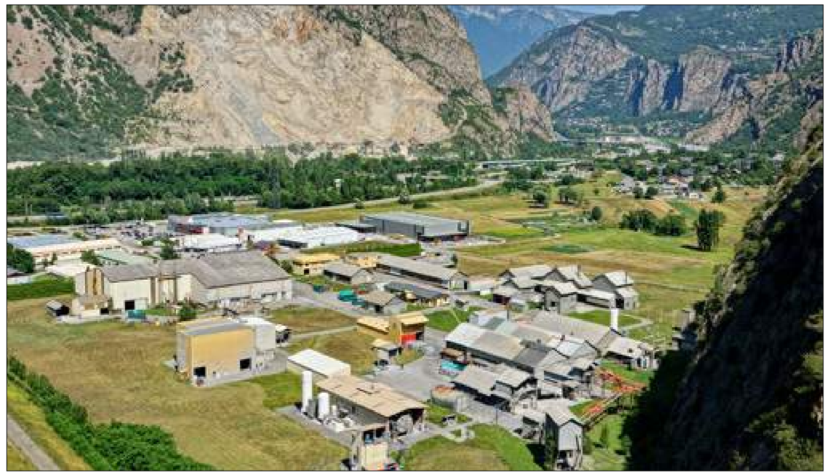

Fig. 1 USMP's Poudres Hermillon SARL aluminum powder plant in Hermillon, France

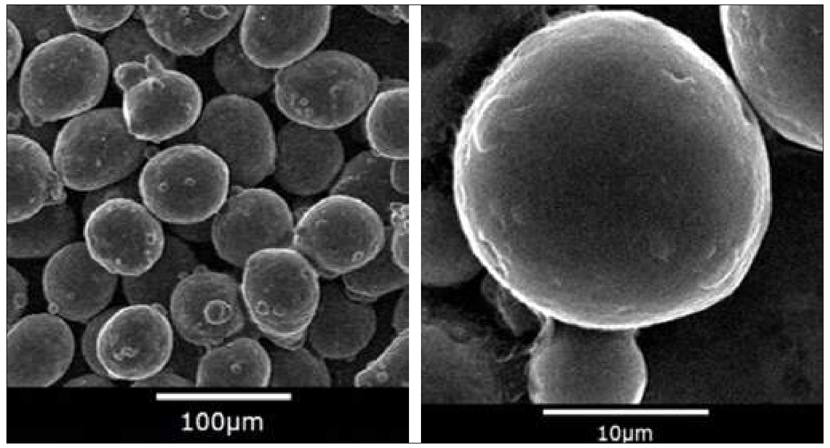

Fig. 2 Spherical AlSi10Mg powder

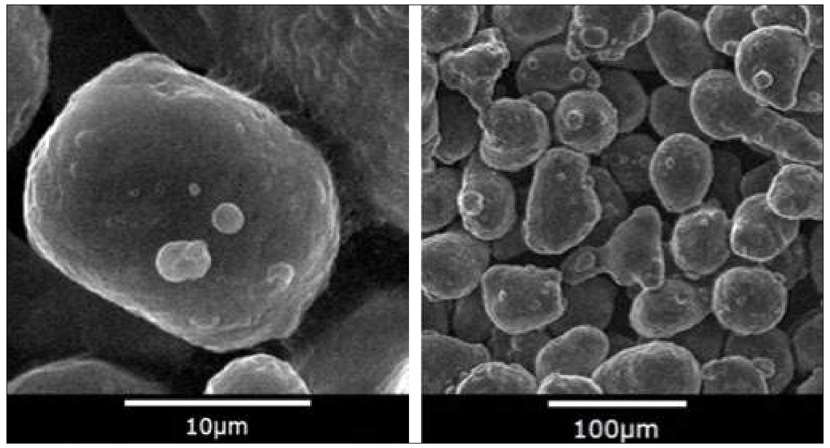

Fig. 3 Spheroidal AlSi10Mg powder

amongst the most widely known and typically use powders in the size range from 10 µm to around 75 µm. Most of the powders that are being used in these technologies are cobalt, iron, nickel or titanium based alloys. More recently, aluminium alloy powders have surged in popularity within the light metals category.

Aluminium alloy powder production and properties

The majority of the aluminium and aluminium alloy powders that are available in the market are produced by air or inert gas atomisation [1]. The inert gas atomised aluminium alloy powders can be produced with a particle morphology that is spherical, spheroidal or nodular by varying the atomising conditions and modifying the atomisation techniques. The gases that are primarily used in inert gas atomisation are argon, helium and nitrogen. The properties of aluminium alloy powders change with variations in the atomisation process, however metal AM is more suited to powders with a spherical morphology. Spheroidal and occasionally nodular powders will also work, depending on the machine technology used, the powder flow properties and other characteristics of the powder.

One of the most popular aluminium alloy powders in the industry is AlSi10Mg. Two grades of AlSi10Mg alloy powders with different particle morphologies are produced by USMP using proprietary inert gas atomisation technology for application in metal AM. The SEM pictures of these powders are shown in Figs. 2 and 3. Both of these powder grades are being successfully used in two types of Selective Laser Melting machines. However, the spherical powder is much easier to process because of the improved flow. The powder flow characteristics of both of these grades were measured using Hall and Carney flow methods, two established standards that are used in the metal powder industry [2]. While studying the two types of AlSi10Mg powder grades, the spherical powder that had been optimised for metal AM

	Aluminium & Trace elements	Si	Mg	Zn	Cu	Others
F357	Rem.	6.5 – 7.5	0.4 – 0.7			Ti: 0.04 – 0.2
AlSi10	Rem.	9 – 11				
AlSi10Mg	Rem.	9 – 11	0.2 – 0.5			
AlSi12	Rem.	11 – 13				
AlSi14	Rem.	13 – 15				
6061	Rem.	0.4 – 0.8	0.8 – 1.2		0.15 – 0.4	
7075	Rem.		2.1 – 2.9	5.1 – 6.1	1.2 – 2.0	Cr: 0.2 – 0.3

Table 1 Basic chemistry of popular aluminium alloy powder grades in AM

flowed through the Hall flow cup, but the spheroidal powder did not. However, the customer was able to successfully produce parts from both types of powder. This study demonstrated the importance of understanding the capability of the AM machine and optimising the powder properties. One of the key issues in standardising metal powder grades for the AM industry is the wide variety of technologies that are used in the industry and the proprietary nature of developing AM production methods.

Popular aluminium alloy powders used in Additive Manufacturing

Over the past few years, the AM industry has been using several types of aluminium alloy powders and a list of the most popular alloy grades and their standard chemical compositions is given in Table 1. Most of these are silicon-based casting alloys which makes processing easier mainly because of their lower melting points.

A wide range of aluminium AM parts have been developed for a variety of applications using AlSi10Mg and today it is the most popular aluminium alloy powder grade in the metal AM industry.

The majority of the research work on aluminium Additive Manufacturing has used the low melting point casting alloys. However, several other studies have also been conducted, using wrought alloys such as 6061 and 7075. The 6000 series alloy powders have a number of outstanding properties including ductility, machinability, thermal conductivity, electrical conductivity and corrosion resistance. These properties make it one of the most popular alloys for manufacturing parts for the electrical, electronic and other industries. The 7000 series alloy powders, with a high zinc content, are known for their excellent mechanical properties and are heat treatable to achieve even higher strength.

	Carney Flow (Sec/50 g)	Hall Flow (Sec/50 g)
PSD: µm	15 – 70	15 – 70
AlSi10Mg – Type A	9 – 12	60 – 70
AlSi10Mg – Type B	20 – 25	No Flow
F357 – Type A	10 – 14	70 – 80
F357 – Type B	No Flow	No Flow

Table 2 Comparing the powder flow properties of aluminium alloy powders used in AM

Powder flow and particle size distribution

The shape of inert gas atomised powders can be spherical or spheroidal. The capability for processing powder grades with different flow characteristics varies for each type of AM machine, but most metal powder AM part makers prefer a free flowing powder. When it comes to measuring flow there are several standards that have been used in the Powder Metallurgy industry.

Particle size distribution is one of the most important properties and powder bed processes benefit from a uniform, selected narrow distribution of particles, without the fines (<10 µm) and coarse particles (>80 µm) from the distribution curve. The laser diffraction technique is one of the best known methods for analysing particle size distribution and this was discussed in a case study carried out by Kippax and Deffley [6]. In the metal AM industry, particle size distribution ranges vary anywhere from 10-80 µm to 20-40 µm for the laser-based technologies, whereas Electron Beam Melting (EBM) can use much larger particles in the range 40-150 µm.

"The majority of the research work on aluminium AM has used the low melting point casting alloys. However, several other studies have also been conducted, using wrought alloys such as 6061 and 7075"

In a study for this report, two types of AlSi10Mg alloy powder grades, with the same chemistry, were produced by USMP via inert gas atomisation. The particle size distribution and flow characteristics of these AlSi10Mg alloy powder samples are shown in Table 2. The major difference between the Type A and Type B grades are in relation to particle morphology, where Type A alloy powder grades have more spherical particles compared to Type B. Type A grades were atomised to have the most spherical shape and were classified very closely to have the optimum powder flow characteristics. Even with poor flow, the Type B grade of AlSi10Mg has been successfully used in the AM industry and this makes it very difficult to determine the minimum required flow properties of powder for AM. The American Society for Testing and Materials (ASTM) is working on a new test method (ASTM WK55610) for characterisation of powder flow properties for AM applications and this will hopefully address the concerns surrounding powder flow test methods designed for metal AM powders. Some standards have been published for use in the AM industry,

Fig. 4 The specific surface area of aluminium powders is determined by the size distribution and the morphology

Aluminium	PM	MIM	AM
Typical particle size distribution	70 – 110 µm	10 – 40 µm	10 – 150 µm
Particle Morphology	Irregular, Nodular	Spheroidal, Spherical	Spherical, Spheroidal
Surface area, m^2/g	0.4 – 0.6	0.3 – 0.5	0.3 – 0.4
Oxygen content, %	<0.5 %	<0.4 %	<0.3 %

Table 3 Comparison of aluminium PM, MIM and AM powders

but there is still a dearth of known standards for aluminium.

Recycling of the powder from AM processes is extremely important. This is because of the difficulty in handling the aluminium alloy powder and ensuring that the recycled powder is not segregated. A uniformly blended alloy powder with a narrow distribution of particles will always be helpful in minimising the segregation.

> *"Creating aluminium alloy powder grades for the AM industry with standard chemistries may be easier to achieve, but the particle size distribution needs to be tailored to the component manufacturing method"*

Specific surface area and surface roughness

As metal AM shifts its focus from prototyping to manufacturing, powder properties will play an ever more important role. Creating aluminium alloy powder grades for the AM industry with standard chemistries may be easier to achieve, but the particle size distribution of the powder needs to be tailored to the component manufacturing method.

Specific surface area will also become an important parameter, since it is related to the shape of the particles. The specific surface area of aluminium powders is determined by the size distribution and the morphology and is measured by a gas adsorption method based on Brunauer-Emmett-Teller theory (BET) (Fig. 4).

Most parts produced by powder bed processes lack good surface finish and, in some cases, a secondary process is required to obtain an improved result. AM machine manufacturers and part producers are continuing to improve the surface finish and a uniform and narrow distribution of powder will be one of the factors in addressing this.

Other metal powder based part manufacturing processes: PM and MIM

It is beneficial to compare other existing technologies which use similar metal powder to AM. Powder Metallurgy and Metal Injection Moulding are two examples of other processes used to make near net shape parts. PM is primarily the process of making parts via the press and sinter route and many millions of aluminium automotive parts have been produced via this method. The MIM process starts with a feedstock made by mixing metal powders with a thermoplastic binder and then injection moulding the parts, removing the binder and sintering the parts in a controlled atmosphere to make the final parts. MIM is defined as a relatively fast process to make large numbers of complex shaped parts and aluminium MIM is a relatively new process within this category. A table showing the three processing routes and the typical properties of the aluminium alloy powders used is shown in Table 3.

One of the major challenges in the processing aluminium powder is the surface oxide coating on the powder. The surface oxide coating of aluminium powder is typically around 4 nm or higher in thickness and is a major obstruction in liquid phase sintering [4]. In PM and MIM technologies, the presence of magnesium in small percentages helps to break up the oxide layer and aids the achievement of a better sintering process. The growth in automotive parts produced via aluminium PM technology is primarily attributed to the demand for lighter vehicles in order to improve fuel efficiency. Aluminium PM powder grades are prepared by blending elemental powders or via the master-alloy route. However, the segregation of powder is one of the challenges, which has always been present from the powder blending process through to discharge into the compacting press. In the PM process, high purity nitrogen is the most commonly preferred atmosphere in the sintering process. Sample parts produced by PM, MIM and AM are shown in Fig. 5. The PM part is an as-sintered part produced using the high strength PM grade powder AMB 2712. The MIM part was prepared by Ryer Inc., using its proprietary aluminium feedstock prepared from MIM 6061 alloy powder [5] and the AM part was produced from an AM AlSi10Mg alloy powder. SEM photographs of the powders used in each technology are shown in Fig. 6. While PM uses irregular powder particles, MIM and AM technologies prefer a spheroidal or spherical particle morphology. All powder grades were manufactured by United States Metal Powders, Inc.

Examples of the microstructures of the aluminium-based materials using PM, MIM and AM technologies are shown in Fig. 7. The microstructure of the as-sintered aluminium PM part shows some porosity while the MIM and AM show a much better microstructures. Whilst comparing the three processes, a nitrogen atmosphere is essential for all three technologies. The importance of nitrogen has been explained by

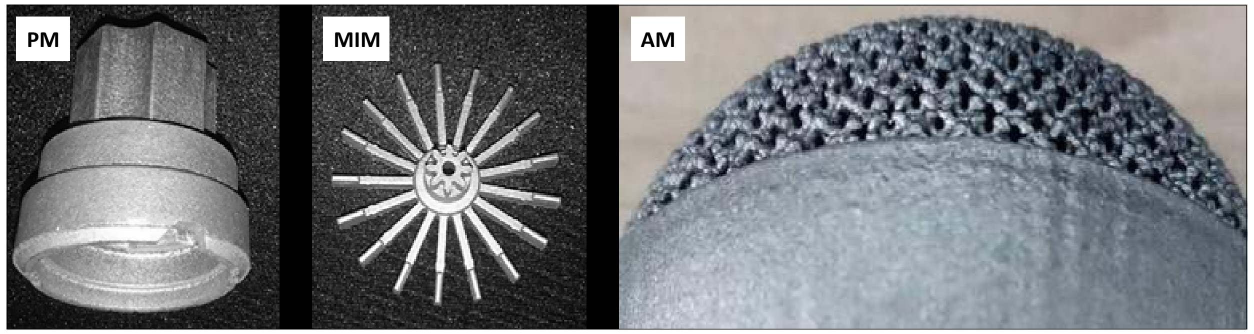

Fig. 5 Sample parts using aluminium manufactured by PM, MIM and AM

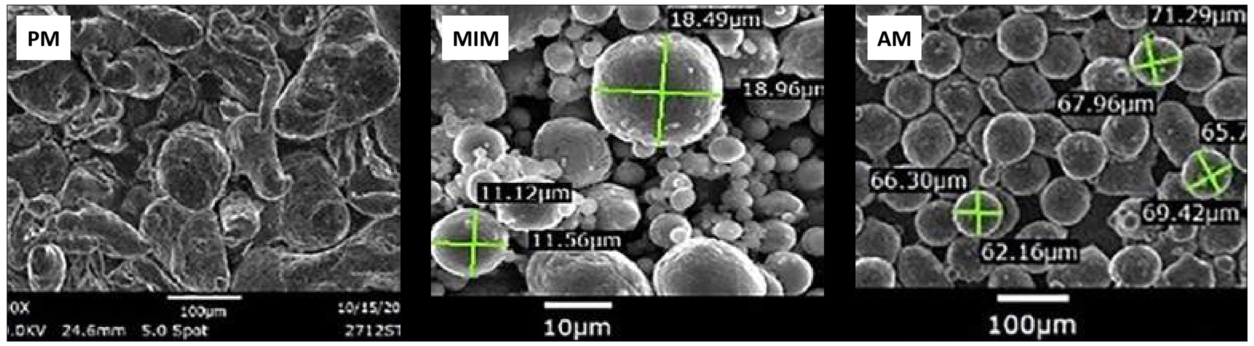

Fig. 6 Powders manufactured by USMP and used in the sample parts shown in Fig. 5

Fig. 7 Microstructures of PM (AMB 2712), MIM (MIM 6061) and AM (AlSi10Mg) parts

Schaffer [7]. Both aluminium PM and MIM processes uses high purity nitrogen with a dew point around -600°C and this improves the sintered properties of the parts.

Aluminium PM has the advantage of making relatively large parts in the range 50 to 500 g, while MIM can produce complex-shaped parts ranging from micro-MIM parts to 100 g in size or larger. As metal AM production speeds improve it could surpass both of these technologies, thus creating a solution for making any type of part regardless of size and shape.

Conclusion

Metal Additive Manufacturing certainly brings numerous advantages that are revolutionising industrial component design. The widely discussed AM fuel nozzle produced by GE, for example, demonstrated the capability of AM technology to make a complex part that was previously produced by combining as many as twenty different components. However, secondary processing such as Hot Isostatic Pressing (HIP) is often required to achieve improved mechanical properties.

In the lightweight category, aluminium carries an advantage over titanium when it comes to both availability and lower handling risks. It is also much more economical where lower strength properties are applicable. The necessity for spherical particles is unavoidable and inert gas atomisation is the cost-effective option compared to the alternative spheroidisation technologies.

Whilst the capability of metal AM production equipment continues to evolve, the optimisation of powder properties will also make a significant contribution to the development of the technology. Exploring blended or bonded powder options may, for example, be interesting in order to offer the greatest flexibility for materials with unique chemical compositions.

As metal AM expands as an industry, the flexibility of being able to select the powder that best fits the manufacturing technology is also evolving. To meet these needs the powder producer will have to ensure delivery of high quality powder with consistent properties. Producers will also have to increase their ability to deliver a narrow particle size distribution, with spherical shape, smooth surface, improved flowability and lower oxygen/oxide content.

As an increased number of custom alloy powder grades evolve for the aerospace industry the quality requirements, as well as the required powder characteristics, will increase. Powder optimisation will become increasingly important and a closer relationship between the equipment manufacturer, the powder producer and the customer will be vital. The speed of metal AM is increasing and, as this leads to a high volume production option, the aluminium metal powder industry will continue to grow.

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AMPM2016: Developments in binder jetting technology highlighted at Boston conference

For the third consecutive year, the Metal Powder Industries Federation's Additive Manufacturing with Powder Metallurgy (AMPM) conference was held in parallel with its long established POWDERMET conference. This year's event took place in Boston, Massachusetts, USA, from June 5-8, 2016. In the first of our reports Dr David Whittaker reviews three presentations that focused on the binder jetting process.

The binder jetting process uses a glue-like binder selectively deposited from a print-head to form 3D shapes, layer by layer, with debinding and sintering of the built component being included in the post-build operations. The build process itself is a low energy and low thermal input process that has the capability to work with any material that can be processed into powder and bonded together. One of the major questions with binder jetting is what process parameters, for both the materials and machine, are optimum for printing parts.

Binder jetting of metals and ceramics

A presentation made by Dongguo Lin (Pohang University of Science and Technology, South Korea) and co-authored by Sundar Atre, Jason Porter, Tim Batchelor and Kunal Kate (University of Louisville, USA), Seong Jin Park (also Pohang University of Science and Technology) and Matthew Bulger and Paul Gangopadhya (Netshape Technologies, USA), described a process optimisation study for the binder jet building of a Type 420 stainless steel and introduced a numerical model for thermal debinding accompanying its application to binder jetting.

The 420 stainless steel powder used had a median particle size of 12 µm and the chemical composition is shown in Table 1. The binder used for the process was Lab Binder 04, a solvent based binder supplied by ExOne. This binder uses polyvinylpyrrolidine (PVP), a water soluble polymer, as its main bonding agent. The parts built in these trials were 7.5 mm cubes. An ExOne M-Lab machine was used to create parts. This binder-jetting machine features a 50 x 70 x 34.5 mm build bed.

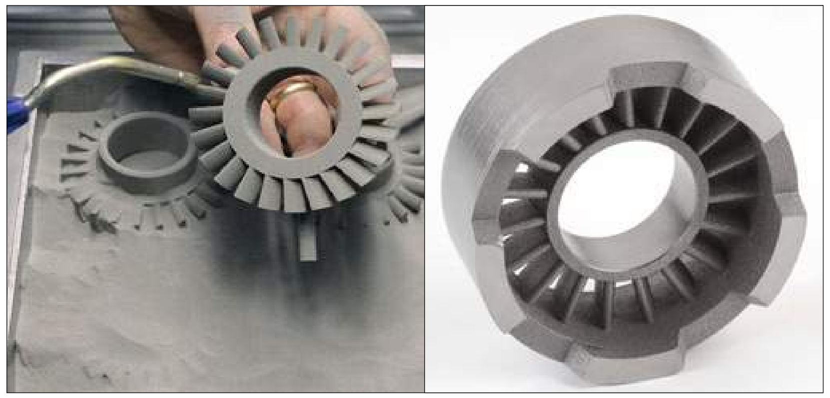
Fig. 1 The binder jetting process can be used to print complex designs from a number of materials [1]

Fe	Cr	Mn	Si	C	S	O	N
85.2998	13.6	0.1	0.5	0.42	0.0002	0.05	0.03

Table 1 Chemical composition of 420 stainless steel powder (wt%) [1]

Trial	Speed (mm/s)	Saturation (%)	Thickness (mm)
1	3	120	0.1
2	3	95	0.085
3	3	70	0.115
4	2	120	0.115
5	2	95	0.1
6	2	70	0.085
7	4	120	0.085
8	4	95	0.115
9	4	70	0.1

Table 2 Taguchi matrix varying spread speed, binder saturation and layer thickness [1]

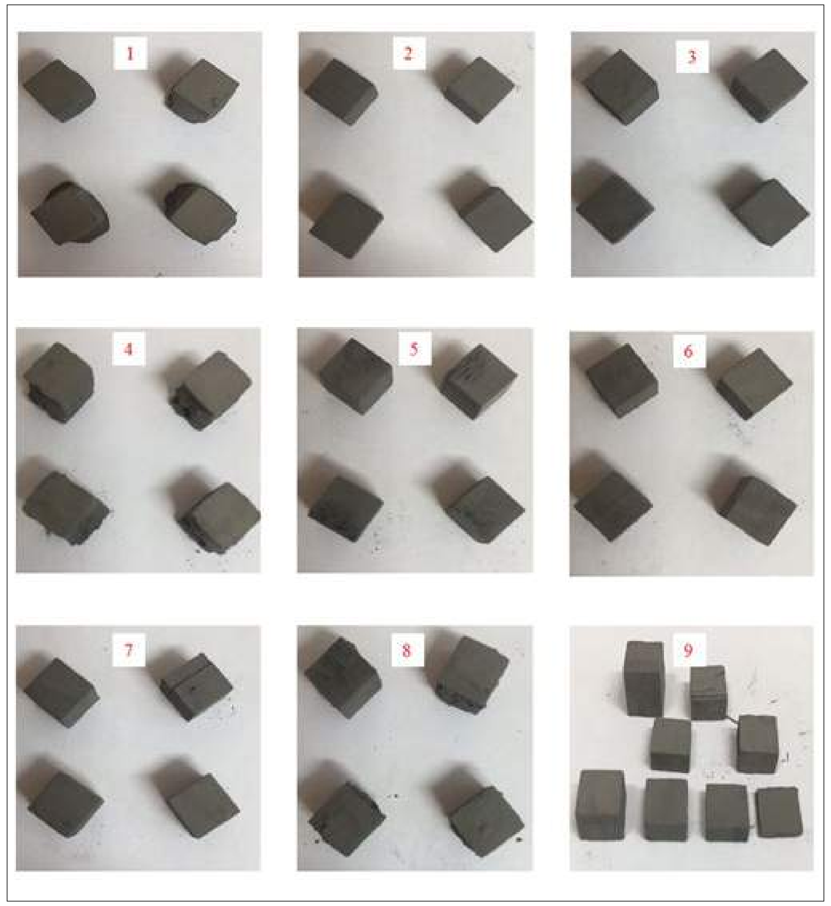

Fig. 2 Cube specimens from Trials 1-9 [1]

For the reported experiments, heater power, heater time and print speed were all kept constant. The layer thickness, spread speed and binder saturation were varied to determine their impact on part quality. Saturation is a computed value within the ExOne program defining how much binder is applied to a given area. This is represented by

$$\text{Saturation Level} = V_{binder}/V_{air}$$

where V_{binder} is the volume of the binder droplets and

$$V_{air} = 1\text{-}(PR/100)^{*}\ X_{spacing}\ {}^{*}Y_{spacing}$$

*Layer thickness

where PR is the packing rate of the powder, a ratio of the tap density and nominal density. The layer thickness controls how much the Z axis of the part changes per layer. The spread speed indicates how fast the roller traverses when spreading the powder over the build chamber.

To determine the influences of these variables, a 3 x 3 Taguchi matrix was created (Table 2). Using the Taguchi method, nine different processing combinations were applied. For each combination, four parts were built and tested, i.e. a total of 36 parts to give an average value and standard deviation for each particular combination. After the parts were built, they were cured in an oven at 200°C for two hours to activate the binder and densify the part. All parts were then evaluated in the green state, before debinding and sintering. Each of the green parts from the trials is pictured in Fig. 2 and is labelled with the particular trial number.

Trial 1 showed large errors in the X and Y directions due to the high saturation value of 120. The binder pooled on the build plate causing extra powder to be bonded to the lower layers of the part. Trial 1 had the highest overall dimensional and weight error.

Trial 2 parts were the second best in terms of dimensional error. The parts showed very good edge definition, although surface pores and deformation could be seen along some of the part sides.

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Trial 3 parts showed very good edge definition as in Trial 2, but featured more pores and deformation on the sides of the parts.

Trial 4 parts experienced the second largest error in the X and Y directions because of the high saturation value. The large amount of binder once again caused excess powder to be bonded to the parts, specifically near the bottom of the parts. Edge definition was poor and many cracks and obvious locations where sections had broken off were observed.

Trial 5 parts showed pores and surface roughness along the sides of parts starting from the bottom of the part. The first layers of the part featured both pores and excess powder, creating a very rough surface.

Trial 6 parts featured very good edge definition and low dimensional accuracy error. The surface finish of the parts was smooth with no obvious pores or defects visible.

Trial 7 parts showed very good edge definition, similar to the parts in Trial 6. One Trial 7 part did show part separation along a crack.

Trial 8 parts showed poor edge definition as excess powder was bonded to the faces of the cubes. The parts featured good edge definition, but the excess powder led to a high dimensional accuracy error.

Trial 9 parts showed very good surface finish and edge definition, but broke into sections. Only one of the four cubes remained intact, with the other three breaking into a total of seven parts.

The average dimensional error and average mass values were calculated for each trial (Table 3). Trials 1 and 4 had the highest mass values because they both used a saturation value of 120. Trial 7 also had a saturation of 120, but had a lower mass because of the smallest layer thickness of 0.085 mm. Using ANOVA and the L9 Taguchi results, the parameters that caused the least dimensional error were determined. This is illustrated by a mean of means graph for each parameter, Fig. 3, which shows that a spread speed of 4 mm/s, a saturation percentage of 70 and a layer thickness of 0.085 mm will create the

Trial	Average Dimensional Error (%)	Average Mass (g)
1	26.4 ± 8.9	2.43 ± 0.09
2	2.8 ± 0.4	1.91 ± 0.02
3	3.5 ± 0.5	1.84 ± 0.03
4	14.2 ± 3.6	2.29 ± 0.04
5	5.9 ± 0.5	2.00 ± 0.01
6	3.1 ± 0.4	2.05 ± 0.02
7	2.7 ± 0.8	2.02 ± 0.02
8	9.1 ± 2.0	2.13 ± 0.02
9	2.4 ± 1.4	1.85 ± 0.02

Table 3 Average dimensional error and mass values for 4 cubes during each trial [1]

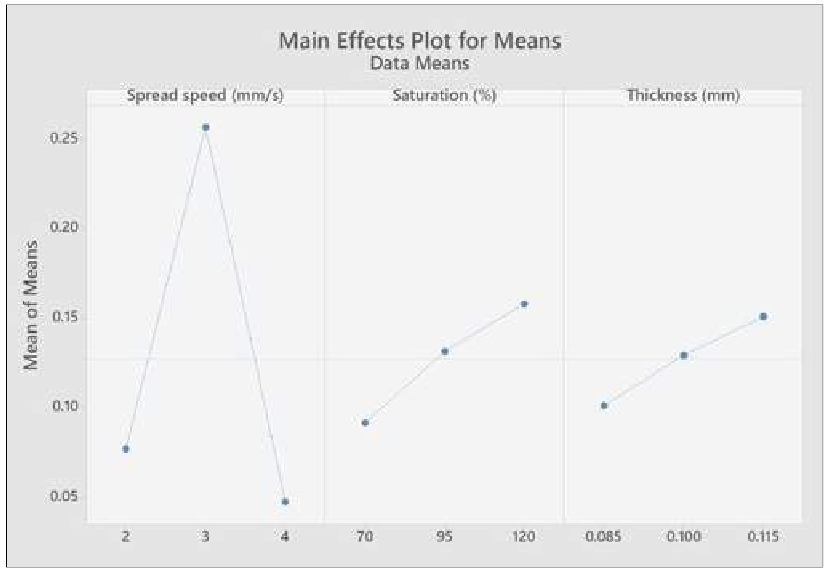

Fig. 3 Mean of Means for spread speed, saturation and layer thickness [1]

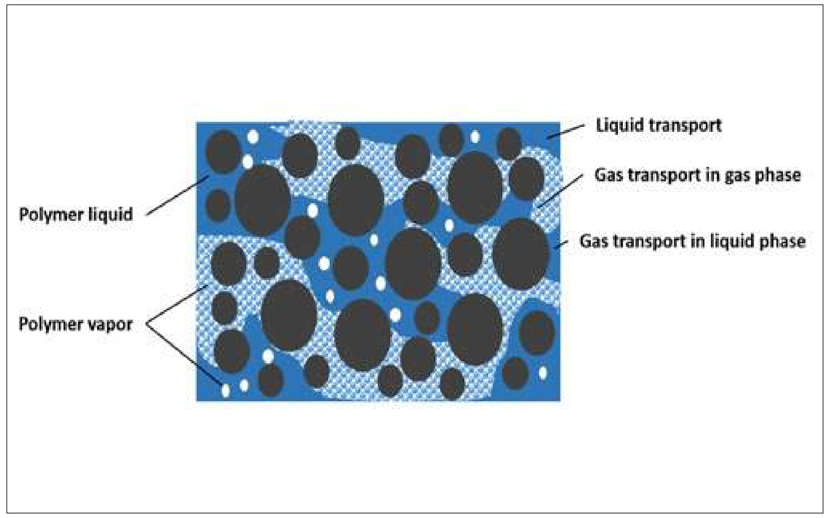

Fig. 4 Schematic diagram of binder removal mechanisms [1]

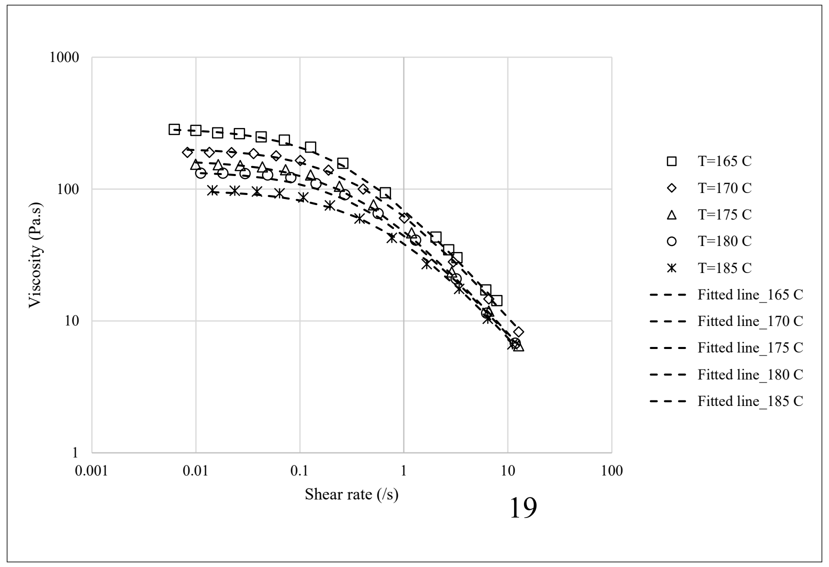

Fig. 5 Relationships among viscosity, shear rate and temperature of liquid binder [1]

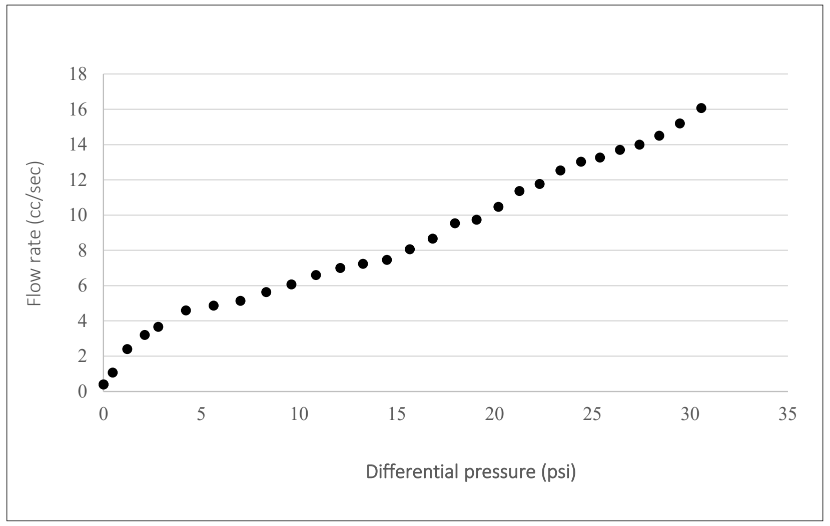

Fig. 6 Relationship between flow rate and differential pressure for the prepared sample [1]

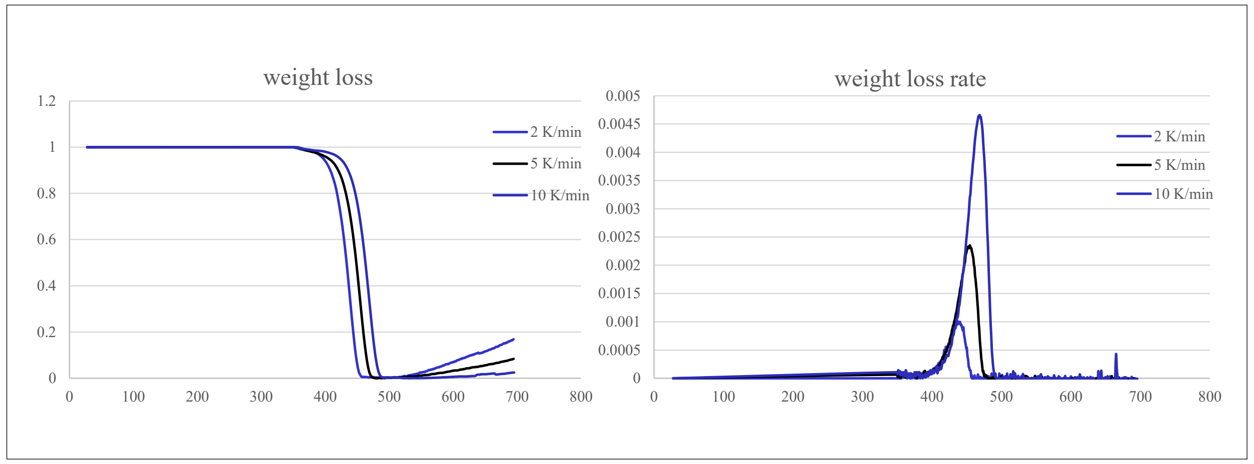

Fig. 7 Polymer pyrolysis behaviour: (a) weight loss vs. temperature, (b) weight loss rate vs. temperature [1]

best parts dimensionally, with sharp corners, a smooth surface finish and few if any surface defects.

The second part of the reported work involved the development of a numerical model for thermal debinding and its application to binder jetting. Thermal debinding is an important methodology for removing the binders in powder-binder mixtures and is widely used in the post-processing of binder jetted parts. Failure in this process can cause defects, including residual binder, cracks and contamination, in the final sintered parts.

Thermal debinding is a complicated process combining binder evaporation, liquid transport, gas transport, pyrolysis of the binder and heat transfer in a porous structure. Fig. 4 shows the status of the thermal debinding process in terms of the complicated phases and phenomena that exist in the intermediate state. A numerical model for the thermal debinding process has been proposed to predict and optimise the binder removal process without trial-and-errors. The parameters affecting the debinding process were determined and systemically studied by a series of experiments. The main constitutive equations used for describing the thermal debinding process include mass conservation, mass concentration and energy conservation equations.

During binder removal by thermal debinding, the mass conservation equations for three different states (i.e. polymer liquid, polymer vapour and atmospheric air) were employed, as shown in following equations:

$$\frac{\partial c_l}{\partial t} + \frac{\partial J_l}{\partial x} = -\dot{m}_l$$

$$\frac{\partial c_v}{\partial t} + \frac{\partial J_v}{\partial x} = \dot{m}_l$$

$$\frac{\partial c_a}{\partial t} + \frac{\partial J_a}{\partial x} = 0$$

where $\dot{m}_l$ is the rate of mass transformation of polymer liquid to polymer vapour, c is the mass concentration and J is flux.

The mass concentration can be also represented using the equations:

$$c_l = \frac{\Delta m_l}{\Delta V} = \rho_l \cdot S_l$$

$$c_v = \frac{\Delta m_v}{\Delta V} = \rho_v \cdot S_g \cdot \delta$$

$$c_a = \frac{\Delta m_a}{\Delta V} = \rho_a \cdot g \cdot \delta$$

where S is the saturation of liquid or gas and δ is the porosity of porous media.

The energy conservation equation used in this work was:

$$\frac{\partial}{\partial x}\left(k_{eff}\frac{\partial T}{\partial x}\right) - (C_l J_l + C_v J_v + C_a J_a)\frac{\partial T}{\partial x} - (\rho C)_{eff}\frac{\partial T}{\partial t} = Q = \Delta H_{vap}\dot{m}_l$$

where, k_{eff} is the effective thermal conductivity, C is specific heat capacity, Q is the rate of heat generated by binder phase transition and $\Delta H_{vap}\dot{m}_l$ is the enthalpy of binder vapourisation.

Using mathematical methods, the constitutive equations can be combined and the final form of the model can be expressed as:

$$A_{21}\frac{\partial S_l}{\partial t} + B_{21}\frac{\partial P}{\partial t} + C_{21}\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(A_{22}\frac{\partial S_l}{\partial x}\right) + \frac{\partial}{\partial x}\left(B_{22}\frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial x}\left(C_{22}\frac{\partial T}{\partial x}\right) + C_2$$

$$A_{31}\frac{\partial S_l}{\partial t} + B_{31}\frac{\partial P}{\partial t} + C_{31}\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(A_{32}\frac{\partial S_l}{\partial x}\right) + \frac{\partial}{\partial x}\left(B_{32}\frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial x}\left(C_{32}\frac{\partial T}{\partial x}\right) + C_3$$

$$A_{11}\frac{\partial S_l}{\partial t} + B_{11}\frac{\partial P}{\partial t} + C_{11}\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(A_{12}\frac{\partial S_l}{\partial x}\right) + \frac{\partial}{\partial x}\left(B_{12}\frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial x}\left(C_{12}\frac{\partial T}{\partial x}\right) + C_1$$

The coefficients in the final form are the functions of several material properties, including polymer liquid viscosity, permeability of porous media, polymer pyrolysis, polymer mobility, polymer diffusivity, capillary pressure, polymer vapour pressure, etc. These parameters should be determined by specific experimental routes or empirical models.

The polymer liquid viscosity at different temperatures was measured using a plate-plate type rheometer and the results were expressed using the Cross model. Fig. 5 shows the relationship between the shear rate and viscosity of polyethylene (the selected polymeric binder). The viscosity decreased with increasing temperature and shear rate.

The permeability of porous powder media was measured using a capillary flow porometer. The sample was prepared by mixing 316L stainless steel powder with a polyethylene binder using a twin-screw extruder and was moulded and debound before measuring its permeability. Fig. 6 shows the permeability testing results.

The polymer pyrolysis behaviour was studied using thermal gravimetric analysis (TGA) experiments. Fig. 7 shows the polymer pyrolysis behaviour of polyethylene, which was expressed using the polymer decomposition equation.

The experimentally derived material coefficients can be introduced into the proposed numerical model for the analysis of the thermal debinding process in binder jetting.

A clear path to large AM parts

A presentation from Eric Bono and Fred Yolton (Puris LLC, USA) discussed their company's focus on the 3D printing of large parts and the reasons why binder jetting AM technology has been adopted as an enabler for this objective. The presentation began with the outlining of the driving forces for the adoption of near net shape forming in general and of powder-based forming technology in particular, with particular reference to large aerospace

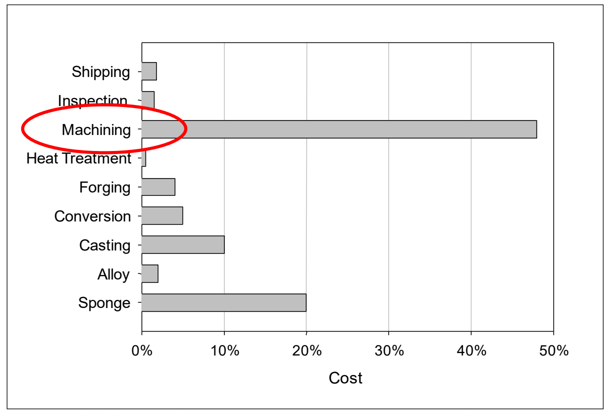

Fig. 8 Contribution of machining costs to total component costs (titanium alloy aerospace applications) [1]

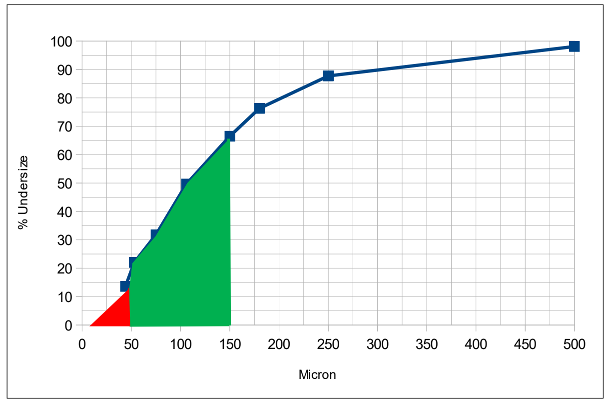

Fig. 9 Economics of powder particle size distribution choice [2]

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AMPM2016: Binder jetting technology

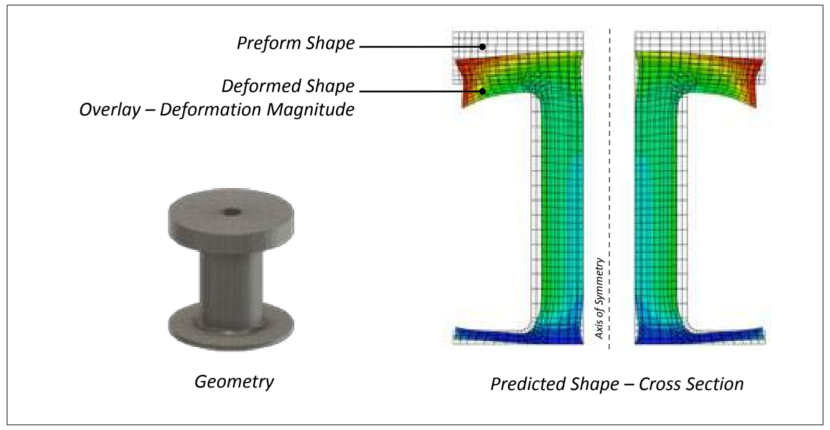

Fig. 10 Near Net Shape Numerical Modelling [2]

components. Near net shaping is driven by the desire to eliminate machining operations as a recognised major contributor to total component costs (see Fig. 8). In addition, powder-based routes offer superior control over fine microstructures, isotropic properties and reduced scatter in achievable properties.

The challenges in Additive Manufacturing of large parts were defined as:

- Residual stress control
- Avoidance of microstructural degradation
- The impact of powder costs
- Processing speed (or lack of it)
- Scalability of equipment

The benefits of binder jetting over AM technologies involving powder melting in addressing these challenges were discussed. It was stated that uneven heating during build up with powder melting makes residual stress control in large parts and at corners challenging. The expedient of removing a part-built component from the system and stress relieving before continuing with printing is often employed. On the other hand, as binder jetting is carried at near-ambient temperatures, residual stress generation is not an issue. Whereas any powder melting technology alters the powder microstructure significantly, binder jetting retains the starting powder microstructure and results in a microstructure akin to direct HIPping.

Powder costs, of great significance in large part AM, can be controlled in binder jetting through the ability to use a somewhat wider and coarser particle size distribution (Fig. 9).

The limitations in the capability for multiple re-use of powder in Electron Beam Melting, without detriment to resultant component properties, were also highlighted in this context.

Although Puris is not an equipment manufacturer, its view is that it would seem easier to scale-up binder jetting in comparison to air-tight systems. Puris' near net shaping approach was described as a holistic one, which was dependent on part shape, size and production quantities. Their 'tool box' was defined as including the largest 3D ExOne printers in the world and patent-pending powder densification technologies. In all cases, the processing technologies start from powder feedstock.

The AM printing approach involves printing of the component, followed by debinding, pre-sintering, canning and HIPping. Use is made of numerical modelling to quantify deformation during the HIP process (Fig. 10). Examples of current near net shape and complex shape applications are shown in Figs. 11 and 12.

In summarising the current capabilities and limitations it was stated that there is a near limitless choice of materials available. The focus is on large components in the 5 -5,000 lb range and, in terms of the level of detail, the current minimum section thickness is 0.1 inch. Ultimately, investment cast tolerances will be targeted.

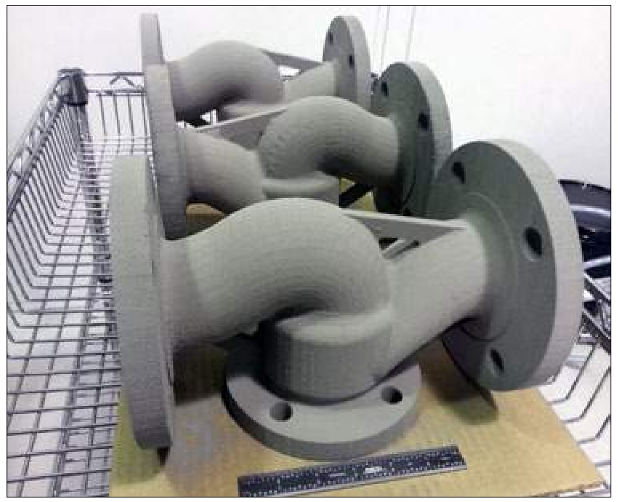

Fig. 11 Near Net Shape product example [2]

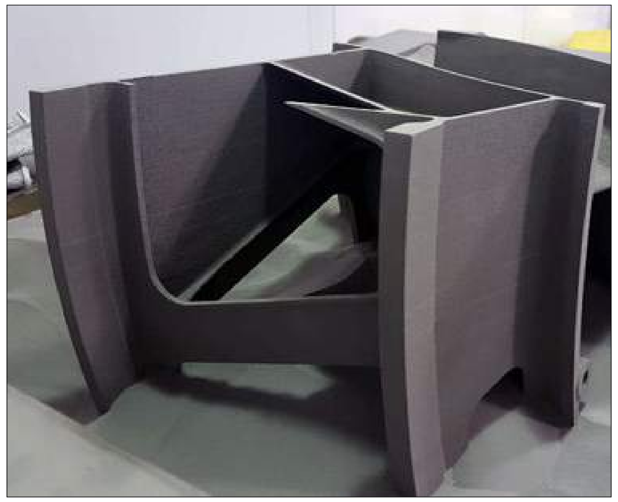

Fig. 12 Complex shape example (compressor housing section [2]

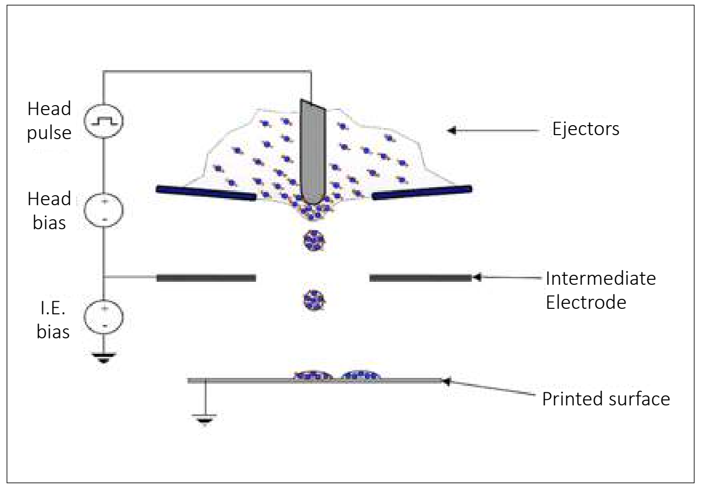

Fig. 13 TTP's nozzle-free inkjet system employing electrostatic ejection [3]

Fig. 14 Direct to packaging printing as shown in this example on a beverage can [3]

Inkjet printing without nozzles

A presentation from Chris Hole (The Technology Partnership, UK) was not directly concerned with binder jetting, but rather discussed a novel 3D inkjet printing technology. In its technology portfolio, The Technology Partnership (TTP) has been a major 2D printing technology supplier for more than 25 years. The presentation first highlighted the potential advantages of using electrostatic inkjet printing (as opposed to conventional mechanical ejection inkjet printing) in a 3D scenario for Additive Manufacturing. Principal among these advantages was the potential for very high build rates, as the use of highly parallel nozzle arrays is routine and the technology avoids the use of powder beds as the powder is carried within the ink.

Mechanical ejection inkjet printing does have some limitations (for example in the required use of low viscosity carrier fluids and in the occurrence of particle sedimentation). TTP has nozzle based (i.e. mechanical ejection) printing technology, which extends the viscosity and sedimentation envelopes significantly and is also capable of handling non-conducting materials (e.g. polymers). However, the key to enabling a step change in build rate was identified as the need to avoid the use of nozzles entirely and the main message of the presentation was therefore 'inkjet printing without nozzles'.

TTP's development of electrostatic ejection as a means of avoiding the use of nozzles was then highlighted. The principles of this technology are shown schematically in Fig. 13. 3D printing with this technology was demonstrated around 15 years ago. However, at that time, the AM market was still small and, therefore, the company chose to exploit the technology in the 2D application area of direct to package printing (Fig. 14). With the surge in interest, the company has recently re-visited the AM market.

Existing solids deposition rate in package printing is 120cm^3/hour (i.e. ten times faster than powder bed SLM) and higher build rates still are expected with the larger particles used in AM. The technology operates with four standard heads and with 5 µm layers, five times thinner than SLM. There is full multi-material capability and the technology could even work with SLM for multi-material powder beds (working as a digitally addressable re-coater bar). Drop size variation is also possible. Systems can be integrated with conventional inkjet heads.

TTP stated that it is now seeking to partner with an established AM equipment supplier in taking this technology forward and also to interact with leading users to develop specifications.

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[2] A Clear Path to Large AM Parts, E Bono, F Yolton, as presented at AMPM2016, MPIF, USA

[3] Inkjet Printing Without Nozzles, C Hole, as presented at AMPM2016, MPIF, USA

AMPM2016: New material developments in metal Additive Manufacturing technology

In the second of our reports from the Metal Powder Industries Federation's Additive Manufacturing with Powder Metallurgy (AMPM) conference, Dr David Whittaker reports on three presentations that highlighted developments in the processing of novel AM materials. These include tungsten for nuclear fusion applications and copper alloys for applications which require high electrical conductivity.

Additive Manufacturing of tungsten

Extending the reach of metal Additive Manufacturing into new material types was the focus of a number of contributions to the AMPM2016 programme. A presentation from Jonathan Wright (University of Sheffield, UK), co-authored by Iain Todd (also University of Sheffield), focused on the Additive Manufacturing of tungsten, with particular reference to components for nuclear fusion reactors.

Nuclear fusion mimics the process of energy generation in the sun and involves the collision of hydrogen nuclei of the isotopes of hydrogen (deuterium and tritium), causing them to fuse together to form helium nuclei and release energy in the form of neutrons. There is significant interest in the potential development of nuclear fusion because, unlike nuclear fission, the process generates no long-lived radioactive waste.

The temperatures involved in nuclear fusion are very high (100 million °C). The most promising means of achieving these conditions is 'magnetic confinement' of the hot gas, as a plasma, in a ring-shaped magnetic chamber known as a tokamak (Fig. 1). A tokamak, developed at the Joint European Torus (JET) at Culham, UK, has produced 16 megawatts of fusion power and proved its technical feasibility using deuterium and tritium. The challenge now is to prove that

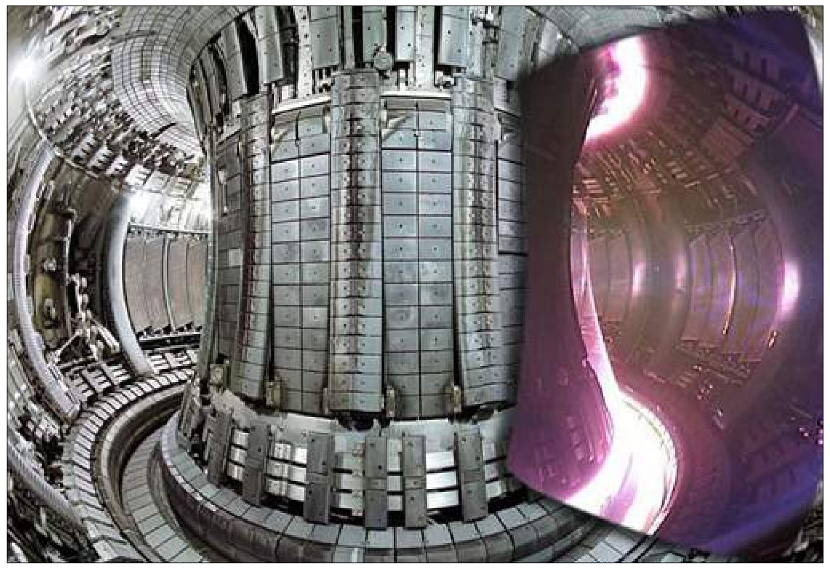

Fig. 1 Nuclear fusion is a promising option for generating large amounts of low carbon energy [1]

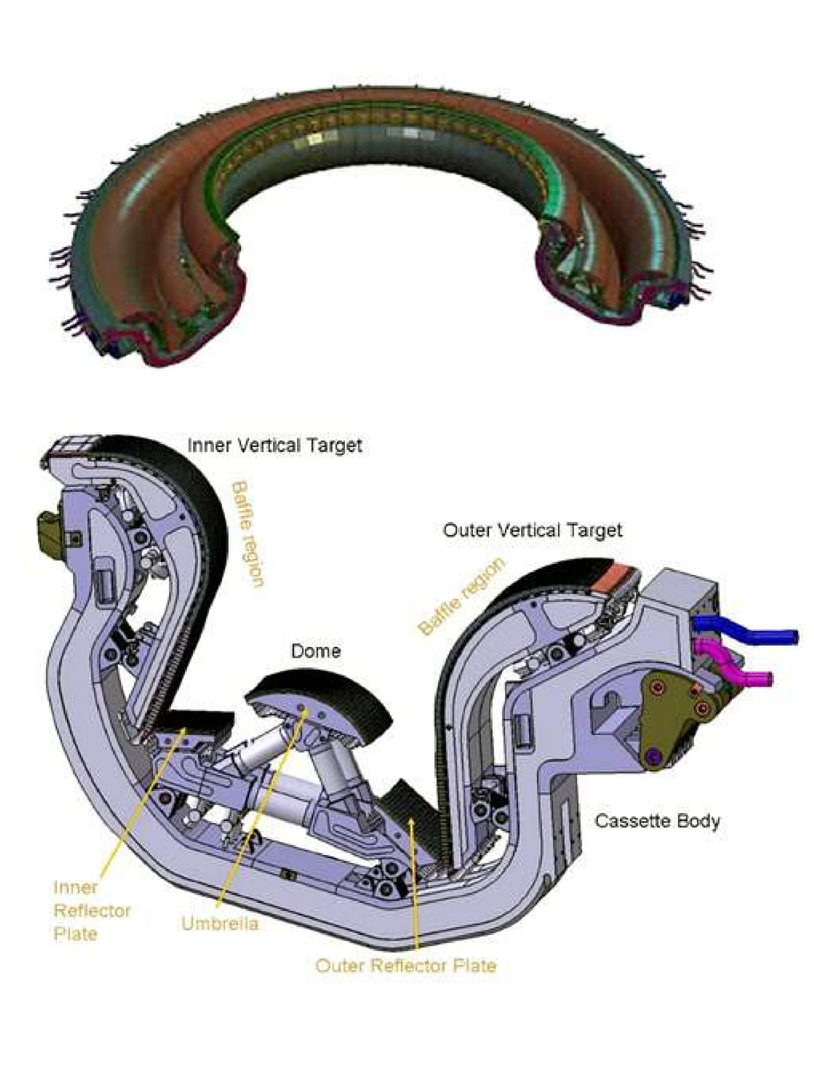

Fig. 2 The divertor is used to remove waste products and extract heat via active cooling [1]

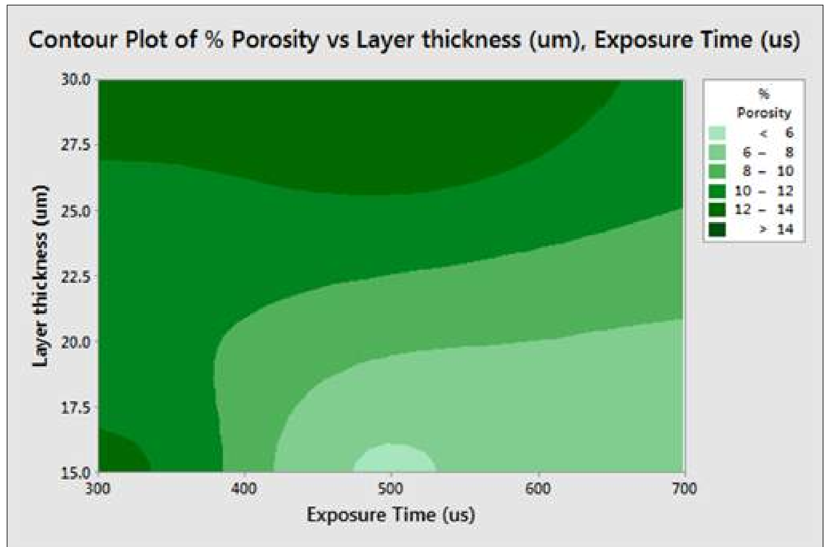

Fig. 3 Contour map of achievable porosity level versus layer thickness and exposure time [1]

fusion can work on a power plant scale. International fusion research is following a roadmap to achieve power generation within 30 years. The next stage in this programme is ITER (the International Tokamak Experimental Reactor), a multinational project at Cadarache in the south of France. ITER will be a 500 megawatt tokamak, equivalent to a small power plant.

Tungsten has emerged as one of the prime candidate materials for the plasma facing components in a tokamak in the next generation fusion plant (ITER), because of its high level of melting point (3683°C), thermal conductivity (174 W/mK) and thermal diffusivity (6.9×10^{-5}). However, because of its high hardness (900 H_v), tungsten is problematic to machine and, therefore, net- and near-net -shape manufacturing technologies are of significant interest. In this context, therefore, Additive Manufacturing is of potential interest and the reported study related to the assessment of the viability of the Additive Manufacturing technologies, Selective Laser Melting (SLM) and Electron Beam Melting (EBM), in this context.

The target application was referred to as a divertor, a component used to remove waste products from the system and extract heat via active cooling (Fig. 2). The SLM study used a Renishaw SLM 125 machine, operating with a pulsed 200 W laser and an argon atmosphere. A full factorial design of experiment study was carried out, with the variables being layer thickness, beam speed and hatch spacing. The results were presented in the form of contour plots of % porosity versus layer thickness and exposure time (Fig. 3). The conclusions drawn were that 95% density was achievable, but that this was limited by layer thickness and power density. The results suggested that, to reduce porosity, higher energy density is needed via either thinner layers or higher beam power. This part of the presentation led to the conclusion that, for SLM, further process optimisation was required.

EBM was studied using the ARCAM Electron Beam Melting process, which involves pre-heating the build plate and powder bed (to 1000°C) and operation in vacuum. Fig. 4 shows a schematic of the process. The advantage of EBM over SLM is that much higher beam power is available (3000 W cf. 200 W). The disadvantage is that the standard ARCAM machine has a large build tank and, therefore, a large powder volume is required.

The first stage of this work was the development of the process to operate with a small build tank (Fig. 5). Initially, the small build tank was evaluated with Ti-6Al-4V powder. The issues identified were heat loss, leading to the creation of smoke or hard sintering, and, as the time for the beam to cover the plate is faster, again smoke generation is a problem. The developed solutions were to maintain the energy density and beam return time in preheating and to introduce additional heating steps during the melt stage to counteract heat loss without raising the maximum layer temperature.

Following this optimisation work, the EBM of tungsten was studied, with a build temperature of around 1000°C, a manual preheat, a hatch melt sequence and a build layout with wafer supports. It was found that, with EBM, a density of 99.9% was achievable. It was concluded that EBM could provide a method for simplifying the manufacture of complex geometries in tungsten for the fusion environment. Further work would involve mechanical and thermal testing of built material and the production of test components.

Metallographic characterisation of copper alloys fabricated via SLM

A presentation from Jack Edgerton (Loewy Institute, Lehigh University, USA) reported on the metallographic characterisation of copper alloys fabricated by Selective Laser Melting. The principal author of the reported study was Anthony Ventura (a PhD

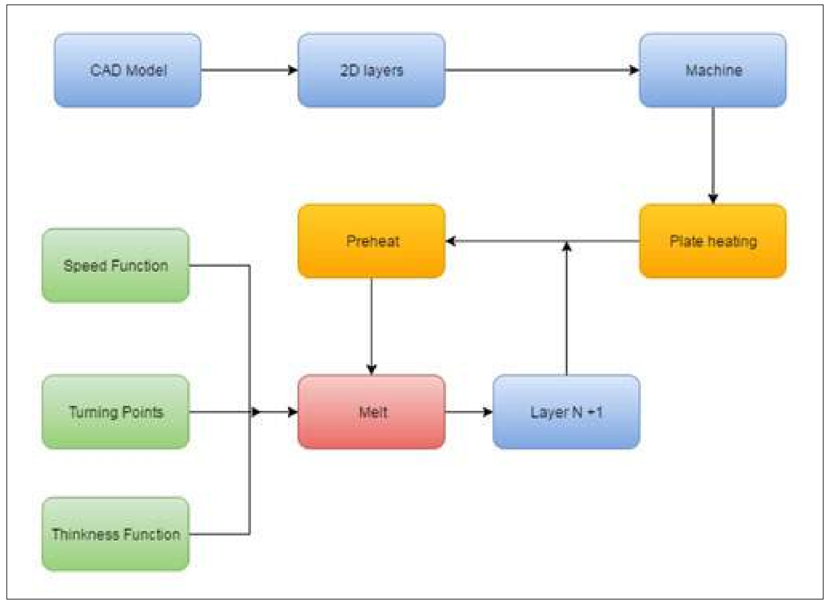

Fig. 4 Schematic of the EBM process [1]

Fig. 5 Small build tank for EBM [1]

Sample	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation at Failure (%)	Conductivity (%IACS)
As Printed	274	334	5.60%	24.10%
Printed + Annealed 873 K (600°C)	208	309	12.40%	21.20%
Printed + Annealed 1173 K (900°C)	102	267	26.10%	21.00%

Table 1 As-printed and heat treated mechanical properties and conductivities for Cu-4.3%Sn alloy [2]

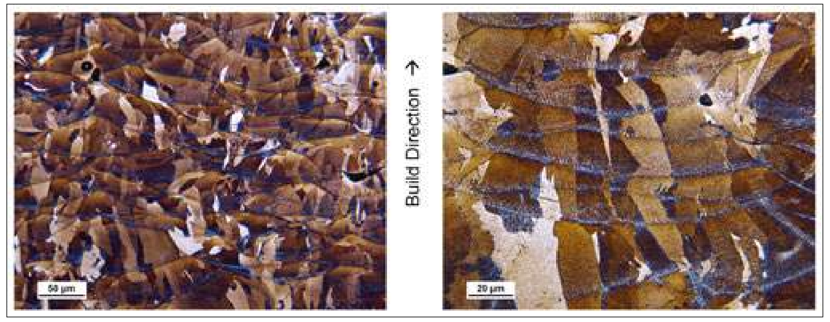

Fig. 6 Base microstructural characterisation [2]

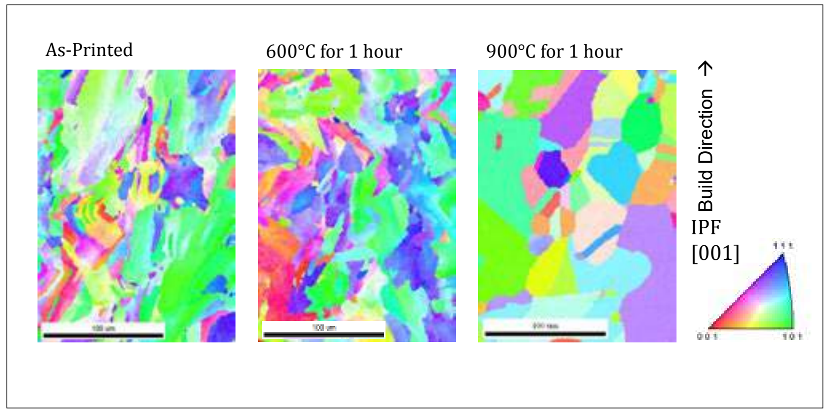

Fig. 7 Grain morphologies with IPF mapping [2]

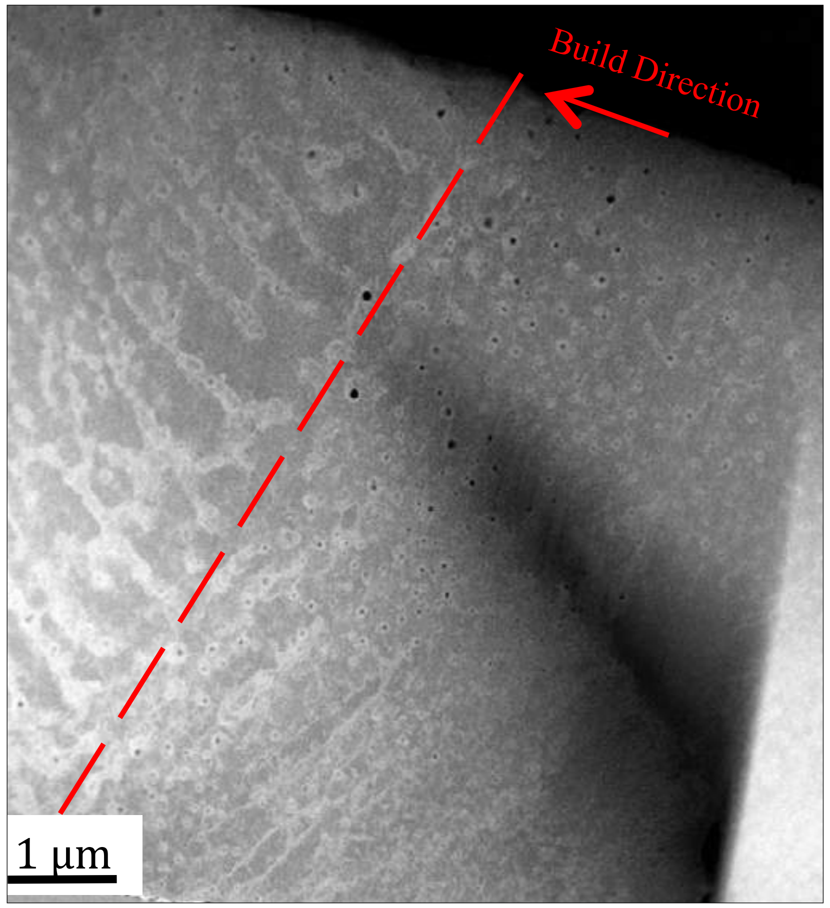

Fig. 8 TEM analysis of a weld line in an as-built sample [2]

student in the Loewy Institute) and the study arose from a collaboration involving other colleagues at the Institute and Greg Pawlikowski and Martin Bayes of TE Connectivity, USA.

The project was motivated by the fact that there are limited existing alloy systems in AM technologies to address applications which require high electrical conductivity. The objectives were to understand the role of alloying element segregation in resulting SLM microstructures and to determine the effect of post-fabrication heat treatment on mechanical properties for a copper alloy. The approach chosen was to optimise the density of the as-printed component by varying the process parameters and to characterise the as-built microstructure and properties and the effect of post-processing heat treatments on the microstructure and mechanical properties to determine and understand a window of attainable properties. The post-processing heat treatments applied were:

- A "standard" anneal at 600 °C for 1 hour (Argon atmosphere)
- A high temperature anneal at 900 °C for 1 hour (Argon atmosphere)

The material used was an air atomised Cu-4.3%Sn alloy powder. This material was defined as being similar to a C-510 bronze, but without a phosphorus addition. AM samples were built at TE Connectivity, using an EOS M280 200W DMLS machine.

The achievable mechanical properties and conductivity in the as-printed and heat-treated conditions are shown in Table 1. In terms of conductivity, the %IACS is based on the resistivity of commercially pure annealed Cu. The measured properties were within the range of currently used conductive alloys. It was concluded that successful and repeatable production of Cu-4.3Sn components via SLM, with reasonable conductivity and a moderate range of mechanical properties, has been demonstrated.

Base microstructural characterisation showed that, in the as-printed condition, grains appear to grow epitaxially from previously un-melted layers (Fig. 6). The IPF results (Fig. 7) showed that annealing at 600 °C had no effect on grain morphology, whereas there was a significant change on annealing at 900 °C. Assessment of dislocation densities in the three conditions tended to mirror the same observations. Annular bright field STEM showed oxide particles to be present in the as-printed condition and the authors believed that these particles arise from oxidation on the surface of the source powder. The oxide particles appear to be similar for the as-printed and the 600 °C annealed conditions, but their size had grown after the 900 °C anneal. It was felt that these particles may be acting as grain boundary pinners. TEM analysis across weld lines in the as-built condition showed a change in the cellular sub-structure (Fig. 8). STEM and corresponding EDS mapping of the cellular substructure showed tin segregation remaining after solidification.

Significant influences of the thickness of printed samples (Fig. 9) and of various surface finishing treatments (Fig. 10) on as-printed mechanical properties were observed. The as printed surface texture was irregular and showed the presence of a porosity band. The grit blasted sample showed an improved surface finish, some cracking at the surface and a possible beneficial compressive stress at the surface. Hand grinding gave the best surface quality, with a very even finish and no cracking. Electropolishing created greater irregularity than in the as printed condition with a visible porosity band. While ASTM recommended specifications had been used in electropolishing, it was considered that some further process parameter optimisation might be possible. However, this was not within the scope of this project.

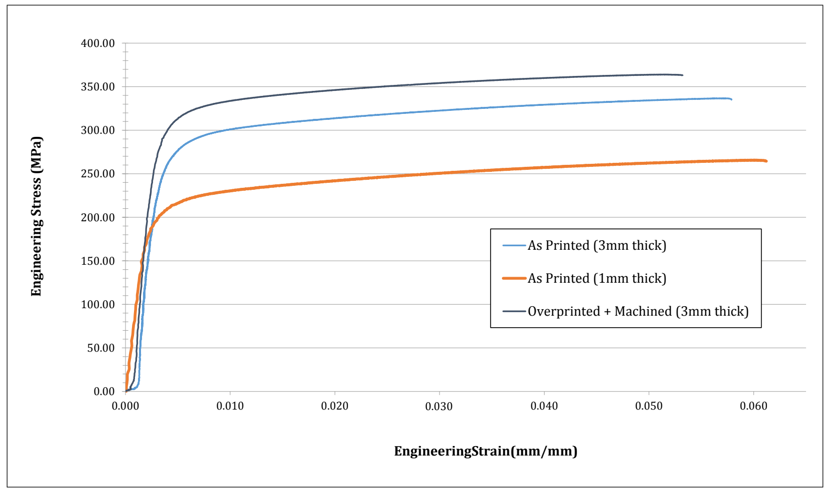

Fig. 9 Effect of as-built sample thickness on the stress-strain properties of SLM Cu4.3Sn [2]

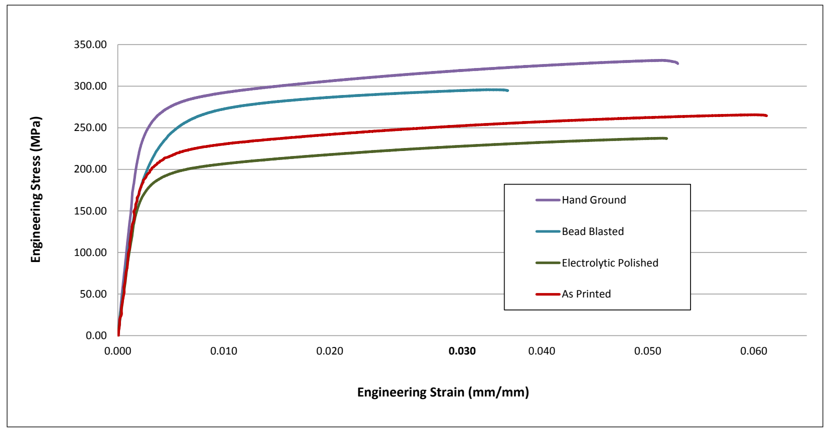

Fig. 10 Effect of surface finish on the stress-strain properties of SLM Cu4.3Sn [2]

Selective laser melting of nickel-base superalloys for turbocharger applications

Finally, the selective laser melting of nickel-base superalloys for turbocharger applications was the subject of a presentation, made by Charlotte Boig (University of Sheffield, UK) and co-authored by Iain Todd (also University of Sheffield), Michael Burkinshaw (Cummins Turbo Technologies, UK) and Andrew London and Michael Moody (University of Oxford, UK). The aim of the reported study was to define the required process and compositional control for the robust manufacture of defect-free IN713C SLM turbine wheel components (Fig. 11).

The identified problem was that SLM is prone to introducing certain defects and the target component is fatigue life limited and therefore very sensitive to the presence of defects. The types of defects that could occur were identified as gas porosity, lack of fusion and micro-cracking (Fig. 12). In order to conduct a systematic study of SLM process effects, the concept of energy density, Eo, was introduced.

$$E_0 = \frac{q}{vlh}$$

where q is laser power, v is laser velocity, l is laser thickness and h is hatch spacing.

In order to include a range of dissimilar materials in an analysis, energy density could be further normalised, through the inclusion of

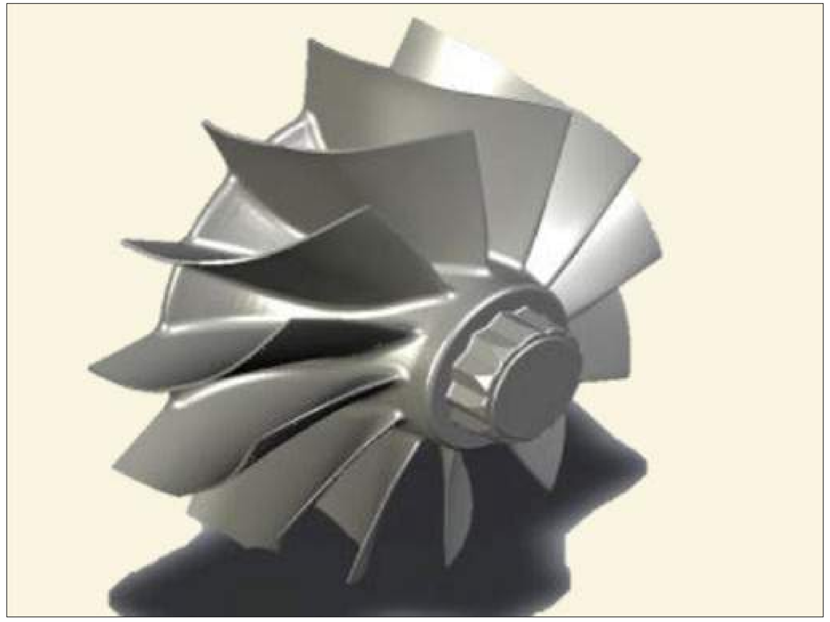

Fig. 11 IN713C SLM turbine wheel (Image from ref. 3 and courtesy of Cummins Turbo Technologies) [3]

material-specific values for material density, heat capacity, melting temperature and bed temperature.

$$E_0^* = \frac{q^*}{v^* \cdot l^* \cdot h^*} = \left[\frac{A.q}{v.l.h}\right]\left[\frac{1}{\rho.C_p.(T_m - T_0)}\right]$$

Process effects can then be considered on the basis of normalised process maps (Fig. 13). Normalised process maps were used to specify a Design of Experiment (DOE) study. Cube samples of varying size were built using a Renishaw 125 SLM system. Layer thickness was held constant at 20 µm and the variables studied were hatch spacing, laser velocity and cube size. Sections in the x-y and x-z planes were examined. Gas porosity and lack of fusion melt splashing defects were observed in both planes. Melt splashing defects were more prevalent when normalised energy density was high and were more prevalent in the x-y plane than in the x-z plane. Regression analysis showed that gas porosity increased as laser velocity decreased and hatch spacing increased. The effect of cube size was found to be insignificant. From this analysis, it was concluded that gas porosity and melt splashing can be minimised through judicious selection of processing parameters. However, for the robust SLM manufacture of IN713C components, the mechanism of crack formation still needed to be understood in order to mitigate against it.

In order to assess the potential contribution of chemical compositional segregation in the as-fabricated microstructure, studies were carried out using Atom Probe Tomography (ATP). The use of this characterisation technology was the University of Oxford's contribution to the collaboration. Needle-shaped ATP specimens were removed from the built microstructure, using a Focussed Ion Beam (FIB) procedure. The atom maps created by the ATP studies showed the clustering of carbon, boron and, to some extent, zirconium at dendrite boundaries (Fig. 14).

These observations could be evidence of segregation of C, B or Zr and B and Zr are known to be deleterious for welding operations, which SLM could be deemed to be on a micro-scale. Alternatively, carbide or boride precipitates could have formed, with such precipitates potentially contributing to crack susceptibility through a high dislocation density created by their incoherence with the matrix.

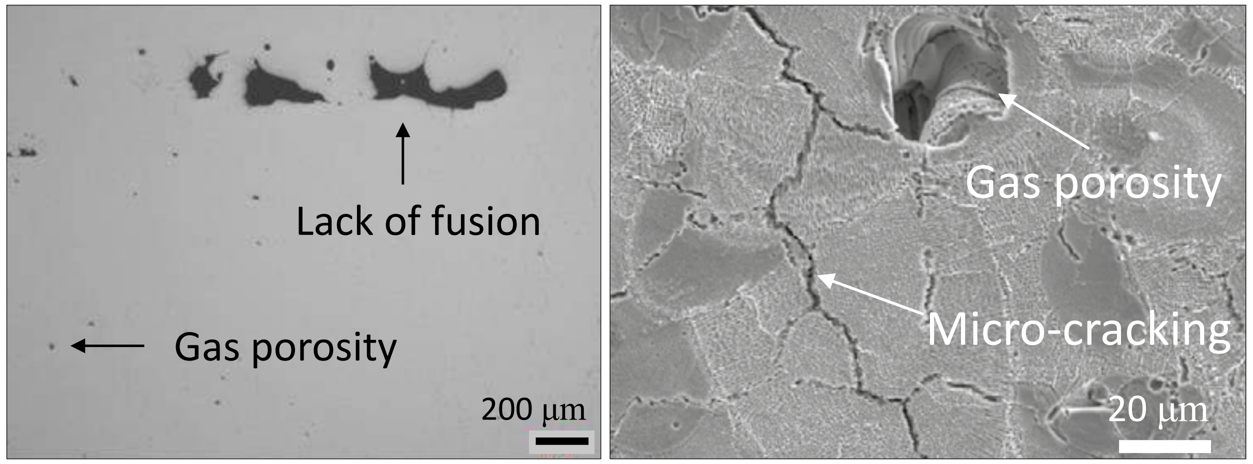

Fig. 12 Defects in SLM IN713C [3]

In future work, line scans in ATP will be carried out over individual clusters to determine whether carbides or borides are present.

At this stage, it has been concluded that ATP is providing valuable insights into nano-scale compositional effects, but that further assessments are needed in the investigation of the crack susceptibility of IN713C. The question to be pursued is to whether minor elemental compositional adjustments could reduce crack susceptibility and make such difficult alloys processable by SLM.

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[3] Selective Laser Melting Of Nickel-Base Superalloys For Turbocharger Applications, C Boig, I Todd, M Burkinshaw, A London, M Moody, as presented at AMPM2016, MPIF, USA

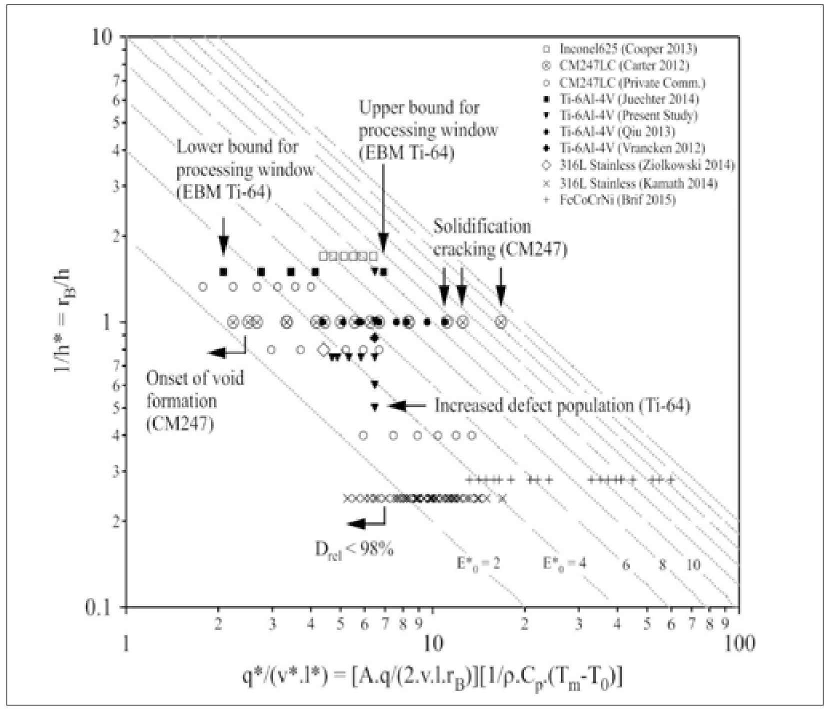

Fig. 13 Normalised process maps (from Meurig Thomas, Gavin Baxter and Iain Todd, Acta Materialia 108 (2016), pp. 20-35) [3]

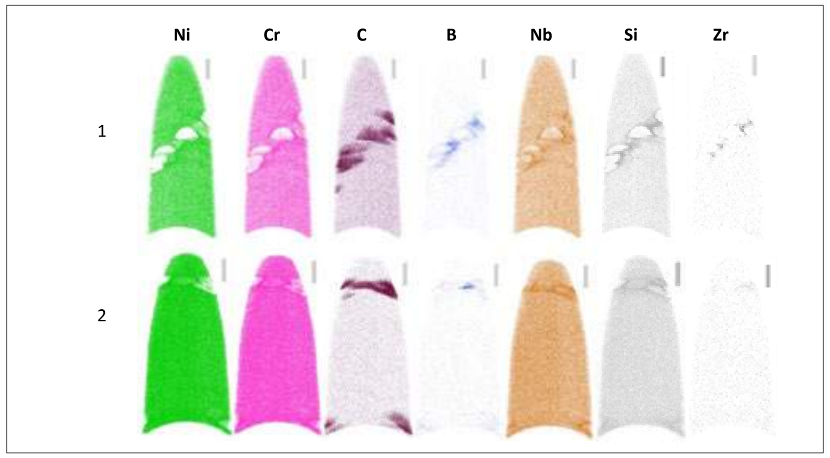

Fig. 14 Atom maps from LEAP analyses (Scale bar = 25 nm) [3]

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