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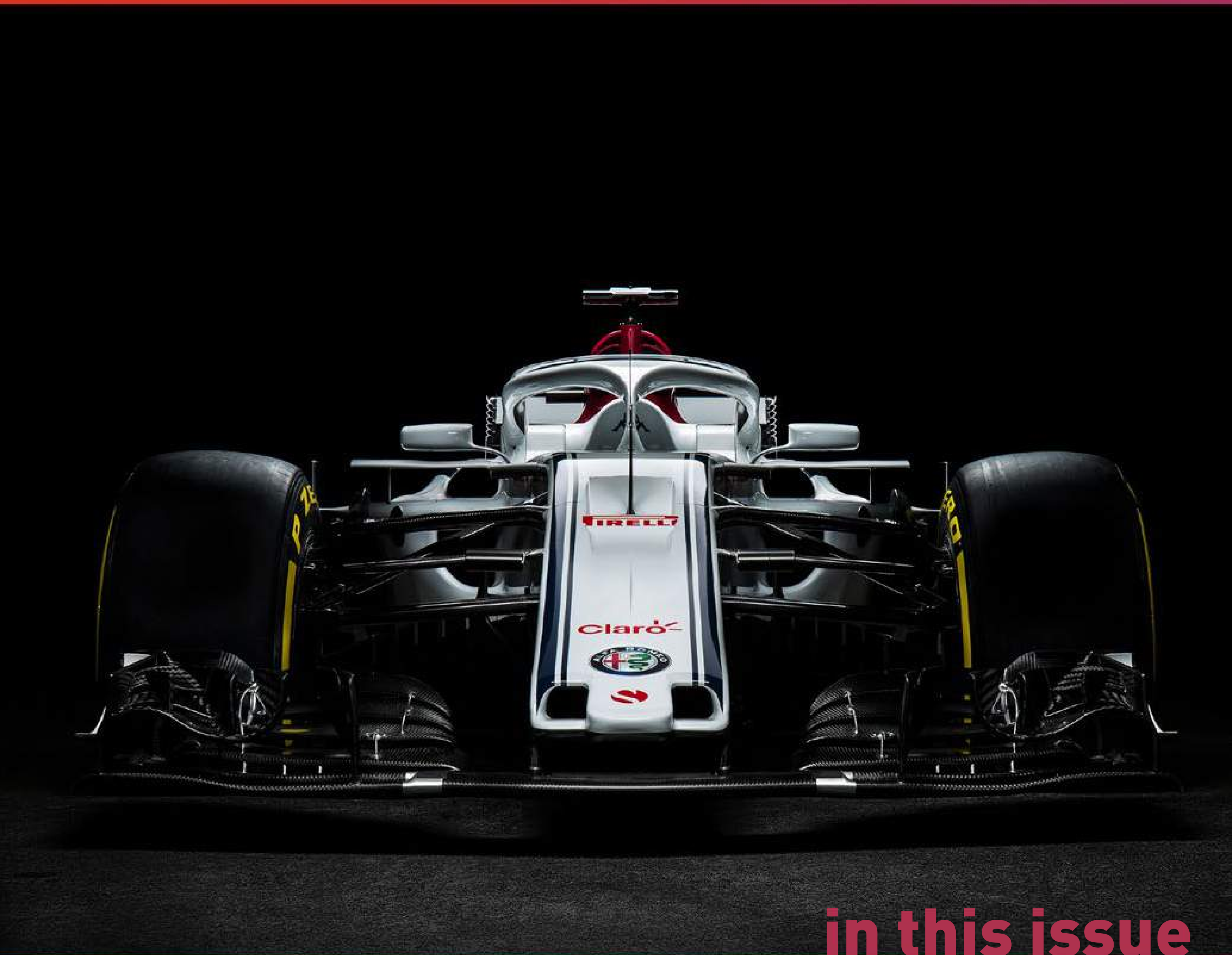

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AM AT SAUBER MOTORSPORT AG
PROFILE: DIGITAL METAL
CHALLENGES OF POWDER REMOVAL

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METAL ADDITIVE MANUFACTURING

The challenges of moving towards a true industrial process

AM's transition from prototyping and short-run production to the higher-volume manufacturing of components is driving fundamental changes in both machine design and best-practice in production environments.

In particular, major PBF machine manufacturers have demonstrated automated factory solutions which promise to dramatically improve productivity across the complete AM process chain, from file preparation through to part build, heat treatment and build plate removal.

Crucially, the industry's drive towards increased production efficiency is paired with a growing awareness of the need to manage risk in powder-based AM processes. These risks come primarily in the form of the explosivity/pyrophoricity of very fine metal powders and toxicity through inhalation. Such risks have been acknowledged for many decades by the wider metal powder processing industries, and there is now an increasing focus on them in the context of metal AM part production.

As highlighted in two articles in this issue, safety considerations are driving both advances in AM machine design (page 91) and innovations in third-party solutions for powder removal and reprocessing (page 113).

Of course, the issues surrounding powder handling extend beyond environmental and safety considerations. The powders used in AM processes are expensive and some can be highly sensitive to air exposure. The development of a holistic approach to powder management in AM processes will, therefore, be of fundamental importance as the industry moves towards true industrial production.

Nick Williams
Managing Director
Metal Additive Manufacturing

Cover image
Front view of the C37 2018 Alfa Romeo Sauber F1 Team race car (Courtesy Sauber Motorsport AG)

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Porsche Classic supplies replacement parts using metal AM

Porsche Classic, based in Stuttgart, Germany, a division of Porsche AG dedicated to classic vehicles, has begun producing rare, replacement parts by metal and plastic Additive Manufacturing.

Traditionally, where a spare part is no longer available, it would be reproduced using the original tools or, if the original tools are not available, replacements would be made. However, this can pose a challenge when ensuring the supply of spare parts which are only required in very limited numbers, due to the inefficiency inherent in producing new tools for the sake of a very short production run.

In order to enable the economic manufacture of rare parts to a high quality in very short production runs, Porsche Classic states that it is now using Additive Manufacturing. One example of such a part is the release lever for the clutch of the Porsche 959 (of which only 292 vehicles were ever produced), originally produced in grey cast iron and subject to very high quality requirements. The company stated that it is now using Selective Laser Melting (SLM) to produce the part from tool steel. The replacement part produced by SLM is reported to have passed both a pressure test with a load of almost three tonnes and tomographic examination for internal faults. Subsequent practical tests, with the lever installed in a test vehicle, were also passed.

Due to the positive results it has received to-date, Porsche stated that it is currently manufacturing eight other parts by metal and plastic Additive Manufacturing, and testing whether a further twenty components could be suitable for AM. The metal AM parts will be produced in steel and alloys using SLM. According to the company, although all parts are subject to the quality requirements of the original production period as a minimum, it has found that most meet higher standards on testing.

www.porsche.com

Porsche Classic is dedicated to the company's classic vehicle ranges (Courtesy Porsche AG)

Stratasys metal AM platform for short-run applications

Stratasys Ltd, based in Minneapolis, Minnesota, USA, and Rehovot, Israel, reports that it is developing a new metal Additive Manufacturing platform designed to offer a viable solution for short-run manufacturing. According to the company, the new system has been developed internally over the past several years and incorporates Stratasys's proprietary jetting technology.

The company has been developing and producing polymer-based AM systems for roughly thirty years, including its popular FDM and PolyJet 3D printing platforms. This will be the first internally developed metal AM system on offer by the company and is reportedly aimed at addressing the needs of customers whose requirements include the production of pilot-series parts, small batch manufacturing during product ramp up and end-of-life, and customised, lightweight and complex parts.

Starting with aluminium, it was stated that the system will offer an economically competitive cost-per-part, with easy to implement post-processing and high part quality.

"We are extremely excited to announce our development of this new Additive Manufacturing platform, targeting short-run production applications for a variety of industries, including automotive, aerospace, defence, machining and metal foundries," stated Ilan Levin, Chief Executive Officer of Stratasys.

www.stratasys.com

GKN confirms plans for sale of Powder Metallurgy business

GKN plc has confirmed that it will look to divest GKN Powder Metallurgy, comprising GKN Sinter Metals and Hoeganaes, within the next 12-18 months as part of its new business strategy to transform the company, including the sale of non-core segments. The new strategy announcement comes in response to Melrose PLC's widely-reported takeover bid in January 2018. After an initial proposal from Melrose to acquire GKN was rejected by GKN's board, both companies have launched campaigns to convince GKN shareholders of their respective plans for the group.

GKN stated that there are three components to its new strategy: the company plans to deliver distinct strategies for different product segments through rigorous capital allocation and focused performance targets; establish a delivery culture based on greater accountability, capability and pace, supported by aligned incentives; and separate operationally now and formally when it maximises shareholder value – with the operational separation of GKN Aerospace and Driveline already underway.

As part of a plan to divest non-core segments, GKN group will also look to sell GKN Driveline's Wheels, Cylinder Liners and Off-Highway Powertrain businesses, while identifying plans to grow Driveline China and further develop its eDrive Systems business. GKN Aero Additive Manufacturing was also identified as a product segment positioned for growth.

The board stated that it is targeting up to £2.5 billion cash return to shareholders over the next three years, with a significant portion of this expected to come from divestments executed in the first 12-18 months, including the sale of Powder Metallurgy. Anne Stevens, Chief Executive of GKN, stated, "The new strategy brings clarity, accountability and focus to GKN's world-class businesses and will allow the group to attain world-class financial performance. GKN has great technologies and great people. We have strong market positions and have delivered good growth, with management revenues last year of over £10 billion."

"But too often we pursued growth at the expense of returns," she continued. "This will no longer be the case. The new strategy brings discipline, both financial and operational." Stevens went on to state that the company expects the new strategy to generate significant cash for shareholders in the short term, and meaningful sustainable cash flows over the mid- to long-term. "We expect to deliver £340 million of recurring annual cash benefit from the end of 2020," she stated.

www.gkn.com

Additive Industries relocates headquarters in major expansion

Additive Manufacturing equipment maker, Additive Industries, Eindhoven, the Netherlands, will relocate its headquarters to a new facility in April, 2018. The new site, also in Eindhoven, has up to seven times more space for growth and will consolidate the business's headquarters, development and system assembly and test operations, currently spread over two facilities.

This move is expected to enable the fast-growing Additive Industries team to expand further, in line with the company's stated ambition to "grow to a top three position in metal AM" in 2022. After a complete renovation, the company stated that the building – formerly occupied by Phillips Electronics since the 1950s – is fully in line with modern energy-efficiency standards and will offer the best work environment for its staff.

"We are proud to again move into a great example of Dutch industrial heritage, where we have been able to preserve the great architecture of the past and simultaneously add a touch of modernism," stated Daan A.J. Kersten, CEO of Additive Industries. "This makes a fantastic home for a fast growing digital manufacturing technology company like us."

www.additiveindustries.com

Celebrating ten years of metal AM hip cups as GE launches validation consultancy for medical devices

The world's first metal additively manufactured acetabular cup for use in a hip replacement was produced a decade ago this year, according to GE. The trabecular titanium AM hip cup was produced by LimaCorporate and Arcam (now a GE Additive company), in partnership with Dr Guido Grappiolo, a surgeon at Italy's Livio Sciutto Foundation Orthopedic Biomedical Research - ONLUS.

The acetabular cup, named the Delta-TT Cup, marked the first venture into one of metal Additive Manufacturing's most successful application areas. Over the years, Arcam states that it has produced 100,000 hip cups on its own machines and estimates that hundreds of thousands more have been made by other metal AM companies.

Key to the success of metal AM implants is their ability to incorporate rough three-dimensional surface structures which imitate natural trabecular bone morphology, according to LimaCorporate. This encourages bone in-growth – wherein the patient's bone 'accepts' the implant as a part of the skeletal structure and begins to grow into it, thereby enhancing patient success rates. This was made clear with the first Delta-TT Cup: a few months after the operation in which it was implanted, Dr Grappiolo reported that a CT scan already showed the patient's bone to be growing into the hexagonal cells on the surface of the implant.

The lifespan of a conventionally manufactured hip cup implant typically ranges from ten to fifteen years, with the maximum lifespan considered to be twenty years, after which it must be replaced with a new implant in a second surgery. Having recently assessed the patient who received the first AM hip cup, Dr Grappiolo stated that he believes metal additively manufactured hip cups have the potential to last "a lifetime."

Arcam states that it has produced 100,000 metal AM hip cups (Courtesy GE)

Arcam's Delta-TT Cup was first produced 10 years ago (Courtesy GE)

GE Additive launches Orthopaedic Validation Consultancy for metal AM medical devices

To further support its customers through the validation, testing and verification of metal additively manufactured medical devices and implants, GE Additive also announced the launch of a new Orthopaedic Validation Consultancy (OVC). The service will be run jointly with GE Additive's AddWorks Engineering Consultancy and is designed for companies using Arcam EBM's Q10plus metal AM systems to produce devices to strict regulatory and compliancy requirements, including FDA standards, ISO 13485 and other regional and global standards.

Anders Ingvarsson, Product Manager at Arcam EBM, a GE Additive company, stated, "The medical technology sector is up there with the aerospace industry in terms of early adoption of Additive Manufacturing and pushing the boundaries of this emerging technology. There are parallels in the way these two sectors are beginning to incorporate and scale Additive Manufacturing from a prototyping solution into more mainstream production – within a heavily regulated market."

The OVC service will be delivered as a collaborative process with GE Additive's customers over a three to eight-month period. The desired outcome will be twofold; firstly, to decrease component time-to-market and help customers get into production with a validated machine; secondly, to create value in a cost-efficient way.

"We have created a five-step approach from assessment through to validation. This way we can provide bespoke modularity and flexibility to map to each customer's point on their additive journey. With each customer, we create an understanding of the production process, identifying needs and critical parameters and what needs to be tested and proven. Finding joint conclusions are the foundations of the process validation."

www.ge.com/additive
www.arcam.com

EOS expands production capacity with move to new plant

EOS GmbH has expanded its production capacity and relocated its system manufacturing facilities to a new facility in Maisach-Gerlinden, near Munich, Germany. The new 9000 m^2 factory will allow EOS to boost its production capacity up to around a thousand systems per year.

Commenting on the announcement, Nikolai Zaepernick, Senior Vice President Central Europe at EOS, stated, "Our technology is the right choice for high-quality series manufacturing applications. Industrial 3D printing has arrived in manufacturing. We installed around 1,000 systems in the first ten years of our existence as a company, this number has increased significantly, particularly during the last two years."

EOS is reported to have an installed base of around 3,000 Additive Manufacturing systems worldwide. "Over the next few years we also expect to see a further significant demand for our technology," added Zaepernick.

As the quality of materials, processes and systems is a top priority for many markets with high quality standards, such as the aerospace, medical technology or automotive sectors, EOS supports qualification of the technology at its customers' premises. In turn, this is said to help shorten the time to market for additively manufactured products.

When a customer buys a system from EOS, factory acceptance tests (FATs) are carried out. At the new plant in Maisach, customers

The new EOS manufacturing site in Maisach, Germany (Courtesy EOS)

also have the opportunity to get involved in acceptance tests for new systems. In addition to the machine qualification customarily performed by EOS, customers can request to have specific test jobs built of parts that they actually want to produce at a later date.

www.eos.info

Sandvik to build $25 million titanium and nickel metal powder plant

Sandvik, headquartered in Stockholm, Sweden, is investing approximately 200 million SEK ($25 million) in a new plant for the manufacturing of titanium and nickel fine metal powders. The new facility, within the business area of Sandvik Materials Technology (SMT), will be located in Sandviken, Sweden, close to the company's in-house titanium raw material supply and centre for Additive Manufacturing. The plant is expected to be operational in 2020.

According to the company, the investment will complement SMT's existing powder offering and strengthen Sandvik's position in the rapidly growing markets for metal powder and metal Additive Manufacturing. Sandvik is a leading producer of fine metal powders and serves a number of Additive Manufacturing companies. Its stainless steel, nickel-based and cobalt-chromium alloy powders are manufactured in the United Kingdom and Sweden and sold across Europe, North America and Asia through the Sandvik Osprey brand.

With demand for metal powder for AM expected to increase significantly in the coming years, the company sees titanium and nickel-based alloys as key growth areas accounting for a significant portion of the metal powder market.

Annika Roos, Head of product area Powder at Sandvik Materials Technology, commented, "This investment is an enabler for future growth and means that we are expanding our metal powder offering to include virtually all alloy groups

Sandvik will manufacture titanium and nickel fine metal powders at its new facility

of relevance today. In addition, it will also support the overall Additive Manufacturing business at Sandvik."

"The metal powder segment and the Additive Manufacturing business are of increasingly strategic importance to us. This investment should be viewed as the latest evidence of our commitment to an area that we believe strongly in", added Göran Björkman, President of Sandvik Materials Technology.

www.home.sandvik

Höganäs completes its acquisition of H.C. Starck's surface coating division

Sweden's Höganäs AB has completed its previously reported take over of H.C. Starck's Surface Technology & Ceramic Powders (STC) business. Reported to be Höganäs' largest acquisition so far, it follows the company's purchase of Metasphere Technology in November 2017 and Alvier PM-Technology in February 2018.

On the closing of this latest acquisition, Fredrik Emilson, President and CEO of Höganäs Group, stated, "STC is a strategically important acquisition for our growth agenda in more areas than traditional Powder Metallurgy. With STC, Höganäs gets access to new markets and product groups within the premium segment for surface coating and Additive Manufacturing. The acquisition means that we start the building of a second strong leg in Höganäs' business, next to metal powder for pressed and sintered components."

STC employs close to 400 people, mainly in Germany, where the company has two production units which Höganäs states will complement its powder production capacity. STC's customer base is mainly European, which is said to complement Höganäs' stronger position in the Americas and Asia-Pacific region.

"Together, we become a large player in surface coating and Additive Manufacturing," added Emilson. "With STC follows a deep knowledge of applications within, for instance, aerospace and oil and gas. These are areas where we see a large development potential and where we can offer our customers solutions for a more sustainable industry."

The acquisition contract was signed in December 2017 and approved by the relevant competition authorities at the end of February 2018. "Now we kick off the collaboration with our new colleagues. Together we will plan for our joint future as world leader within surface coating, AM and PM," concluded Emilson. "We all look forward to that."

www.hoganas.com

CNPC nears completion of facility for AM metal powder production

CNPC Powder Group is nearing completion of a new 30,000 m^2 facility in Anhui, China, that will provide a major increase in capacity for the production of metal powders for Additive Manufacturing. The company is reported to be on schedule to begin manufacturing powders in July 2018, with an annual capacity capable of reaching around 3,500 tons in 2019.

The facility is expected to house six metal powder production lines and will provide clients with services across the metal powder process chain, from alloy development to powder production and testing. The expansion will see CNPC strengthen its position as an international producer of AM materials, adding to the company's extensive range of metal powders for a wide variety of applications.

CNPC Powder Group's new facility is located in Anhui (Courtesy CNPC)

Also housed on site will be CNPC Powder's new research and development facility, which it states is set to focus on three critical projects. Firstly, the team will explore new materials, looking at the production of new alloys for AM and Metal Injection Moulding (MIM) applications. Secondly, the team will investigate the optimisation of material production and cost reduction, which it hopes will lead to greater cost savings for clients. Finally, the facility will serve as a research hub for innovation in AM.

CNPC Powder is a family owned and operated business established in 1998, which specialises in the development and commercialisation of powdered metal materials. The company has invested in a number of expansions over the years to increase its capacity and secure its position in the market. From 2003-2005, three factories were established to serve a growing domestic market and in 2009 the Shanghai office was opened to enable exports of powders to international clients. In 2015 a North American subsidiary, CNPC Powder North America, was established to expand services in the Americas.

As a result of its North American expansion, CNPC Powder states that it has been able to establish connections with North and South American powder users as well as a growing presence in Europe. As the company develops new powders for advanced manufacturing processes such as Additive Manufacturing, the new facility and R&D Centre at Anhui will allow for continued support. "This facility is a step in line with our core values of long-term relationship building and developing a high-quality product for our clients," concluded Abigail Franco, CNPC's Marketing Director.

www.cnpcpowder.com

Carpenter builds on AM capabilities with acquisition of part maker CalRAM

Carpenter Technology Corporation, Philadelphia, Pennsylvania, USA, reports that it has acquired MB CalRAM LLC, a metal Additive Manufacturing service provider. CalRAM supplies powder bed fusion AM services to the aerospace, defence, power generation and oil & gas industries from its 25,000 ft^2 manufacturing facility in California, USA. The company holds Nadcap accreditation and is AS9100 certified, as well as being a Digital Product Definition (DPD) approved supplier.

Tony Thene, Carpenter's President and CEO, stated, "This strategic acquisition builds upon our existing Additive Manufacturing capabilities and provides direct entry into the rapidly expanding part production segment of the Additive Manufacturing value chain."

"The addition of CalRAM brings industry leading technology and processes coupled with a talented team and is a strong complement to Carpenter's deep technical experience in producing highly engineered metal powders and wire for Additive Manufacturing applications, including mission-critical applications such as jet-engine fuel nozzles, rocket-thrust chambers, and orthopaedic implants," he continued.

"CalRAM's proven expertise and strong customer relationships will accelerate and enhance our capabilities and will further strengthen our ability to be the preferred provider of end-to-end next generation Additive Manufacturing solutions. As Additive Manufacturing continues to evolve into more advanced components with increasing complexity, our customers are seeking partners who can not only produce parts, but also possess metallurgical expertise to help determine the best materials and processes to fit their needs in demanding applications."

"Our unique combined capabilities will not only allow us to deliver the best solution for the customer, but also allow us to be a leader in the advancement of the evolution of the Additive Manufacturing industry," he concluded.

Carpenter Technology is a key producer and distributor of speciality alloys, including titanium alloys, nickel and cobalt based super-alloys, stainless steels, alloy steels and tool steels. Carpenter's powder technology capabilities support a range of next generation products and manufacturing techniques, including Additive Manufacturing.

www.cartech.com/calram

Bodycote to provide manufacturing services to Safran Group

Bodycote, Macclesfield, UK, has entered into a long-term agreement with France's Safran Group to provide manufacturing services including thermal spray coatings, electron beam welding, Hot Isostatic Pressing (HIP), heat treatment and others to Safran companies and their key strategic first-tier suppliers.

Bodycote's processes and technologies are used to prolong the working life of critical components and provide in-service protection from factors such as abrasion, temperature and wear. The company stated that the agreement would be supported by its global network of facilities, and will initially operate from strategically located facilities in France and Belgium.

According to the partners, the agreement aims to ensure that the manufacturing requirements of Safran will be met by a quality-focused supplier, supporting the growth in Safran's civil aerospace programmes. These include the CFM LEAP for Safran Aircraft Engines, helicopter engine programmes for Safran Helicopter Engines and landing gear systems for Safran Landing Systems. The availability of Bodycote's international network of thermal processing and other specialist services is expected to offer security and mitigate risk in the supply chain.

www.bodycote.com | www.safran-group.com

Audi producing automotive components, prototypes and spare parts

SLM Solutions Group AG, Lubeck, Germany, reports that its Selective Laser Melting (SLM) systems are being used by Audi AG for the metal Additive Manufacturing of components for special and exclusive automotive series, as well as in the production of prototypes and rare spare parts. Among the rare spare parts said to be produced using AM are the water adapters for the Audi W12 engine, now manufactured on-demand using an SLM®280 system.

Dr Alexander Schmid, After Sales Manager at Audi, explained, "Manufacturing on-demand is a vision for us to ensure supply with original spare parts – which are required less often – economically and sustainably in the future. Regional printing centres would simplify logistics and warehousing." The ability to digitally send a part design and produce it by AM in a 'regional printing centre', rather than shipping the part itself, has been a driving factor in the technology's adoption by many automakers to produce rarely-ordered spares.

Audi has been working with SLM Solutions to produce components, prototypes and spare parts

In prototyping, metal AM enables the relatively rapid adjustment and production of multiple design iterations of a part. Harald Eibisch, a member of Audi's Technology Development Department, stated, "The new constructive freedoms provided by this technology are especially interesting. Components for prototypes and spare parts requested extremely rarely are better suited for SLM processes than conventional manufacturing procedures thanks to the benefits of free geometric design."

"The load capacity of the components is comparable with parts manufactured using traditional methods," he added. According to Audi, the W12 engine's SLM-produced water adapter shows that metal AM "sets no limits in terms of loads." The company has identified no direct disadvantage in the material properties and reported that even highly stressed parts such as pistons can be printed.

The SLM 280 machine has a build chamber measuring 280 x 280 x 365 mm, said to be one of the largest construction spaces in its class, and uses SLM Solutions' patented multi-beam technology. It is available in several configurations, providing single optics (1x 400 W or 1x 700 W), dual optics (1x 700 W and 1x 1000 W) and twin optics (2x 400 W or 2x 700 W). Depending on how the components are arranged, SLM Solutions states that an 80% higher build rate can be achieved.

Ralf Frohwerk, SLM Solutions' Global Head of Business Development, commented, "The trust of automobile manufacturers in metal-based 3D printing is increasing daily. Thanks to a growing understanding of 'real and meaningful' 3D-suitable designing, previously unimaginable designs for vehicle parts are being created."

Looking to the future of metal AM in the automotive industry, he stated, "Knowing that nearly every automaker also has vehicle programs with numbers of pieces less than 2000-3000 units per year in its portfolio, there are also already aluminium die cast components today, for example, that can be produced more economically using additive processes."

www.slm-solutions.com
www.audi.com

Oerlikon to supply China's Farsoon Technologies with range of qualified metal powders

Farsoon manufactures a range of metal AM systems (Courtesy Farsoon)

Swiss technology and engineering group Oerlikon has signed a long-term collaboration agreement with China's Farsoon Technologies to supply qualified Oerlikon metal powders for Farsoon's metal Additive Manufacturing systems. It was stated that the purpose of the collaboration is to accelerate the adoption of Additive Manufacturing in China by providing customers with a combined solution of printer hardware and fully certified metal powders.

The agreement between Oerlikon and Farsoon reportedly could establish a new business model for the Chinese AM market. Oerlikon will serve as the global partner for Farsoon as a preferred and primary metal powder supplier. Farsoon will be qualifying MetcoAdd powders to its AM systems, enabling customers purchasing Farsoon technology to receive Oerlikon AM powders at the same time. Farsoon added that it is committed to creating an 'open platform system' for all metal AM systems, which it says will give end users the freedom to innovate and expand the boundaries of AM technology.

The companies announced they will further collaborate on research and development projects to optimise process performance for applications, especially for the Chinese market. Furthermore, Oerlikon will work with Farsoon to develop customised alloys for their AM systems in order to accelerate the adoption of AM in industries such as aerospace, power generation, tooling and automotive.

Florian Mauerer, Head Business Unit AM, Oerlikon, stated, "For new technologies, such as AM, partnerships and the development of new business models are key to unlocking their potential. Working together with Farsoon, a fast-growing AM machine manufacturer with a well-established presence in China, can set a new standard in the AM industry to bring integrated quality products and services to customers."

"We look forward to working with a company known for its excellence and quality in the metal powder industry," added Dr Xu Xiaoshu, Farsoon's Chairman. "Partnering with Oerlikon as one of our preferred material suppliers can guarantee our customers a high level of material quality for their current and future applications."

www.oerlikon.com/am

www.farsoon.com

AM Centre of Excellence for offshore and marine sector in Singapore

Norwegian-based DNV GL, a global quality assurance and risk management company, has established a Global Additive Manufacturing Centre of Excellence (CoE) in Singapore. According to the company, the centre will focus particularly on AM in the oil & gas, offshore and marine (O&M) sectors.

DNV GL aims to enable the adoption AM technology in the O&M sector by providing the industry with technical standards and guidelines for qualifying and certifying AM equipment, processes, products, materials and personnel. The centre will offer assurance and advisory services in AM and allied technologies and – DNV GL believes – has the potential to position Singapore as a world leader in the technology.

DNV GL has been investigating the opportunities and challenges posed by AM in the O&M sector since 2014. In December 2017 it partnered with Aurora labs to certify metal AM parts for the oil & gas, renewables and marine industries and develop an AM certification standard to cover the entire value chain from powders to parts. Through the newly established CoE, it is reported to be running a collaboration with Singapore's Sembcorp Marine, Singapore Institute of Manufacturing Technology (SIMTech) and National Additive Manufacturing Innovation Centre (NAMIC) to develop and certify laser aided Additive Manufacturing (LAAM) technology for the production of large-scale structures for new marine-going vessels.

Remi Eriksen, DNV GL's Group President & CEO, explained, "The establishment of the centre is timely due to the rising interest in adopting AM. With our long track record in R&D and strong position in developing industry technical standards, DNV GL's Global Additive Manufacturing Centre of Excellence will play a catalytic role in the oil & gas, offshore and marine sector."

"We are committed to building a centre that will contribute to helping Singapore create a vibrant Additive Manufacturing ecosystem," added Brice Le Gallo, Regional Manager for DNV GL South East Asia and Australia. "The competence and knowledge gained through research and development and advisory engagement with our customers will support Singapore to maintain its competitive edge in the global offshore & marine market."

www.dnvgl.com

ZYYX 3D Printer to launch benchtop metal AM system in 2019

ZYYX 3D Printer, Gothenburg, Sweden, a brand of Magicfirm Europe AB, revealed its first metal Additive Manufacturing system at TCT Asia 2018. During the show, the company stated that the system will be suitable for 'benchtop' Additive Manufacturing in small workshops and offices.

The company showcased a number of demonstrator parts in steel, copper and bronze, produced on a prototype of the system at its Gothenburg facility. The system reportedly includes a sintering solution and uses a patent-pending AM process combining metal powder with a non-toxic binder which is safe to handle without special atmospheric requirements.

Following the initial build process, the binder is removed from the 'green part' using non-toxic substances, resulting in a 'brown part' which is then sintered using what ZYYX reports to be a simplified process. The new system is said to be capable of Additive Manufacturing parts with a resolution of around 50 µm. Currently, parts have a sintered density of more than 98% and show shrinkage of about 21%.

Mats Moosberg, CEO of Magicfirm Europe and founder of ZYYX 3D Printer, stated, "We have been developing our metal 3D printing technology for some time and we are now ready to show an early stage proof of concept. We're still fine-tuning the process and the objects we are showing now highlight the spectrum of materials and print volume."

The company expects to add further metal materials to the system's AM capabilities in the near future. "We see a great opportunity to build upon our ZYYX pro 3D printer for engineering materials and give our customers access to another ZYYX tool for doing real prototyping and one-off production in metal – in a safe way regardless of facilities," stated Moosberg. "We have also started talking to different parties for funding the continued development and commercialisation of the product."

The system is expected to retail at less than €10,000 and to begin shipping in 2019.

www.zyyx3dprinter.com

Demonstration parts produced on a prototype ZYYX 3D Printer (Courtesy ZYYX 3D Printer)

Laseradd showcases its range of metal Additive Manufacturing systems

Laseradd Technology Co., Ltd, Guangzhou, China, showcased its range of metal Additive Manufacturing systems at the recent TCT Asia exhibition in Shanghai, China. The company specialises in Selective Laser Melting (SLM) systems manufacture and sales, as well as providing a number of metal Additive Manufacturing services to its customers.

On display at the show was the company's DiMetal series of metal AM systems, said to be capable of processing a range of materials including titanium, high-temperature alloys, cobalt-chromium alloy, stainless steel and aluminium alloys.

The DiMetal range includes three systems – the DiMetal-50, DiMetal-100 and DiMetal-280. The DiMetal-50 model offers the smallest build area at 50 x 50 x 50 mm, with the DiMetal-100 offering a maximum build area of 100 x 100 x 100 mm and the DiMetal-280, the largest of the systems, offering a build area of 250 x 250 x 300 mm for larger scale part production.

Founded by a team with a reported fifteen years' experience in the development of Powder Bed Fusion (PBF) metal Additive Manufacturing equipment and technology, Laseradd states that it is devoted to the development of a brand, technology, products, services and training to support local and national manufacturing and scientific research enterprises at all levels.

www.laseradd.com

The DiMetal-280, the largest of Laseradd's metal AM systems, offers a build area of 250 x 250 x 300 mm (Courtesy Laseradd)

Metal Additive Manufacturing of structures "smaller than a speck of dust"

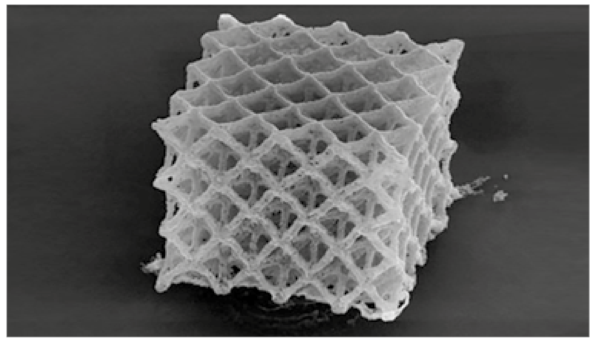
A group of scientists at the California Institute of Technology (Caltech), California, USA, have reportedly developed a new process which enables the metal Additive Manufacturing of structures smaller than a human hair and invisible to the naked eye. In a paper published in *Nature Communications*, 'Additive Manufacturing of 3D Nano-Architected Metals', the group stated that the process could be scaled up for use in a wide variety of applications, including the production of tiny medical implants, ultralightweight aircraft components and 3D logic circuits on computer chips.

The principal researchers on the project were Julia Greer, Professor of Materials Science, Mechanics and Medical Engineering at Caltech's Division of Engineering and Applied Science, and graduate student Andrey Vyatskikh. While Greer has previously additively manufactured nanostructures from materials such as ceramics, polymers and organic compounds, this is the first time the team has successfully applied her nanoscale AM technique to metals.

Greer's process works by lasing a liquid or resin in specific locations with just two photons, in a process called 'two-photon lithography'. This generates enough energy to harden liquid polymers into solids, but is not strong enough to fuse metal. "Metals don't respond to light in the same way as the polymer resins that we use to manufacture structures at the nanoscale," explained Greer. "There's a chemical reaction that gets triggered when light interacts with a polymer that enables it to harden and then form into a particular shape. In a metal, this process is fundamentally impossible."

The solution, developed by Vyatskikh, is to use organic ligands (molecules with the ability to bind to trace metals in the aquatic dissolved phase) to create a resin comprising primarily of polymer, but 'carrying with it' a metal which can then be additively manufactured. Vyatskikh's technique bonds nickel with organic molecules to create a liquid 'syrup' which was then lased with a two-photon laser to build a structure according to a CAD design. Under the laser, the organic molecules hardened into 'building blocks' for the structure, which the nickel atoms were incorporated into. The result was an additively manufactured nanostructure comprising a blend of metal ions and nonmetal organic molecules.

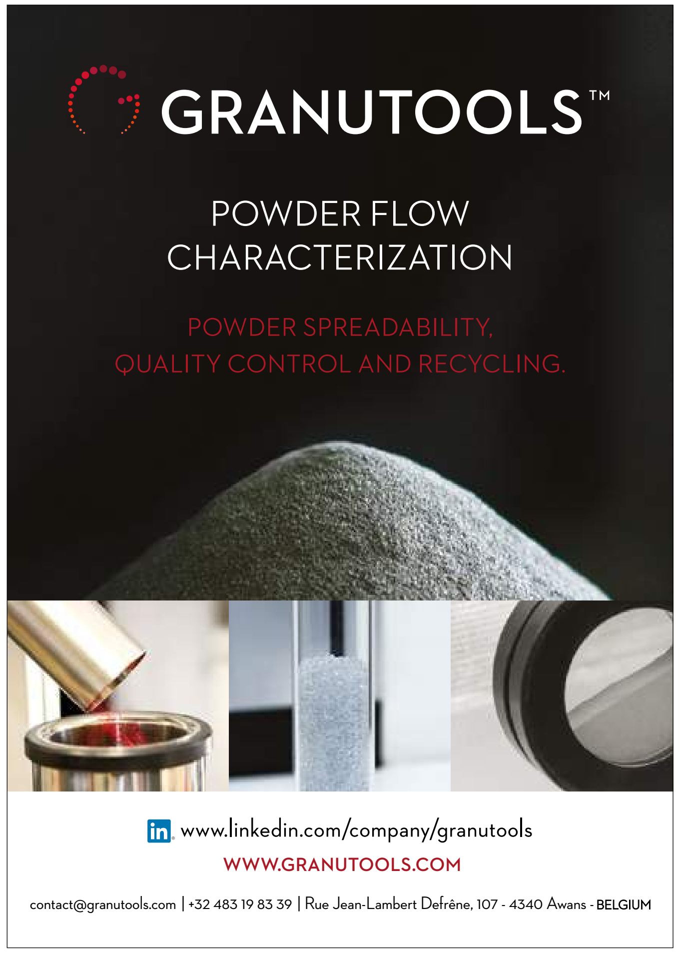
Vyatskikh then heated the nanostructure slowly in a vacuum to 1000°C – below the melting point of nickel, but hot enough to vaporise the organic materials in the structure and leave only the metal. This heating process also resulted in fusing of the metal particles, as well as structural shrinkage of about 80%. The combination of Greer's nanoscale AM process and the part shrinkage resulted in a final structure which was reported to be smaller than a speck of dust.



The final metal AM nanostructure was reported to be smaller than a speck of dust (Courtesy Caltech)

"In the structure we built for the paper, the diameter of the metal beams in the printed part is roughly 1/1000th the size of the tip of a sewing needle," stated Vyatskikh. Greer and Vyatskikh report that the process requires some refinement, with the initial structures showing some voids left behind by the vaporised organic material as well as some minor impurities. The research team stated that it is interested in adapting the process to work with other metals, such as tungsten and titanium, which are challenging to produce at very small scales.

www.caltech.edu



Siemens invests £27m in new Materials Solutions facility

Siemens is to make a £27 million investment in a new, state-of-the-art manufacturing facility for its UK-based Additive Manufacturing business. Materials Solutions Ltd, located in Worcester, UK, will open the new site in September 2018, enabling it to increase its number of AM machines from fifteen to fifty over the next five years. The expansion of the business is also expected to support the creation of around fifty-five new jobs, increasing Materials Solutions' team to eighty.

The new factory will be fully powered by Siemens Digital Enterprise technologies solutions, said to be an end-to-end portfolio comprising software-based systems and automation components. Siemens states that this will cover every conceivable requirement arising along the industrial value chain, thereby harnessing the potential of digitalisation. The new facility will also be a focal point for collaboration between Materials Solutions and the already sizeable UK Siemens Digital Factory division.

"This significant investment underlines our belief that there is huge potential for innovation and growth within the Additive Manufacturing sector. It is also the next step towards achieving our ambition of pioneering the industrialisation of 3D printing," stated Juergen Maier, Siemens UK CEO.

Materials Solutions' new facility will open in September 2018 (Courtesy Siemens)

Materials Solutions also offers comprehensive services for engineering and printing up to the complete manufacturing of parts for the aviation industry, the automotive industry, power generation and motor sports. The new facility will be a global centre of excellence for the business, and act as the launch pad for its global growth plans.

Phil Hatherley, General Manager of Materials Solutions, added, "We were incredibly proud to have achieved a world first last year – the production of a successfully tested 3D printed gas turbine blade – and I believe our new factory will facilitate similar achievements for our customers operating in other highly demanding environments, allowing us to maintain our position at the leading edge of this incredibly exciting industry."

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

Geo Kingsbury enters AM sector with AddUp

Geo Kingsbury, a supplier of turnkey metal cutting systems to the UK and Irish manufacturing industry, has announced it is now also offering Additive Manufacturing solutions from AddUp Global Additive Solutions. The company, based in Gosport, Hampshire, UK, has been named as exclusive distributor within the UK and Irish markets for AddUp's range of metal Additive Manufacturing systems. "We have created a new Additive Manufacturing division at our offices in the Midlands, headed by Richard Hughes, to operate alongside our Large Prismatic Machines (LPM) and Milling Turning Grinding (MTG) technology divisions," stated Richard Kingsbury, Managing Director of Geo Kingsbury.

"We will be looking to include further Additive Manufacturing processes in our portfolio in the coming months, signalling our intention to move strongly into this expanding area of manufacturing," added Kingsbury.

Addup's FormUp metal Additive Manufacturing machines are suited to a range of applications and offer a flexible and upgradeable system designed so that options can be added as needs and uses change. The powder bed systems are designed to be compatible with all types of materials including stainless steels, maraging steels, nickel alloys, titanium alloys and aluminium alloys.

www.geokingsbury.com
www.addupsolutions.com

Husun to bring Optomec LENS Systems to Chinese market

Optomec, Albuquerque, New Mexico, USA, has signed a partnership agreement with Husun Technologies, Beijing, China, to resell its LENS Systems for metal Additive Manufacturing in China. Founded in 2011, Husun is focused on the promotion of advanced industrial AM solutions in China and reports that it has established a diverse customer base in the automotive, aerospace, academic and other industries.

"Optomec is an internationally famous company in the field of metal Additive Manufacturing and we are pleased to partner with them in their global development strategy," stated Ms Qiao, Husun Technologies' General Manager. "We see a large market opportunity for metal Additive Manufacturing technology in the region and are expanding our sales and sales service teams to promote and support LENS technology to various application fields in China."

"We are very happy to partner with Husun to expand sales of LENS metal Additive Manufacturing systems in China," added Pascal Pierra, Optomec's Director of Asia Pacific Sales. "The Husun team has an excellent track record delivering advanced industrial manufacturing solutions including equipment, application technology and post-sales support. They're already off to a great start with sales of two LENS systems."

One-hundred Optomec LENS systems are currently in operation in fifteen countries. The company states that its latest LENS Machine Tool Series is capable of additively manufacturing metals ten times faster than powder bed fusion AM systems.

www.optomec.com

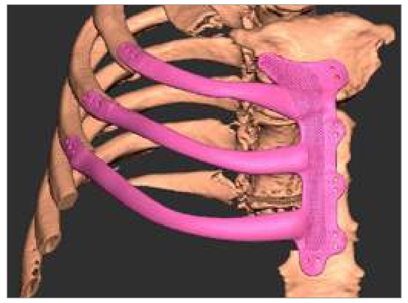
www.husun.com.cn

Hospital reconstructs patient's chest using titanium Additive Manufacturing

Using metal AM, the surgical team was able to produce a titanium implant to the patient's exact fit and specifications (Courtesy NHS Wales)

Surgeons at Morriston Hospital, Wales, UK, have successfully rebuilt part of a patient's chest using metal Additive Manufacturing. The titanium implant was additively manufactured on a Renishaw system, as part of a collaborative innovation project between the company and the hospital.

According to NHS Wales, the 71-year-old patient required the implant following surgery to remove an extensive sarcoma – a cancer growth in the soft tissue – from his chest, resulting in the removal of part of the breastbone and three ribs altogether. Though necessary, the surgery left the patient at risk of chest wall destabilisation and potential collapse.



To achieve a custom fit, the implant was designed by hospital staff based on CT scans of the patient's chest (Courtesy NHS Wales)

Traditionally, the chest would have been reconstructed using a cement prosthesis. However, although hard-wearing, cement prosthetics do not provide an exact fit and can move within the body, causing issues such as dislocation, explained Ira Goldsmith, Cardiothoracic Surgeon at Morriston. In addition, cement prosthetics take around an hour and a half to prepare during surgery, putting the patient at increased risk of complications on the operating table.

Using metal AM, the surgical team was able to produce a titanium implant to the patient's exact fit and specifications, as well as reducing the overall surgery time by around two hours. To achieve a custom fit, the implant was designed by Heather Goodrum, Morriston's Biomedical 3D Technician, and Peter Llewelyn Evans, Morriston's Laboratory Services Manager, based on CT scans of the patient's chest.

During a reconstructive surgery taking approximately eight hours, the finished titanium implant was sewn into place and covered with a section of latissimus dorsi muscle harvested from the patient's upper back. Following the procedure, Goldsmith stated, "We are very pleased with the outcome. The implant is a perfect fit. Titanium is very strong and any problems like dislocation are reduced or even eliminated because the implant is anchored securely to the ribs and breastbone."

According to Morriston Hospital, this is the first time an implant of this kind has been produced using metal Additive Manufacturing in the UK. The hospital stated that Goldsmith will give a presentation on the implant's development at the next meeting of the British Sarcoma Group, as well as the Society for Cardiothoracic Surgery in Great Britain and Ireland.

www.renishaw.com

Additive Industries reveals the winners of its Design for AM Challenge

Aidro Hydraulics, winner in the professional category of the challenge (Valeria Tirelli, CEO, and Gaetano Corrado, AM Specialist)

Additive Industries, Eindhoven, the Netherlands, revealed the winners of its Design for Additive Manufacturing Challenge during an awards dinner at the 6th Additive World Conference. In the professional category, the winner was Italy's Aidro Hydraulics, and the student prize was awarded to Yogeshkumar Katrodiya, a Master's student at Fraunhofer IGCV, Germany.

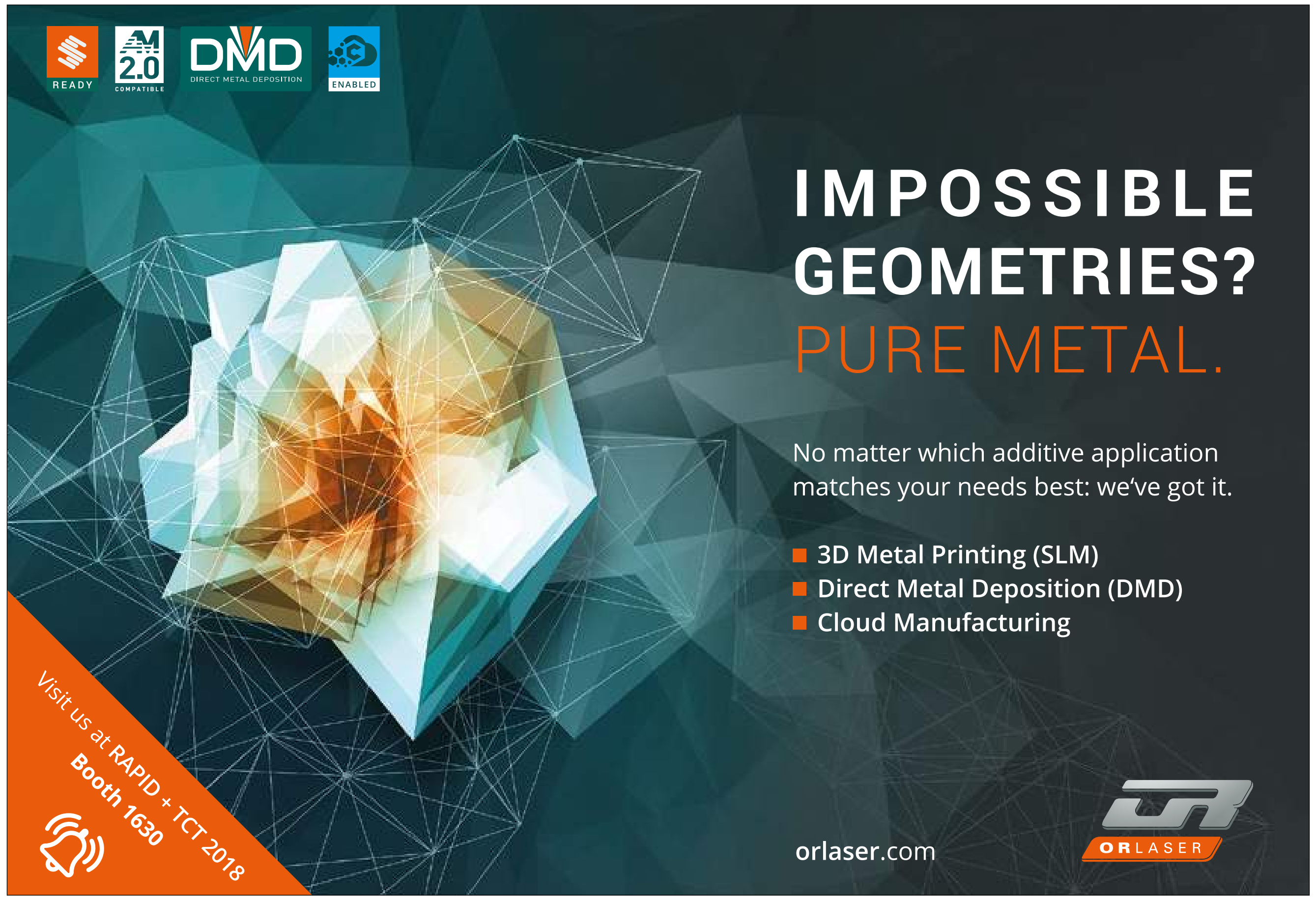
For the challenge, Valeria Tirelli, Aidro Hydraulics CEO, presented a compact redesign of a generic hydraulic manifold for a street cleaning vehicle. Designed by Gaetano Corrado, the redesigned component consolidated two parts into one at a smaller scale than the existing manifold and achieved optimised flow thanks to the incorporation of improved, curved channels. The redesign also addressed the problem of fluid leakage in the original part, which was caused by auxiliary plug failure, and reduced the weight of the part by 70%. According to the Additive Manufacturing Challenge jury, Aidro Hydraulics was recognised for the "massive applicability and commercial viability of their design."

Katrodiya won for his design of a fully integrated shaft and gear with internal channels transporting lubricant to the gears for cooling. Helix-shaped cooling channels were applied to increase the cooling capacity, taking full advantage of the geometric freedom offered by Additive Manufacturing in comparison to more traditional technologies.

By consolidating the parts of the component and optimising the component topology, Katrodiya stated that he obtained a weight reduction of 50%. The jury stated that this entry was rewarded for the "generic applicability and the large number of potential applications" of the design.

All six challenge finalists received a one-year licence for Altair's Inspire and Autodesk's Netfabb software. Katrodiya, as student winner, was awarded an Ultimaker 2+ polymer AM system while the Aidro Hydraulics team were awarded an Ultimaker 3.

www.additiveindustries.com



Huisman load tests metal additively manufactured offshore crane hook

A typical offshore crane aboard a subsea vessel (left), additively manufactured crane hook under load test (right) (Courtesy Huisman Equipment)

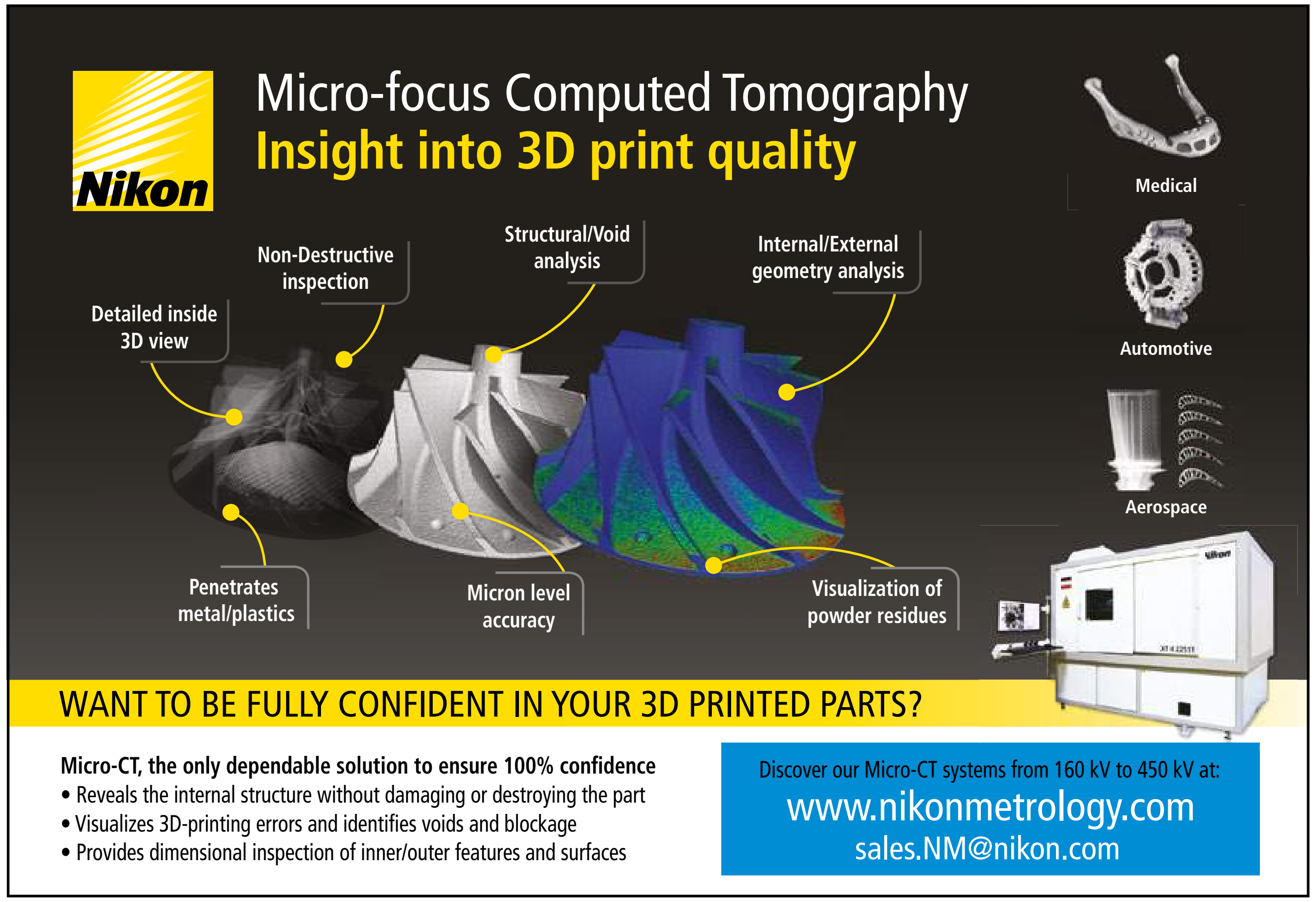
Huisman Equipment, headquartered in Schiedam, the Netherlands, has successfully load tested what is reported to be the world's first offshore crane hook produced by Wire Arc Additive Manufacturing (WAAM). The crane hook passed load testing up to 80 mt, along with all associated quality control checks according to strict criteria.

This component would typically be manufactured using casting or forging. In using WAAM, Huisman states that it significantly reduced the delivery time and cost of producing this large component. The company also stated that the AM hook was produced to a more consistent level of quality than cast or forged hooks.

Huisman employs Additive Manufacturing to produce mid-size to large components with high-grade tensile steel, including a large four-prong hook, with an own printed weight close to 1,000 kg. The process allows the manufacture of simple or complex shapes, offers short delivery times and can include local alternative material properties to improve wear and corrosion resistance, for example.

The successful WAAM test results will enable Huisman to extend its range of reliable components that were either physically impossible or commercially unfeasible by other methods. The company reportedly aims to improve the WAAM process further by reducing the cost price for the technique and increasing its manufacturing capability to include the production of items weighing up to 2,500 kg.

www.huismanequipment.com



STELIA Aerospace demonstrates additively manufactured aircraft fuselage panels

STELIA Aerospace's 1 m² aluminium WAAM demonstrator part (Courtesy STELIA Aerospace)

STELIA Aerospace, Toulouse, France, has produced a demonstrator part for wire-arc additively manufactured (WAAM) fuselage panels, made in aluminium with stiffeners manufactured directly on the surface. The part was produced as part of the R&T project DEFACTO (DEveloppement de la Fabrication Additive pour Composant TOpologique), on which STELIA is collaborating with aluminium product specialist Constellium, Centrale Nantes engineering school and the engineering group CT Ingénierie.

The company expects that the new production method should, in the long term, eliminate the need for added stiffeners, which are either screwed or welded to the fuselage panels. The demonstration part measures 1 m² and was manufactured by depositing layers of aluminium wire welded by electric arc. The new design was derived from fuselage topological optimisation studies carried out by STELIA and CT Ingénierie over several years.

STELIA Aerospace, an Airbus-owned company, designs and manufactures the front fuselage sections for the entire Airbus family of aircraft, as well as fuselage sections and specific sub-assemblies for Airbus, fully-equipped wings for ATR, fully-equipped central fuselages for Bombardier's Global7000 and complex metallic and composite aerostructure parts for companies including Boeing, Bombardier, Embraer and Northrop-Grumman.

The company launched the DEFACTO project in 2017 as part of a research strategy, at which time it began topological optimisation studies with the aim of additively manufacturing demonstrator parts for elementary components (such as fittings), large dimension parts (frames) and large sub-assemblies. The project is co-financed by the French Directorate General for Civil Aviation (DGAC) and expected to run for two and a half years.

Among the benefits targeted by the project are the integration of part functions, a reduction in ecological impact, component weight, material use and manufacturing cost. Cédric Gautier, CEO of STELIA Aerospace, explained, "With this additively manufactured demonstrator, STELIA Aerospace aims to provide its customers with innovative designs of very large structural parts derived from new calculation methods (topological optimisation)."

"Through its R&T department, and thanks to its partners, STELIA Aerospace is therefore preparing the future of aeronautics, with a view to developing technologies that are always more innovative and will directly impact our core business, aerostructures," he concluded.

www.stelia-aerospace.com

Metal AM engine part completes maiden flight on Finnish fighter jet

The part was installed on an F/A-18 Hornet fighter operated by the Finnish airforce (Courtesy Finnish Air Force)

Finland's first metal additively manufactured aircraft engine part has completed its maiden flight. The part, developed by Patria, was installed on an F/A-18 Hornet fighter operated by the Finnish airforce and flew for the first time on January 5, 2018.

Full details of the part have not been disclosed, however Patria reports that it was additively manufactured from Inconel 625 superalloy. The engine part was designed in accordance with Military Design Organisation Approval (MDOA), meeting European Military Aviation Requirements (EMARs) and granted by the Finnish Military Aviation Authority (FMAA).

Ville Ahonen, Vice President of Patria's Aviation business unit, stated, "For this part, the development work has been done over the last two years, with the aim of exploring the manufacturing process for 3D printable parts, from drawing board to practical application."

"Using 3D printing to make parts enables a faster process from customer need to finished product, as well as the creation of newer, better structures. We will continue research on Additive Manufacturing methods, with the aim of making the new technology more efficient," he concluded.

www.patria.fi

PyroGenesis receives ISO 9001:2008 certification for metal powder production

PyroGenesis Canada Inc., Montreal, Canada, reports that it has received certification for the production of metal powders under a quality management system which complies with the requirements of ISO 9001:2008. This certification is an amendment to the company's existing ISO certification and pertains specifically to metal powder production. It was received under the auspices of independent risk and standards company SAI Global.

P. Peter Pascali, President and CEO of PyroGenesis, stated, "As we all know, having an ISO certification confirms that our management systems, manufacturing processes, and documentation procedures have met all the requirements for standardisation, quality assurance, traceability and batch to batch consistency. This gives prospective customers assurances that our house is in order. In addition, such efficient quality management systems will ultimately save time and money, as well as improve efficiencies."

"We have found that many of our customers will only do business with vendors that are certified as ISO 9001 compliant," he added, "and many requests for quotes are from companies that make ISO 9001 certification a 'must-have.' We are also in the process of applying to AS9100D for the aerospace industry, and ISO 13485 for the medical devices industry. In short, having this certification gives potential customers the additional confidence to accept PyroGenesis as a qualified vendor."

With its extensive plasma expertise, PyroGenesis is able to convert many metals and alloys into high-purity spherical powders, as its plasma torches use argon gas and the reactor is backfilled with argon. This ensures that the powders produced are not exposed to any oxygen during the production process and, as a result, PyroGenesis is able to produce powders with extremely low interstitial (ELI) such as Ti 6Al-4V ELI. The company's standard offering includes commercially pure titanium (CPTi), grades 1, 2, and 3, and Ti 6Al-4V, grades 5 and 23.

www.pyrogenesis.com

Roboworker establishes first North American base

Roboworker Automation GmbH, headquartered in Weingarten, Germany, has established its first North American base. Located in Lewis Center, Ohio, USA, the sales office is expected to provide a new point from which the company can promote its technologies in the marketplace, as well as serving and supporting the needs of its North American Customers.

The company's new base will be headed by Michael Starn, who is reported to offer extensive experience and knowledge in metal cutting technologies. Stern commented that he is looking forward to further strengthening Roboworker's position in the US, Canada and Mexico.

Established in 1989, Roboworker Automation is a manufacturer of systems for automation and for the inspection of precision parts, such as cutting inserts and wear parts and automotive components. The company specialises in three core areas of powder press automation, cutting insert automation and inspection processes.

www.roboworker.com

AMBER launches €4.3 million AM research laboratory in Ireland

Ireland's Advanced Materials and BioEngineering Research centre (AMBER), funded by the Science Foundation Ireland and headquartered at Trinity College, Dublin, has announced the establishment of a new Additive Manufacturing research laboratory. The AR-Lab was founded with a €4.3 million investment from Science Foundation Ireland and the European Research Council, as well as strategic funding from Trinity College.

According to AMBER, the AR-Lab will focus on research into new materials and AM methods, as well as extending the capabilities of AM to enable the development of new medical, electronic, mechanical, optical, acoustic, heat transfer and sensing devices. AMBER has invested in a suite of AM technologies for use at the AR-Lab, spanning the full spectrum of materials including metals, ceramics, polymers and biomaterials. Prof Michael Morris, AMBER Director, explained, "AMBER's AR-Lab will be a pivotal component of AMBER's research focused on the fundamental material science challenges associated with 3D printing, e.g. the range and complexity of the materials that can be printed, the size of these features and how a number of material sets can be integrated into a functioning device."

"This investment will play a leading role in the emerging 3D printing national research ecosystem. It will enable AMBER to build on our foundation of innovative excellence in materials science and become leaders in this emerging technology which is critical to the manufacturing industries that support the Irish economy," he continued.

The AR-Lab will focus on research into new materials and producton methods (Courtesy AMBER)

Prof Mark Ferguson, Director General of Science Foundation Ireland and Chief Scientific Adviser to the Government of Ireland, added, "Science Foundation Ireland is delighted to support the establishment of a new Additive Manufacturing laboratory at the AMBER SFI Research Centre through the latest SFI Infrastructure Call. Ireland has built a reputation for cutting-edge science and engineering and now attracts top international talent from across the globe."

www.ambercentre.ie

Bugatti to trial additively manufactured titanium brake calipers

Bugatti Automobiles S.A.S. has designed a metal additively manufactured titanium brake caliper said to be the largest in the automotive industry. Developed in partnership with German-based Laser Zentrum Nord GmbH, the first trials of the brake calipers for use in production vehicles are due to take place in the first half of 2018.

"Vehicle development is a never-ending process. This is particularly true at Bugatti," sated Frank Götzke, Head of New Technologies in the Technical Development Department of Bugatti Automobiles S.A.S. "In our continuing development efforts, we are always considering how new materials and processes can be used to make our current model even better and how future vehicles of our brand could be designed."

Made in Ti6Al4V, a titanium alloy primarily used in the aerospace industry for highly stressed components, the new AM caliper is 41 cm long, 21 cm wide and 13.6 cm high, weighing just 2.9 kg. In comparison, similar aluminium components currently used by Bugatti weigh 4.9 kg – around 40% more.

Bugatti is already said to use the most powerful brakes in the world for its new Chiron supercar. The brake calipers for that vehicle were forged from a block of high-strength aluminium alloy and incorporate eight titanium pistons on each of the front calipers and six on each of the rear units. These are currently the largest brake calipers installed on a production vehicle.

Ti6Al4V offers considerably higher performance than aluminium, with the alloy having a tensile strength of 1,250 N/mm² in its additively manufactured form. According to Bugatti, this means that a force of slightly more than 125 kg would have to be applied to a square millimetre of the alloy to cause a rupture. While this extreme strength is an advantage for vehicle component production, it makes it unfeasible to produce geometrically complex titanium components such as the Chiron's brake calipers using conventional manufacturing processes such as milling or forging.

By using Selective Laser Melting, Bugatti and Laser Zentrum Nord report that they have been able to produce a complex structure which is significantly stiffer and stronger than would be possible with any conventional process. According to Bugatti, the final, geometrically complex component incorporates walls with thicknesses between a minimum 1 mm and maximum 4 mm.

"It was a very moving moment for the team when we held our first titanium brake caliper from the 3D printer in our hands," stated Götzke. "Everyone who looks at the part is surprised at how light it is – despite its large size. Technically, this is an extremely impressive brake caliper, and it also looks great."

According to Bugatti, the development time for the new calipers was very short, spanning around three months from concept to finished component. Initially, the basic concept, strength and stiffness simulations, calculations and design drawings were sent to Laser Zentrum Nord as a complete data package.


Bugatti and Laser Zentrum Nord report that they have been able to produce a complex structure which is significantly stiffer and stronger than would be possible with any conventional process (Courtesy Bugatti)

The institute then carried out process simulation and support structure design, followed by the first Additive Manufacturing of the component. According to Laser Zentrum Nord, the component was manufactured in 2,213 layers over a total build time of forty-five hours on a system equipped with four 400 W lasers.

The AM component was heat treated, in order to eliminate residual stress and ensure dimensional stability, and its surface smoothed in a combined mechanical, physical and chemical process to further improve its fatigue strength. In the final manufacturing step, the contours of the component's functional surfaces, such as its piston contact surfaces and threads, were machined in a five-axis milling machine in an operation spanning a further eleven hours.

"We were thrilled to be contacted by Bugatti. I do not know any other carmaker which makes such extreme demands of its products. We were pleased to face up to this challenge." stated Prof. Dr.-Ing. Claus Emmelmann, formerly Managing Director of Laser Zentrum Nord GmbH and now Head of the Fraunhofer Institute for Additive Production Technologies (Fraunhofer IAPT) since Laser Zentrum Nord was incorporated in the Fraunhofer research organisation.

www.bugatti.com

www.lzn-hamburg.de

Oerlikon and Boeing collaborate on metal Additive Manufacturing for aerospace

Boeing, Chicago, USA, has signed a five-year collaboration agreement with Swiss technology group Oerlikon, Pfäffikon, Schwyz, Switzerland, for the development of standard materials and processes for metal Additive Manufacturing. The research will initially focus on industrialising titanium powder bed fusion (PBF) Additive Manufacturing and ensuring parts made with this process meet the flight requirements of the US Federal Aviation Administration and US Department of Defence.

Boeing and Oerlikon will use the data collected from this collaboration to support the qualification of AM suppliers to produce metallic components using a variety of machines and materials. "This programme will drive the faster adoption of Additive Manufacturing in the rapidly growing aerospace, space and defence markets," explained Dr Roland Fischer, CEO Oerlikon Group. "Working together with Boeing will define the path in producing airworthy AM components for serial manufacturing. We see collaboration as a key enabler to unlocking the value that AM can bring to aircraft platforms and look forward to partnering with Boeing."

Boeing and Oerlikon stated that their collaboration will enable the companies to meet the current challenges to qualify materials and processes for aerospace and provide a route for the adoption of AM with a qualified supply chain that achieves quality and cost targets. Boeing has been researching and implementing AM in the aerospace industry since 1997 and reports that it currently has roughly 50,000 AM parts flying on commercial, space and defence programmes. Oerlikon is a key AM service provider, offering integrated AM services along the entire value chain, from metal powder production to component design, manufacturing, post-processing and quality inspection.

"This agreement is an important step toward fully unlocking the value of powder bed titanium Additive Manufacturing for the aerospace industry," stated Leo Christodoulou, Boeing's Chief Technologist. "Boeing and Oerlikon will work together to standardise Additive Manufacturing operations from powder management to finished product and thus enable the development of a wide range of safe, reliable and cost-effective structural titanium aerospace components."

www.oerlikon.com/am
www.boeing.com

Inert launches new filtration systems for powder handling

Inert, Amesbury, Massachusetts, USA, has launched a new line of Powder Filtration Systems designed for Additive Manufacturing and other industries that require the safe collection and disposal of particles and particulate which may be reactive, corrosive or otherwise require special handling considerations. The new systems, named PF-1, PF-2, and PF-3, can be integrated into Inert's PowderShield enclosures or purchased separately for retrofitting into existing systems.

The systems are said to offer safety features including a quad HEPA filter cluster to collect reactive powders, water passivation of particulates, isolation valves and an electrically grounded design that prevents static electricity build-up or the potential ignition of particles. Other features include an easily accessible lockable cabinet, stainless steel piping, 60 CFM blower and Magnehelic gauge to display pressure and indicate when the filter needs replacement.

Inert reports that the new systems have been designed to be compact, enabling them to fit into both large and small facilities, and come in a variety of models for different user needs. The PF-1 is said to be ideally suited for removing soot created as a by-product of laser welding or laser-based Additive Manufacturing. The PF-2 has a high max flow rate for larger industrial AM processes. The PF-3 contains a ceramic filter that can be used safely with higher temperatures

The company's PF Systems are the latest addition to the growing line of AM solutions offered. Inert's PowderShield is a glovebox enclosure for post-processing AM components safely, while collecting and reclaiming excess powders for reuse. The company also produces argon management systems, which create and maintain non-reactive <1 ppm O_2 and H_2O inert atmospheres for integration with AM systems, PowderShield enclosures and other closed-loop systems for handling, using and printing with reactive powders.

www.inert-am.com

The PF-1, said to be ideally suited for removing soot created as a by-product of laser-based Additive Manufacturing (Courtesy Inert)

AM systems maker Farsoon Technologies launches European subsidiary

Farsoon Technologies, Hunan, China, recently announced the establishment of a new subsidiary in Germany, with the aim of expanding Farsoon operations into Europe. The company has appointed Dirk Simon, currently employed by BASF New Business GmbH, as Managing Director of Farsoon Europe GmbH.

Dr Xu Xiaoshu, Chairman of Farsoon Technologies, stated, "Europe is central to the growth of Additive Manufacturing. Farsoon is eager to work with and support the growing market here and we are very happy to have someone with the experience and integrity of Dirk Simon be our representative."

Dirk Simon has worked at BASF for nearly six years, and is said to have been a key driver in the development of AM within the company. He holds a PhD in Polymer Science and is said to have over twenty years working experience in various chemical companies in Germany and Switzerland.

www.farsoon.com

Renishaw appoints new CEO


William Lee has been appointed Chief Executive

Renishaw plc has announced that William Lee has been appointed Chief Executive. The company reported that its former Chief Executive, Sir David McMurtry, has decided to hand over his Chief Executive responsibilities but will remain as Executive Chairman, with responsibility for group innovation and product strategy

Lee joined Renishaw in 1996, starting his career in new product research and subsequently headed up the laser and calibration product line and the machine tool product line before being appointed to the board as Group Sales and Marketing Director in 2016. He has a degree in Physics from Oxford University and an MBA from Bath University.

Commenting on the changes, Sir David stated, "I am delighted that Will has demonstrated to me the leadership capabilities to continue to develop the Renishaw business and as result I am pleased to hand over my role as Chief Executive. I am confident that Will can inspire the next generation to build on Renishaw's heritage and we are looking forward to working closely together."

Renishaw manufactures a range of metal Additive Manufacturing machines in addition to offering AM services for medical and dental customers.

www.renishaw.com

Innovative cutting tools made possible with metal Additive Manufacturing

Germany's Komet Group, a leading supplier of precision cutting tools headquartered in Besigheim, is reported to be using metal Additive Manufacturing technology from Renishaw to produce new ranges of innovative cutting tools. As well as allowing special cutters to be produced more quickly, the use of AM is said to enable more complex shapes to be generated, both for the external shape of the tooling and for the internal cooling channels.

Komet has been working with Renishaw for the last year, and stated that the UK based equipment manufacturer has contributed a wealth of knowledge to help it find the parameters that are needed to produce a good tool. "We are aiming for a win-win situation," explained Ralph Mayer, the manager responsible for Additive Manufacturing services at Renishaw GmbH. "Parts produced with Additive Manufacturing can reach an up to 99.9% consistent structure, just like rolled or cast metal components. However, the correct strategy must be applied for every component. Our strength lies in our skill in analysing the technical challenges of our customers' components and working with our customers to find the most effective solution."

Multiple cutter parts are produced on a single build plate (Image Courtesy Komet Group)

A new range of PCD screw-in milling cutters

The first of the projects handled jointly between Komet and Renishaw was the development of a new range of PCD (Poly-Crystalline Diamond) screw-in milling cutters. The main bodies of the cutters are manufactured on a Renishaw metal AM system, with multiple bodies produced during each cycle of the machine, and then fitted with PCD blades and screwed onto their tool holders. The use of the Renishaw technology to manufacture the tools allows geometries to be produced that would be almost impossible by conventional means. "Thanks to the additive process we have been able to place many more PCD blades on each tool," explained Dr Reinhard Durst, Research and Development Manager for hard metal tools at Komet Group.

"We have changed the arrangement of the blades and achieved a substantially greater axis angle. Compared to conventional milled tools, we have greatly shortened the grooves. These changes mean that the tool is a lot more productive for the user." For example, with a 32 mm screw-in head, the number of grooves and blades has been increased from six to ten, achieving a feed rate that can be up to 50% higher.

In addition, the ability to optimise the paths of the coolant channels ensures that each cutting edge is supplied precisely with coolant through a separate channel, while the external design of the bodies helps to ensure that chips are removed reliably from the face of the tool. AM also offers the potential to reduce component weight since material can be used only where it is necessary for the optimum functionality in the component. It also outperforms conventional production methods in terms of delivery time for any special or experimental tools needed by Komet's customers.

"The ability to freely design the internal and external tool geometry alone means that excluding this additive process from our future plans would be inconceivable," commented Dr Durst. "It gives us the ability to increase tool performance and productivity to such a great extent that it creates considerable added value for our customers."

www.renishaw.com | www.kometgroup.com

GE's new binder jet metal AM system built with aim of "challenging casting"

Engineers at GE Global Research, GE Aviation and GE Additive report that they successfully built and tested thirty different prototypes of a football-sized jet engine component in just twelve weeks. The prototypes were produced on GE Additive's H1 binder jet Additive Manufacturing system, which it states is capable of manufacturing at speeds "ten times faster" than Powder Bed Fusion and can be used to produce larger parts.

The part is destined for use in the LEAP jet engine, developed by CFM International, a joint venture of GE Aviation and Safran Aircraft Engines. The original part is said to have taken several years to develop using casting

GE's new H1 binder jet system

and other conventional manufacturing processes. Using binder jet AM, the engineers were able to design, build and test designs to the required heat and durability standards within a much shorter time-frame.

Compared with PBF manufacturing, binder jet AM consumes much less energy, making the technology more cost effective as well as environmentally sustainable. Arunkumar Natarajan, a senior scientist at GE Global Research and technical lead on the company's binder jet programme, explains: "Instead of firing high-power lasers over a bed of metal powder, we're depositing a binder glue like ink on paper." According to Natarajan, the speed and power of the technology mean it could disrupt the multi-billion-dollar casting industry.

GE is reported to have developed a 'special binder' for its binder jet process, which Natarajan states is key to the project's success. "We're very excited about the binder jet concept, given the opportunity it provides for faster printing of more parts versus other additive and even conventional manufacturing techniques," stated Natarajan. "We already have successfully printed several complex metal test parts, using this advanced binder jet process."

GE's binder jet system is said to have been developed over just forty-seven days, with the express aim of "challenging casting." On the first announcement of the machine, Mohamed Ehteshami, Vice President and then-General Manager of GE Additive, stated, "We consume so much casting inside GE. Billions and billions of dollars – and we can disrupt this, not only for ourselves, but for everyone else. We will use this and we will sell this."

www.ge.com/additive

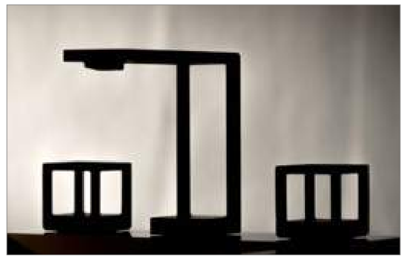
Designer tap manufacturer takes advantage of AM technology

3D Systems, Rock Hill, South Carolina, USA, reports that luxury kitchen and bath product manufacturer Kallista has produced a metal additively manufactured sink tap / faucet. The Grid® faucet was produced by third-party metal AM service provider 3rd Dimension on a 3D Systems ProX® DMP 320 machine. To avoid rust and corrosion, the tap was produced from 3D Systems' LaserForm® 316L, a stainless steel 316 powder material.

In deciding to produce the tap's spout via AM, Kallista's designers were able to design without limitations to create an open form and discreet interior channels that allow water to flow easily through the base. "Designers usually need to consider a manufacturing process and design around that process," explained Bill McKeone, Design Studio Manager, Kallista.

"By choosing to produce this faucet via 3D printing, we opened ourselves to limitless design possibilities. 3D Systems' breadth of materials and technologies allowed us the freedom to create a unique, functional faucet which would not have been possible with a traditional manufacturing process."

In addition to the increased design flexibility, developing the product for AM meant that Kallista was able to avoid the common delays of weeks or months needed for any kind of production tooling. "In order to realise the best product, you have to start with the best tools," added Bob Markley, 3rd Dimension President. "The strength of the 3D Systems technology and materials, coupled



Designers were able to create an open form and discreet internal channels (Courtesy 3D Systems)

with the expertise of our engineers and machinists, allowed us to rapidly produce and deliver these high-end faucets for Kallista."

"This is just one example of the value 3D printing brings to a production environment," said David Cullen, Director of Applications Engineering, 3D Systems. "Through the combination of materials, print technology, software and services, Kallista was able to bring their visionary design to market."

www.3dsystems.com

Permanent magnets for electric motors by cold spray Additive Manufacturing

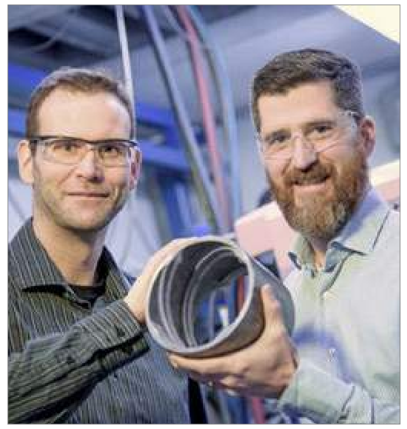
Researchers at the National Research Council of Canada (NRC), Ottawa, Ontario, Canada, have developed a method to produce permanent magnets for electric motors by cold spray metal Additive Manufacturing. Fabrice Bernier and Jean-Michel Lamarre, the team who developed the new method, state that this technology could make it possible to produce magnets in complex shapes and for complex parts without the need for assembly.

Currently, high-performance magnets used in electric motors are typically made using processes such as powder compaction for sintered magnets or injection moulding for bonded magnets. In these processes, magnets must first be fabricated and then shaped and assembled into a final product. The NRC's cold spray technology reportedly combines all the steps into one and could lead to significant cost reductions. It also opens up a range of design possibilities not achievable using traditional manufacturing processes.

The NRC also states that its cold sprayed magnets have excellent mechanical and thermal properties. The high velocities used in the deposition of the material and the absence of polymer in the material matrix are said to give the magnet mechanical properties superior to conventional magnets, including increased thermal conductivity, corrosion and oxidation resistance. The adhesion of the magnetic material to the surface of the part is also reportedly exceptional, since neither glue nor assembly is used, and magnets created using cold spray Additive Manufacturing are said to be easy to machine when compared to more brittle sintered magnets.

Prototype magnets have been constructed using the new material and tested with success, and the NRC's researchers state that they are already looking into new ways to use cold spray Additive Manufacturing to enhance motor designs. Currently, the team is working on the development of soft magnetic materials to complete the range of available resources.

"This technology will allow the creation of more compact, better performing motors for the future and could pave the way for building entire motors using cold spray technology, offering significant advantages such as cost reduction, better thermal management and more complex geometries and functionalities," stated Bernier.



NRC researchers Jean-Michel Lamarre and Fabrice Bernier with a product made using their new magnet manufacturing technology (Courtesy NRC)

As the automotive industry strives to reduce CO_2 emissions in the next generation of vehicles, much of the NRC's recent development efforts have been focused on electric motors. However, additional industries could benefit from the new technology, with key potential applications including magnetic cooling, wind turbines and telecommunication devices.

www.nrc-cnrc.gc.ca

RPM Innovations relocates to new facility as demand increases

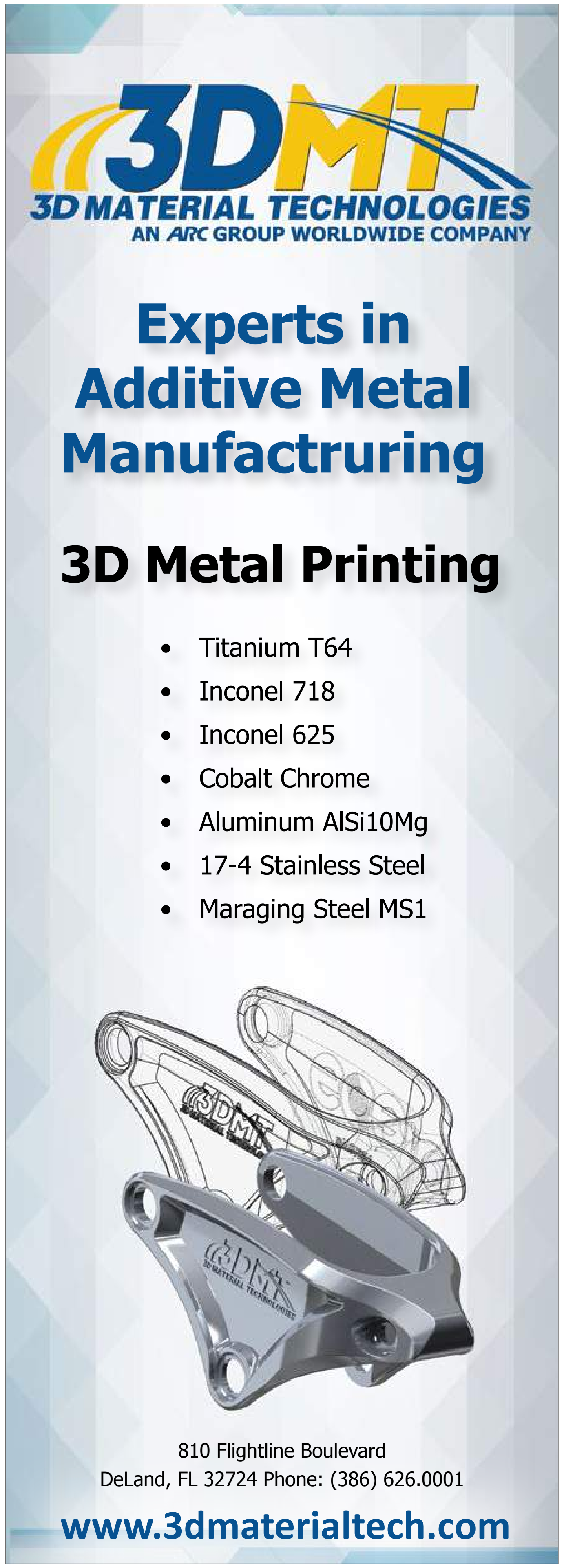
RPM Innovations, Inc. (RPMI) has relocated to a new facility in Rapid City, South Dakota, USA. The new site will provide the space necessary to nearly triple its current capacity in Laser Deposition Technology (LDT) production services and in manufacturing some of the industry's largest LDT systems. It was stated that the new facility also boasts the necessary infrastructure to meet the security requirements associated with the technology's commercial, aerospace and defence applications.

RPMI provides specialist powder-based Additive Manufacturing services for part manufacturing, metal part repair and the fabrication of critical features on parts or forgings. Typical applications include the construction and repair of components associated with turbine engines, ducting, hypersonics, satellites, rocket engines, aerostructures, oil and gas processing, chemical processing and power generation.

According to the company, increasing demand for its services has resulted in its five LDT systems running "nearly 24/7." Relocation to a larger facility will enable the installation of additional machines and allow the company to maintain machine availability and quick turnaround times to meet its customers' delivery requirements.

Robert Mudge, RPMI President, stated, "First, I must say thank you to our customers for challenging RPMI and giving us the opportunity to employ LDT in solving your manufacturing and repair problems. We are very excited and proud of this new facility as it provides RPMI with the space and tools necessary to offer the highest quality and most cost effective solutions available in the AM world."

www.rpm-innovations.com



Sintavia partners with Taiyo Nippon Sanso on gas flow optimisation

Sintavia, LLC, Davie, Florida, USA, will partner with Taiyo Nippon Sanso Corporation (TNSC), Tokyo, Japan, to develop and commercialise gas flow processes for optimised metal AM. TNSC provides industrial gases and related welding solutions to precision industries globally and stated that it sees the partnership as a strategic extension of its expansion into Additive Manufacturing, which includes investments and partnerships with a number of AM companies.

Brian R Neff, Sintavia's Chairman and Chief Executive Officer, commented on the partnership, "Gas flow dynamics are the single most important — and single most overlooked — aspect of successful quality AM builds. In TNSC, we are partnering with a true leader in industrial gas flow optimisation. We look forward to jointly developing and marketing gas flow solutions that will benefit our mutual customers and result in superior builds."

The optimisation of industrial gas for AM involves perfecting the chemistry, mix and flow within the build chamber of each manufacturing run. Poorly flowed or poorly mixed gas can result in builds that lack proper mechanical properties, have unacceptable porosity, or a general lack of fusion.

www.sintavia.com | www.tn-sanso.co.jp

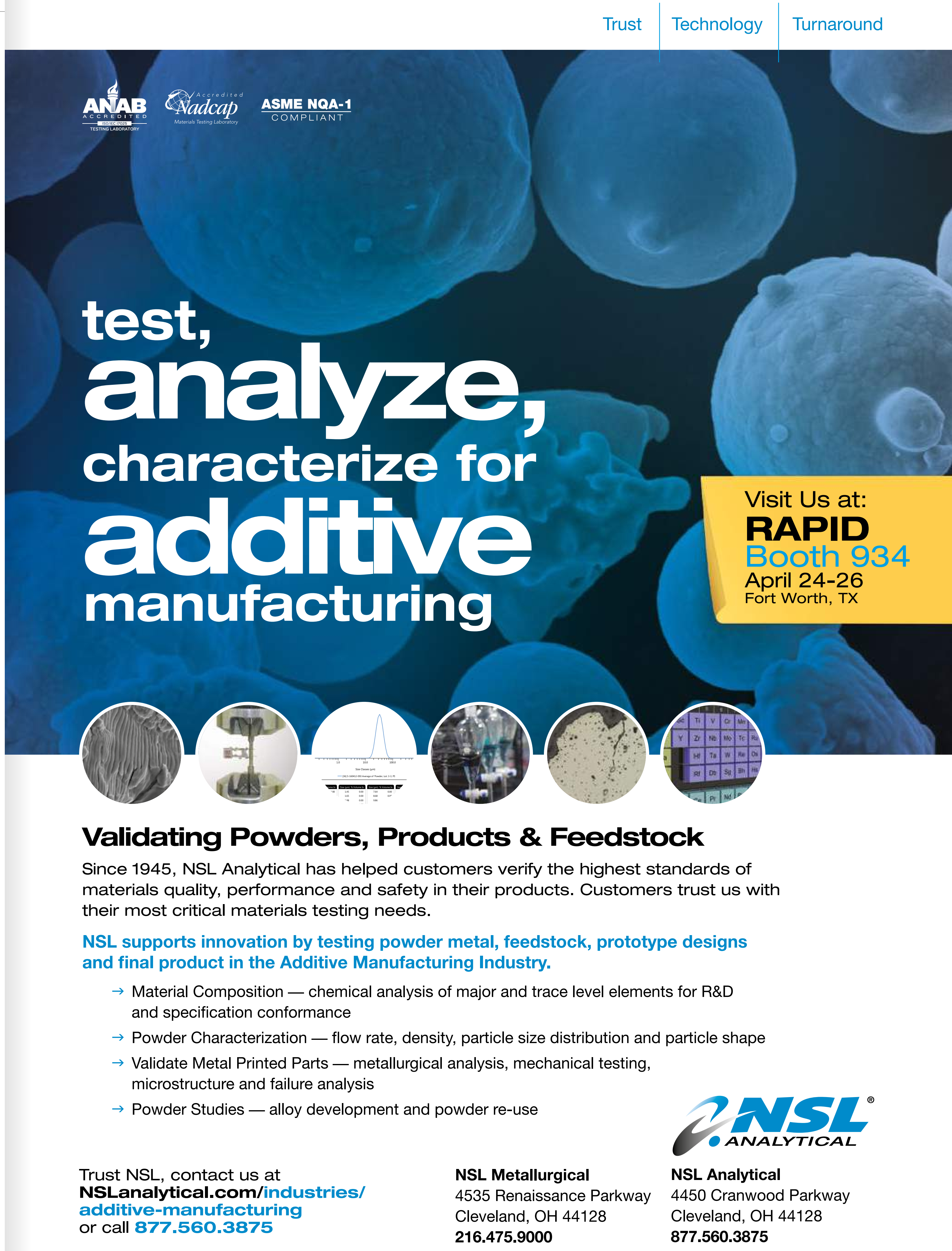
Xi'an Sailong Metals reports success with Selective Electron Beam Melting of tantalum

Xi'an Sailong Metal Materials Co., Ltd., based in Xi'an, China, reports success in the Additive Manufacturing of tantalum components using the company's latest Selective Electron Beam Melting (SEBM) system. Sailong is said to have made both highly dense (99.08±0.04) and highly porous (porosity > 70%) products from tantalum, as well as Ti-6Al-4V and TiAl alloys.

The production of the tantalum samples was part of a recent National Key Research Project funded by the Ministry of Science and Technology of China, titled 'Development of Key SEBM technologies for the fabrication of custom-made tantalum implants for clinical applications.'

Sailong was established in 2013 to commercialise technologies developed by the State Key Laboratory of Porous Metal Materials. Its SEBM system, developed in-house, operates at 3 kW with a preheating temperature of up to 1350°C.

www.slmetal.com



Bodycote to expand European HIP capabilities

Bodycote's Hot Isostatic Pressing (HIP) facility at Sint Niklaas, Belgium, is awaiting delivery of a new 'Mega-HIP' unit which is expected to be operational by the end of 2018. According to the company, the new high pressure, high-temperature Mega-HIP is Nadcap capable and is expected to aid the company in meeting growing demand from the European aerospace market over the next five years and beyond.

This investment is expected to significantly increase Bodycote's Nadcap HIP capacity globally and follows an increase in Nadcap capable HIPing capacity, which it completed in 2017. These recent investments were said to highlight the company's commitment to expanding its global HIP capacity to meet market requirements.

Bodycote operates the world's largest HIP equipment network and continues to invest in recognition of the growing demand for HIP technology. Having established its HIP expertise over several decades, Bodycote has over fifty HIP vessels of varying sizes in multiple locations. Its processing capabilities can reportedly accommodate components which are nominally up to 2 m diameter by 3.5 m high and weighing from 0.1 kg to over 30,000 kg. In addition to standard quality and environmental accreditations, Bodycote's HIP facilities also hold ASTM and NORSOK accreditations.

In addition to aerospace, Bodycote HIP serves clients around the world in markets as diverse as the medical, power generation, marine, nuclear, automotive and electronics industries, with both HIP services and its Powdermet® technologies.

The recently launched Powdermet® technologies incorporate new, patent-pending techniques that combine Additive Manufacturing with well-established net shape and near net shape (NNS) techniques. This new hybrid technology is said to dramatically reduce the manufacturing time and production cost of a part compared to producing the same part using AM alone.

www.bodycote.com

Jason Oliver appointed head of GE Additive

Jason Oliver has been appointed as the new CEO and Vice President of GE Additive, after current CEO Mohammad Ehteshami announced his retirement later this year. As CEO, Oliver will lead GE Additive's operations including Concept Laser, Arcam and GeonX, reporting to David L Joyce, GE Vice Chairman. Oliver joined GE on January 1.

A graduate of the University of Kansas, USA, Oliver joins GE Additive from Dover Corporation, where he served as President of the company's Digital Printing Group from May-December 2017. Prior to working at Dover Corporation, he was Senior Vice President of Digital Print Solutions at Heidelberger Druckmaschinen AG for four years. In 2004, he co-founded digital label printer Jetrion.

"I am thrilled to have Jason join our team," commented Joyce. "We held a thorough search process and I'm confident we have the right leader to further develop GE Additive and establish the business as the leader in the industry."

In a statement on LinkedIn, Ehteshami also introduced his successor Jason Oliver, stating, "He is a great leader, we are lucky to have found him." Ehteshami will transition to an advisory role focusing on additive product strategy until his retirement later in 2018.

Under Ehteshami's leadership, GE Additive integrated the operations of Concept Laser and Arcam, grew their combined workforces from under 450 to more than 1,100 employees, expanded production capacity threefold, and invested more than $200 million in research and development. He helped to launch new machines (including Project ATLAS and Project Hustle) and oversaw the establishment of new facilities in Montreal, Canada; and Munich, Germany; and the expansion in Lichtenfels, Germany.

"What Mohammad has accomplished in one year is a business case for how to industrialise new innovative technologies utilising GE resources across organisations and disciplines," Joyce added.

www.ge.com/additive

ASM adopts Freeman's FT4 Rheometer for powder testing

Freeman Technology reports that ASM International recently adopted the FT4 Powder Rheometer for metal powder testing. Designed to characterise the flow properties of powders, the FT4 Rheometer is also able to test shear strength, along with bulk properties such as density, compressibility and permeability.

ASM International is described as "the world's largest and most established materials information society," an organisation connecting a global network of members to facilitate the transfer of content, data and research. The organisation also offers a variety of educational training courses on many topics and, where appropriate, incorporates dynamic powder testing into its courses to further educate industrial users.

Both organisations stated that this collaboration will support greater use of the FT4 Rheometer to improve the manufacture and use of metal powders across a range of industries.

www.powderflow.com

Honeywell Aerospace approves Sintavia for AM of flightworthy parts


Sintavia's newest Additive Manufacturing facility, currently under construction (Courtesy Sintavia)

Sintavia, LLC, Davie, Florida, USA, has received internal approval to manufacture flightworthy production parts for Honeywell Aerospace, Phoenix, Arizona, USA, using powder bed Additive Manufacturing. The approval covers all programmes within Honeywell Aerospace and represents the first approval granted to a tier-one additive manufacturer by Honeywell.

Brian R Neff, Sintavia's Chairman and CEO, stated, "We have been working with Honeywell for over eighteen months as part of their rigorous supplier qualification. We are grateful that all of our team's hard work has paid off and are looking forward to demonstrating the many benefits of Additive Manufacturing within Honeywell's supply chain in the form of lower costs, short manufacturing times and dramatic design improvements."

A division of Honeywell International, Honeywell Aerospace is widely regarded as a leader in the adoption of metal Additive Manufacturing in the aerospace industry. With dedicated facilities in five countries, it is at the forefront of the development of new commercial aerospace applications, as well as the supply chain needed to implement series production.

This first approval of an external AM company is reported to mark the next step towards Honeywell building a robust and reliable supply chain to advance the adoption of AM for production aerospace components to the required standards.

www.sintavia.com
aerospace.honeywell.com

Russia's Rosatom establishes subsidiary for AM technologies

Russia's nuclear technology group Rosatom has reported that its TVEL Fuel Company has established a subsidiary, Rusatom – Additive Technologies (RusAT, JSC), to manage the development of Additive Manufacturing technologies within Rosatom. The company is expected to focus on key areas including the manufacture of AM systems and their components, the production of materials and metal powders for AM, software development, AM services and the introduction of AM technologies at industrial enterprises.

Equipment and consumables for AM will be produced at Rosatom enterprises, primarily at TVEL Fuel Company's NPO Tsentrotech and Ural Electrochemical Integrated Plant facilities, both located in the Urals region of Russia. RusAT, who will coordinate product development while managing orders and contracts, is targeted with growing its annual revenue up to RUB 50 billion (approx. $860 million) by 2025.

Alexey Dub, First Deputy Director General of Science and Innovation at Rosatom's Science Division (JSC), has been appointed Director General of RusAt. "Rosatom has developed a pre-production prototype of Gen II 3D printer," he stated. "Commercial production of the printer is scheduled for this year in Novouralsk. The Russian-made printer will be 20% cheaper than the foreign models and have a better performance. At the same time, if we consider just medical institutions in Russia, they need up to one hundred of endoprostheses each year and we can produce them with our 3D printers."

Rosatom's TVEL Fuel Company comprises nuclear fuel fabrication and uranium enrichment facilities, gas centrifuge manufactures, as well as research and engineering companies. It is the only supplier of nuclear fuel for Russian nuclear power plants and states that it supplies nuclear fuel for seventy-five reactors in fourteen countries, research reactors in eight countries and propulsion reactors for the Russian nuclear fleet.

www.tvel.ru | www.rosatom.ru

SLM Solutions announces new addition to Management Board

Dr Axel Schulz has joined the Management Board of SLM Solutions Group AG as Chief Sales Officer. Schulz will assume responsibility for the company's sales, marketing, business development and service departments, as well as the 3D Metals business unit.

"We are happy that Dr Schulz will join our team," stated Hans-Joachim Ihde, Chairman of the Supervisory Board of SLM Solutions. "He has a lot of experience in sales and business development, as well as in after sales business, and supplements the Management Board around Uwe Bögershausen and Henner Schöneborn."

www.slm-solutions.com

Bosch and GE Additive collaborate on metal AM engine part

GE Additive reports that it has collaborated with the automotive parts team at Bosch in Bamberg, Germany, to redesign and additively manufacture a metal oil header for use in a common rail injector (CRI) on a diesel engine.

With conventional diesel injection systems, fuel pressure has to be generated individually for each injection. Conversely, in CRIs, pressure generation and injection are separate, meaning that diesel fuel is constantly available at the required pressure for injection. According to Bosch, it has become increasingly important that newer generations of CRI, which have different surface properties, are lubricated on the outside diameter of the thread to prevent friction. In a recent examination of the oil process during CRI assembly at Bosch's Bamberg plant, the part was found to have 'lubrication blind spots'.

Dr Anna Ebert, who is responsible for CRI assembly at the plant, discovered that the component was wet with oil only on the upper thread geometry and not on the bottom side. Initially, the team attempted to rectify this with a redesign of an oil header in three or four parts using conventional machining, but reportedly found this approach too complex and cost-prohibitive.

On deciding to explore metal AM for the redesign, the team partnered with Concept Laser, a GE Additive company. The conventional design was assessed by Concept Laser and a redesign created incorporating a new geometry for the oil channels, for production in CoCr. Though a Concept Laser M2 cusing system was already installed at Bosch's Nuremberg facility, a smaller Mlab cusing system was selected as the more suitable choice to produce the oil header due to the part's size and complexity.

Having tested the redesigned component, Dr Ebert stated, "The process fluctuations were visibly smoothed out. The 3D printed oil header was much better at delivering the right amount of oil to the right place." She reported that wetting now takes place not just at the top of the thread, but also at the bottom, meaning that the lubrication blind spots identified in the previous design have been eliminated in the new header.

"The new oil header looked different – smaller and more compact," added Wolfgang Schliebitz, Production Planner at Bosch in Bamberg. "But what was really surprising was the effect on our process during trials." GE Additive reported that the redesigned component has now been introduced to four other Bosch plants in Korea, Turkey, Germany and France.

www.ge.com
www.concept-laser.de
www.bosch.com

By re-engineering an oil header for AM, Concept Laser reduced the component from two parts to one (Courtesy GE Additive)

The final metal additively manufactured oil header (Courtesy GE Additive)

Successful first test of Advanced Turboprop Engine

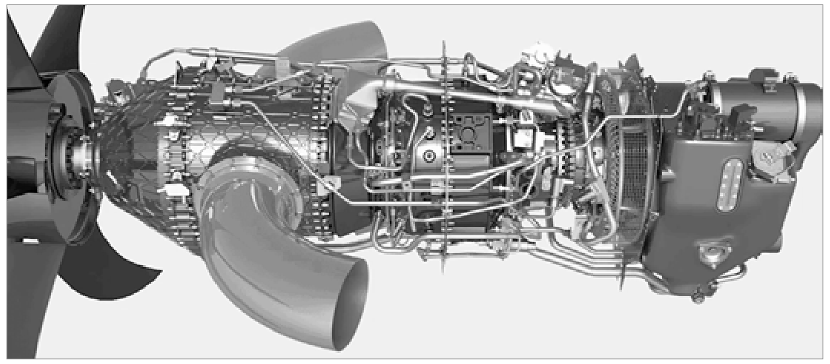
GE Aviation's Advanced Turboprop Engine (ATP) passed its first test in December 2017, reports GE. Developed over two years by approximately 400 GE designers, engineers and materials specialists in the Czech Republic, Italy, Germany, Poland and the US, this is the first civilian turboprop engine to contain metal AM components. According to GE, more than a third of the ATP is metal additively manufactured from advanced alloys.

In using metal AM, alongside other new technologies used for the first time in a civilian turboprop engine, the development team states that it was able to consolidate the number of separate components in the engine from 855 to twelve, reduce the engine weight by 100 lb, improve fuel burn by up to 20%, increase power by 10% and simplify engine maintenance. The metal additively manufactured engine components are produced at GE group company Avio Aero's Italian plant.

This first test, which was conducted in a GE Aviation test cell in Prague, the Czech Republic, saw the ATP exposed to simulated flight conditions in a controlled testing environment. Information was then gathered about vibrations, torque, thrust and other inputs while a number of cameras monitored the engine for fuel and oil leaks. Following the first successful test of the engine, Paul Corkery, General Manager of the ATP programme, stated, "This is a pivotal moment. We now have a working engine. We are moving from design and development to the next phase of the programme, ending with certification."

GE stated that it plans to build a total of twelve ATP test vehicles, which will be tested in various specialised test cells across Europe and Canada. The company will continue to test the engine, including performance and high-vibration tests, over the next two years before it can be certified by government authorities for passenger flight. GE expects to conduct a test at altitude late in 2018.

www.ge.com



According to GE, more than a third of the ATP is metal additively manufactured from advanced alloys (Courtesy GE Reports)

BEAMIT strengthens investment in heat treatment for metal Additive Manufacturing

BEAMIT SpA, Fornovo di Taro, Italy, has expanded its heat treatment capability for the processing of metal additively manufactured components. In addition to the installation of a new, higher capacity vacuum furnace, the company will add a new furnace for the treatment of aluminium alloys. BEAMIT also announced the establishment of a new department dedicated entirely to heat treating.

The heat treatment department now consists of two high vacuum furnaces conforming to standard AMS2750. According to BEAMIT, the furnaces have been assessed as Class 3 Type B and are ready for Nadcap accreditation.

The first vacuum furnace installed by the company in 2015 offers a loading chamber of sufficient dimension to cover the production of most components built on standard-sized platforms. The most recently acquired furnace, installed in October 2017, incorporates a charge room with a greater capacity and is able to accommodate components of over 400 mm in height and depth, produced using the latest large-scale SLM 500 and EOS M400-4 Additive Manufacturing machines installed at BEAMIT's facility in 2017.

To maximise the potential and performance of its additively manufactured aluminium alloys, BEAMIT will also install a new furnace specifically for the treatment of aluminium alloys, which will perform water solubilisation treatments, ageing and stress relief. This furnace complies with AMS2750 Class 3 Type C, accreditable Nadcap.

Founded in 1997, BEAMIT supplies components produced using metal Additive Manufacturing to the biomedical, motorsports, aeronautical and aerospace, and energy industries, as well as developing, studying and qualifying metallic materials. The company is ISO 9100 certified and lists a wide range of metal Additive Manufacturing machines at its facility.

www.beam-it.eu

Siemens metal AM gas turbine blades recognised by ASME

Siemens has received an award from the American Society of Mechanical Engineers (ASME) for technological achievement with its first successfully metal additively manufactured and fully tested gas turbine blades. Run by Mechanical Engineering magazine, the Emerging Technology Awards are the ASME's first ever such awards, and recognise future-focused technologies, new products and processes entering commercialisation and which are expected to have a significant impact on industry.

The ASME selected the winning technologies from each of five focus areas: advanced manufacturing, automation and robotics, bioengineering, clean energy and pressure technology. Speaking on Siemens' award, Charla K Wise, ASME President, stated, "The 3D printed turbine blade places Siemens at the forefront of a technology trend that is spurring a global revolution in product design and production. Mechanical Engineering magazine is pleased to present one of the five Emerging Technology Awards to a leader in manufacturing and we thank the design team on the 3D printed blade for advancing technology excellence."

Earlier this year, Siemens successfully completed its first full-load engine tests for the gas turbine blades, which are produced entirely by metal Additive Manufacturing. During testing, the company successfully validated multiple AM turbine blades with a conventional blade design at full engine conditions, i.e. 13,000 revolutions per minute at temperatures above 1,250°C. Furthermore, Siemens tested a new AM blade design with a completely revised and improved internal cooling geometry.

"We are especially proud to be honoured by such a recognised organisation as ASME," commented Jenny Nilsson, who led the team that realised the blade project. "The project objective was to try out and map this radical new way of working. The outcome is another confirmation that we are on the right path toward further improvements of our gas turbine technology."

Siemens has received an award from the American Society of Mechanical Engineers (ASME) for technological achievement with its first successfully metal additively manufactured and fully tested gas turbine blades (Courtesy Siemens)

The gas turbine blades were manufactured at the Siemens Additive Manufacturing facility in Finspong, Sweden and at the recently acquired Materials Solutions facility in Worcester, UK. This is the third award for this project, following the International 3D Printing Industry Award and the internal Werner von Siemens Award.

www.siemens.com

Sciaky achieves record December with sale of four EBAM systems

Sciaky, Inc., Chicago, Illinois, USA, a subsidiary of Phillips Service Industries, Inc. (PSI), posted record machine sales in the month of December with the sale of four Electron Beam Additive Manufacturing (EBAM®) systems.

According to the company, the machines were purchased for the production of titanium structures for aerospace applications, as well as large parts for ground-based military vehicles and warships.

Three EBAM 110 machines and one EBAM 150 machine were sold, the latter of which has a nominal part envelope of 3708 mm x 1575 mm x 1575 mm (146 in x 62 in x 62 in), making it possible to additively manufacture large metal parts in-house. All four systems will be delivered around mid-2018.

Scott Phillips, President & CEO of Sciaky, Inc., stated, "Sciaky is proud to deliver more best-in-class EBAM metal 3D printing systems to the marketplace, which will be leveraged in a wide range of land, sea, air and space applications. Now, more than ever, manufacturers are looking for ways to reduce time and cost associated with producing large, high-value parts and Sciaky EBAM systems have a proven track record of helping manufacturers achieve these business-critical goals."

Bob Phillips, Sciaky's Vice President of Marketing, added, "January is shaping up to be another great month for EBAM machine sales and there will be more exciting industry news coming from Sciaky in the near future."

Sciaky reports that, in terms of work envelope, its EBAM systems are the most widely scalable metal AM systems in the industry. The company's machines can produce parts ranging from 203 mm (8 in) to 5.79 m (19 ft) long at gross deposition rates from 3.18 – 9.07 kg (7-20 lbs) per hour.

www.sciaky.com

Diamond coatings enhance the biocompatibility of titanium AM implants

A team of researchers from Australia's RMIT University, Melbourne, report that they have been able to enhance the biocompatibility of titanium additively manufactured orthopaedic implants by creating a surface coating of synthetic nanodiamonds.

Leading a research team at RMIT's School of Engineering, Dr Kate Fox explained that, while titanium is the best widely-available solution for the fast and accurate Additive Manufacturing of orthopaedic implants, the human body can still sometimes reject the material. This is due to the chemical compounds of titanium, which may prevent tissue and bone from interacting effectively with biomedical implants.

"Currently, the gold standard for medical implants is titanium but too often titanium implants don't interact with our bodies the way we need them to," Fox stated. "To work around this, we have used diamond on 3D scaffolds to create a surface coating that adheres better to cells commonly found in mammals."

Synthetic nanodiamonds applied as a surface coating on a titanium scaffold may increase the biocompatibility of titanium AM implants (Courtesy RMIT University)

"We are using detonation nanodiamonds to create the coating, which are cheaper than the titanium powder," she continued. "This coating not only promotes better cellular attachment to the underlying diamond-titanium layer, but encouraged the proliferation of mammalian cells. The diamond enhances the integration between the living bone and the artificial implant, and reduces bacterial attachment over an extended period of time."

"Not only could our diamond coating lead to better biocompatibility for 3D printed implants, but it could also improve their wear and resistance. It's an exceptional biomaterial." The application of the surface coating is reported to have been made possible by recent advances in the AM of titanium scaffolds at RMIT's Advanced Manufacturing Precinct. The coating itself is created via a microwave plasma process at the Melbourne Centre for Nanofabrication and the titanium scaffolds and diamond then combined to create the biomaterial.

"It will be a number of years before a technology like this is rolled out, and there are many steps to take until we see it available to patients," Fox added. "But what we have done is taken the first crucial step in a long and potentially incredible journey."

Aaqil Rifai, a PhD researcher and part of Fox's team, states that diamond is so effective because carbon is a major component of the human body. "Carbon has an incredible level of biocompatibility," Rifai said. "Our body readily accepts and thrives off diamond as a platform for complex material interfacing."

In addition to orthopaedics, diamond has also been used to coat cardiovascular stents – tubes that help keep the heart's arteries open – and in bionics and prosthetics. "The scalability of 3D printing is growing rapidly, so we can expect to see diamond coatings to become common in orthopaedics sometime in the near future," Fox concluded.

www.rmit.edu.au

Desktop Metal granted patents for separable support layer technology

Desktop Metal, Burlington, Massachusetts, USA, has been granted two patents by the United States Patent and Trademark Office for its interface layer technology. The technology is used in both its Studio and Production Systems™ and enables the production of metal additively manufactured parts with 'separable supports' – support structures which can be removed by hand.

Under U.S. Patent No. 9,815,118 and U.S. Patent No. 9,833,839, Desktop Metal now has exclusive rights to the patented technologies, in addition to its existing portfolio of over a hundred pending patent applications covering more than two hundred inventions.

"As a company driven by invention, we are committed to both innovating and protecting our technology through strategic intellectual property achievements," explained Jonah Myerberg, Chief Technology Officer and Co-founder of Desktop Metal. "The technological innovation in these patents enables users, for the first time, to print large metal parts with complex geometries that can be easily removed from their support structures by hand or to print metal objects with separable interlocking structures."

"Traditional laser powder bed methods for metal Additive Manufacturing are restricted to single materials and are both difficult and costly to implement," he continued. "Desktop Metal has designed new approaches for metal AM that now allow multiple materials to be used during printing. This makes it possible to print support structures that do not bond to parts and consolidate during sintering with the part."

Desktop Metal's separable supports work by using ceramic powder as the interface between the part surfaces and the support structures. Because the ceramic powder does not bond completely to the metal surface of the part during manufacture, tapping the parts on a bench top and/or using a small ball-peen hammer is usually enough to remove the supports. "We believe the benefit of this technology covered by the patents will enable substantially increased adoption of metal AM," concluded Myerberg.

According to Desktop Metal, its Studio System is the first office-friendly metal AM system, includes an AM machine, a debinder and a sintering furnace and is reported to be ten times less expensive than existing technologies. The company's Production system is designed for industrial-scale, mass part production.

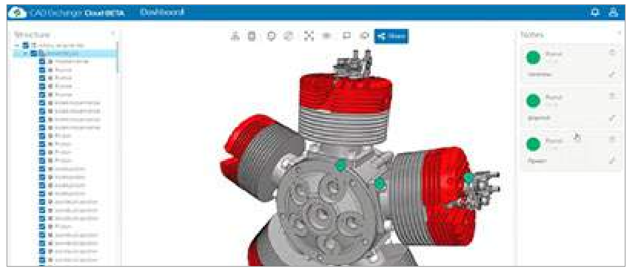
www.desktopmetal.com

Secure CAD collaboration tool for design sharing and feedback

CADEX Ltd., Nizhny Novgorod, Russia, has launched a free-to-use beta version of its CAD Exchanger Cloud, a private or public service designed to accelerate collaborative CAD design processes. The tool is said to enable multiple users to view 3D models, explore product structure, annotate designs, share 3D files with project members (including those who do not have any CAD software installed) and convert CAD designs to a convenient file format for offline work.

After signing up for the beta service, users of CAD Exchanger Cloud in private mode can selectively give access to certain people, with adjustable access levels for each participant. By default, access is given for file viewing only, with the option to allow downloading, annotating and re-distribution.

In public mode, users will have the option to share CAD files publicly using a targeted URL, to direct users to view the model. According to CADEX, this option has been designed with freelance designers and students in mind, enabling the easy showcasing of design portfolios. Users will also have the option to embed a 3D CAD model viewer on any web-page.



CAD Exchanger Cloud allows multiple users to 'annotate' designs and provide design feedback (Courtesy CADEX Ltd.)

The beta tool supports most commonly used CAD file formats, including STEP, IGES, ACIS, Parasolid, JT, Rhino, STL, OBJ, X3D and VRML, and CADEX stated that more are expected to be added shortly. During the beta period, users may upload files up to a maximum size of 50MB.

The original line-up of CADEX's CAD Exchanger applications is available in for Windows, MacOS and Linux, as well as a mobile app for Android. It is also available as SDK for software developers aiming to build their own engineering applications.

According to its developers, CAD Exchanger is used by more than six thousand engineers from over fifty-five countries a month. Customers are said to include Altium, General Electric, JVC, Fujitsu, OMRON, Nokia, Stanley Black & Decker, SENER and more.

cloud.cadexchanger.com

ASME draft standard for product definition in AM

The American Society of Mechanical Engineers (ASME) has published its 'Product Definition for Additive Manufacturing (Draft Standard for Trial Use)', Y14.46-2017. Developed under the Y14 Engineering Product Definition and Related Documentation Practices Standards Committee, this draft standard extends the Y14 series of standards to establish the definitions for model-based products for AM.

Y14.46 covers definitions of terms and features unique to AM technologies, with recommendations for their uniform specification in product definition data sets and related documents, and encompasses relevant AM details including design, manufacturing and quality engineering. ASME expects this draft standard to help improve efficiency in manufacturing by providing a method on how to control product definition to the model by using annotations that are semantically associated to the feature geometry.

ASME has issued the new document as a 'Draft Standard for Trial Use', and invites public comment and requests for revisions. To ensure the highest quality standards, comments and user experiences during the trial use period will be taken into consideration prior to the standard's formal submission to the American National Standards Institute (ANSI) for acceptance as an American National Standard.

www.asme.org

Wipro launches experience centre for metal Additive Manufacturing in India

Wipro3D, the Additive Manufacturing business unit of Wipro Infrastructure Engineering, has opened a metal Additive Manufacturing solution and experience centre in its home-city of Bengaluru, India. The 3,600+ m^2 centre is said to offer all metal AM capabilities including leading edge build technology, post-processing, research, characterisation and validation facilities.

Wipro3D offers standard and customised Additive Manufacturing solutions, products and services to industries including aerospace, space, industrial, automotive, healthcare, oil & gas and heavy engineering. Benefiting from an ecosystem of partners including EOS, the company has reportedly become a solutions provider of choice to industry-leading organisations in India. "Based on the confidence developed from our India operations, we are planning to take Wipro3D global," stated Pratik Kumar, CEO of Wipro Infrastructure Engineering.

"India's first functional metal AM component in space was built by Wipro3D. We have built competencies and offerings across additive consulting, engineering, manufacturing, research & development as well as turnkey solutions to deliver impactful business outcomes for our customers," added Ajay Parikh, Wipro3D's Business Head. "We see 3D printing or Additive Manufacturing as a critical component in the digital manufacturing and future proofing strategy of any enterprise."

www.wipro-3d.com

AM-Motion Summer School registration open

The EPMA's AM Summer School, part of the AM-Motion European H2020 Project, will be held from the September 4-7, 2018, at Prodintec, Gijon, Asturias, Spain. The overall objective of the AM-Motion CSA is to contribute to a rapid market uptake of AM technologies across Europe by connecting and upscaling existing initiatives and efforts, improving the conditions for large-scale, cross-regional demonstration and market deployment, and by involving a large number of key stakeholders, particularly from industry.

The AM Summer School will focus on the main Additive Manufacturing concepts, existing materials and processes as well as design and manufacturing paradigms, market relevance and specific best practice examples. It is expected to allow students to gain a thorough insight into the world of Additive Manufacturing, whilst spreading knowledge and providing an entry-path into specific AM-focused vocations.

www.am-motion.eu

NASA completes hot-fire testing of RS-25 rocket engine with metal AM component

NASA and Aerojet Rocketdyne have completed hot-fire testing of an RS-25 rocket engine containing its largest metal additively manufactured component to date. During a 400-second test at Stennis Space Center, Mississippi, USA, Aerojet Rocketdyne was able to evaluate the performance of its metal additively manufactured vibration damping device, known as a 'pogo accumulator assembly'. It is hoped that the use of AM to produce aerospace components will help to lower the cost of future missions for NASA's Space Launch System (SLS) heavy-lift rocket.

The pogo accumulator assembly is a complex piece of hardware consisting of two components – the pogo accumulator and pogo-z baffle – and acts as a shock absorber to dampen oscillations caused by propellants as they flow between the vehicle and the engine. The pogo accumulator assembly is important to ensuring a safe flight by stabilising these potential oscillations.

By additively manufacturing both the pogo accumulator and pogo-z baffle using Selective Laser Melting (SLM), Aerojet Rocketdyne reports that it was able to dramatically simplify production, cutting back on the number of pieces to be welded together by 78%. A reduction in the number of welds shortens component development timelines and enables enhanced design flexibility.

Eileen Drake, CEO and President of Aerojet Rocketdyne, stated, "This test demonstrates the viability of using Additive Manufacturing to produce even the most complex components in one of the world's most reliable rocket engines. We expect this technology to dramatically lower the cost of access to space."

The SLS is designed to send astronauts and cargo to explore the moon and other deep space destinations and uses four Aerojet Rocketdyne-built RS-25 engines, produced at the company's facility in Los Angeles, California, USA.

"As Aerojet Rocketdyne begins to build new RS-25 engines beyond its current inventory of 16 heritage shuttle engines, future RS-25 engines will feature dozens of additively manufactured components," explained Dan Adamski, RS-25 programme director at Aerojet Rocketdyne. "One of the primary goals of the RS-25 program is to lower the overall cost of the engine while maintaining its reliability and safety margins. Additive Manufacturing is essential to achieving that goal."

www.aerojetrocketdyne.com

Singapore start-up allows users to 'hitch a ride' on third-party metal AM builds

A new Singapore-based digital platform, Hitch3DPrint, has launched to enable companies to take advantage of spare capacity in third-party metal Additive Manufacturing build lots. According to its founder, Dr Alexander Liu, the secure digital platform is aimed at making metal Additive Manufacturing more accessible and affordable to smaller companies.

While adoption of the technology is accelerating within major companies, it is widely recognised that the high-cost of metal AM systems and builds continues to be a major hurdle to its adoption within smaller companies and for short product runs.

According to Hitch3DPrint, users of its new platform have the option to 'hitch onto' an AM build at a relatively attractive price point, due to the lack of additional set-up costs required. "In general, there is spare capacity in most metal print jobs," reports the company. "Essentially, we are providing a platform that is based on a hitch concept, allowing users to hop onto a 3D print job, similar to that of hitching a car ride. The lead time is short and the price is around 30–50% cheaper."

To take advantage of spare capacity in an AM build, users simply upload a file for an instant quotation from Hitch3DPrint and choose their preferred material and technology. The finished product will then be manufactured by one of the company's global network of partners.

Hitch3DPrint lists a global network of partners, including equipment manufacturers, powder manufacturers and service providers

In total, the company reports that its users will have access to more than 4,000 Powder Bed Fusion (PBF) metal Additive Manufacturing systems. Taking into account the customer's preferred AM technology and material, it stated that it is typically able to assign a request to a suitable build within three days of submission.

www.hitch3dprint.com

Fraunhofer ILT develops optimised powder jet for laser material deposition

Engineers in the department of Process Control and System Technology at Fraunhofer Institute for Laser Technology (ILT), Aachen, Germany, state that they have developed an inline system for testing, qualifying and adjusting the focused powder jet of the nozzles of laser material deposition-based Additive Manufacturing systems.

With this system, nozzles can be certified and the caustic characterised completely. The user can also visualise and monitor the process using a camera module with integrated illumination.

Laser material deposition is used in a variety of areas, including tool repair and the application of anti-corrosion coatings. However, Fraunhofer ILT states that the process results depend considerably on how evenly the laser beam applies the powder to the targeted surface, and it can be difficult to optimally adjust the process parameters, such as the speed and volume of the powder feed into the melt pool, which plays a key role.

Nozzles and caustics must, therefore, be regularly checked, certified and calibrated before any laser material deposition is carried out. But the sequence of these steps has until now, according to the engineers, been very complex and cumbersome.

Graduate engineer Oliver Nottrodt, Project Manager for Process Control and System Technology at Fraunhofer ILT, stated, "An employee applies a powder trace on a metal sheet, which is then checked by an expert. But only a few specialists can perform this task in reproducible quality".

The machine-supported inline system developed by the engineers consists of a camera module along with movable optics and illumination, all of which are mounted on the machining head. The nozzle is measured with a laser module, which is placed in the system.

The control of these two modules is then provided by electronics integrated either into a separate cabinet or the machine control cabinet. "For the documentation, it is important to know where the axes of the system are located. Their exact position can be transferred from the basic machine via common data bus interfaces," explained Nottrodt.

In order to detect and measure the particle density distribution and caustics of the powder jet, the jet is illuminated with a laser line perpendicular to the powder gas flow and observed by the coaxially arranged camera through the powder nozzle. The system changes the relative position of the laser and the machining head several times for further measurements.

Finally, the evaluation of 2,000-3,000 images shows the statistical distribution of the particles in one plane. "If I use this method to gradually capture the so-called caustics – i.e. the focusing area in which the powder particle beam is bundled – it can be calculated and characterised very precisely in terms of the most important parameters, such as the minimum diameter and the density distribution," Nottrodt continued.

The measuring system is said to be able to enable a user to measure and certify the powder feed nozzles and completely characterise the respective powder jet. It is also reported to help with process set-up by taking over a number of tasks from the user – such as measuring and marking the positions of the processing laser as well as documenting all work steps. In addition, the measuring system uses the geometric characteristics of the melt pool to monitor the laser metal deposition process, which it also visualises and documents.

Fraunhofer ILT will demonstrate the new technology at CONTROL 2018, Stuttgart, Germany, April 24-27, 2018. Engineers from the institute will be available at the joint booth of the Fraunhofer Alliance VISION 6302 in Hall 6 of the trade fair, where they will present a camera module with integrated lighting mounted on a typical working head and demonstrate how the laser module functions on the computer.

www.ilt.fraunhofer.de

Laser material deposition is used in a variety of areas, including tool repair and the application of anti-corrosion coatings (Courtesy Fraunhofer ILT)

Malvern Panalytical's Morphologi 4 for particle imaging and characterisation

Malvern Panalytical, Eindhoven, the Netherlands, has launched its new Morphologi® range of automated static imaging systems for particle characterisation. The Morphologi 4 and Morphologi 4 ID are said to offer tools for the rapid, automated component-specific measurement of particle size, shape and chemical composition. According to Malvern, the new range offers substantial improvements to measurement speed, image definition and material range compared to previous iterations.

The tools are targeted at analytical environments where a deeper understanding of a process and/or sample is required, such as during the development and processing of metal powders, pharmaceuticals and battery materials. The Morphologi 4 is suitable for the characterisation of particles ranging in size from less than one micron up to a millimetre and higher. Compared to its predecessor, it is said to offer measurement time savings of around 25%, while delivering simpler, more intuitive method development and greater particle definition.

A key feature of the new tool, states Malvern, is its automated segmentation/thresholding algorithm, titled Sharp Edge. This is said to make it easier to detect and define particles, by using an 18 MP camera for boosted sensitivity and by enclosure of the sample during imaging. These developments are said to make it possible to accurately measure light-sensitive and low-contrast samples and deliver enhanced shape parameter sensitivity for all types of sample.

The Morphologi 4-ID makes available Morphologically-Directed Raman Spectroscopy (MDRS®), integrating the static imaging capabilities of the Morphologi 4 with Raman spectroscopy. Offering significantly faster spectral acquisition times than the previous model – a reported time reduction of up to 80% – it also allows acquisition conditions to be customised to the sample.

This enhanced control, combined with an extended spectral range, is said to maximise the range of materials that can be identified and/or differentiated within a mixture. The instrument is fully automated and has been designed to allow both particle characterisation scientists with limited spectroscopy experience and more experienced spectroscopists to gain an in-depth understanding of their particulate samples.

www.panalytical.com

New powder recovery system aims to cut material and labour costs

Kason, headquartered in Millburn, New Jersey, USA, has released a new metal powder recovery system which is reported to make it easier for users to recover and recondition used powders to exact particle sizes. The 3D-ReKlaimer™ Metal Powder Recovery System offers fully automated powder recovery, and has the potential to reduce material, operational and labour costs.

The system is said to be suitable for the recovery of metal powders used in a wide range of AM processes. The unit is capable of accepting bottles of used powder connected manually, or removing used powder from the build chamber using its integral vacuum conveying system, which automatically transfers used powders into a filter receiver or hopper located above the screening chamber of the 3D-ReKlaimer system.

The 610 mm diameter Vibro-screen® vibratory screener uses multi-plane, inertial vibration to force on-size metal powder particles to pass through apertures in the screen, and oversized particles to travel across the screen surface into a sealed container. A Kasonic™ ultrasonic anti-blinding device, supplied as standard, transmits ultrasonic frequencies in the direction of the screen, allowing sifting as fine as 25 µm/500 mesh with no screen blinding.

Screened powders ready for reuse can then be discharged into bottles for manual connection to the inlet of a metal AM system, or transferred automatically via an integral pneumatic conveyor into a filter receiver or hopper located above the AM system's inlet. Kason states that the system is self-contained, pre-engineered and capable of serving multiple Additive Manufacturing stations.

The 3D-ReKlaimer™ system offers fully automated powder recovery (Courtesy Kason)

To prevent contamination of powders, the closed-loop system can be purged with inert gas to isolate contamination-sensitive powders from ambient air and moisture. The system is also dust-tight, preventing contamination of either the powder or the plant. Kason also offers optional HEPA filtration and ground resistance monitoring for enhanced emission containment and operator safety.

www.kason.com

Russell Finex AMPro Sieve Station boosts ease of powder recycling

Russell Finex, Feltham, London, UK, has released its new Russell AMPro Sieve Station™, a powder handling system designed to ensure the quality of powders for Additive Manufacturing. The fully automated system has a flexible design which makes it suitable for numerous powder handling tasks, while a modular design is said to allow it to be configured to meet users' exact requirements. Among the system's typical uses are the sieving of virgin powders, closed-loop powder recovery, build chamber evacuation and powder vessel transfer.

A key advantage of the sieving system is its use for the requalification of powders reclaimed from an AM system's build chamber after a build is complete. Due to the physical changes that can occur in a powder during Additive Manufacturing, reclaimed powder cannot simply be recycled and reused; the existence of deteriorated and oversized particles in the powder-bed would compromise the quality of the next build.

According to Russell Finex, a number of processes are involved in the requalification of powders. The first and most critical is to remove contaminated particles from the reclaimed powder. This is especially important for medical, automotive and aerospace applications – major AM growth industries – where the quality and reliability of the final product is critical.

As a result of this growing need, the company states that it has applied over eighty years of experience in sieving and separation solutions to develop its new AM Sieve Station, helping to guarantee a fully controllable, repeatable powder handling process with minimal operator involvement.

The system's 'one-button' operation includes a touch-screen interface which is fully programmable for multiple settings, enabling the automatic processing of different powders and particle sizes. Once settings are established, the integrated sieving process, feed and flow management systems and weighing systems can be initiated by pressing a single button. According to its designers, the system has been developed to fit into any AM production process and is compatible with powder vessel transfer or as part of a closed-loop powder recovery system.

www.russellfinex.com

The Russell AMPro Sieve Station has a flexible design which makes it suitable for numerous powder handling tasks (Courtesy Russell Finex)

Materialise & PTC extend integrated capabilities in Creo CAD software

Materialise NV, Leuven, Belgium, has collaborated with US software company PTC to increase the Additive Manufacturing capabilities of PTC's Creo suite of Computer-Aided Design (CAD) software. The companies stated that the collaboration will expand access to AM and allow manufacturers to more easily integrate the technology into their manufacturing process.

With recent advancements in metal AM, the technology is increasingly being adopted to solve specific manufacturing challenges and create customised, complex end-user products. As the manufacturing industry continues to discover its potential, the two companies stated that the need to integrate advanced AM as part of a product lifecycle management system will continue to increase.

Powered by Materialise's Build Processor, the solution is said to offer manufacturers a seamless connection between PTC's software and AM systems equipped with a Materialise Build Processor. It will also include Materialise's support generation technology.

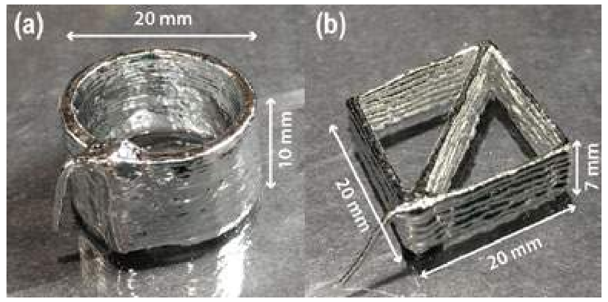
Stefaan Motte, Vice President and General Manager, Materialise Software, stated, "Our collaboration with PTC will bring improved 3D printing capabilities to PTC's CAD software and makes it easier for manufacturers to integrate 3D printing into their operations. This collaboration with PTC will expand access to 3D printing and help engineers and designers think in terms of additive, rather than traditional manufacturing for rapid product design and development."

"As 3D printing becomes a more prominent part of the manufacturing toolkit, we are working with Materialise to create robust support for the technology in Creo," added Brian Thompson, Senior Vice President and General Manager, CAD segment at PTC. "Together with Materialise, we will bridge the gap between CAD design software and the 3D printing machines."

www.materialise.com

www.ptc.com

AM alloy shows promise for flexible electronics and soft robots



Demonstration structures produced using the modified gallium alloy (Courtesy OSU)

Researchers at Oregon State University (OSU)'s College of Engineering, Corvallis, Oregon, USA, report that they developed a modified, highly conductive gallium alloy which can be additively manufactured to produce flexible and stretchable structures. The development of the alloy, undertaken by a team within the college's Collaborative Robotics and Intelligent Systems Institute, is potentially a first step toward the Additive Manufacturing of tall, complicated structures with a highly conductive gallium alloy.

The team developed the alloy by adding nickel nano-particles into galistan, the liquid metal, in order to thicken it into a paste with a consistency suitable for Additive Manufacturing. Gallium alloys are already being used as the conductive material in some flexible electronics, thanks to their low toxicity and good conductivity. They are also inexpensive and 'self-healing' – having the ability to attach back together at break points. However, prior to development of the modified gallium alloy at OSU, galistan's wetness meant that it could only be used to produce two-dimensional designs.

"The runny alloy was impossible to layer into tall structures," explained Yiǧit Mengüç, assistant professor of mechanical engineering and co-corresponding author on the study. "With the paste-like texture [after the addition of nickel], it can be layered while maintaining its capacity to flow, and to stretch inside of rubber tubes. We demonstrated the potential of our discovery by 3D printing a very stretchy two-layered circuit, whose layers weave in and out of each other without touching."

The researchers at OSU used sonication – sound energy – to mix the nickel partcles and oxidised gallium into the liquid metal paste. The result was a paste thick enough to produce three dimensional, layered structures. For the purpose of the study, the alloy was used in the manufacture of structures up to 10 mm x 20 mm.

"Liquid metal printing is integral to the flexible electronics field," added co-author Doǧan Yirmibeşoǧlu, a robotics Ph.D. student at OSU. "Additive Manufacturing enables fast fabrication of intricate designs and circuitry."

The potential field of applications features a range of products including electrically conductive textiles; bendable displays; sensors for torque, pressure and other types of strain; wearable sensor suits, such as those used in the development of video games; antennae; and biomedical sensors. There is even potential for the production of robots from the new alloy. "It's easy to imagine making soft robots that are ready for operation, that will just walk out of the printer," stated Yirmibeşoǧlu.

According to another of the co-corresponding authors, Uranbileg Daalkhaijav, PhD candidate in chemical engineering, the gallium alloy paste demonstrates several features new to the field of flexible electronics. "It can be made easily and quickly," he explained. "The structural change is permanent, the electrical properties of the paste are comparable to pure liquid metal and the paste retains self-healing characteristics."

This research project was supported by The Office of Naval Research Young Investigator Program. The team's findings have since been published in *Advanced Materials Technologies*. The team stated that future work will explore the exact structure of the paste, how the nickel particles are stabilised and how the structure changes as the paste ages.

www.oregonstate.edu

3D Systems launches 3DXpert for SolidWorks users

3D Systems has announced the launch of 3DXpert™ for Dassault Systèmes' SolidWorks. By combining the tools that designers need from 3DXpert with SolidWorks, the company states that it will provide a distinct and exclusive advantage to all SolidWorks users.

3DXpert for SolidWorks is said to provide a number of new tools, accessible in a familiar CAD environment, which are expected to make it easier to prepare and optimise designs for both metal and plastic Additive Manufacturing. Users of the software will be able to maintain design integrity by working with native CAD solids without converting them into STL, or toggling between several software programs to accomplish all tasks.

The software will also allow users to optimise builds with rapid creation of lattice-based structures for light-weighting. The use of automated analysis and setting of support structures is said to help designers ensure surface quality and prevent part distortion. Preparation time can also be accelerated by employing automatic features such as tray setup, estimation of material usage and build time.

Vyomesh Joshi, 3D Systems' President and CEO, stated, "We are excited to partner with Dassault Systèmes and help customers experience the reality of 3D printing through the new 3DXpert for SolidWorks. This collaboration enables SolidWorks users to create more shapes, more ways, and accelerate product development cycles while lowering costs. We are offering designers a true competitive advantage while redefining the design and manufacturing process."

"We've seen a tremendous increase in the adoption of Additive Manufacturing," added Gian Paolo Bassi, CEO, SolidWorks, Dassault Systèmes. "As a result, we collaborated with 3D Systems to provide SolidWorks users with the tools to help them design specifically for Additive Manufacturing, which requires a different set of operations and rules than more traditional, subtractive manufacturing. Available with all SolidWorks 3D CAD subscriptions, 3DXpert for SolidWorks will allow designers to optimise their design for Additive Manufacturing, check for manufacturability without any waste of time and material, and attain a competitive advantage in the market."

www.3dsystems.com
www.solidworks.com

Jesse Garant Metrology Center launches high-energy CT inspection

Jesse Garant Metrology Center, Dearborn, Michigan, USA, has launched a new high-energy industrial computed tomography system. The company will reportedly be the only private lab in the world to provide this specialised inspection service, which it says could transform the landscape for non-destructive testing (NDT) and support for Additive Manufacturing.

The system pairs a 3 MeV cone-beam X-ray source with a large format 2k x 2k flat panel digital detector

The system pairs a 3 MeV cone-beam X-ray source with a large format 2k x 2k flat panel digital detector. It will reportedly be able to accommodate rapid inspection of mid-size parts, up to 113 cm in diameter by 160 cm in height. While existing high-energy CT services may take between four and sixteen hours to complete scans, the new system is reported to be able to scan parts in less than an hour.

The system's capabilities are expected to directly support Additive Manufacturing, allowing for feasible internal inspection and validation of both metal and plastic additively manufactured parts. This includes the identification of defects like porosity, residual powders, first article inspection, wall thickness variations and actual to nominal comparisons for determining out of tolerance features.

Jesse Garant, President of the Jesse Garant Metrology Center, stated, "We're helping manufacturers qualify and validate printed parts that either weren't possible because of limitations with existing technologies or weren't feasible because the service was too costly or took too much time. We aim to support innovation by providing internal inspection of parts that would otherwise go into production without proper inspection."

In addition to the reported reduction in inspection time for parts and assemblies, the service will also enable the inspection of complex assemblies, with the potential to allow for cleaner separation of internal components and inspection of higher density materials not possible with lower energy systems.

This new technology is the result of three years of planning, design, development and construction by the centre, amassing a total $4.5 million investment. The new system is said to have required sourcing from both local and international manufacturers, vendors and specialists, including the construction of what is thought to be the largest 1 m x 1 m flat panel detector in the world.

www.jgarantmc.com

Volkswagen identifies key automotive applications

VW is already using on demand AM to make rarely needed water connectors for the Audi W12 engine (Courtesy VW Group)

Volkswagen Group, headquartered in Wolfsburg, Germany, recently reported on the present and future applications it has identified for metal Additive Manufacturing in automotive production. In the report, Volkswagen stated that, like many companies, the primary benefit of AM has so far been in the rapid production of prototypes and one-off parts in very small lot sizes.

Metal AM has been found to be ideally suited to the production of parts for special and exclusive series vehicles, with some already in production on metal AM systems. Original replacement parts no longer held in warehouses are also being reproduced using AM, including the gearstick for the Porsche 959 and water connector for the Audi W12 engine.

Alexander Schmid, a member of After Sales and Sales at Audi AG, explained, "Reproduction on demand is a vision for us. In the future, we will be able to economically and sustainably ensure supply with fewer original replacement parts. Regional printing centres will simplify logistics and warehousing operations."

The group also identified the potential for weight saving and freedom of geometric design as key advantages offered by Additive Manufacturing technology, with one application being the production of tools for hot forming, plastic injection moulding and die-casting applications with conformal cooling channels under the surface, enabling improved cooling and reduced process times.

A research project is also currently underway at Volkswagen Osnabrück to reinforce an A-pillar using metal Additive Manufacturing. Using AM, the number of individual parts in the component has reportedly been reduced by 74%, significantly reducing its weight without negatively impacting its durability.

However, Volkswagen clarified that much work remains if Additive Manufacturing in the automotive industry is to graduate from prototyping to mass production technology. Jörg Spindler, Head of Equipment and Metal Forming at the Audi Competence Center, stated that he doesn't believe metal Additive Manufacturing will replace other technologies, comparing it to other technologies which were seen as disruptors when they emerged.

"Carbon-fibre-reinforced polymer didn't knock steel sheets out of the game. Rather, it created new possibilities," he explained. "Metallic 3D printing is also not a competing process in mass production. But it will certainly lead to significant progress in some sub-areas. Today, 3D printing pays off when you make up to 200 units throughout the life-cycle of a product. With the help of optimisation in process and plant engineering, we will be able to reach cost-effectiveness at a level of 3,000."

www.volkswagenag.com

Continental adds EOS systems for series production of metal AM parts

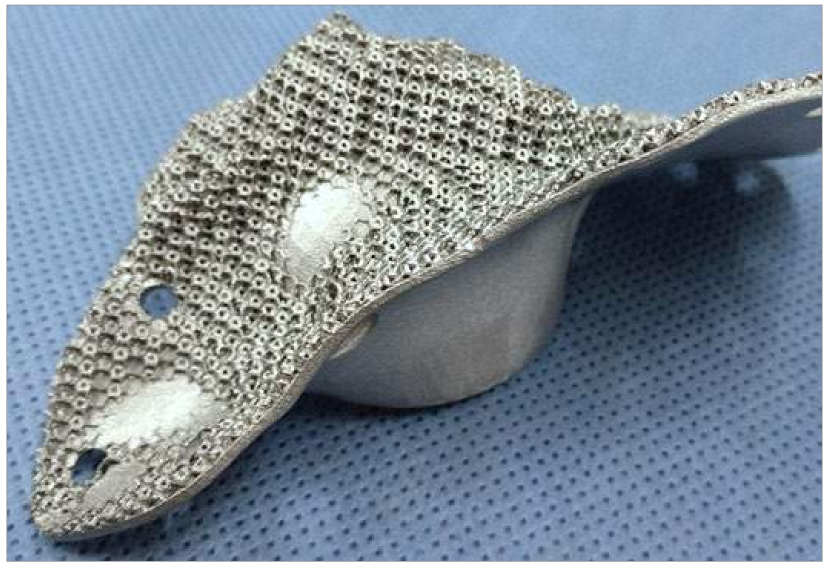
EOS GmbH states that it has now sold several EOS M 290 systems to Continental AG, Hanover, Germany. Continental produces a wide range of products for the automotive sector and is said to be investing in industrial Additive Manufacturing as a production technology. It was stated that the company will employ the EOS systems for the series production of metal additively manufactured parts. EOS installed the systems at Continental's plants and has assisted with the machines' launch. The two companies stated that they will continue to cooperate closely through the EOS service network.

Markus Glasser, Senior Vice President Region Export at EOS, stated, "We are very proud of our joint project with Continental and look forward to supporting the customer throughout every stage of the project."

"In particular, the strong spirit of teamwork between our two companies was a key criterion in Continental's decision to work together with EOS. We will also be very happy to provide Continental with any assistance it may need in other fascinating projects going forward," he concluded.

www.continental-corporation.com
www.eos.info

Link3D enables Argentinian orthopaedic implant maker's first step into metal AM



Imeco's first AM hip replacement was developed for a patient with a special medical condition (Courtesy Link3D)

Argentinian orthopaedic implant company Imeco S.A. reports that it has recently installed its first metal additively manufactured hip replacement. The company first discovered the potential of metal AM orthopaedic implants at a 2014 US trade show, but stated that it didn't begin actively pursuing the technology until roughly six months before completing its first implant.

This first AM hip replacement by the company was developed for a patient with a special medical condition. According to Imeco, 10-15% of all orthopaedic conditions could benefit from additively manufactured implants. However, the cost of metal AM technologies and the knowledge gap between conventional medical manufacturing and medical AM pose significant obstacles for some smaller medical companies.

Dr Santiago Pierce, Imeco's Head of R&D, explains, "Even though we have a lot of articular orthopaedic design experiences for special conditions, we don't have partners to teach us 3D printing and manufacturing. It is not cost-effective to purchase machines worth upwards of $1-2 million dollars when we are at an experimental phase."

The ideal solution, therefore, was to outsource the project to an AM service provider. Having spoken with Link3D representative Christian Rice, Imeco was subsequently able to use Link3D's On Demand™, a secure platform which enables its users to search and connect with a global network of AM solutions providers, to compare qualified and certified service bureaus for medical implants.

Through the On Demand platform, Dr Pierce made contact with CEIT-Ke, a biomedical engineering service bureau based in Slovakia. "Link3D provided Imeco with exactly what we needed to propel forward with 3D printing," he added. "To complete such a surgery is a great success because it truly symbolises a massive shift from forty years of traditional medical manufacturing – like CNC and forging – to the era of Additive Manufacturing."

www.link3d.co

www.imeco.com.ar

www.ceit-ke.sk

Inspire 2018 software release to accelerate pace of product innovation

Altair has announced the release of its Inspire 2018 simulation software. The new software will be made available through Altair's solidThinking channel partner network and directly to its HyperWorks user community.

"Inspire 2018 enables designers and engineers to leverage simulation in new and inventive ways to accelerate the development of high-performance, innovative products," stated James Dagg, CTO for User Experience at Altair. "Inspire integrates well into large manufacturing enterprises for rapid simulation and lightweighting insights, and has an intuitive user experience that is ideal for small and medium-size businesses with little or no simulation experience."

Inspire simulation-driven design software is said to allow designers and engineers to rapidly assemble and simulate dynamic mechanical systems to automatically resolve loads on system components. It will generate weight-efficient design proposals, unique to specified conventional or AM processes with Altair's topology optimisation technology. The software is capable of simulating the performance of competing design concepts for static loads, normal modes and buckling. Users can directly export Inspire CAD geometry to AM systems.

Andy Bartels, Inspire Program Manager explained, "In order to stay competitive while pushing the innovation envelope, simulation must drive the entire design process from the early concept design phase all the way through to production. We continue to add tools to make Inspire more beneficial to its users in each step of the design process."

www.altair.com

Keynote speakers announced for AMUG 2018

The Additive Manufacturing Users Group (AMUG) has announced Todd Grimm and Dr Ing Dominik Rietzel as keynote speakers for its 2018 AMUG Education & Training Conference (AMUG 2018), set to run from April 8-12, 2018, in St Louis, Missouri, USA.

Grimm, President of T. A. Grimm & Associates and AMUG's AM industry advisor, will open the conference on Monday, April 9. In a presentation titled 'Light at the End of the Tunnel', he is expected to blend industry updates with observations of a palpable shift in expectations and attitudes in the AM industry. While he sees this shift as encouraging, he will reportedly also share his thoughts on what he perceives as a hidden obstacle which must be addressed for AM to succeed. This will be his eighth appearance as an AMUG keynote speaker.

"We invite Todd back year after year because his presentations have set the tone for the conference, engaged our members, provided a concise update on the industry and challenged all to think differently. The energy, passion and knowledge he displays are a perfect kickoff to AMUG's week-long information transfer," stated Paul Bates, AMUG's President.

Rietzel, head of BMW Group's Additive Manufacturing Centre (Non-Metal), will take the stage on Thursday, April 12, with his presentation titled 'Additive Manufacturing on the Road. A Journey from Prototyping to Production.' The 'journey' is said to represent his own experiences as BMW Group transferred from using Additive Manufacturing solely for prototype applications to using it as an important technology for their digitalisation strategy.

"Our attendees have a huge appetite for information on applications and how, as well as why, to make the transition from conventional processes to Additive Manufacturing. Hearing a first-hand account from within a company like BMW will provide much-wanted insights," added Bates.

Featured presentations for April 10 and 11 will be the Innovators Showcase and the Global AM Review. The Innovators Showcase is an on-stage, conversational interview that elicits valuable insights and personal stories from AM industry leaders. This year's guest of honour will be Fried Vancraen, founder and CEO of Materialise. Stefan Ritt of SLM Solutions and Graham Tromans of G. P. Tromans Associates will offer attendees an insight into AM activities around the world in the Global AM Review. The conference will also include over 200 presentations, workshops and hands-on training sessions.

www.amug.com

Bossard Group enters metal AM market with Trumpf

Bossard Group, a leader in fastening technology headquartered in Zug, Switzerland, has entered the Additive Manufacturing market with the signing of three new partnerships. The company will sell industrial AM systems and related consumables to the Swiss market from Trumpf, German RepRap and Henkel, as well as offering consultant services for those looking to design complex parts for AM.

The partnership with Trumpf will give the group access to laser-based metal Additive Manufacturing technology, with German RepRap offering fused filament systems and Henkel providing stereolithography. The company stated that, "The Bossard Group views 3D printing as a forward-looking technology that will transform some areas of industrial manufacturing. Our involvement relies on partnerships with three manufacturers of premium industrial 3D printers and related technical support services. The Group contributes with its technical expertise, vast experience in solving industrial manufacturing problems and an established sales network."

Bossard expects to continually expand the line of AM systems it offers. The group stated that it has chosen to offer systems designed specifically for professional use in a number of areas, including product development, prototyping and product design.

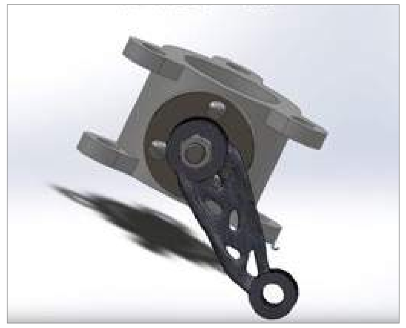
www.bossard.com | www.trumpf.com

Desktop Metal to offer experimental Live Parts technology

Desktop Metal, Burlington, Massachusetts, USA, has previewed its Live Parts™ tool, an experimental software which is said to offer a new solution to simplify generative design for AM. The tool preview will be available exclusively to users of Dassault Systèmes' SolidWorks with which Desktop Metal also announced a strategic partnership to advance design for Additive Manufacturing (DfAM) through education and an integration between SolidWorks applications and Desktop Metal systems.

Live Parts, developed by Desktop Metal's research and innovation group DM Labs, is stated to be an experimental generative design tool that "applies morphogenetic principles and advanced simulation to shape strong, lightweight parts in minutes." Powered by a Graphics Processing Unit (GPU)-accelerated multi-physics engine, Live Parts reportedly auto-generates designs in real-time. This is expected to enable users to quickly realise the full potential of AM for chosen applications – including material and cost efficiency, and design flexibility.

According to Desktop Metal, the tool produces functional parts with complex, efficient geometries ideally suited to AM. "A GPU-accelerated multi-physics engine models parts as living organisms so that parts can be generated in real-time based on constraints and load conditions," the company stated. "Nature-inspired algorithms drive Live Parts. Unlike topology optimisation, no pre-existing part design is needed. Parts grow and adapt like plants and bones, changing shape to find the best form for their environment and function." It also reports that users of Live Parts will require no prior knowledge of DfAM techniques or guidelines to be able to take full advantage of the design tool.

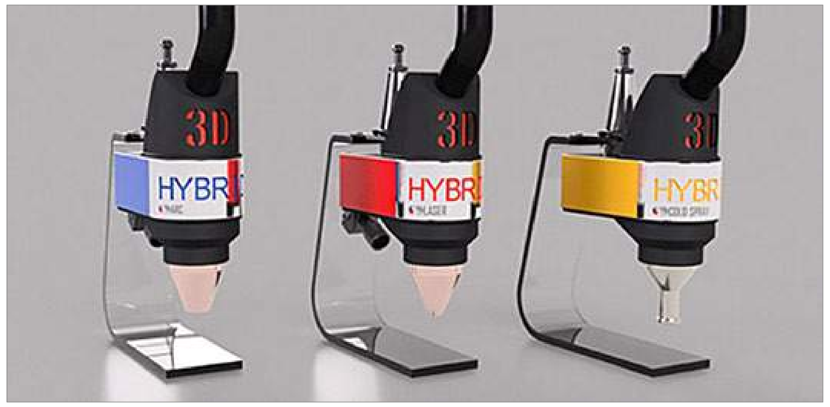

Live Parts is said to offer a new solution to simplify generative design for AM (Courtesy Desktop Metal)

An early-stage version of Live Parts is now available for preview use by SolidWorks users. During the preview of the tool, user feedback is invited to help guide its feature development.

www.desktopmetal.com

3D-Hybrid launches range of metal AM tools for CNC machines

3D-Hybrid's Wire-Arc tool offers build speeds of more than 35 in³/min and can be used with a number of materials including aluminium alloys, stainless steel alloys and nickel-based super alloys (Courtesy 3D-Hybrid)



3D-Hybrid is offering a number of specialised tools targeted at different Additive Manufacturing technologies including arc based, laser based and cold spray (Courtesy 3D-Hybrid)

3D-Hybrid, Los Angeles, California, USA, has launched a range of tools aimed at simplifying metal Additive Manufacturing using existing CNC machines. The company, which was founded with the goal of applying advanced hybrid manufacturing processes to new applications, believes that its tools will lower the cost of metal AM, increase production speed and offer new capabilities such as the fabrication of multi-material parts.

The company is offering a number of specialised tools targeted at different AM technologies including arc based, laser based and cold spray. "Our commitment to solving complex manufacturing problems with advanced AM methods has led us to revolutionise and integrate AM technologies to any CNC machine," stated Karl Hranka, Founder of 3D-Hybrid. Each of the company's tools is reportedly designed to enable its users to take advantage of the most cost-effective solution for a given application.

3D-Hybrid's Arc tools are based on electrical discharge technology for long duration, controlled Additive Manufacturing processes in a CNC machine. According to the company, the Arc tools' technology will enable the AM of a wide variety of feed-stock alloys. The tools also include process monitoring and control mechanisms.

A 'Wire-Arc tool' is said to offer build speeds of more than 35 in³/min and can reportedly be used with a number of materials including aluminium alloys, stainless steel alloys and nickel-based superalloys. The company's 'Wire+Powder tool' expands the Wire-Arc tool's capacity by enabling the co-deposition of powders in a wire-based process. This makes it possible to produce parts from alloys which are unavailable in wire form, and the tool is said to be able to alloy material in-situ. This also enables the production of metal matrix composite structures, bulk metallic glass structures and more.

For laser-based applications, its 'Laser-Powder tool' is available with a laser power of between 500W and 25,000W, a closed-loop temperature control and custom laser spots (0.1 mm – 10+ mm). The tool incorporates a concentric powder feed with a single nozzle, plus an anti-gravity nozzle for printing at angles less than 90° to horizontal. A 'Laser-Wire tool' offers a joined dual beam for multi-directional AM and is said to enable 100% material efficient wire deposition. It offers multiple wire feedstock capabilities. 3D-Hybrid states that it offers a number of customisations for its laser tools, with many being built to order based on customer requirements.

Typical build rates with 3D-Hybrid's cold spray tools are said to be around 5 lb/hour, varying based on process. The 'Cold Spray tool' offers multiple hoppers for long duration builds, custom alloying and gradient alloying, and is suitable for use with copper, nickel, aluminium, titanium, niobium, metal matrix composites and tantalum. The 'High Velocity Cold Spray tool' is designed for processing harder alloys which require higher energy for efficient plastic deformation, while the 'Laser-Assisted Cold Spray tool' is designed for the high-speed deposition of harder alloys.

3D-Hybrid is said to have experience in the rocket, aerospace, oil & gas and industrial sectors. The company offers its hybrid tools for any CNC machine, in addition to process development services for customers.

www.3dhybridsolutions.com ■■■

Boeing and Norsk recognised for metal AM structural components

Boeing and Norsk Titanium have been selected as one of the winners of Aviation Week & Space Technology's 61st Annual Laureate Awards. The awards, said to honour 'extraordinary achievements in the global aerospace arena,' are in recognition of the companies' qualification of the first structural titanium parts for a commercial aircraft made using Additive Manufacturing.

Norsk Titanium and Boeing qualified the first AM structural titanium parts for a commercial aircraft in 2017 (Courtesy Norsk Titanium)

John Andersen, Norsk Titanium Chairman & CEO, commented, "We are honoured to be recognised for our work with Boeing to achieve this milestone. The Aviation Week Network's Laureate Awards have a long history of recognising the very best in the industry and we are thrilled to win this distinction."

Norsk stated that it received its first production order from Boeing Commercial Airplanes for the Additive Manufacturing of structural titanium components for the 787 Dreamliner in early 2017. "The delivery of these first parts represents significant progress for Additive Manufacturing," commented Andersen. "Qualification with the OEM, certification with the FAA, and the ability to transition to production and meet customer cost, quality and delivery expectations."

"Norsk Titanium delivering on a significantly reduced timeline further signals the ancillary cost benefits that customers may realise with Additive Manufacturing," he continued, "lead time reduction, lower inventory requirements, and future spare parts continuity assurances."

"Additive Manufacturing is a highly disruptive capability that will support Boeing's success in our second century of aerospace innovation," added Kim Smith, Boeing Commercial Airplanes Fabrication Vice President and General Manager and Boeing Additive Manufacturing Leader. "By working closely with the FAA and our suppliers, Boeing is forging a path for the design and certification of additively manufactured flyaway parts for the aerospace industry. This technology will enable us to offer our customers more cost competitive products customised to meet their needs, faster than ever before."

www.norsktitanium.com
www.boeing.com

Ariane Vulcain 2.1 engine completes first successful test firing

ArianeGroup, Issy-les-Moulineaux, France, reports that its Vulcain® 2.1 engine has completed its first successful test firing at the German Aerospace Center in Lampoldshausen, Germany. The engine incorporates a metal additively manufactured gas generator and is designed to power the main stage of the Ariane 6 launcher.

The Vulcain 2.1 engine has been adapted from the Ariane 5 Vulcain 2 to simplify production and lower costs. To achieve this aim, the decision was made to incorporate metal Additive Manufacturing into the redesigned engine. The first AM gas generator was delivered to Airbus Safran Launchers by GKN Aerospace in June 2017, at which time the company reported that it had achieved a 90% reduction in the number of component parts in the generator, from approximately 1000 parts to 100 parts.

This first successful firing is one of a number of tests which will be carried out at Lampoldshausen to test the new engine throughout its flight envelope. These tests will observe the engine's thrust, mixing ratio and propellant supply conditions to ensure the safe launching of payloads into space.

Qualification is also ongoing for the Ariane 6's upper stage Vinci® engine, with more than 130 test firings performed to-date at Lampoldshausen and in Vernon, France. Both Additive Manufacturing and Powder Metallurgy are used to manufacture components in the Vinci engine, which the engine's designers report improve cost and time efficiency.

The Vulcain 2.1 engine incorporates a metal AM gas generator and is designed to power the main stage of the Ariane 6 launcher (Courtesy ArianeGroup)

The Ariane 6 is scheduled to enter service in 2020. ArianeGroup acts as design authority and industrial lead contractor for the development and operation of the Ariane 6 launcher on behalf of the European Space Agency (ESA), and reportedly coordinates an industrial network of more than 600 companies in thirteen European countries.

www.ariane.group
www.gkn.com

Machining AM parts for high-precision tooling

A component before, during and after machining (Courtesy GB Precision)

Specialist subcontract engineering company, GB Precision, Birmingham, UK, reports that it has been transforming additively manufactured parts into high precision tooling components at its Birmingham facility. The work is being undertaken for a customer in the high-volume, high-precision packaging sector, and highlights the potential benefits of Additive Manufacturing for tooling component consolidation, improved cooling performance and reduced price/performance of tooling overall.

The design programme is being carried out in a multi-stage approach to ensure that each set of changes is completely tested before moving on to the next. The first stage was to amalgamate three conventionally machined components into a single additively manufactured one, said to have resulted in a 10% cost saving. Once this part was produced, GB Precision had the task of transforming it into a finished, high-accuracy, fine-tolerance component using its machining equipment.

When the AM parts first arrive at GB Precision the surface finish is often rough and granular. One of the first challenges, says GB Precision, is to determine where the machining datum should be. In addition, where conventionally the components would have been machined out of solid bar, making work holding straightforward, the AM parts have more complex shapes, meaning that both the machining process and work holding must be adapted.

The material itself is also said to pose significant machining challenges. GB Precision reported that it has had to experiment with speeds and feeds, depths of cut and differing finishing tools and grinding wheels, as the parameters used for conventionally machined parts do not always apply when machining additively manufactured parts.

Paul Turner, GB Precision Director, explained, "This has really been a 'learning by doing' experience. The first batch proved to be very much of an education: the sintered material was incompatible with the tools and roughing process that was used for the conventionally machined parts. However, we have overcome these problems and have developed a process that solves all these issues."

"There is no doubt in my mind that a combination of laser sintering, conventional machining and surface treatments will provide significant cost, time and material savings and really is the future – and we are determined to be part of that future," he concluded.

www.gbprecision.co.uk

Kanfit 3D achieves ISO certifications for metal Additive Manufacturing

Kanfit 3D, Ltd., Migdal HaEmek, Israel, a manufacturer of metal additively manufactured parts, has achieved ISO 13485:2016 and ISO9001:2015 certification following a successful review conducted by the Standards Institution of Israel. The company produces parts primarily in Ti-64 for the aerospace, medical and dental industries.

ISO 13485:2016 is the international standard for quality management systems specifically for medical device manufacturers and their suppliers, while ISO9001:2015 ensures that services and products meet the needs of all clients through an effective Quality Management System.

These certifications are intended to verify that a company implements stringent industry standards concerning the safety and reliability of its products, as well as the required risk management procedures. Samuel Rosenbaum, Kanfit 3D's General Manager, stated, "We are very proud of this first-time achievement. As a young company, earning both ISO certifications is a great accomplishment. It shows our commitment to deliver the highest level of regulatory compliance and quality products to our customers in all industries."

The company reported that is in the process of expanding its product offerings and market opportunities by adding aluminium materials to its metal AM capabilities for the aerospace, medical and high-tech industries. Two new machines are also being added to support its new manufacturing line.

www.kanfit3D.com

German AM company receives FDA clearance to supply spinal cages to US

Emerging Implant Technologies GmbH (EIT), a German medical device maker focused exclusively on additively manufactured technologies for spinal application, reports that it has received full 510(k) approval from the US Food and Drug Administration (FDA) for its metal AM spinal cages. EIT offers a number of spinal products suitable for ALIF (Anterior Lumbar Interbody Fusion), TLIF (Transforaminal Lumbar Interbody Fusion), PLIF (Posterior Lumbar Interbody Fusion) and Cervical procedures.

The implants combine an osteo-influential scaffold with designs which address spinal alignment, and are produced in EIT Cellular Titanium®, a porous titanium structure designed according to research on the ideal pore shape and size to optimise osseointegration (bone in-growth).

Each implant combines an osteo-influential scaffold with designs to address spinal alignment.

All of the company's implants are produced using Selective Laser Melting, and are said to have been subject to a number of clinical case studies which demonstrate extensive bone in-growth in a short time frame. They have been used in over 10,000 cases in over fifteen countries including Germany, France, Australia, Korea and the Netherlands. Following the 510(k) approval, EIT stated it is moving towards full commercialisation.

Guntmar Eisen, EIT Co-Founder and CEO, stated, "This is a major milestone for EIT. We look forward to bringing our unique technologies to the United States and partnering with top-tier surgeons and institutions to bring the best results to patients that are in need of these devices."

www.eit-spine.de


EIT's metal AM spinal cages for TLIF (pictured left) and ALIF (pictured right) procedures (Courtesy EIT)

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Industry News

AlphaSTAR adds metal AM simulation tool to GENOA 3DP

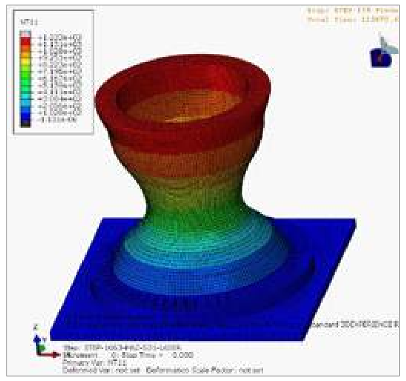
California based AlphaSTAR Corporation (ASC) has released an update to its Additive Manufacturing Simulation Tool, GENOA 3DP, which adds metal AM simulation capabilities. GENOA 3DP is said to allow users to accurately predict deformation, residual stress, damage initiation and crack growth formation associated with as-built AM parts.

Using multi-scale progressive failure analysis methods to replicate the entire AM process, from material characterisation to advanced structural analysis, GENOA 3DP is reported to be able to determine voids, cracks and other manufacturing anomalies. Additionally, the tool provides end users with the ability to import a G-Code file, generate a structural mesh, run test validated analysis and optimise the AM build.

With the cooperation of industry partners, GENOA 3DP has reportedly been tested and verified through real life tests from the beginning to the end of metal AM product life cycles. The updated tool offers high fidelity and low fidelity process simulations for thermal and thermal-structural analysis. It includes an automatic mesh generator from g-code, environmental effects (such as oxidation) on material properties, and scatter and uncertainty prediction. Void and damage is calculated using global/local material modelling with grain and grain boundary approach. There is post-build simulation as well as qualification and certification with as-built part performance prediction.

The ASC team states that it has been working over the years to ensure GENOA 3DP's metal capabilities match the existing toolset for polymeric materials. "We are very excited to introduce this product to the metal Additive Manufacturing market and make it available for real industry use," stated Kay Matin, ASC President. "The toolset has the potential to revolutionise the way engineers alike solve their AM challenges."

www.alphastarcorp.com


GENOA 3DP is able to determine voids, cracks and other anomalies (Courtesy AlphaSTAR)

Sauber Motorsport AG and Additive Industries: Formula 1® engineering meets metal AM

As the new Formula 1 season gets underway, Additive Manufacturing will have played a vital role in the development and manufacture of the cars on track. *Metal AM* magazine's Nick Williams recently visited Sauber Motorsport AG at its headquarters near Zürich, Switzerland, and discovered how a partnership with Dutch AM technology supplier Additive Industries has supported both the development of in-house AM applications and an expansion of Sauber Motorsport's AM services for third parties.

Formula 1 has long been recognised as a hub of technological innovation, so when it comes to Additive Manufacturing (AM) it is no surprise that the sport has been at the forefront of the use of AM technology for many years. In terms of the application of metal AM parts in F1®, in 2015 it was estimated that there were between forty and sixty parts per car [1]. Given the rapid advancement in the speed and capabilities of metal AM processes over the past three years, as well as the increased availability and affordability of AM machines, it is not surprising that applications have continued to increase.

Whilst, a decade ago, the use of AM in F1 would have been shrouded in secrecy, today teams and Additive Manufacturing technology providers are openly publicising their partnerships. In January 2017, Stratasys signed a four-year technology partnership with McLaren Racing as their 'Official Supplier of 3D Printing Solutions' and, back in 2015, EOS GmbH entered into a three-year technical partnership with Williams F1.

It was therefore a logical step when, in June 2017, Dutch metal AM technology provider Additive Industries and Switzerland's Sauber Motorsport AG announced their own three-year partnership. Sauber became the launch customer for Additive Industries' entry level machine, the MetalFAB1 Process & Application Development Tool, and invested in two of these systems as it built its own in-house metal AM capability.

Fig. 1 Sauber Motorsport's factory in Hinwil, near Zürich, Switzerland

Fig. 2 The C37 2018 Alfa Romeo Sauber F1 Team race car

The story of Sauber

Although Sauber's involvement in motor racing dates back to the 1970s, Sauber Motorsport began its involvement in Formula 1 in 1993. Founded by Peter Sauber, this private team has launched the careers of some of motorsport's most famous names, including Michael Schumacher, Kimi Räikkönen, Felipe Massa and Sebastian Vettel. Whilst the team's fortunes have fluctuated as engine suppliers and partners entered and withdrew from the sport, the team has nevertheless enjoyed numerous successes, including twenty-seven podium finishes and one race win.

Recent management and ownership changes have put Sauber Motorsport on a fresh footing. Swiss investment firm Longbow Finance S.A. became the owner of Sauber in 2016, coinciding with Peter Sauber's retirement from the sport. Pascal Picci was appointed as Chairman of Sauber Holding AG and, in Summer 2017, Frédéric Vasseur was appointed Managing Director & CEO of Sauber Motorsport AG, as well as Team Principal of the Formula 1 team.

Thanks to an engine deal that gives Sauber use of the latest 2018 Ferrari power unit and an influx of both capital and experience, there are high hopes for the team's two drivers, Charles Leclerc and Marcus Ericsson. Additionally, a new multi-year technical and commercial partnership with Alfa Romeo has seen the team renamed the Alfa Romeo Sauber F1 Team.

Whilst the use of the current generation of Ferrari engines will certainly bring a performance boost, the team's ability to improve its cars' aerodynamic performance is recognised as being of potentially greater significance. It is here that Sauber's established Additive Manufacturing capabilities, combined with its recent metal AM investments, is playing a vital role.

> *"...this private team has launched the careers of some of motorsport's most famous names, including Michael Schumacher, Kimi Räikkönen, Felipe Massa and Sebastian Vettel..."*

Additive Manufacturing at Sauber

Sauber is no stranger to Additive Manufacturing and, over a period of more than ten years, the company has developed a high level of expertise and production capacity in plastic AM. Selective Laser Sintering (SLS) and Stereolithography (SLA) are used primarily for the manufacturing of the aero parts required for testing new car designs in Sauber's state-of-the art wind tunnel. Current regulations require teams to perform all wind tunnel testing on a 60% scale model car, so SLS and SLA systems are used to create the required high-precision scale components.

AM is the perfect technology for this, enabling the production of individual components featuring numerous minor variations of aero surfaces, details and angles to achieve an optimised airflow.

Christoph Hansen, recently appointed as Sauber's Head of Additive Manufacturing, has worked at the company for more than ten years. With a background in both mechanical and design engineering, his career with the team is firmly embedded in the world of aero development, beginning as an aero designer and progressing to the position of Chief of Wind Tunnel Production in 2014. This path inevitably brought him into contact with the world of AM and he was pivotal in establishing the company's plastic AM capability.

Today Sauber's plastic AM 'machine park' comprises eleven large volume production machines; six SLS machines and five SLA machines, all supplied by 3D Systems. Hansen told *Metal AM* magazine, "We spent several years building up our SLS and SLA expertise to the point where we were confident that we could achieve the world class production of components. There is a strong learning curve in AM, whether metals or plastics. We learned a lot from our years of experience to-date, from environmental controls for both production stability and safety to highly optimised material reprocessing."

Thanks to the diverse skills base within Sauber, Hansen and his colleagues were able to take a very hands-on approach to the optimisation of their plastic AM operation. The laser cooling systems on their SLS machines, for example, were fully customised to deliver optimum performance and the SLS systems' integrated material recycling stations were also upgraded with a customised tablet interface to monitor and control their operation. The result, stated Hansen, was a dramatic improvement in the quality and efficiency of the facility.

The focus on learning to control all aspects of process and product engineering in-house also encompasses material development. The company's proprietary HiPAC SLS material is based on a carbon-reinforced polyamide 12.

Fig. 3 A view within Sauber's wind tunnel facility

Fig. 4 A car ready for testing in the wind tunnel facility

Fig. 5 Christoph Hansen, Head of Additive Manufacturing at Sauber Motorsport AG, stands in front of one of the company's MetalFAB1 Process & Application Development Tools

With extremely low water absorption compared to other polyamides, it offers extremely high dimensional stability, with mechanical properties that are barely affected by moisture. As a result, Sauber's AM HiPAC brake cooling ducts are used on the final F1 cars.

A focused approach to facility development

Competing in Formula 1 requires a huge amount of engineering capability. Sauber's extensive facility at Hinwil, near Zürich, is a modern complex which today consists of three sections, built in stages over a period of nearly fifteen years yet connected seamlessly. Totalling more than 15,000 m^2 of offices and production space, the layout of the facility is guided by minimising the travel distances between related operations and optimisation of workflows. Whilst the scale and capability of the carbon-fibre and machining departments is impressive, it is the company's wind-tunnel, opened in 2004, that provides one of the facility's most striking features.

Sauber's closed-circuit wind tunnel is capable of reaching wind speeds of up to 300 kph and the same velocity is achieved by the steel belt of the rolling road, simulating the relative motion between the car and the track surface. Advanced simulation of cornering or side-slip conditions can also be achieved.

Whilst the wind tunnel was manufactured and installed by an external contractor, the approach that Sauber takes to managing and staffing it also offers an insight into how the company is approaching its new metal AM facility. "What we learned from the wind tunnel and from the plastics side of our AM operation is the importance of developing knowledge in-house, and then ensuring that this knowledge is effectively distributed within our operation," Hansen explained. "An F1 team cannot afford downtime – when the pressure is on, we cannot afford for a system to fail on a Friday evening and then wait until Monday morning for support."

Major repairs of the wind tunnel facility are undertaken by the specialists of Sauber's wind tunnel group, but the company's engineers and operators also have a deep understanding of all systems and have the ability to notice any issues at an early stage, investigate and take remedial action. "To wait until a system has failed and then face a situation where it is out of operation for a week would be disastrous for an F1 team, where the constant pressure to progress is felt much more keenly than in other industry sectors." This approach has been echoed in the development of Sauber's new metal AM operation.

The move into metal AM

Sauber's first experience of metal AM component development was through the use of external service bureaux. The push to replace some SLA nano-composite epoxy resin aero testing components with metal parts has, however, resulted in a significant increase in the volume of components required, making the case for investing in the technology more attractive. Hansen explained, "For some of our wind tunnel tests, SLA parts did not always offer the rigidity to achieve repeatability, resulting in unreliable test data. We therefore started using metal AM aero test parts to overcome this problem."

Armed with the knowledge that had been built up from the development of the existing plastics operation, Hansen started evaluating the major suppliers of laser Powder Bed Fusion systems in 2016. Initially he was frustrated at the responsiveness of some AM production technology providers, which cast doubt over the level of support that he might expect to receive as a customer. "The AM industry has been growing at a phenomenal rate and, perhaps as a result of this, we had some frustrating customer service experiences. Such teething problems may be inevitable when firms grow at such a fast pace, but for us it was the motivation to look further afield."

Hansen's 'shopping list' was guided in part by his experience of AM health and safety considerations, particularly in relation to the working environment, so systems that he believed sufficiently addressed the issues of powder contamination and safe powder handling were targeted. This, combined with the requirement for a multi-laser machine with a large build area of at least 400 x 400 x 400 mm, prompted him to open a dialogue with Additive Industries.

"Following our initial discussions, I immediately got the sense that we were not just another number. There is a particular way of thinking at Additive Industries that chimed with Sauber. Their responsiveness and enthusiasm gave us confidence that they could be a company that we could collaborate with." The discussions resulted in the announcement of a partnership between the two companies at the Rapid.Tech conference and exhibition in Erfurt, Germany, in June 2017.

Fig. 6 A build plate with parts for the 60% F1 wind tunnel model and for the 1:1 F1 race car made from AlSi10Mg

By November 2017 the first Additive Industries system had been installed in the new metal AM facility at Sauber's Hinwil base. The second machine was installed in February this year.

The metal AM facility

Sauber's two MetalFAB1 Process and Application Development Tool systems are housed in a bright, open hall which also houses a Nabertherm heat treatment furnace. New gas infrastructure supplies high-purity gases and, based on the lessons learned in Sauber's plastic AM facility, the ancillary laser cooling systems have been upgraded and backup power supplies installed to protect against process interruption.

> *"Hansen's 'shopping list' was guided in part by his experience of AM health and safety considerations, particularly in relation to the working environment..."*

Fig. 7 Rear wing endplate louvre manufactured at 60% for the F1 wind tunnel model, material AlSi10Mg

Fig. 8 A front wing flap manufactured at 60% for a wind tunnel model, material AlSi10Mg

Fig. 9 Front wing strakes produced at 60% for the F1 wind tunnel model, material AlSi10Mg

Rooms off the main hall are used as offices and for the removal of builds from the MetalFAB's build chambers, or 'AM cores'. Climate management in the facility uses an over pressure system to ensure that, in the event of metal powder dust being accidentally released from a powder removal chamber, it does not contaminate other parts of the facility.

Following powder removal, build plate removal and the removal of support structures takes place within Sauber's extensive machining facility, which is equipped with a range of equipment including a large CNC portal milling machine, wire EDM systems and precision milling centres. As one would expect for an F1 team, the quality testing of AM components takes place in an equally well-equipped quality control department.

When commissioning was completed on the first of Sauber's MetalFAB systems, the team was aware of the much talked about 'learning period' for metal AM systems. "We were told that when we started using an AM machine we should 'go-easy' with some simple shapes but, driven partly by enthusiasm and partly by pressure to get components ready for testing, we started immediately with some impressive parts and were very quickly up and running. The tolerances that we were able to achieve when producing relatively large aero components were quite impressive."

The ease with which Hansen and his team made progress with their metal AM operation should of course be considered in the context of the team's significant experience in SLA and SLS. However, they also credit the stability and usability of the Additive Industries system, along with the support received from the company.

Metal AM components for car development and on-track use

The production of aero components for wind tunnel testing accounts for the greatest use of the metal AM systems at Sauber, with a variety of shapes that make the most of the full build volume of the MetalFAB1

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Metal AM at Sauber Motorsport

Fig. 10 Titanium race car tailpipe with the central section manufactured by metal Additive Manufacturing

system. "We manufacture a large number of aero components for the front wing, in particular, that offer a significantly higher level of wind-tunnel performance. The beauty of AM is of course that we can build numerous variations of angles and shapes for testing before the final component is manufactured in carbon fibre." Where necessary, metal AM aero parts are joined together to enable the manufacture of much larger structures.

Metal AM components designed by Sauber for use on the final cars include exhaust components (Fig. 10), the Scalmalloy® roll hoop, with complex internal structures, which protects the driver in the case of the car inverting (Fig. 11), and radiator inlets and outlets (Figs. 12 and 13). As Sauber receives its engines and gearboxes from Ferrari, it has no involvement in the development of metal AM parts for these systems. In the case of radiator inlets and outlets, several sets of these are used on each car, with each having a unique design.

Fig. 11 A Scalmalloy roll hoop, with complex internal structures, which protects the driver in the case of the car inverting

Fig. 12 F1 race car cooler with additively manufactured inlet tanks

Fig. 13 Detail of the AM inlet tanks

Sauber's previous experience in designing for AM has put it in a strong position to adapt existing components for Additive Manufacturing. Hansen stated, "For functional components redesigned for metal AM, we believe that we are able to push these to a very high level of optimisation." Support structures and build plate orientation are processed using Materialise Magics software. "Whilst Magics generates an initial set of support structures, we always manually adapt or enhance these to our own requirements," added Hansen.

The appeal of the Additive Industries system

Additive Industries is a relative newcomer to the world of Laser Powder Bed Fusion (LPBF) systems. Founded in Eindhoven, the Netherlands, in 2012 by Jonas Wintermanns and Daan Kersten, the company designed its system 'from the ground up' specifically for the industrial production of metal AM components. This has been achieved through the combination of a modular, expandable design for maximum flexibility, the integration of proven technology from third party sources where appropriate, and a focus on a system design which minimises the risk to operators through metal powder exposure.

In 2016, Additive Industries announced that Airbus' APWorks division would be the first beta customer for its full-size MetalFAB1 system, followed by the Dutch bakery systems developer Kaak Group and global Powder Metallurgy specialist GKN Sinter Metals.

The AM systems installed at Sauber, called the Process & Application Development Tool, incorporate the modular architecture of the full size MetalFAB1 system family but are aimed at lower initial production runs and do not feature the automation technology of the larger systems. Their modular design does, however, allow users to upgrade to a larger system at a later date. The technology and build volume of 420 x 420 x 400 mm are identical to the larger systems designed for series production. In the case of Sauber's installation, both feature the quad-laser 'exposure module' and have already been expanded with automated build plate and product handling.

AM cores provide production flexibility

"For us, the modularity of the Additive Industries system is a big plus," explained Hansen. "It enables a wider material mix and equates to a much lower investment when, for example, you want to process four different materials. An AM system needs to run 24/7 in order to recoup the necessary investment and if a machine has to be out of service for an extended period for cleaning, then this has a serious impact on our production capacity and schedules." Thanks to swappable build modules, or 'AM cores', each machine offers a high level of production flexibility. Sauber has ordered two AM cores for each machine, meaning that it will have the capability to process four different materials if required without the need to strip and clean the machine.

Speaking to *Metal AM* magazine, Additive Industries' Daan Kersten explained how further materials could

Fig. 14 The two MetalFAB1 systems at Sauber Motorsport

be added to a customer's operation. "In the case that Sauber wanted to process a fifth material, they have three options. They can either send one of their cores back to us for cleaning, rent an additional core for a fixed period, or purchase an additional core. In the case of returning a core to us for cleaning, the process can take a few weeks as this involves the disassembly of sub-systems. If required, a replacement core can of course be sent when collecting the core to be cleaned, making what you could describe as a 'hot-swap'."

Design influenced by safety

The risks posed by metal powders are well known in the wider metal powder processing industries, whether through the danger posed by the inhalation of fine metal dust, particularly when considering the carcinogenic nature of materials such as cobalt, or the danger of fire and explosion, which is of particular concern with fine metal powders and reactive metals such as titanium.

Kersten explained, "In our system there is no direct contact between a machine operator and the powder. In 2012, we bought two Laser Powder Bed Fusion systems from our competitors and were astonished how people were working with open powder. We were, of course, fully aware of how dangerous fine metal powder can be and immediately took steps to protect the operator. Whilst it is possible to provide operators with protective masks and clothing, these machines are intended to be used in a busy industrial environment where there is a risk that such precautions may end up being overlooked. Our philosophy is, therefore, to simply avoid the risk of exposing the operator to powder altogether. The safety of the operator is of the utmost importance."

"With our system, the only time that powder is exposed to air is during machine maintenance and cleaning. This not only has safety advantages, but of course also helps maintain powder specification by avoiding contamination and oxidisation."

Partnering on R&D and process development

As already highlighted, Sauber's philosophy is to build internal expertise for all critical processes and facilities and to ensure that this knowledge is shared within teams. This remains the case with the metal AM facility and the partnership that has been formed with Additive Industries will enable in-depth knowledge of the system to be achieved.

Kersten explained to *Metal AM*, "Our system is designed to be very open and customers have a great deal of freedom to influence system settings and the ways that processes are managed. The technology partnership with Sauber allows us to work with them on improving our technology; with their high-performance applications and high throughput, they are able to 'stress-test' our systems for very specific types of applications. We are constantly in close dialogue with them and together with their engineering

Fig. 15 Front view of the C37 2018 Alfa Romeo Sauber F1 Team race car

expertise, we get vital feedback which helps us to continuously improve our systems."

The partnership will also help support materials development by the team at Sauber. "Without doubt, this technology partnership will add value to both parties," stated Kersten. "From our initial beta customers to this technology partnership with Sauber, all improvement suggestions from our customers are taken seriously."

In addition to the strategic long-term development of the MetalFAB1 system's capabilities, Additive Industries believes that it offers industry-leading customer support for more immediate operational issues. "We want to be the benchmark when it comes to customer service in the Additive Manufacturing industry," Kersten stated. "A technology supplier needs to be able to guarantee uptime. Our philosophy is therefore to grow our service team in anticipation of sales growth, rather than after sales have been made. We also encourage 'smart service', through which we can give remote support to our customers in order to get them up and running again as quickly as possible. Our 'remote coach' system consists of an earpiece, camera and microphone that a customer's engineer can wear in order to be guided through a repair or maintenance procedure, all with the aim of avoiding the production delays that can result from an engineer callout. Time is further saved by having a service engineer dedicated to each customer, so there is an established understanding of a customer's processes and equipment in advance of a support call."

"Our priority to-date has been internal process and application development, but we are also committed to offering specialist AM application development services to third party customers..."

Training facility for Additive Industries' customers

A further aspect of the partnership between Sauber and Additive Industries sees the new AM facility being used as a training venue for Additive Industries customers. Kersten stated, "Sauber has built a world class facility, fitted out to a very high standard and benefits from the ability to offer all process steps in-house, from design and engineering to post-processing and testing. As such, it is the perfect training facility for our customers' engineers and machine operators. We run biannual training sessions that cover software upgrades and any processing enhancements that have become available."

The future of metal AM at Sauber

Sauber has for a number of years manufactured end-use SLS and SLA components and prototypes for third parties, making use of spare capacity in its operations. As a natural expansion to this, the company is now also offering this service for metal components. Hansen stated, "Making some of our capacity available to third parties is now part of a growth strategy for us. We can be considered as a service bureau for metal and plastic Additive Manufacturing, but with the 'USP' that we are an operation founded on a rigorous and advanced approach to product engineering."

"As an F1 team we have more than 400 employees who are the best in their field of speciality, be it component design, lightweight structures, testing and analysis or aero engineering. As such, we consider ourselves to be a total solutions provider. Our priority to-date has been internal process and application development, but we are also committed to offering specialist AM application development services to third party customers."

The investment in metal AM at Sauber not only highlights the importance of the technology to the niche world of high-performance motorsport, but also the rapidly growing business opportunities in the area of third party AM services. These services will be even more attractive where a company can not only offer the entire AM process chain in-house, but the accompanying experience of more than thirty years heritage in engineering at the highest level.

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Digital Metal: High-precision Additive Manufacturing technology from a metal powder giant

Sweden's Digital Metal® has enjoyed a significant increase in its profile over the last year. This was achieved, in part, by a major brand relaunch, but more significant was the move to begin selling its machines to third parties, rather than offering AM component manufacturing solely in-house. *Metal AM* magazine's Emily-Jo Hopson reports on the evolution of the company, its unique approach to developing its technology and the benefits of being owned by the world's largest producer of metal powders.

In September 2017, Digital Metal announced that it would begin sales of its binder jet metal Additive Manufacturing system. The DM P2500 could now be purchased or licensed from the company, giving customers external access to Digital Metal's long-serving and proven technology for the first time. Part of Sweden's Höganäs AB, the company has been using its binder jet AM technology in-house to produce precision small-scale components for customers since 2013, and had manufactured more than 200,000 parts before making its system commercially available.

In the competitive and fast moving AM market, holding back on a machine launch until the technology it offered was truly proven could be considered at once risky and commendable. On the release of the DM P2500, Ralf Carlström, Digital Metal's General Manager, stated, "With the DM P2500 we are bringing to market a tried and tested Additive Manufacturing system with the capability to produce objects with unparalleled accuracy and surface finish at high volume - from day one we were able to deliver complex parts in large volumes." By the time they were made commercially available, Digital Metal machines had already been used successfully to produce parts for the aerospace, luxury goods, dental and industrial equipment markets.

At the time of the DM P2500's release, Digital Metal reported that its business has doubled year-on-year since its inception. Speaking to *Metal AM* magazine, Carlström expanded on the strategy behind the company's development from part manufacturer to machine producer. "Selling machines is a more efficient

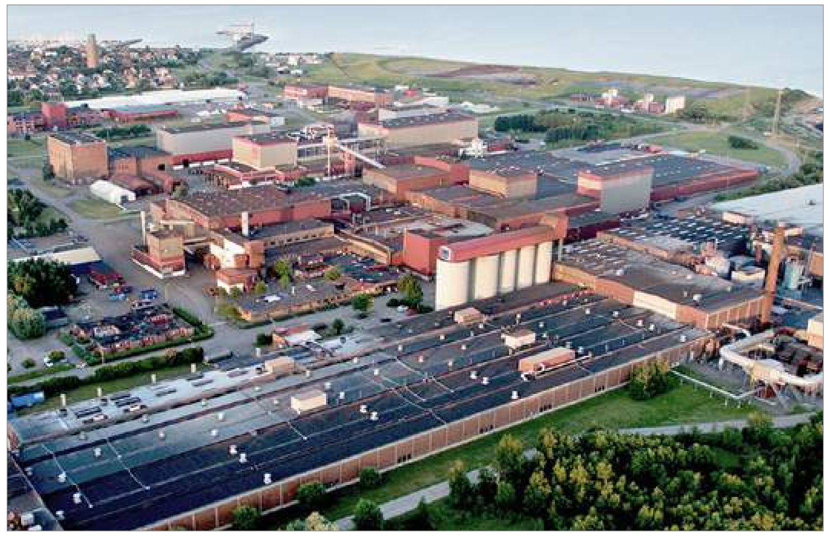

Fig. 1 Digital Metal is located at Höganäs AB's headquarters in Höganäs, Sweden

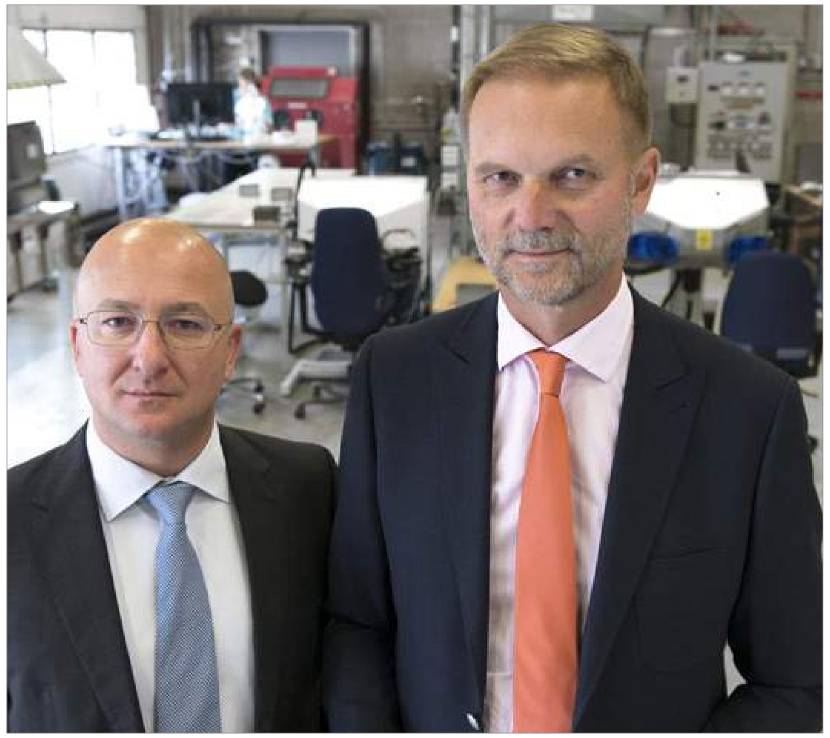

Fig. 2 Alexander Sakratidis (left), Sales and Marketing Manager, and Ralf Carlström (right), General Manager, Digital Metal

way of creating awareness and finding more users," he explained. "This goes hand-in-hand with increased experience of using our own machines in production since 2013, as well as serving our first licensee who got a machine installed in 2015. After more than 200,000 parts produced, we feel confident with the reliability and repeatability offered by our technology. Simultaneously, the interest from the market to purchase our technology has increased substantially."

The benefits of metal powder expertise

Given that it is owned by leading international metal powder producer Höganäs AB, Digital Metal also represents a rare combination of a company that combines AM machine development with an unrivalled level of powder metal expertise. Established in 1797, Höganäs is the second oldest company in Sweden and the world's leading producer of metal powders by volume, producing several hundred thousand tons annually.

Initially founded as a coal mining company in 1797, the organisation is a major contributor to Sweden's reputation as a centre of competence for Powder Metallurgy (PM) technology and currently serves 2,500 customers in 75 countries, providing more than 1,500 products, many of them customer-specific. The bulk of the company's powder production consists of iron-based powders for PM automotive components and in 2016 it reported full year earnings of SEK 7,265 million (approx. $905 million).

For some forty years, the key to Höganäs's business has been its focus on the development of new opportunities and applications for metal powders. As a rapidly growing technology, it was recognised that Additive Manufacturing has the potential to add considerable value to the group's metal powder production business. The group has been producing AM powders for a number of years, drawing on its deep material knowledge of ferrous metal powders and their manufacturing processes, combined with extensive knowledge of the relevant processing technologies.

The company's AM powders are produced primarily at its Belgium facility, which houses four gas atomisers and three water atomisers with typical batch sizes between 60 kg and 5,000 kg. At Höganäs North America there are a further three water atomisers and one gas atomiser. Metal powder research and development is supported by the group's global network of Power of Powder (PoP) and Tech Centres, focused on adding value through material, process and design optimisation. Höganäs's first move into Additive Manufacturing production technology was in September 2012, when the organisation announced that it would acquire a 100% interest in fcubic AB, which it immediately rebranded to become Digital Metal.

"Metal powder is the core business of Höganäs," explained Carlström. "This powder technology know-how has been very beneficial for improving the reliability and repeatability of the Digital Metal process." More recently, Höganäs has grown increasingly focused on resource efficiency, challenging established metalworking processes to identify more sustainable solutions. Digital Metal's technology is a natural extension of this aim; while laser-based AM technologies can consume a large amount of power and generate a large quantity of material waste, for example from support removal, Digital Metal's binder jet-based process allows for the manufacture of complex parts without supports, at room temperature, and enables a high level of powder reuse.

Digital Metal's high-precision binder jet AM

Binder jet Additive Manufacturing is a process in which parts are built layer-by-layer by applying a liquid binding agent on each metal powder layer, as opposed to melting layers of powder with a laser or electron beam as in Powder Bed Fusion (PBF) processes. Typically, binder jet AM makes use of 'MIM-cut' powders, a

Fig. 3 Digital Metal's DM P2500 machine entered commercial production in September 2017

particularly fine metal powder grade traditionally used for Metal Injection Moulding (MIM) and usually featuring particle sizes between 5-20 µm.

Digital Metal's binder jet process takes place at room temperature, in a build box that doesn't require a protective atmosphere. Because no melting takes place during the process, the surrounding powder in the build box provides enough support for even very complex geometric structures to hold their shape during manufacture; therefore, no support structures are required (Fig. 4).

This makes the removal of powder during cleaning much easier and reduces the need for post treatment of parts. "The ability to print without supports, and the short down-time between different jobs, enables the high productivity offered with Digital Metal technology," explains Carlström. "In addition, because the excess powder in the build box has not been exposed to high temperatures or a protective atmosphere, all loose powder removed during cleaning can be reused."

Upon their removal from the build box, all components must be debound and sintered to achieve the required final density and material properties for their applications. According to Digital Metal, the separation of the AM and heat treatment processes allows a wider selection of materials to be used with its DM machines, with the capability to optimise each step individually for the material in use. "Theoretically, the material offer is substantially wider with binder jetting versus melting technologies due to the nature of Powder Metallurgy," stated Carlström.

Advantages of Digital Metal vs PBF Additive Manufacturing

While Digital Metal is not the only Additive Manufacturing company to have embraced binder jet AM as a process, it states that its patented technology is unique in the high resolution, surface finish and productivity it offers for very small components. In a comparative study conducted by CETIM, the Technical Centre for the Mechanical Industry, St Etienne, France, researchers additively manufactured identical parts using Digital Metal's binder jetting process and a laser PBF process.

The study identified a considerably improved surface quality and accuracy in Digital Metal parts made in 316L stainless steel, CoCr and Ti6Al4V versus parts made using laser PBF. As well as the immediate improvement in surface quality offered in comparison to some conventional AM processes, Digital Metal offers processes to further enhance the surface quality of its parts, such as peening, blasting and tumbling (avg. Ra 3.0 µm) and superfinish (avg. Ra 1.0 µm).

"We felt many times like an outsider in the field of metal AM when we started our service offer back in 2013, struggling to take some space among the large laser and electron beam players," Carlström recalls. "However, there is a strong demand from the market to improve the productivity of metal AM in order to widen the range of applications.

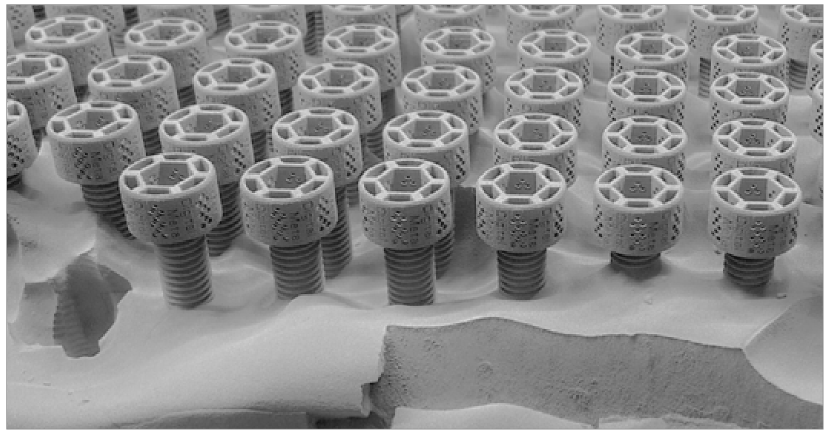

Fig. 4 Parts in the build box during powder removal

Fig. 5 The accuracy of a Digital Metal part (right) compared to an SLM part (left) (Courtesy CETIM)

Fig. 6 An award winning nozzle with internal channels manufactured by Digital Metal, diameter approximately 15 mm

Therefore, the next challenge for the AM industry is to move from predominantly prototyping to volume production. Binder jetting's capability to offer high productivity goes very well with current market development."

"In laser and electron beam AM, the more energy being used to melt layers together, the higher productivity. But this also results in less detail and rougher surfaces of produced parts," he continues. "PBF can improve the surface finish and detail of parts by reducing power and layer thickness at the expense of productivity. Digital Metal technology results in high detail accuracy, fine surface appearance and tight tolerances in combination with high productivity of small metal components."

Overlap with Metal Injection Moulding

Table 1 offers a comparison of some of the strengths and weaknesses of a number of net shape processes. Here, it is clear that when it comes to the resolution and surface finish of parts produced, the only process with the ability to produce similar results is Metal Injection Moulding, from which binder jet AM borrows much of its technology.

With the two technologies offering similar USPs, Carlström stated that he sees binder jet Additive Manufacturing as a complementary technology, rather than a threat, to MIM. "There are many similarities with MIM and Digital Metal technology," he explained. "Sintering, used by both processes, provides the strength of the components. It results in similar

Process	Small series	Part complexity	Productivity	Surface finish	Resolution	Large part capability	Material choice
SLM	very good	very good	average	average	good	good	very good
EBM	very good	very good	good	poor	poor	good	average
DED	very good	good	very good	poor	poor	very good	good
Digital Metal	very good	very good	good	good	very good	poor	good
MIM	poor	average	very good	very good	very good	poor	very good

Table 1 A comparison of some of the strengths and weaknesses of a number of net shape processes (Courtesy CETIM)

Fig. 7 A windshield washer nozzle for supercar manufacturer Koenigsegg containing a number of internal performance-enhancing functions

mechanical properties, densities and microstructures. The established standards used by the MIM industry are also therefore applicable for our technology; the depth of knowledge and infrastructure, in terms of sintering furnaces for example, already exists in MIM. Therefore, we see our technology as a logical complement to MIM for the production of prototypes or small series."

An area in which binder jet AM might pose a threat to Metal Injection Moulding, Carlström notes, is in the production of parts with complex internal features, for example cooling channels or ducts for the transmission of fuel or fluid. Using MIM, parts with hollow internal structures must be moulded in two parts and subsequently welded together. By enabling the production of such components as a single part, binder jetting has major potential for the series production of components for aerospace, automotive and other industries where part consolidation, and the resulting weight, material and time savings, are key.

While some customers consider the need for debinding and sintering of parts as an obstacle to their adoption of the technology, Digital Metal is confident that its technology remains the more economic option, in terms of both time and cost savings. "Our process is a two-step process, with printing and debinding/sintering as the primary steps," stated Carlström. Comparatively, he suggested, PBF processes are multi-step process that include the build process, removal from the build plate, support removal and plate reconditioning, as well as any stress relieving heat treatment.

"This means that it is not enough to purchase a laser AM machine and get started, you also have to invest a substantial amount in post-treatment equipment," he continued. "The Digital Metal process uses standard sintering furnaces as used by the MIM industry worldwide. We invested in one of the smallest batch furnaces a few years ago for our production of components. Although the sintering chamber is small, the furnace will still be able to handle the output from four to five of our DMP 2500 machines."

Thanks to the use of standard MIM sintering equipment, it may also be possible for companies to make use of external 'toll-sintering' service contracts, further minimising the required investment in adopting binder jet AM processes. "MIM has a track record of more than thirty years, with an impressive global footprint supplying a diverse number of different industries today, with primarily small metal components," stated Carlström. "Due to the size and capability of the industry there may be possibilities for contract sintering in the future."

New applications for AM

Rather than attempt to compete with established manufacturing processes, the key focus of Digital Metal is to develop completely new applications for its technology. Alexander Sakratidis, Sales and Marketing Manager, explains, "Our technology is well-suited for breaking new ground. As an example, twelve different components were in different stages of volume production at our site during 2017 and a common factor is that none of them have been produced before."

"Out of a total of 50,000 parts shipped in 2017, one single geometry accounted for 25,000. This is for

Fig. 8 A Montfort watch showing the complex additively manufactured face produced using Digital Metal technology

an industrial application that dates back to 2016. The serial production parts that we have delivered cover industrial, dental and luxury applications, meaning that small metal AM components are, like MIM parts, suitable for most market segments. Developing new components which have not been produced before means creating new markets. This takes time, but for those who have patience big opportunities lie ahead."

Automotive application

Digital Metal was selected by supercar manufacturer Koenigsegg to produce the windshield washer nozzles for a new vehicle using its binder jet AM technology. These tiny, exceptionally complex components feature a mirror glass finish, a cut-out of the company's logo on the outlet and a nozzle containing a number of hidden performance-enhancing functions (Fig. 7).

With the vehicle in question being valued at several million US dollars, the highest degree of function and quality was crucial, as well as the weight concerns familiar to the automotive industry. Because the type of Additive Manufacturing developed by Digital Metal doesn't require support structures, it is much cheaper to produce lightweight, hollow shapes such as these without the additional cost or wastage of support materials.

Koenigsegg's logo was produced to an extremely high degree of accuracy using Digital Metal's capacity for very high horizontal resolution, making it possible to additively manufacture designs in minute detail, while the high strength of its finished components made the logo robust and resistant to the environmental wear and corrosion any windscreen washer nozzle is exposed to.

Watch application

In November 2016, Swiss start-up Montfort approached Digital Metal to print the dials for its watches, designed to have a finish resembling the mineral, crystalline structure of rocks. The detail required would have been beyond most other Additive Manufacturing processes, but Digital Metal's high precision made it possible to achieve the tiny geometric patterns Montfort required. An example watch with the Digital Metal face is shown in Fig. 8.

Opportunities in the aerospace sector

For such critical applications as those in the aerospace sector, laser and electron beam Additive Manufacturing have, to-date, been preferred to binder-based systems due to the requirement for fully dense components. However, Carlström stated that Digital Metal has identified a number of opportunities in the aerospace industry in which the company's binder jet process may compete with laser and electron beam AM. "It is true that the aerospace sector prefers technologies that offer fully dense capability. The MIM industry has until recently not been very successful in this segment, and consequently we did not see this as our primary target when we entered into the AM market," he explained. "However, MIM is now starting to make inroads into aerospace and we have met more and more players who have a need for complex small metal AM components made with standard materials. We have therefore revised our view and see a very interesting potential in this field."

"On top of this, there is also a need for non-weldable AM parts in aerospace," he continued. "The aerospace industry wants to replace cast parts with AM technology to increase the geometrical complexity. AM technologies that melt different layers together generate high cooling rates resulting in stresses, often ending with cracking of the part. Binder jetting offers an interesting possibility to solve this dilemma with non-weldable grades. An additional HIP step after sintering has the potential to solve the aerospace industry's density requirements."

In September 2017, it was announced that Honeywell Aerospace and Digital Metal were exploring a number of joint Additive Manufacturing projects to merge Honeywell's expertise in aerospace engineering with Digital Metal's unique AM technology.

"The binder jetting technology Digital Metal uses to print small metal parts has the potential for various applications within the Honeywell Aerospace programme," explained Don Godfrey, Engineering Fellow - Additive Manufacturing at Honeywell Aerospace. "We believe this will also be critical to applications in other key areas of the broader aerospace industry."

Fig. 9 The pictured part, with extremely fine holes of variable diameters, demonstrates the precise detail that can be achieved with Digital Metal technology

The evolution of Digital Metal's technology

Fcubic began as a project at the Swedish industrial institute IVF, which began to explore binder jetting for the printing and sintering of ceramics to full density in the 1990s. When this project ended, a member of the research team made the decision to pursue the work independently as fcubic, applying the technology to metals. After building its first Additive Manufacturing system in 2006, fcubic began looking for a partner to bring the technology to market and eventually came into contact with Höganäs, which evaluated the technology over two years before acquiring the company.

One year later, in November 2013, the company reported that it had established a production line for the manufacture of parts using Digital Metal technology at its Höganäs headquarters. At the time, the vast majority of the AM industry's revenue was derived from plastic Additive Manufacturing, and the technology was in the early stages of its progression from rapid prototyping to the series production of components. Using its new binder jet technology, Höganäs reported that it had successfully produced a selection of complex shaped components for prototype and series production.

In October 2014, Höganäs expanded Digital Metal's production capacity and staffing levels, driven by increased interest in the company's technology. Two new Digital Metal machines, designed in-house, were added to its facility, bringing its total capacity to four machines and the necessary staff to operate them. At the time, the company was only producing stainless steel components, but had already begun developing titanium, silver and copper for commercialisation.

On the capacity expansion, Carlström stated, "The interest in Digital Metal is based on our ability to offer a combination of good tolerances, surface finish and detail accuracy. These benefits are further enhanced by the ability to offer high productivity. Digital Metal will continue to build more printers based on the evolving market demand."

Indeed, the company announced a further boost to Digital Metal's capabilities in late 2015, when a new sintering furnace was added to increase its output of metal AM components and offer additional material alternatives. "The new sintering furnace significantly increased our capacity," Carlström commented, "enabling us to sinter a wide range of metal powders."

The addition of this high-temperature sintering furnace, with variable sintering atmosphere settings and

Fig. 10 Additional enhancements to surface quality are available using Digital Metal's post-processing options

very precise temperature adjustment controls, marked another step in Digital Metal's steady drive to develop its in-house expertise, better understand its technology and produce the kind of high-quality, high-strength metal components required by its target markets. In the same year, the first of Digital Metal's licensees installed and began to operate a DM machine at its plant, marking the first DM system in use outside of the company's own facility.

Over the following two years, Digital Metal continued to additively manufacture a range of components for external customers, develop its technology and expand the range of materials it offered. The technology was used primarily to manufacture prototypes of small components - often smaller than 50 mm. However, in April 2016, Carlström reported that the company was also meeting an increasing demand for small series production. At the same time, the owner, Höganäs, stated that it would increase its focus on the post-processing of products, as well as investing in new equipment.

A Digital Metal system, the DM P2000, was licensed and delivered to CETIM in July 2017. This machine was equipped with an upgraded build box, binder supply and powder handling system, stated Hans Kimbald, responsible for Digital Metal's technical development. In the same month, the company announced that it had further extended the range of materials compatible with its machines, adding titanium Ti6Al4V to its offerings, which already included stainless steels 316L and 17-4PH. Widely used throughout the metal AM industry, Ti6Al4V's combination of high strength, hardness and ductility are highly valued for a number of components, particularly in Digital Metal's target aerospace, dental, medical and industrial markets. The material also offered a 45% part weight reduction compared to conventional steels.

Capacity expansion as machine sales take off

In November 2017, Digital Metal revealed that the production of machines for sale to external customers was well underway; in line with its plans, the company is considerably expanding its operations and creating a number of new roles within the organisation. Recruitment of engineers, technicians and sales representatives has begun and more will be added to assist in the development of new materials and systems, as well as serving increased market demand. To accommodate serial machine production, the company's office and plant at Höganäs are being expanded by 50% of their original size.

The company's DM P2500 has been adapted for commercialisation with updated technology and a reduced footprint. Carlström explained, "The first batch consists of six new printers containing the latest automation control systems. In addition, we have reduced the overall dimensions of the machine, making it more easily positioned. Our existing machinery will be upgraded to the latest technology at the same time."

The DM P2500 can produce smaller and more intricate components than any previously known AM system and has a print speed of 100 cm^3/h to a resolution of 35 µm and average surface roughness of Ra 6 µm before finishing. Offering an overall print volume of 2500 cm^3 and the potential to manufacture up to 50,000 small, complex objects in a single print run, with zero support structures, the DM P2500 is tailored to AM's increasing focus on industrialisation. Fig. 11 shows the intricate details that can be achieved.

Included in Digital Metal's expansion plans are additional facilities for the in-house Additive Manufacturing of custom parts, still key to the business. These include separate on-site facilities for quality control and isolated spaces for the AM of materials requiring special handling in a controlled environment. Some of these expanded facilities are expected to enable the company to further enhance its materials offering, creating the potential for new partnerships. "By developing our range of materials, we open up for new collaborations with companies in industries such as aerospace, where there is a great need for components that can withstand extremely high temperatures, made with superalloys," explained Carlström. On the expansion of the company overall, he added, "For us, this expansion is just a beginning. We are no longer thinking linearly. Instead, we are planning for exponential growth."

Fig. 11 In 2017, in a demonstration of the high resolution achievable using its technology, Digital Metal produced a batch of figurines representing a part of its team. Standing at roughly the same height as a matchstick, the figurines have toured with Digital Metal to some of the AM industry's key events

Digital Metal looks to the future

When fcubic was acquired in 2012, the market potential of Additive Manufacturing was estimated to be $1 billion. Five years later in early 2017, Wohlers Report calculated the current value of the Additive Manufacturing industry at more than $6 billion. Yet, amid ever-growing hype around AM, Industry 4.0 and 'the 3D printing bubble', Digital Metal has maintained its focus on core markets and applications for its technology.

Looking back on the rapid evolution of the AM landscape over the past five years, Carlström is confident about the bright future of metal Additive Manufacturing and of Digital Metal's place in it. "We have made many different types of advanced prototype for a large number of global customers since the start in 2013 of Digital Metal," he stated. "Twelve different geometries have evolved from the prototyping stage into serial production during this period."

"The longer I have been involved in this industry, the more convinced I have become of the positive future for metal AM." The industry, of course, still has challenges to overcome. "There is an expectation that metal Additive Manufacturing will move to the next level, from prototyping to serial production," he added. "Productivity or cost per produced unit is an essential parameter that needs to be improved in order to meet long-term growth expectations outside aerospace or medical implant markets. There are different initiatives ongoing to improve productivity around the world and I'm confident that this industry has a prosperous future. The productivity offered by Digital Metal fits very well into this future requirement."

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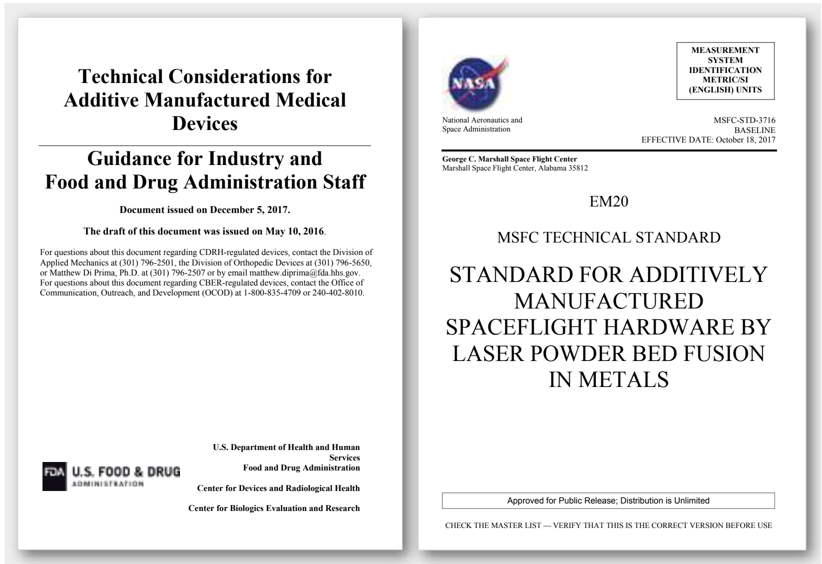
The challenges of metal powder removal: Managing risk, productivity and quality

One of the goals for the metal Additive Manufacturing industry is the automated series production of components through a streamlined manufacturing process. Such an ambitious goal faces a major obstacle: the challenge of powder removal. Joseph Kowen reviews some of the significant risks facing AM producers at this stage of the process, from health and safety considerations to the impact on quality and productivity, and highlights some of the technologies being developed to address them.

In January 2003 an explosion occurred at a plant in North Carolina, USA, belonging to West Pharmaceutical Services. Six workers at the plant were killed and thirty-eight were injured. Debris from the blast was found up to two miles from the plant, the explosion was felt twenty-five miles away, and the plant suffered significant damages and destruction. The plant manufactured synthetic rubber products for the medical industry and the cause of the blast turned out to be an accumulation of polyethylene dust from powders and fillers that were used in the manufacturing process. Something had disturbed the dust accumulation, resulting in a cloud of particles which ignited. The blast triggered a study by the Chemical Safety Board, a US government agency. Its report in 2006 found that in the twenty-five year period between 1980 and 2005, 281 incidents of chemical dust-related explosions had caused 119 deaths and 718 injuries.

Dust has for years presented a recognised hazard in many industries and the metal powder industry has not been immune. In December 2010, an explosion at the titanium plant belonging to AL Solutions in New Cumberland, West Virginia, USA, resulted in the deaths of three workers. In January 2011, an explosion at a Hoeganaes iron powder facility in Gallatin, Tennessee, USA, resulted in fatal injuries to five workers. These are just two examples. There are others from elsewhere in the world.

Metal AM is a relatively new industrial endeavour and powder management is a central part of


Technical Considerations for Additive Manufactured Medical Devices

Guidance for Industry and Food and Drug Administration Staff

Document issued on December 5, 2017.

The draft of this document was issued on May 10, 2016.

For questions about this document regarding CDRH-regulated devices, contact the Division of Applied Mechanics at (301) 796-2501, the Division of Orthopedic Devices at (301) 796-5650, or Matthew Di Prima, Ph.D. at (301) 796-2507 or by email matthew.diprima@fda.hhs.gov. For questions about this document regarding CBER-regulated devices, contact the Office of Communication, Outreach, and Development (OCOD) at 1-800-835-4709 or 240-402-8010.

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U.S. Department of Health and Human Services
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NASA
National Aeronautics and Space Administration

MEASUREMENT SYSTEM IDENTIFICATION METRIC/SI (ENGLISH) UNITS

MSFC-STD-3716
BASELINE
EFFECTIVE DATE: October 18, 2017

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

EM20

MSFC TECHNICAL STANDARD

STANDARD FOR ADDITIVELY MANUFACTURED SPACEFLIGHT HARDWARE BY LASER POWDER BED FUSION IN METALS

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Fig. 1 Left, the FDA Technical Considerations for Additive Manufactured Medical Devices, published December 5, 2017 and right, NASA Standard MSFC-STD-3716, October 18, 2017

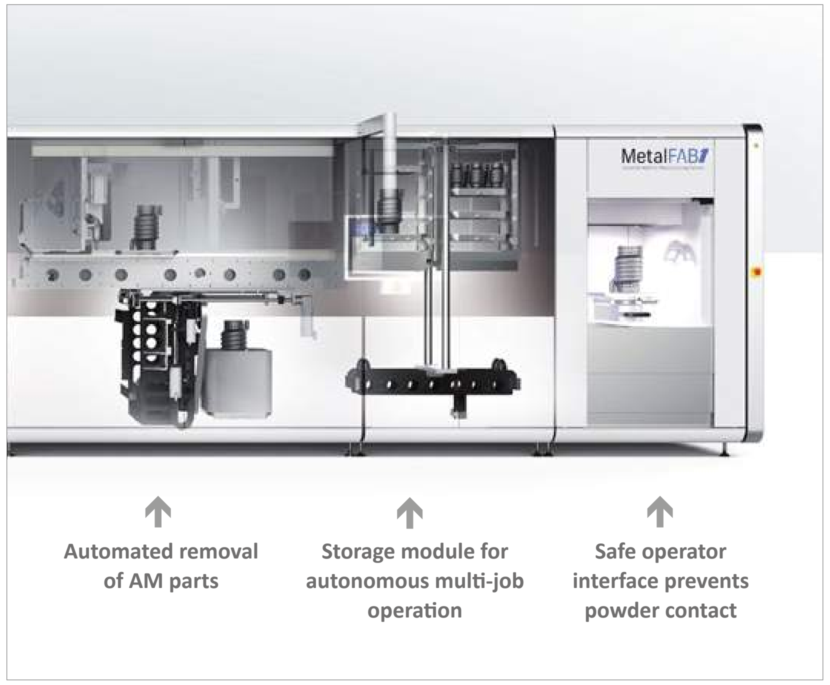

Fig. 2 Additive Industries' integrated product removal module, part of the MetalFAB1 Powder Bed Fusion system, can be seen on the left of this image (Courtesy Additive Industries)

that activity. Manufacturers of AM systems are aware of the hazards posed by dust in general, and by reactive powders in particular, and systems take those risks into account. But what exactly happens after the build process has been completed, and the parts are ready for post-processing, has not been systemically addressed. Systems manufacturers have not, in general, offered equipment to manage the problem. Users have been left to their own devices to manage the risks and inconvenience of part and powder removal in the way they best see fit.

The moment the build has run its course, and the parts are ready to be transferred out of the machine for further processing, turns out to be the weak link in the workflow. The build plate's exit from the machine is a watershed moment in the process, one for which there is no clear modus operandi or standard. If not managed, then powder removal could turn out to be a chilling factor limiting the growth and industrialisation of metal Powder Bed Fusion (PBF).

The pain points for AM part producers

So what exactly is the pain suffered by operators of metal PBF in connection with part removal? It turns out that there are many more concerns than just safety. A list of what operators tend to think about includes:

Explosion risk
Far and away the most important factor is reducing an explosion risk. This means preventing fine powder from finding its way into the factory environment and presenting a risk of explosion. This is critical for reactive metals such as aluminium and titanium.

Occupational health
Even if there was a lower risk of explosion, such as for non-reactive metals, ingestion of fine metal powder is an underestimated occupational health factor. Asbestos was handled openly before its detrimental health effects were shown. You would be hard-pressed to find a risk manager for all sizes of companies who would dare claim that ingestion or inhalation of metal powder has no effect on humans, even though its effects might not be precisely or fully understood at this stage.

The manual cleaning of parts, whatever the precautions taken to prevent ingestion of powder, is fraught with occupational health risks; nano-scale metal particles have been shown to penetrate the skin, and it is too early to know what this might mean for humans at the cell level. A face mask is unlikely to sufficiently prevent metal powder residue from entering the body. The best answer is reducing the powder at source before humans come into the picture.

Labour costs
Even if there were no occupational or health hazards associated with metal powders, the labour costs of powder removal are always going to be important. Manual labour is directly correlated to part complexity and part complexity is one of the factors that offers the greatest justification, though not the only one, for making the part in AM in the first place. So AM planners desire systems that can process complex parts with minimal effort, because each additional hour spent toiling to remove powder from inside complex lattice structures or internal channels chips away at the very viability of making that part by AM. In high labour cost locations, a reduction in the time needed to depowder a part could be the critical factor in assessing the viability of making the part by AM.

Powder recovery
Failure to recover powder is an economic loss, even without considering the other risks that have already been described. As the cost of the powder increases, so too does the incentive to recover more of it. Titanium alloys are one of the most popular metal powders today, and increasingly so, due to their applicability in aerospace and medical applications. The price of a kilogram of titanium alloy for AM systems is in excess of €200. In a manufacturing environment, saving even a modest percentage of wasted powder over time turns into a significant amount of money. A manufacturer's nightmare is seeing profits almost literally slipping away between one's fingers. The last 5 to 10% of powder is the most expensive to remove.

Fig. 3 Solukon SFM-AT800 depowdering systems at FKM Sintertechnik GmbH, Biedenkopf, Germany (Courtesy Solukon Maschinenbau GmbH)

Cleaning quality
Even if the powder is cheaper than titanium, manufacturers desire to produce parts that are as clean as possible. The price of aluminium powder is only about €35 per kg, but even if the manufacturer were to concede a higher degree of powder waste in the interest of a saving in processing time, imperfectly cleaned parts are highly undesirable, especially those with complicated geometries such as internal channels. Powder residue inside the part can cause significant downstream headaches and complications and, as we shall see, attracts attention from regulators and standards authorities.

Process repeatability
As Additive Manufacturing moves into the mainstream, the need to adhere to standardised protocols becomes more important and in some cases might be required as part of a certification process. This is most relevant in industries such as aerospace and medical device manufacturing. Manual cleaning results may vary according to the time of day the part is cleaned, or the industriousness and skill of the particular worker assigned to clean it. This is not a recipe for the good industrialisation of AM processes. If a part is going to be less than perfectly clean, then at the very least all parts in a series should be equal in their imperfection.

"Powder residue inside the part can cause significant downstream headaches and complications and, as we shall see, attracts attention from regulators and standards authorities."

Regulation and standards

As AM matures into a fully-fledged manufacturing modality, we can expect various regulatory frameworks to begin devoting more attention to how things are made additively. This has already begun to occur. One prominent example is the USA's

Fig. 4 Internal view of the Solukon SFM-AT800 system. Part designed by Airbus Operations GmbH and produced by Robert Hofmann GmbH (Courtesy Solukon Maschinenbau GmbH)

Food & Drug Administration (FDA). Titanium medical implants are one of the most promising applications of metal AM and many of the applications involve complicated structures where powder removal may not be straightforward. Manufacturers will be increasingly under the microscope as to the procedures they use to manufacture these products.

> *"The production engineering records shall provide specific procedures for removing powder for any part with geometry precluding line-of-sight confirmation of powder removal..."*

In December 2017, the FDA published guidance entitled 'Technical Considerations for Additive Manufactured Medical Devices' [1] which provides the agency's thinking on the subject. Though not yet binding, it signals the direction that regulation is going to take. On the subject of post-processing, the relevant part of the guidance states, "Final device performance and material properties can be affected by post-processing steps of AM... These steps could include removing manufacturing residues from the device... All post-processing steps should be documented and include a discussion of the effects of post-processing on the materials used and the final device... Manufacturers must establish and maintain procedures for monitoring and control of process parameters for validated processes to ensure that the specified requirements continue to be met. The broad utility and ability to make multiple devices at once through AM means that some post-processing may be documented for a design, a device, or a build."

Similarly, NASA says that part process control for AM processes should govern "all operations needed to produce a given part to a defined part process," and this specifically includes powder removal. The technical standards issued by the Marshall Space Flight Center (MSFC-STD-3716), published in October 2017 [2], state, "The production engineering records shall provide specific procedures for removing powder for any part with geometry precluding line-of-sight confirmation of powder removal, including methods to confirm powder removal prior to further part processing." The rationale here is that powder remaining in the part presents hazards to proper part and system operations.

The standard goes on to state that removing residual powder following the Hot Isostatic Pressing (HIP) process may not be feasible and that, therefore, it is important that all passages are verified clear of powder prior to this step. Proper cleanliness of HIP-treated parts may be impossible to achieve later on for debris-sensitive hardware, the standard concludes.

The message is clear. AM is being encouraged, and may soon be required, to become more procedure-driven throughout the process chain. One thing is for sure: stay tuned for more regulation of AM process and post-processes.

Is there an ideal solution?

Combining all of these factors, the industry's wish list could be rendered down into one composite statement that would look something like this: "A cost-effective, automated and programmable system, lowering the risk of explosion, with minimal worker exposure to dust, offering maximal powder recovery through minimal manual effort."

Like other industries before it, the metal AM community will have to come up with smart and economically sensible solutions to meet the needs of the industry as it moves into the industrial stage.

Given the long list of issues that concern metal AM operators, what solutions are out there? The industry is able to learn from powder management solutions employed in other industries. However, the special characteristics of AM present some unique problems, mostly in connection with the geometry of the parts. The good news is that the industry is starting to turn its attention to alleviating the pains of metal AM production.

Fig. 5 Solukon SFM-AT300 depowdering system for build plates of up to 60 kg (Courtesy Solukon Maschinenbau GmbH)

Integrated Systems

Some system manufacturers are beginning to offer integrated solutions to build and powder management. At formnext in November 2017, Dutch company Additive Industries announced a part removal module for its MetalFAB1 system (Fig. 2). The company was founded with the vision of automating metal PBF by including as many functions within one machine as possible. After completion of the build, the plate is advanced into the part removal module and rotated to an upside-down position which allows the excess powder to fall off by gravity from supports and channels. A bandsaw is used to cut the parts off the build plate, and these fall into a padded container for removal and further processing. The build plate is rotated back into an upright position and a milling cutter prepares the plate for the next build. An ATEX grade vacuum cleaner removes excess powder. The system does not vibrate the parts or rotate the build plate into multiple positions to maximise the recovery of trapped powder.

Also at formnext, UK company Renishaw displayed a concept that does something similar to the Additive Industries module. It too flips the build plate on its head in order to remove powder and parts. While this idea is not yet a product, and there is no indication yet as to when Renishaw might commercialise it, it does show that the issue of process automation, and in particular powder removal, is on the company's radar. Presumably they are listening to what customers are telling them.

The DMP 8500 Factory Solution outlined by 3D Systems also conceptualises an idea for powder removal as a module within a future AM manufacturing facility.

It is not completely clear if the integrated approach, comprising one removal device for each manufacturing system, is the efficient way to go. Time will tell.

Fig. 6 Inert PowderShield system (Courtesy Inert Corporation)

Standalone systems
Another approach is to build standalone systems which focus on powder removal as a dedicated speciality. An important advantage of standalone solutions is that one piece of equipment can serve a number of manufacturing units.

Solukon Maschinenbau has developed a range of powder removal solutions in a number of sizes and configurations. The top of the line is the SFM-AT800, a machine that can accommodate a build plate containing parts to a volume of 800 x 400 x 550 mm (Figs. 3 and 4). It features an automated and programmable full 2-axis rotation device and an automatically-opened roof for crane access for loading of a large part, or several parts, on build plates weighing up to 300 kg. The SFM-AT300 handles build plates of up to 60 kg (Fig. 5). More automation features like robot access are expected later this year.

The company believes that mechanical vibration with variable frequency, together with two-axis rotation, offers the best possibility of getting stubborn powder residues out of complicated internal passages. All machines come with the option of inert gas infusion, meeting European explosive standards for reactive materials. The powder can be removed into special inert containers or to external sieving systems. Users of non-reactive metals can opt for simpler versions of the machine without inert gas infusion capabilities, but with an effective HEPA dedusting system. The company has shown, with the help of clients' statistics, that the use of industrialised depowdering can result in labour cost reductions of up to 90% for complicated geometries. Solukon's solutions are intended for integration in the future into automated production lines.

Inert is a supplier of gas management solutions, and recently decided to adapt this knowledge to AM. Its PowderShield is a cabin dedicated to metal powder removal (Figs. 6 and 7).

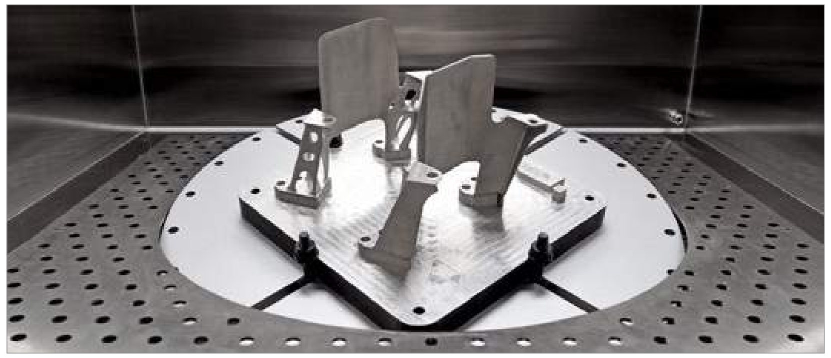

Fig. 7 Interior view of the Inert PowderShield system (Courtesy Inert Corporation)

The depowdering procedure is conducted within an argon atmosphere controlled by Inert's argon gas management system. Features include a 533 mm diameter rotating tilt table, argon blow off gun, ultrasonic vibration, unidirectional flow, perforated floor for powder collection and other customisations. The tilt direction can be set to a maximum of 45° and the rotation on the base plate is manual. The table can support builds of up to 50 kg. It is easily integrated with automated sieves, powder hoppers, and other third party equipment to create unique, closed loop post processing systems.

Conclusion

The good news is that the industry is turning its attention to finding operational solutions and it is only the start. We can expect increasing attention to the problems of powder removal, and post-processing in general, with which Additive Manufacturers must deal. We can also expect the solutions being offered to improve and expand, becoming more automated. Expect robots to be deployed too. More efficient post-processing will help spur growth of metal AM and that in turn will incentivise the development of even more efficient post-processing solutions. That is a positive upward spiral of growth that the whole industry can enjoy.

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formnext 2017: Business perspectives and expectations of the AM industry

The formnext powered by TCT exhibition, held from November 14-17, 2017, in Frankfurt, Germany, featured a parallel four-day conference that addressed a wide range of issues of relevance to the Additive Manufacturing community. Besides technical and application innovations, a whole day of the conference was devoted to business considerations and expectations relating to the future development of the AM industry. In this exclusive report for *Metal AM* magazine, Dr Georg Schlieper highlights a number of key business-related considerations for the future of the industry.

Understanding the risks associated with AM start-ups

In his keynote address at formnext 2017, Terry Wohlers, President of international AM consulting firm Wohlers Associates, warned that, in his experience, 90% of all start-ups fail. The reasons for this are diverse, but first and foremost is insufficient demand for a new product or business idea. Often, the market is not ready for or does not accept a proposed new product. Secondly, start-up companies often lack the financial resources to survive a longer lean period, thereby entering into insolvency. Start-ups also often lack sufficient experience in manufacturing technologies and, consequently, the quality of a product may not meet the expectations of the market. Entrepreneurs, stated Wohlers, are well advised to consider these risks thoroughly before embarking on such an adventure.

As far as Additive Manufacturing is concerned, Wohlers stated that design is of prime importance for the success of the technology. "We have just scratched the surface of what bionic design has to offer," he said. Designing and building a product by AM, however, is just a part of the manufacturing process, a fact that is all too often forgotten. Using the aerospace sector as one example, Wohlers stated that 70% of the total costs in Additive Manufacturing are incurred by pre- and post-processing operations.

Fig. 1 Delegates at the formnext 2017 conference (Courtesy Mesago/Thomas Klerx)

Fig. 2 formnext 2017 drew 21,492 visitors, with 46% of attendees from outside of Germany (Courtesy Mesago/Thomas Klerx)

Many processing steps such as powder removal, stress relieving heat treatment, removal from the build plate, removal of support structures, surface finishing, machining critical tolerances, surface treatment and inspection are required before a product is finished. An important aspect of AM design is therefore to reduce post-processing costs by, for example, avoiding or minimising the need for supports through intelligent orientation of the part in the build chamber.

Material costs for metal AM products are generally considered very high at the present time. According to Wohlers, these high material prices are usually tolerable for prototyping applications, but for production quantities this may comprise a major proportion of the total build cost and is a major factor in the profitability of AM production. Wohlers commented that he expects substantial price reductions of AM materials in the future.

The human resources challenge

Nick Pearce, Director of Alexander Daniels Global, a personnel recruitment specialist based in the United Kingdom, highlighted factors that should be taken into account when hiring in the AM industry. In an industry such as AM that is undergoing rapid technological change, new jobs are constantly being created which may not have existed a year ago. It can, therefore, be impossible to find applicants with exactly the right training for the job. Instead, an employer should assure themselves that an applicant has a broad technical background and the knowledge to enable them to quickly become involved in a new task. In-depth knowledge in one or two areas relevant to the job may give the applicant an advantage over their competitors.

Pearce also talked about the 'soft skills' that employers should identify in order to be successful in the long term. According to Pearce, those companies with the ability to adapt quickly to change will be the most successful. Skills such as complex problem solving, critical thinking, creativity and people management are among those most highly ranked by the World Economic Forum. The speaker explained that many challenges still exist in AM which require further research, for example relating to materials, machines and processes, and the AM industry urgently needs creative problem solvers to tackle these challenges. Such complex problems can only be solved with diverse expert knowledge, including software development, electronics, mechanical engineering, materials science, physics and chemistry. Teamwork is therefore vital for technological advancement. It is the combination of in-depth expert knowledge and soft skills that make a company successful in the long term.

Pearce predicted that in the future, industrial companies will be much smaller and leaner than today, be more flexible to adapt to technological change, react quickly to new customer needs and bring new products and services to market faster. These future companies will tend to form small core teams and draw on the help of an increasing number of freelancers that offer their skills and services to industry. To be large as a business may no longer be regarded as an advantage. Few people will be able to manage huge turnovers in a digital world; this means that recruitment has to change with the changing needs of the industry. In a small core team, the skills of each individual employee will have a greater impact on a company's success than in a large organisation.

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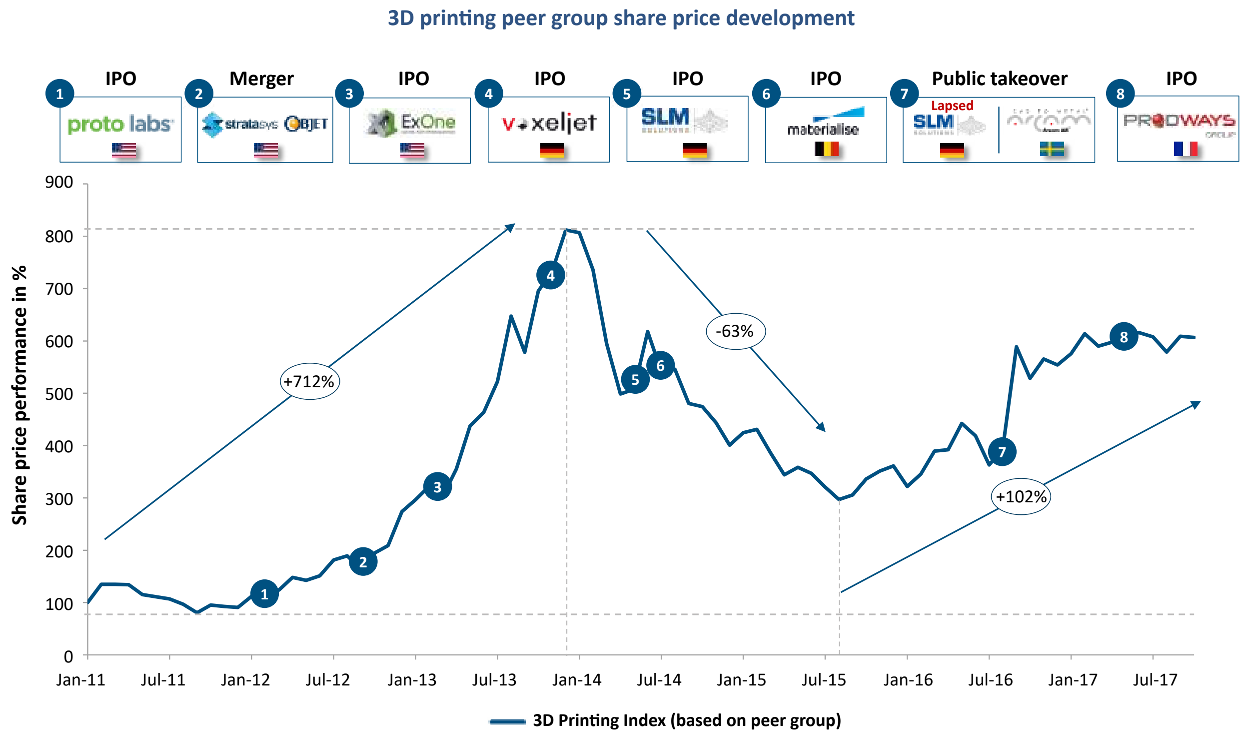

Fig. 3 Business development of the AM industry 2011-2017 (Courtesy Stephens)

An investor's view of AM

An investor's view of the metal Additive Manufacturing industry was presented by Gerhard Gleich and Marcel Steidl of Stephens Europe Limited, the European branch of the privately-owned US investment company Stephens, Inc. Stephens investigated the business performance of selected manufacturers of Additive Manufacturing systems and service providers from 2011-2017 (Fig. 3). The steep rise in business performance between 2011 and 2014 was followed by a consolidation period which lasted until mid-2015. Since then, the industry has picked up an organic growth rate. The Wohlers Report 2017 was quoted as stating, "The Additive Manufacturing industry is expected to continue strong growth over the next several years. By 2018, the industry is forecast to reach nearly $9.5bn worldwide."

The response of the capital markets to the emerging Additive Manufacturing industry was reported to be very positive due to the diversified application of the technology. The aerospace market is considered to be crucial, but it is not the only market. The healthcare, automotive, tool making, robotics, jewellery and consumer goods markets also promise to make AM technology a lasting success. Service providers, it was stated, are well advised not to focus on just one market segment, but to target a solid mix of applications.

The speakers from Stephens referred to a number of investments that have already been made in the AM industry. The biggest was the acquisition of Sweden's Arcam and Germany's Concept Laser by the General Electric Company (GE), whose GE Additive division is now a major player in the field of laser and Electron Beam Melting technology, with a wide range of Additive Manufacturing systems. In addition, Swiss technology group Oerlikon invested in citim and the Belgian software provider Materialise acquired the German aluminium casting company ACTech, taking advantage of its experience in the rapid prototyping and post-processing of highly complex metal parts. These acquisitions are an indication of how attractive investments in Additive Manufacturing are today.

Fig. 4 The formnext exhibition has become the main event in the metal AM calendar for the launch of new production systems. 2017's event was no exception, with notable announcements including GE Additive's Project A.T.L.A.S. metre-class metal AM system

According to Stephens, the main criteria for investors in the Additive Manufacturing industry are businesses with experience in industrial applications, innovative customer groups and a strong growth potential. Specifically, AM service providers should have a solid background knowledge in metal powders and Additive Manufacturing processes, have integrated pre- and post-processing facilities, and a strong historic growth rate as well as attractive future growth potential. They should have a diversified customer base including the key sectors of AM applications. The aerospace sector is regarded as highly relevant since AM components can offer significant cost savings through weight reduction.

Stephens strongly believes in the future prosperity of the AM industry worldwide. Commenting on the adoption of metal AM technologies, Gleich stated that this is expected to increase thanks to price reductions and easier accessibility in the years to come. The range of alloys offered by the AM industry will continue to be extended, leading to new AM designs and stimulating further market growth. Production quantities will inevitably increase in the future thanks to productivity increases and new low-cost AM technologies. Therefore, Gleich concluded, "Additive Manufacturing will stay on top of the strategic agendas of industrial conglomerates worldwide."

Aerospace, medical and industrial applications are most attractive

Frederik Klöckner, Technology Manager at KEX Knowledge Exchange AG, a provider of technology and market information based in Aachen, Germany, considered if in the future AM technology will play a significant role in industrial manufacturing, approaching the issue both from a technological and a market perspective.

The results of a study based on a large consortium of industrial partners and research institutes are

summarised in Fig. 5. The consortium identified aerospace, medical and industrial applications as being technically demanding and also having a high market potential. This combination was considered advantageous because the customer benefit of technically demanding products is great enough to allow for pricing that both covers costs and allows for adequate profits.

The automotive sector, although technically demanding, was only classified as having a low-to-medium market potential, mainly because it is primarily a high-volume market where the margins per unit are usually small. Consumer and energy applications were judged as having a medium market potential and their technological potential was also allocated in the medium range.

More specifically, the study shows that the aerospace market benefits most from AM technology through material and weight savings as well as an increase in product performance. Industrial applications benefit from cost reductions for parts with very low production volumes and where a product has a very short time to market. The medical sector, it was stated, profits from the ability to produce individualised products at reduced costs. These benefits, it was suggested, may also offer attractive opportunities for manufacturers of consumer products. The energy sector benefits from better product performance, reduced costs and shorter time to market, and for the automotive industry, short time to market is also attractive.

KEX expects that many applications that are still uneconomical today will have become attractive for AM technology by 2020 thanks to reduced material and manufacturing costs. The break-even point will shift towards lower values because of technical advancements and market development. Therefore, the initial question regarding the future role of AM technology in relation to other manufacturing technologies was clearly affirmed because, "AM enhances what is feasible with manufacturing technology today and complements the current manufacturing technology landscape."

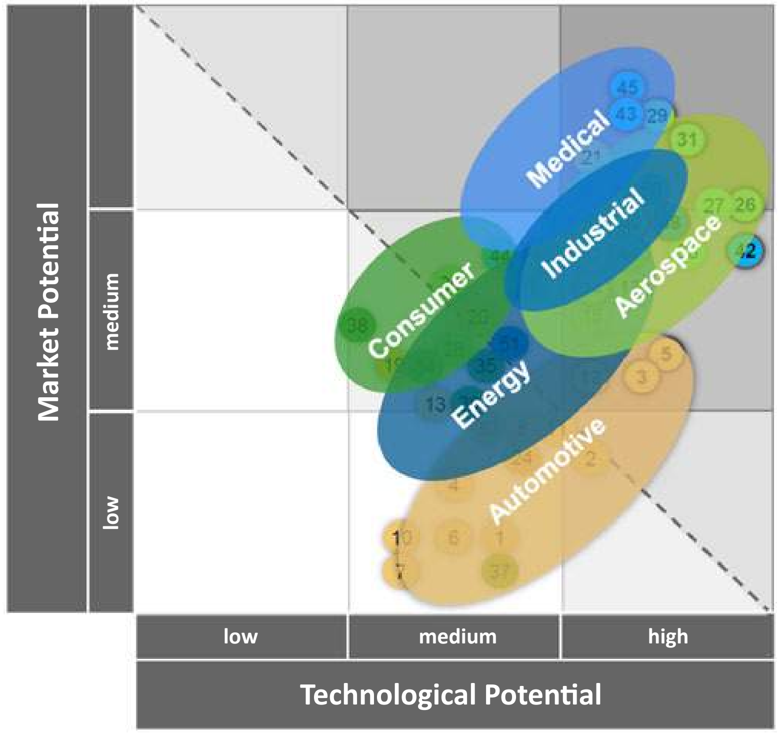

Fig. 5 Technological and market potential of AM technology (Courtesy KEX)

Ways to systematically identify AM products

KEX also studied a method by which products that are suitable for AM can be systematically identified. Klöckner

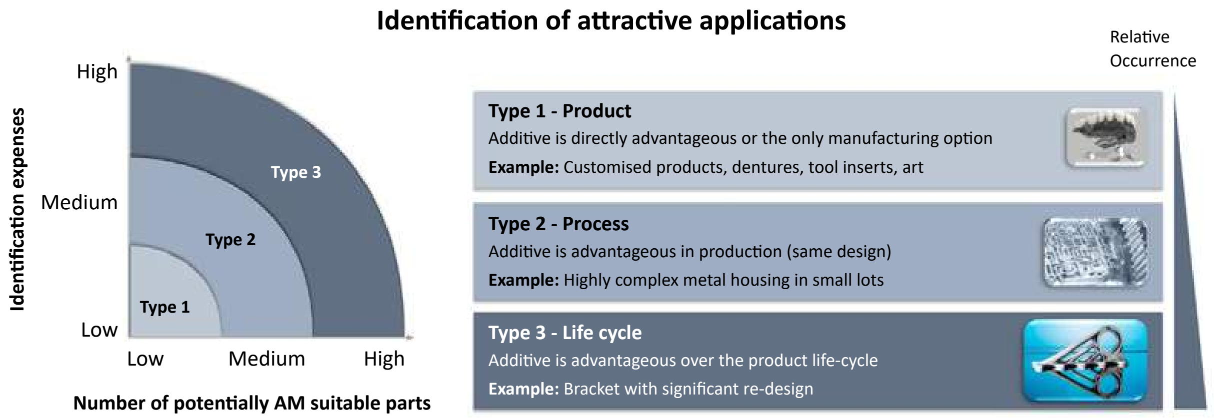

Fig. 6 Identifying suitable AM products (Courtesy KEX, Airbus SAS 2017)

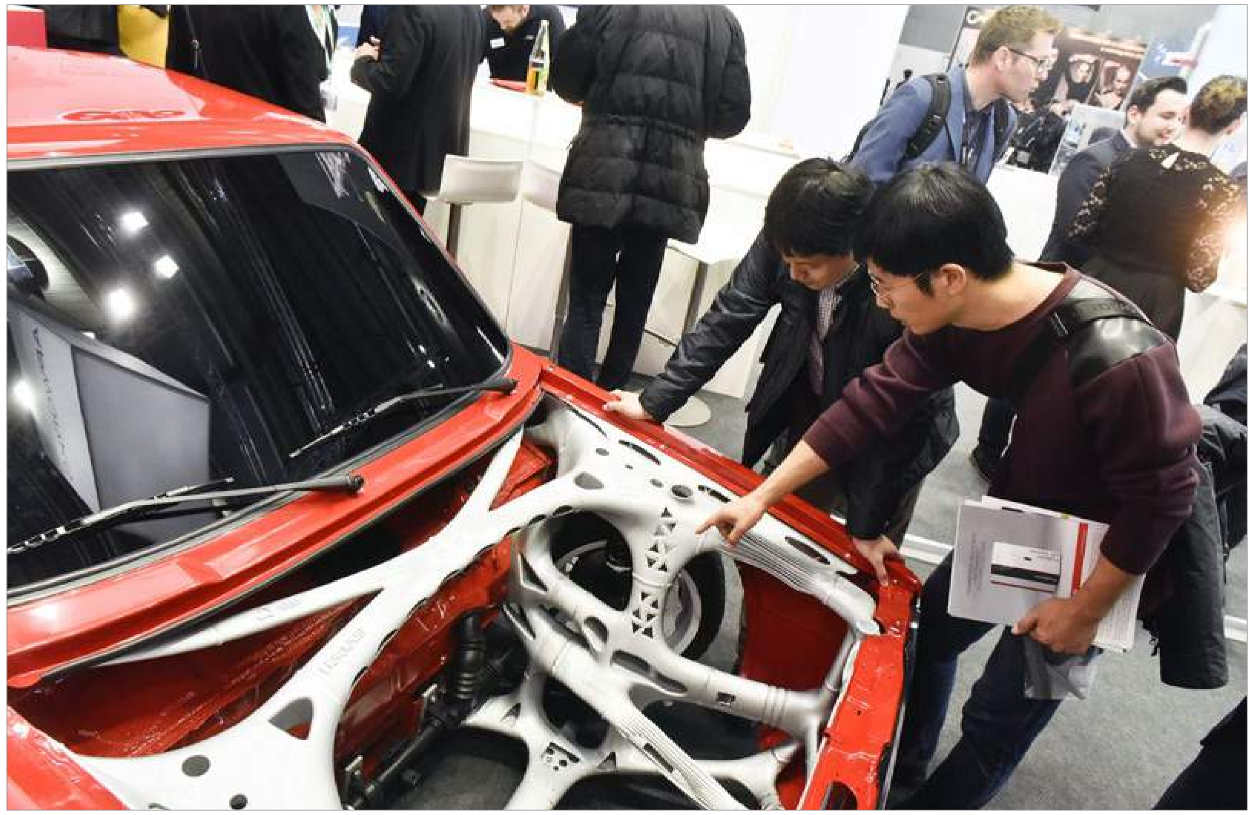

Fig. 7 The front-end structure of a VW Caddy redesigned using AM was shown on the APWorks booth. This was a project that also included Altair, csi entwicklungstechnik, EOS, GERG and Heraeus (Courtesy Mesago/Thomas Klerx)

distinguished between three types of products (Fig. 6). Where AM offers an obvious advantage or where it is the only feasible manufacturing process, products were classified as type 1. Examples include customised parts such as medical implants, dentures, tool inserts with conformal cooling channels, works of art and jewellery. It is relatively easy to identify these products, but the number of applications is limited.

Products whose design is basically unchanged but are so complex that AM is an advantageous manufacturing technology, such as complex metal housings, were defined as type 2. The effort required to identify these parts, as well as the potential number of suitable products, was considered higher.

Finally, most other parts which may benefit from AM technology were categorised as type 3 products. These were defined as parts for which the total benefit over the product lifecycle is in favour of AM technology, even though the initial cost of AM production is higher than for conventional manufacturing technologies.

The advantage of AM technology in these latter cases can only be exploited with an expensive redesign of the product. A well-known example used by KEX was a titanium bracket redesigned by Airbus Industries specifically for Additive Manufacturing, which entered series production on a commercial aircraft in mid-2017. In this case the benefit over the lifecycle is in weight saving. Often, the redesign process requires designers to rethink the function of a whole system of components in order to find the optimal solution.

Klöckner predicted that design for AM technology will become a core competence of design engineers and that the progressive diversification of AM technologies will stimulate market growth by encouraging the development of new AM applications.

Results of a global survey by Ernst & Young

Stefana Karevska, Senior Manager at global accountancy firm Ernst & Young GmbH, Mannheim, Germany, considered the question, "What has to be done to bring Additive Manufacturing to the breakthrough point where it is a serial production technique?"

To answer this, Karevska firstly analysed the structure of the AM market. On the demand side, she allocated industrial companies, manufacturing companies, service providers and consumers as the end users of AM equipment and products. The supply side consists of AM system manufacturers, raw material suppliers (primarily metal powder producers), software developers and service providers. The demand side is most important for the analysis, Karevska said, since changes on the supply side are driven by demand.

Ernst & Young conducted a global survey of 900 companies in twelve countries and evaluated the

Fig. 8 HP featured example parts made using its forthcoming metal AM technology (Courtesy Mesago/Thomas Klerx)

awareness and expectations of their executives with respect to Additive Manufacturing, in order to find out how the AM industry could best serve their expectations. Karevska pointed out that emerging new technologies are faced with a relatively small group of 'early adopters' who are enthusiastic about the potential options and fascinated by the technology itself.

In the survey, the size of this group was determined to be 4% of all respondents. On the other hand, the survey identified a majority of pragmatic, sometimes sceptical players who are mindful of the risks and will not accept the new technology at any cost. Between the two groups there is a gap that has to be closed before the new technology can substantially increase its level of adoption. However, a remarkable interest in AM was identified, with 11% of the interviewed already having begun to test AM technology in one way or other. This group is not yet convinced of the technology, but chances are that they will reach that point in the foreseeable future.

Progress required in AM technology

Karevska further discussed some of the activities required by the AM industry to improve acceptance of the technology. She concluded that the choice of AM materials is still very limited as compared to other manufacturing technologies and that the material costs of AM metal alloys are still too high. This is regarded as a major barrier on the way to a wider acceptance of the technology. A similar challenge is the price of AM equipment, which was rated too high by 40% of the surveyed companies.

Karevska called on AM system manufacturers to strive for substantial cost reductions in both materials and machinery and stated that she already believed she could see some movement in the market. The standardisation of AM processes, including post-processing, was also recognised as an important backbone of acceptance. Karevska said that there is a lack of software for the integration of AM technology in the supply chain of the manufacturing industry. Finally, the AM knowledge base is still insufficient in many industrial sectors. Many companies do not introduce AM products because their engineers simply do not know enough about the process. Although universities have started to include Additive Manufacturing in their curricula, it will take time for this knowledge to be spread in the industry.

According to Karevska, service providers play a key role in the further development of the AM industry because they provide the link between system manufacturers and end users. For companies with little or no experience, service providers are the first point of contact and the fastest way to adopt the technology. Service providers will also be used to produce spare parts on demand in a short period of time. In conclusion, it was stated that AM technology is expected to support and profit from the trend towards greater flexibility in industrial manufacturing.

Fig. 9 Metal AM parts on display in the exhibition hall, formnext 2017 (Courtesy Mesago/Thomas Klerx)

Factors affecting the decision to adopt AM technology

A master's thesis in Business Administration was presented by Luuk Nollet of the University of Twente in the Netherlands. Nollet's goal was to understand the main factors influencing the adoption decisions of executives in industrial companies with regards to Additive Manufacturing. His survey was based on ten companies in the Netherlands, five so-called 'adopters' who have a positive attitude towards AM and five 'non-adopters' who were sceptical and refused to invest in AM equipment. Nollet admitted that this was not a representative survey and was focused on potential investors in AM equipment, but the results give some insight into how these types of decisions are made.

The functions of persons involved in the decision-making process are firstly the initiator, i.e. the person who has a problem that they hope to solve with the new technology and who starts the decision-making process. The influencer strategically evaluates possible alternatives to solve the problem. The gatekeeper controls access to information for the influencers. The decider has the authority to make the final decision for or against the new technology, and the purchaser acquires the technology. The user finally consumes and uses the product.

Nollet found that decisions regarding innovation are influenced by technological, organisational and environmental factors. Technological factors include the capabilities, complexity and compatibility of the technology. Organisational factors are the resources and skills within the company and environmental factors are determined by the supply and market environment in which the company operates, its business partners, competition, suppliers and so on.

Adopters usually believed that AM technology was in alignment with their business and often underestimated the complexity of the process. Non-adopters, meanwhile, had a typically negative perception of the technology. A major investment in AM technology should be based on a cost-benefit analysis, and Nollet believed that it is very difficult to prove that an investment is profitable. For the adopters, therefore, the positive decision was based mainly on a gut feeling, rather than on a sound business plan illustrating a proper return of investment. The anticipated benefit to the 'image' of the company could also be an argument in favour of the technology. One adopter replied, "My most important reason was that I wanted something new for my company. How do I get attention as a company? And then it is more a commercial factor than a technical one."

In an organisational context, a positive decision appeared more probable if the decision maker was free to decide without having to consult shareholders. If the decision maker was also the initiator, it positively influenced the decision to adopt. If the influencer was also the decision maker, the decision was probably negative because the business case was most important and the case could not be made for certain that the technology was profitable. In the case of one non-adopter, there was at least one individual who was enthusiastic about the technology, but had to ask for permission and was unable to present a positive business case.

Fig. 10 One of the exhibition halls at formnext 2017 (Courtesy Mesago/Thomas Klerx)

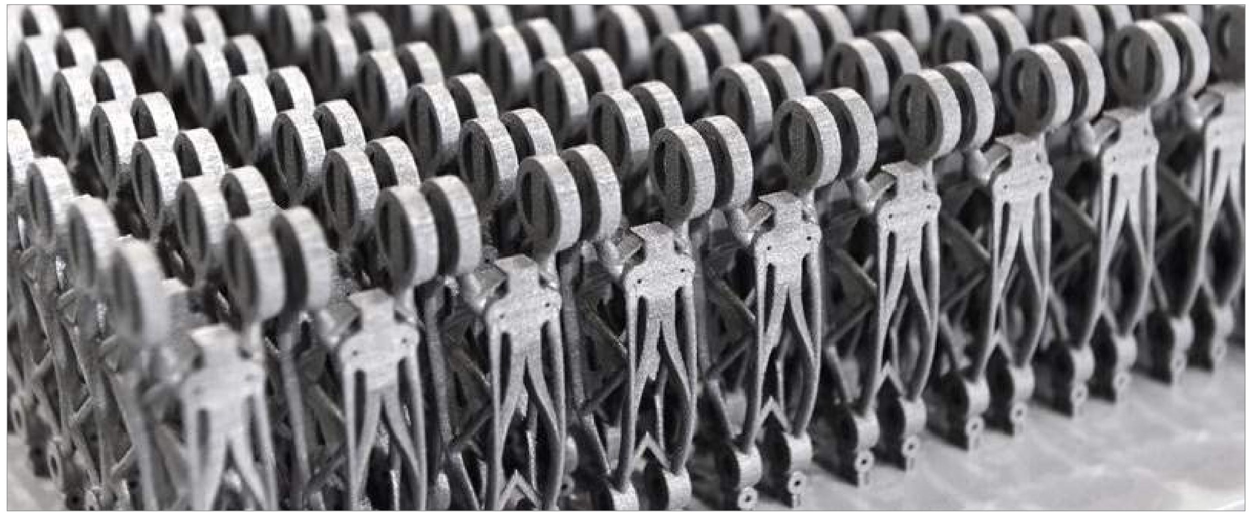

Fig. 11 Parts displayed on a build plate at formnext 2017 (Courtesy Mesago/Thomas Klerx)

The opportunities for market development were regarded as the most important environmental factor in favour of or against the technology, both for adopters and non-adopters. The growing demand from customers for metal AM products, as well as competitors who had already invested in AM, exerted pressure on the companies to adopt the technology. Nollet concluded that adopters are often visionary leaders who have the power to decide, but run the risk of underestimating the complexity and neglecting the economics of AM. Non-adopters are cautious managers with internal investment guidelines who are looking to reduce the risk of the investment. It was concluded that a gradual entry into the technology through the use of service providers is one way in which companies can develop the market and gain experience before making a major investment decision on their own.

Standards for metal Additive Manufacturing

The existence of industrial standards is a reliable indication of a mature technology. The Association of German Engineers (Verein Deutscher Ingenieure – VDI) embarked on the development of industrial standards for Additive Manufacturing at an early stage and Dr Erik Marquardt presented the activities of VDI in this area.

The first standards of the series VDI 3405 were published as early as 2013. Since then, VDI has followed the progress of AM technology and continuously updated the VDI 3405 standards series. The standards published to-date include recommended testing procedures for AM products, design rules, powder characterisation and material data sheets for selected materials. Further standards in progress are more material data sheets, a standard for Powder Bed Fusion, user safety of laser beam melting systems and legal aspects of Additive Manufacturing.

Conclusion

In light of the examples and knowledge offered by these presentations, it can be concluded that Additive Manufacturing technology is on track to becoming an integral part of industrial manufacturing processes, particularly in the aerospace industry where it has already gained a strong foothold. We are already seeing a remarkable increase in the speed of industrial AM systems thanks to multi-laser technology, improvements in quality systems, an increasing number of producers and service providers, and a steady move towards the automation of AM processes.

Some of the challenges highlighted in this report represent the inevitable growing pains associated with a new technology, but what is abundantly clear is that there is a huge desire amongst all stakeholders in the industry, from materials and equipment suppliers to producers and end-users, to respond quickly to these challenges and drive the technology's capabilities to new heights

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Formnext 2018

The formnext 2018 conference and exhibition will take place in Frankfurt, Germany, from November 13-16.

www.mesago.de/en/formnext/

Alternative metal Additive Manufacturing technologies highlighted at Euro PM2017

A session at the Euro PM2017 congress, organised by the European Powder Metallurgy Association (EPMA) and held in Milan, October 1-5, 2017, focused on a number of alternative technologies for the Additive Manufacturing of metallic components. In the following report Dr David Whittaker reviews three papers that highlighted the potential of the lithographic Additive Manufacturing of metal-based suspensions, the characteristics of porous Ti6Al4V materials produced by three-dimensional fibre deposition and bio gelcasting, and Fused Filament Fabrication for the production of metal parts.

Lithographic Additive Manufacturing of metal-based suspensions

A paper from Gerald Mitteramskogler, Martin Schwentenwein and Simon Seisenbacher (Lithoz GmbH, Austria), Carlo Burkhardt (Pforzheim University of Applied Sciences, Germany), Oxana Weber (OBE GmbH & Co. KG, Germany) and Christian Gierl-Mayer (Technical University of Vienna, Austria) presented a study on the lithographic AM of metal-based suspensions [1]. Stereolithography was the first commercialised AM technology, for the building of polymeric prototypes by a spatially controlled solidification of a liquid resin by photo-polymerisation, and was invented by Chuck Hull in the mid-1980s. Following the definitions in ISO/ASTM 52900, similar processes are now categorised under 'Vat Polymerisation'.

Industrial-scale vat polymerisation processes are already applied for the shaping of specialised materials, such as toughness-modified plastics or high performance ceramics. As the AM process is a layered process, a certain level of translucency of the suspension is required to attach the layers on top of each other and to ensure sufficient mechanical strength of the manufactured part.

Within particle-filled photo-reactive suspensions, the penetration of light is highly governed by the degree of absorption of the powder particles (a material constant), the filler content of the suspension (usually around 50 vol.%), the physical size and shape of the particles and the scattering of the light at the particle/binder interface (i.e. the difference in refractive indices).

Fig. 1 The Euro PM2017 congress and exhibition was held in Milan, Italy, and attracted over a thousand participants (Courtesy EPMA)

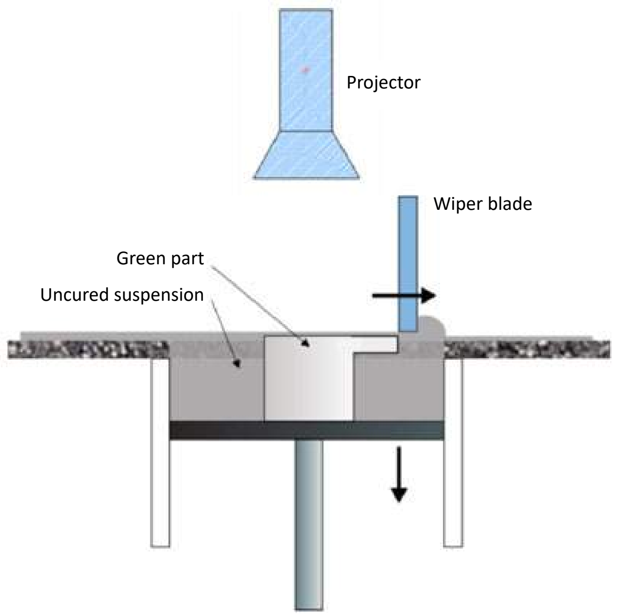

Fig. 2 Sketch of the prototype machine setup [1]

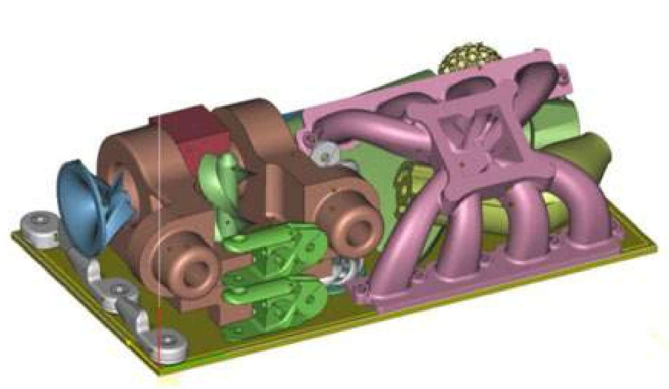

Fig. 3 Volume-based placement of multiple parts resulting in 18% occupancy [1]

To-date, these limitations have hindered the exploitation of the potential benefits of the vat polymerisation AM technology for the shaping of high quality, metal-based green parts, because metal powder is optically dense and shows a high level of absorption.

This paper introduced a novel vat polymerisation process, developed by Lithoz GmbH during a European Commission Horizon 2020 project, REProMag, which is suitable for the manufacture of highly complex green parts based on 316L stainless steel. The issues previously highlighted have been solved by developing a novel slurry composition and a new generation of AM machines. The aligned interaction of machine and material allows the application of thin layers of material with precision down to the micrometre level.

A photo-reactive suspension was prepared based on commercially available di- and polyfunctional methacrylates (60 wt.%). The slurry included an initiation system with a proprietary photo-initiator, which absorbs light in the specific wavelengths emitted by the light engine. Using this formulation, a solid loading of 316L powder up to 50 vol.% was achieved. A homogeneous mixture was prepared by centrifugal mixing, with both the organic and the metallic powder being added in the cup and homogeneously dispersed.

A novel AM machine was developed based on the principle of vat polymerisation (Fig. 2). The liquid starting material was polymerised from above by a high-performance projection unit. The building platform with the green parts was lowered layer-by-layer, according to the set layer thickness. For the 316L material, a thickness of 50 µm was chosen. After the curing of a layer, the wiper blade applies a fresh film of material. The size of the building platform was 75 x 43 mm and the resolution in the X and Y directions was 40 µm. The printing time of a single layer was 35 s, which resulted in a build speed of 6 mm/h in the Z direction (or around 20 cm³/h in volume terms).

The self-supporting function of the material enabled volume-optimised placement of different parts on a single building platform without the need for additional support structures. The only manual operation necessary was to load the parts into the respective program (Netfabb by Autodesk® or Magics by Materialise). The 3D nesting operation was automatically performed by the software. The print job in Fig. 3 was generated, resulting in volume occupancy of 18% of the overall building volume. The minimum distance between the parts was set at 1 mm. However, smaller values down to 0.1 mm are possible. The software slices the parts to create the image information for each layer.

Thermal debinding of the three-dimensional green parts was performed in an inert atmosphere up to 320°C to avoid oxidation. Fig. 4 shows the temperature program used, which was optimised for a cylinder of 10 mm in diameter and height. The debinding was optimised by thermo-mechanical and thermo-gravimetric analyses. After the debinding, the parts were sintered in a hydrogen atmosphere at Ohnmacht & Baumgärtner GmbH & Co. KG (OBE). The maximum sintering temperature was 1360°C with a 2 h holding time.

To evaluate the mechanical strength of the sintered parts, tensile test specimens (Fig. 5) were manufactured and sintered. The geometry of the parts was based on DIN EN ISO 6892-1, with the test length being 36 mm and the test area 6.5 x 3 mm. During manufacturing, the parts were oriented parallel to the building platform.

The tensile tests were performed under a quasi-static load using a universal testing machine at ambient conditions (20°C, laboratory air). It was shown that a yield strength of 233 ± 26 MPa and a tensile strength 502 ± 13 MPa could be achieved. The density of the samples was around 96% of the theoretical density of 316L. The additively manufactured material performed similarly to traditionally processed 316L, which showed a yield strength 220 MPa and a tensile strength 530-680 MPa.

Tensile data are only available for a single build direction, so, to evaluate any dependencies on the build direction of the green part, further studies need to be conducted. Also, the fatigue strength of the material will be a topic for further studies.

Fig. 6 shows an etched micrograph of a sintered 316L sample. The remaining porosity is closed, which would allow further densification by Hot Isostatic Pressing. This micrograph also confirms the measured density levels.

Fig. 7 shows sintered parts printed with the developed material and process. After the AM process, the parts have been cleaned and the excess material could be recycled for reuse. Due to the densification process, debinding and sintering caused a homogeneous shrinkage of about 22%. Slight distortions due to gravitational forces during high temperature sintering are visible. To minimise these distortions, the structures could be placed on a customised setter plate, such as a machined porous alumina material.

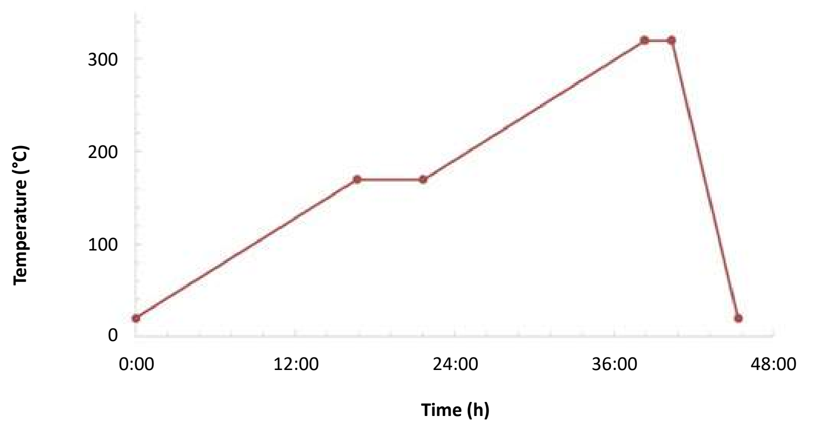

Fig. 4 Temperature program for thermal debinding and corresponding thermo-mechanical analysis (TMA) measurement [1]

"These early results demonstrate the great potential of the LMM process to be used either as a complementary technology to MIM, or other AM processes"

These early results demonstrate the great potential of the LMM process to be used either as a complementary technology to MIM, or other AM processes such as Powder

Fig. 5 Sintered tensile test specimen made from 316L stainless steel [1]

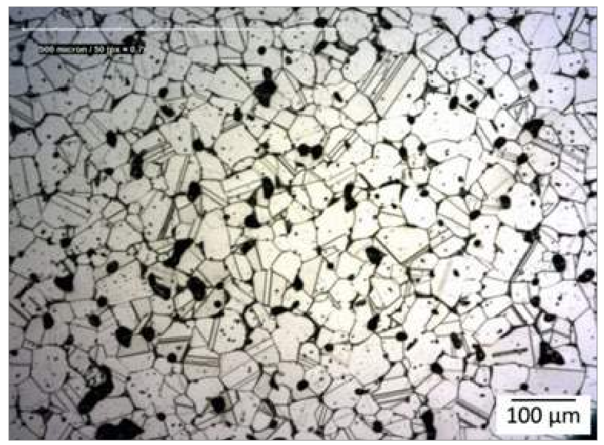

Fig. 6 Polished and etched micrograph of a sample sintered at 1355°C for 2 h [1]

Fig. 7 Sintered parts made from 316L, according to the building platform shown in Fig. 3 [1]

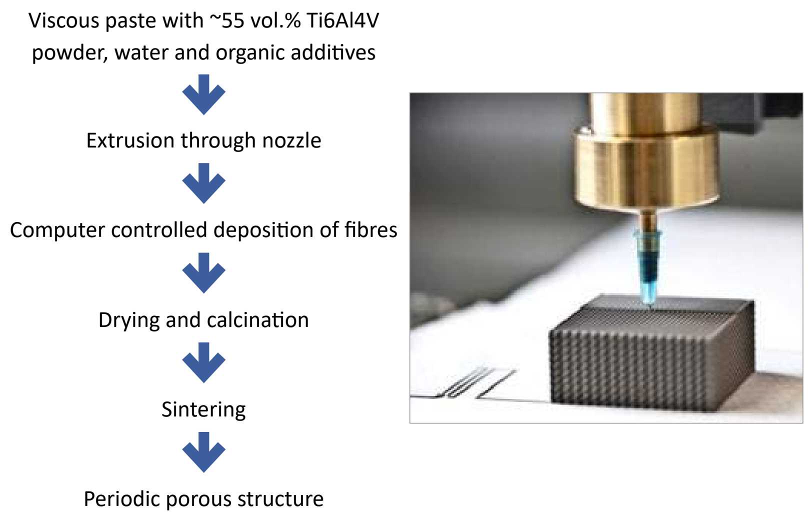

Fig. 8 3DFD (Robocasting) technology [2]

Bed Fusion or Binder Jetting. It shows high advantage when focusing on smaller, more complex parts that require a high feature resolution and improved surface quality. The process can be used to directly produce parts in a small-scale series or to manufacture prototypes prior to a MIM-based mass series production. Since the final geometry of the part is developed by means of a sintering process, similar microstructural characteristics compared with MIM can be achieved.

Characteristics of porous Ti6Al4V materials produced by three-dimensional fibre deposition and bio gel casting

In the second paper, Marleen Rombouts, Steven Mullens and P Weltens (Vito, Belgium) compared the processes of three dimensional fibre deposition (robocasting) and bio gel casting for the manufacture of porous Ti6Al4V structures.

For biomedical implant applications, the porosity level of Ti6Al4V is varied to control the material's elastic modulus (to match as closely as possible that of bone to avoid stress shielding) and to provide interconnected porosity for the in-growth of new bone tissue. The optimum pore and interconnection for bone in-growth has been reported as being in the range 100-500 µm.

Robocasting is an AM technology originally developed at Sandia National Laboratories in the 1990s and is particularly suited to the production of structured porous materials. Some characteristics of robocasting technology, compared to other more common metal AM technologies such as Selective Laser Melting, are:

- It is an indirect process, in which, after printing, the parts are densified by a thermal process
- There is no powder bed and thus cleaning procedures for the removal of powder from internal cavities are avoided
- Good mechanical properties can be achieved, with an absence of residual stresses, as the shaping is performed at room temperature and specific furnaces are used for calcination and sintering in controlled atmosphere
- The possibility is offered to induce surface roughness and micro-porosity within the fibre by a phase inversion technique
- The technique is applicable to all powder materials
- The technology is somewhat more limited in porous design compared to powder bed based AM technologies.

Gel casting is a direct foaming technique which starts from a water-based slurry of titanium powder to which a foam-forming, gelling and stabilising agent and a binder are added.

Spherical Ti6Al4V powder, produced by Electrode Induction-melting Gas Atomisation and finer than 45 µm (d50 ~ 30 µm), was used in both the robocasting / 3D Fibre Deposition process (3DFD) and gelcasting process studies. 3DFD is an AM method based on the concept

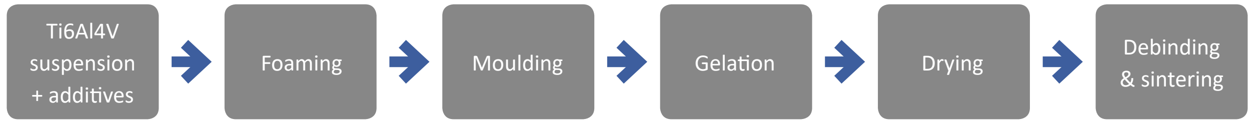

Fig. 9 Bio gel casting flow chart [2]

of micro-extrusion combined with computer controlled movement in three dimensions. The core in this process is the highly loaded paste, which is extruded through a nozzle. The typical flow chart for the 3DFD technology is shown in Fig. 8. Parts are printed with a nozzle with a diameter of 0.4 mm and layer thickness of 0.3 mm. The last step in the flow chart comprises a thermal treatment, in which the parts are calcined to remove the binder from the paste and subsequently sintered in an argon atmosphere. The samples are first heated at 0.5°C/min to 500°C and, after a dwell time of 1 h, are heated to 1350°C with a holding time of 1 h.

The bio gel casting process is shown schematically in Fig. 9. Different porosities and pore size distributions have been obtained by changing the mechanical mixing time. The same heating cycle for debinding and sintering, as for the 3DFD samples, has been applied.

The products resulting from the two processes have been compared through structural characterisation and static compressive mechanical property measurements.

In terms of structural comparisons, gel cast Ti6Al4V foams are characterised by a broad pore size distribution (Fig. 10) and an average pore size in the range of 50 - 200 µm, whereas robocast metals are characterised by a well-controlled porosity and a narrow pore distribution (Fig. 11).

The overall average width of robocast fibres, produced with a nozzle diameter of 0.4 mm, is 0.35 mm. The standard deviation of the fibre diameter is 0.02 mm (i.e. around 5%). By changing the fibre spacing between 0.8 mm and

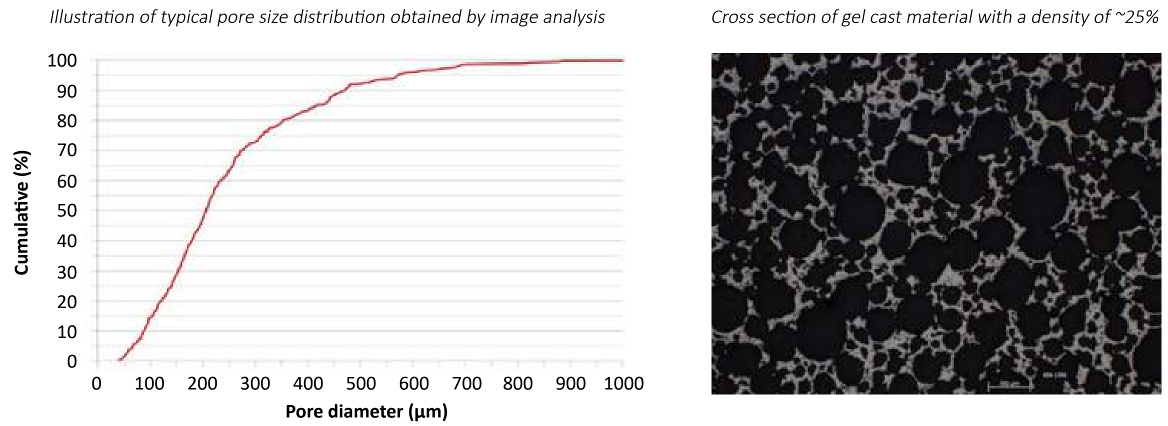

Fig. 10 Gel cast porous titanium alloy structures [2]

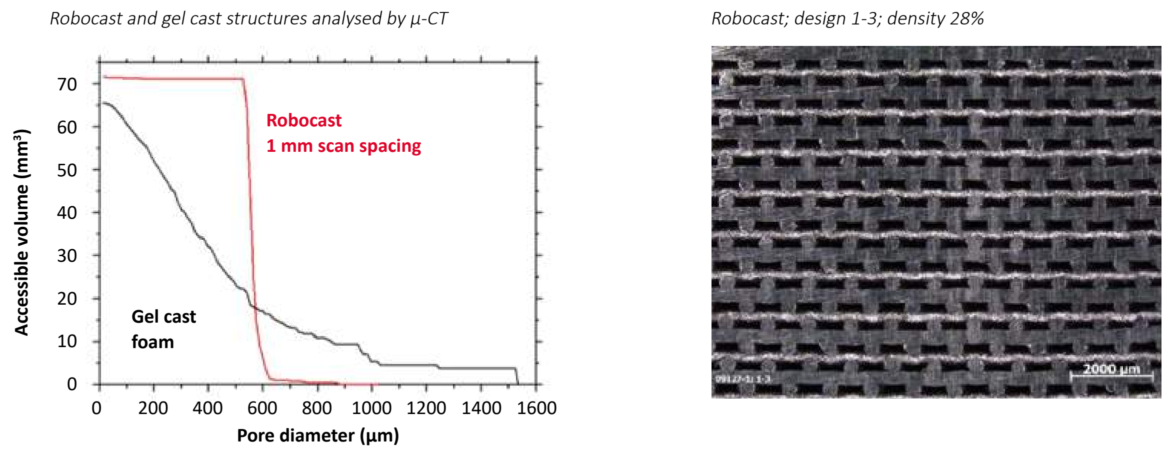

Fig. 11 Robocast titanium alloy structures [2]

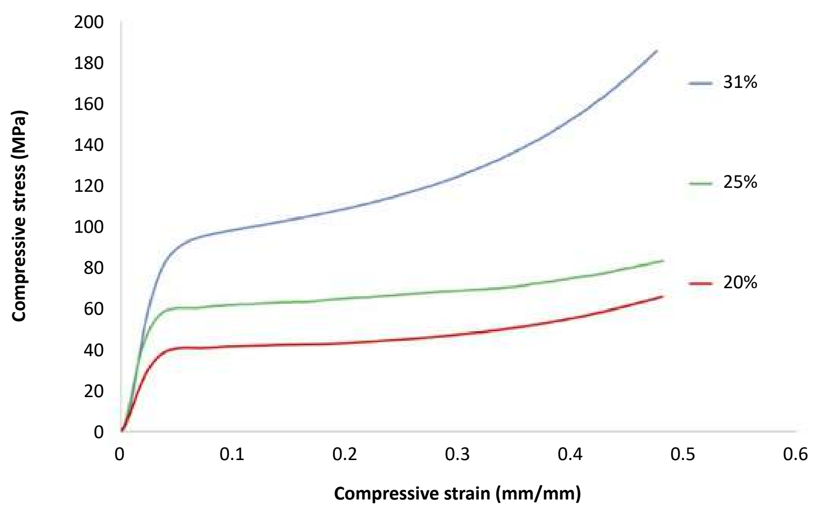

Fig. 12 Compression curves of gel cast Ti6Al4V foams. The relative densities of the foams are indicated [2]

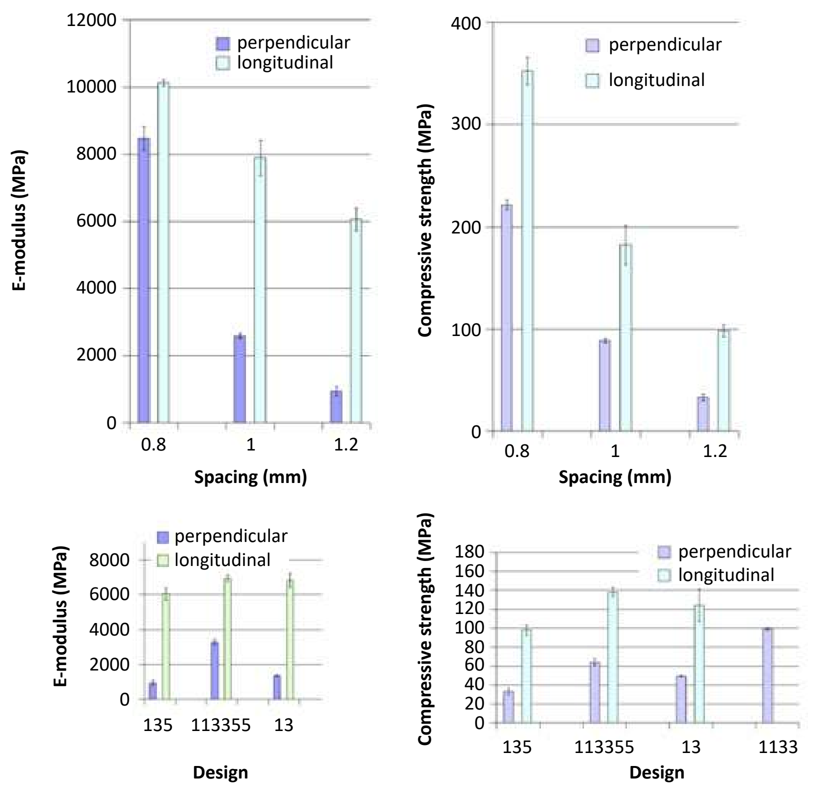

Fig. 13 Mechanical properties obtained by static compression testing of robocast samples with (top) 1-3-5 design and (bottom) 1.2 mm spacing between the fibres [2]

1.2 mm, the final relative density varies from 54.5% to 27.6%. The volumetric shrinkage during sintering of the robocast structures is 33.9 ± 0.6%.

The compressive mechanical behaviour of gel cast materials is illustrated in Fig. 12. The foams show a higher strength and stiffness at a higher density. Stiffness values in the range 2-4 GPa are obtained (cf. trabecular bone: 0.2-2 GPa). Compressive strengths in the range 45-100 MPa are obtained (trabecular bone is in the range of 15-50 MPa) at relative densities of 20-35%.

For robocast material, a higher spacing between fibres results in a lower stiffness and compressive strength (Fig. 13). The stacking design has a smaller effect on the mechanical behaviour than the scan spacing. The stiffness and strength upon loading along the layers are significantly larger than those measured perpendicular to the layers, especially at higher scan spacing. Fibres stacked twice on top of each other (design 113355) lead to a higher stiffness and strength.

Additive Manufacturing of metal parts using Fused Filament Fabrication

Finally, a poster, associated with this session and presented by a Fraunhofer team of Sebastian Riecker, Sebastian Boris Hein, Thomas Studnitzky, Olaf Andersen and Bernd Kieback, focused on the AM of metal parts by Fused Filament Fabrication (FFF). FFF is one of the most popular and most widely used AM technologies because of its relative simplicity and, therefore, low investment cost for the machines.

During the printing process, a filament with a diameter of 1.75 mm to 3 mm is melted and extruded through a small nozzle of typically 0.4 mm to 0.8 mm in diameter. Controlling the nozzle's movement, the extruded strand is printed in a defined geometry to form the component layer by layer. The filament, being the printing material, also acts as the push rod for the extrusion. It is moved by a driving wheel and has to transfer the driving force to the liquified filament material in the nozzle (Fig. 14). Therefore, the filament must have sufficient strength to be processed in the printing machine. While being flexible enough to be coiled, strength and stiffness is necessary to act as a push rod for the filament extrusion without buckling.

In general, a low viscosity at the process temperature is necessary for the extrusion through the small nozzle and a high filament stiffness is favourable. In addition, the printed strands must have good adhesion to the printing substrate and the already printed structures and show little warpage due to thermal expansion.

To allow debinding and sintering after printing, either two different polymer materials with different decomposition temperatures must be used in the feedstock, or an otherwise removable phase (e.g. wax) must be present in addition to the polymer.

Filled thermoplastic filaments that feature improved physical, optical or haptic properties by using reinforcements such as carbon fibres, wood fibres or metal or ceramic powders have been developed. However, the volume content of the filling materials lies mainly between 10 and 40 vol.%, making them unusable for further sintering processing steps. Only a few research studies have, to-date, focused on filament materials that can be debound and sintered following the printing process to achieve a dense ceramic or metal part.

The presented work was, therefore, aimed at developing a feedstock material that can be printed, debound and sintered to full density. The studies focused on three different material types for the filament production: PLA, PA and Polypropylene PP. Dispersing agents and softeners were used to modify the rheology of the melt as well as the physical properties and debinding performance. 316L stainless steel powder with a D50 of 7 µm was the metal powder used as filling material throughout this work. An overview of the tested filaments is provided in Table 1 by showing examples of the filaments in each experiment set, although the exact feedstock composition was kept confidential.

The filaments were produced by two different manufacturing routes. In the first route, a twin screw extruder with six heating zones was used to compound and extrude the feedstock mixtures to filaments with a diameter of 3 mm. The kneading temperature given in Table 1 refers to the heating zones 1-5 of the extruder, the extrusion temperature refers to heating zone 6. In the second route, a kneader and a table extruder were used to produce filaments with a diameter of 1.75 mm.

The filaments showed a large variance in quality between the different polymer types used in the study, an overview being given in Table 2. As anticipated, the physical properties of the polymer matrix had a large influence on the filament properties.

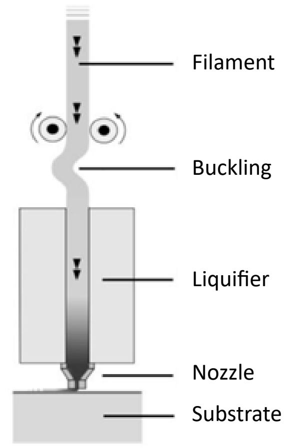

Fig. 14 Schematic printing process with soft filament that causes buckling between liquifier and driving wheels [3]

Brittle materials tended to become significantly weak at high volume loadings (F1), whereas the properties were maintained up to volume loadings as high as 59 vol.% for flexible and ductile feedstock materials (F4, F5). According to these results, the PLA samples were too brittle and the PP samples were too flexible to perform printing trials. The addition of a softener had only a small impact on the tested flexible PP filaments

Filament	Process Route	Material type	Softener	Dispersing agent	Kneading temp. [°C]	Extrusion temp [°C]
F 1	Route 1	PLA	S 1	D 1	215 - 220	215
F 2	Route 1	PA 1	S 2	D 2	270 - 275	280
F 3	Route 2	PA 2	S 3	-	170	170
F 4	Route 2	PP 1	S 4	D 3	180	155
F 5	Route 2	PP 2	S 4	D 3	170	160

Table 1 Examples of filaments of different compositions produced at Fraunhofer IFAM [3]

Filament	Bending radius at break [mm]	Strength	Extrusion torque [Ncm]	Density	Particle content [vol.%]	Surface quality	Buckling tendency
F 1	> 150	good	n.a.	3.9	43	medium	very low
F 2	5 - 10	very good	n.a.	4.6	51	medium	low
F 3	10	medium	40	4.2	46	very good	medium
F 4	no break	low	10	4.3	48	good	very high
F 5	no break	low	15	5	59	good	very high

Table 2 Extruded filaments and their mechanical and extrusion behaviour [3]

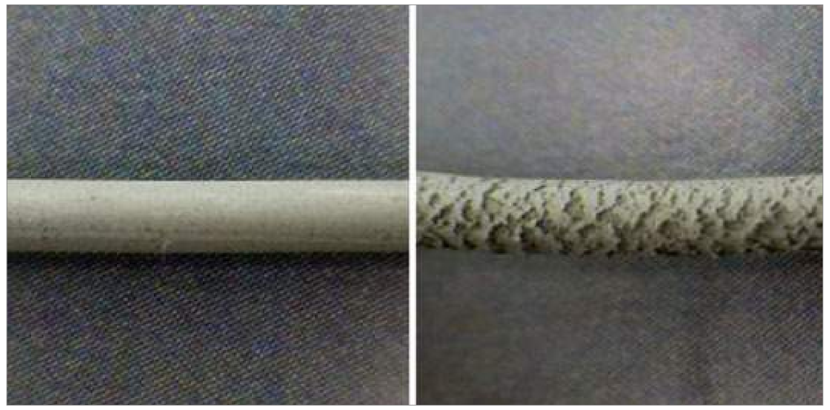

Fig.15 Extruded filaments F4 (left) and F3 (right) with a diameter of 1.75 mm [3]

and led to a significant decrease of strength of the PA filaments. Surface quality of the filaments and the extruded strand was equally influenced by the material composition and the process parameters. Fig. 15 shows the surface of filaments F4 and F3. A similar difference in surface quality could be observed on filament F4 with different extrusion temperatures. Generally, the filament extrusion gave the first insights into feedstock behaviour. Artefacts, such as bearding, shape loss or low surface quality, were reproduced with a small printing nozzle. In addition to the observations of the extruded filament, the extrusion torque and flow rate of the extruded filament were used as an orientation value for rating the extrusion behaviour. Materials with a lower value of extrusion torque showed better extrusion behaviour through the small printing nozzle.

A lower temperature and a medium extrusion speed led to the best results in the tests. Examples of the results can be found in Fig. 16 for filament F2 using a nozzle size of 0.8 mm. A good surface quality of the filament and of the extruded strand was found to be important for the avoidance of large pores in the printed parts.

Printing trials were performed on filament type F2 using a commercial printer that used a Bowden cable for feeding of the filament. A temperature of 235°C with a printing speed of 25 mm/s was set for the trials. Sintering experiments were performed on chemically and thermally debound filaments as well as printed parts at temperatures of 1300°C to 1350°C under a hydrogen atmosphere.

With the selected printer, only filaments of type F2 could be printed due to the high filament strength that is required for the Bowden cable feeding system. Due to the low melt strength, the retraction setting was set to very low values and a layer height of 0.1 mm was set in the example given in Fig. 17. The box could be printed with a wall thickness of about 1.5 mm and a side length of 1 cm. After thermal debinding and sintering, the walls show a small warpage caused by the shrinkage of about 18% and the box's geometry without a dense bottom layer. As can be seen in the cross section, the remaining porosity was still high at around 10% in this example. However, no layering effect could be found within the dense compact in the investigated cross sections. It can therefore be assumed that the anisotropy in mechanical strength found for plastic components can be minimised in printed and sintered parts. Furthermore, filaments of type F4 could be sintered to almost full density of 99% under a hydrogen atmosphere with a partial pressure of 850 mbar and a sintering temperature of 1350°C. A thermal debinding route was performed under the same atmospheric conditions between room temperature and 500°C, leading to a slight deformation of the filament. Printability still has to be validated. Due to the flexibility of the filaments, a printer setup with the driving wheels above the nozzle is required in this case.

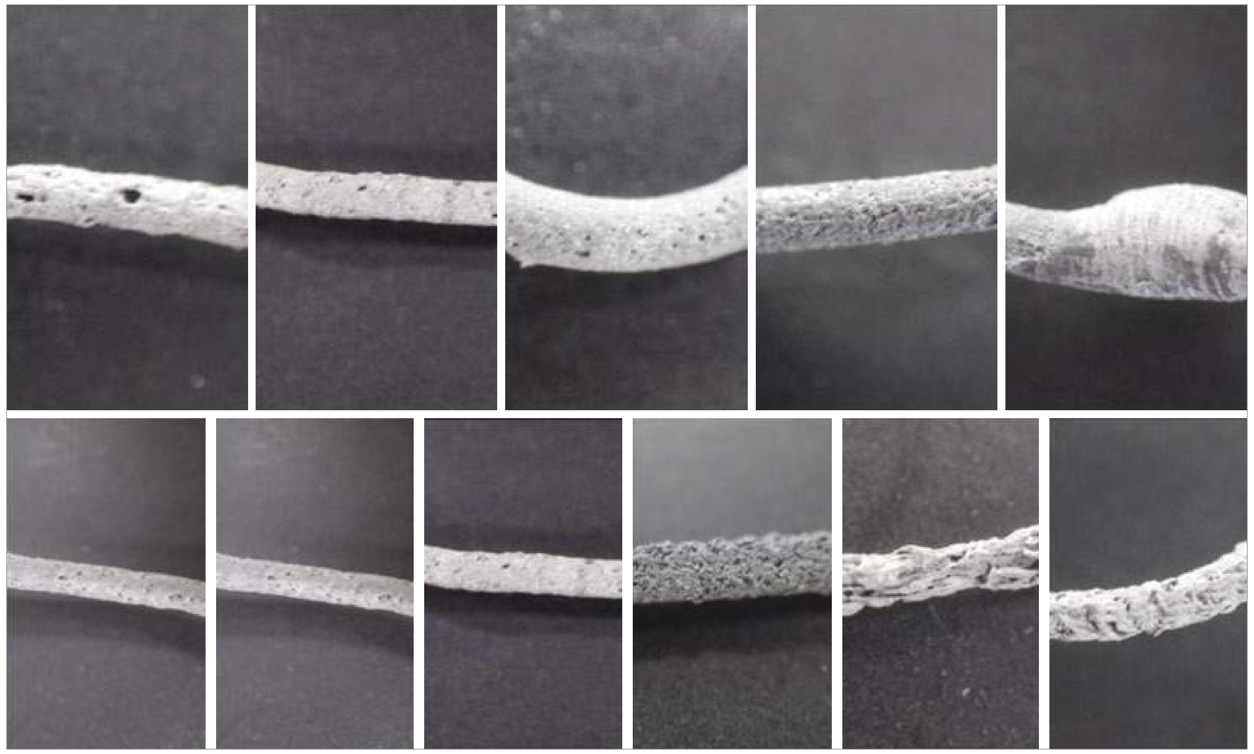

Fig. 16 Parameter testing with filament extruder setup for filament F1 and a nozzle of 0.8 mm. Top image: T = 250 °C, Extrusion Speeds from left to right: 7 mm/s [0.88 mm³/s], 14 mm/s [1,76 mm³/s], 42 mm/s [5.3 mm³/s], 70 mm/s [8.8 mm³/s], 98 mm/s [12,37 mm³/s]. Bottom image: 14 mm/s extrusion speed, temperatures extruded at 14 mm/s from left to right: 225°C, 235°C, 250°C, 270°C, 280°C, 290°C [3]

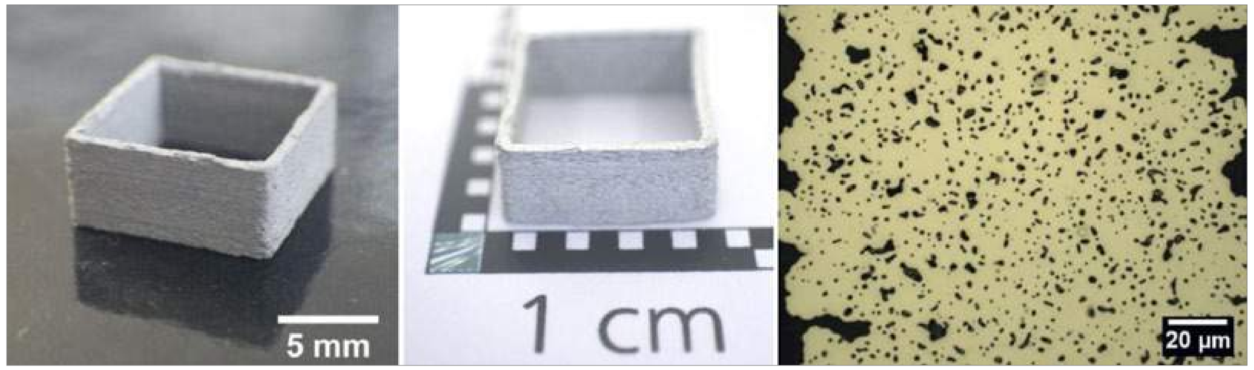

Fig. 17 Images of a printed box with a side length of 1 cm and a wall thickness of about 1.5 mm in green state (left), and thermally debound and sintered (middle, right). The cross section was taken perpendicular to the wall and feedstock F2 was used [3]

Work undertaken between the conference manuscript submission and the preparation of the conference poster recorded significant progress in the refinement of the technology. The latest filament composition has a content of 60 vol.% of metal powder and shows good printability. The green parts can be debound in ethanol, isopropanol or acetone before thermal debinding and sintering to relative densities up to 98%, with a linear sintering of shrinkage of around 16% without any major printing defects despite the layer-by-layer printing process (Fig. 18).

"The latest filament composition has a content of 60 vol.% of metal powder and shows good printability. The green parts can be debound in ethanol, isopropanol or acetone before thermal debinding and sintering..."

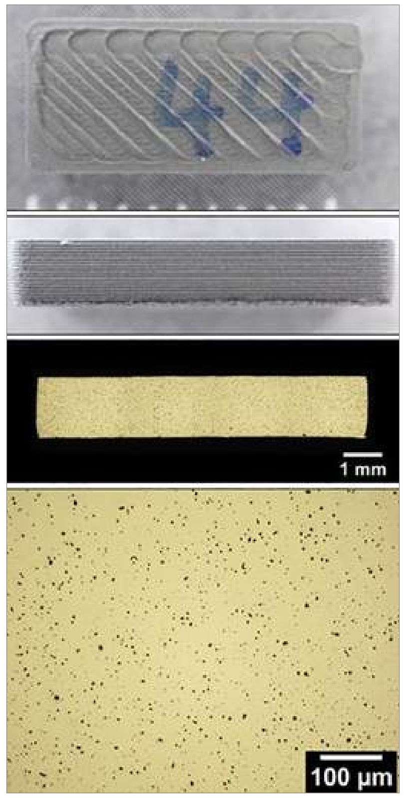

Fig. 18 Cross section of a cuboid part showing no layering effect [3]

The printability and sinterability of the filament was demonstrated on more complex parts, such as the twisted box shown in Fig. 19, with good dimensional stability after sintering. The authors stated that the next steps include the design and construction of an integrated process line for the printing, debinding, sintering and CNC machining of complex metal parts.

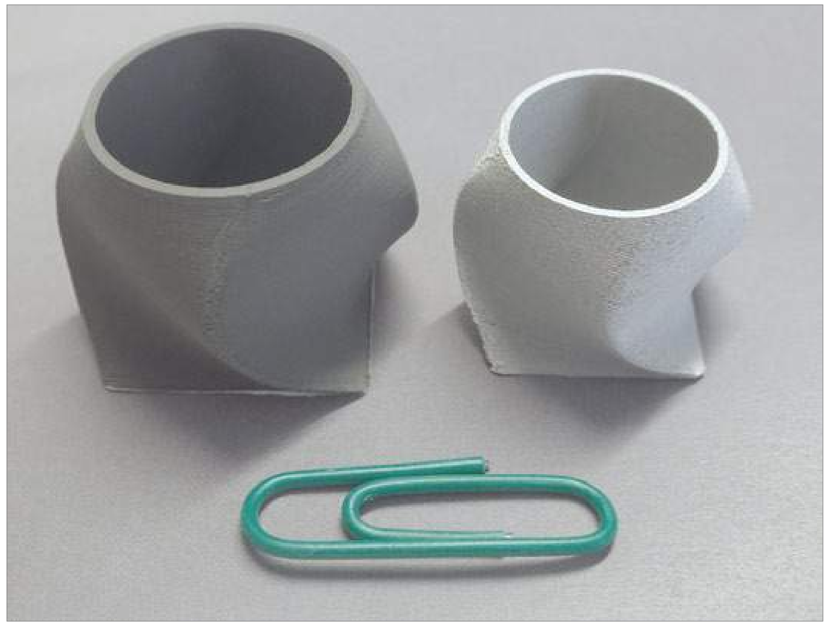

Fig. 19 A twisted box in the as-printed and as-sintered condition shows the capabilities of the FFF process when using a metal feedstock [3]

The authors summarised their findings by concluding that the FFF process with subsequent debinding and sintering can be realised with highly filled filaments. Low investment costs and the high complexity of printable designs makes this manufacturing method interesting both for small companies and small batch sizes.

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Component design for cost-efficient metal Additive Manufacturing

Some companies approach Additive Manufacturing as a drop-in replacement for conventional manufacturing technologies. This approach, however, does not take into account the unique possibilities that additive processes offer and can result in parts that are not commercially viable due to cost. By designing parts specifically for AM, companies can reduce costs and improve efficiency while taking advantage of the possibilities offered by the technology. In this report, Olaf Diegel and Terry Wohlers look at the impact of good AM part design on machine operating costs.

The Additive Manufacturing of parts that have not been designed specifically for AM production can be very expensive. Industrial AM systems are also expensive, and part production rates are slow. An AM system capable of producing metal parts can cost from $500,000 to more than $1 million.

One can optimistically assume that a metal AM machine will run about 80% of the time, which is around 7,000 hours per year. It is not uncommon for a return on investment (ROI) period for capital equipment to be in the range of two years. This varies from company to company, but for high-tech equipment, a two-year ROI period is a reasonable average for cost calculations. This means that the typical hourly operation costs of a metal AM machine can, depending on the value of the machine, range from about $37 per hour to $90 per hour.

Using a "middle-of-the-road" hourly operation cost of $65 per hour, a part that takes ten hours to build would therefore incur a machine cost of $650. With metal AM, however, build times are often substantially more than this. In fact, it is not uncommon a part to take forty, sixty or even 100+ hours. If a part requires 100 hours to build, the machine cost, alone, is $6,500.

This underscores the importance of finding methods to reduce the build time whenever possible. It is also important to consider design methods that will reduce build time and material. The methods described in this article focus on metal Powder

Pre-processing and printing		Effected by design
Clean the AM system		no
Purge the system of oxygen		no
Preheat the AM system		no
Print the parts	Spread layer of powder (recoating time)	no
	Print contour lines	yes
	Print interior hatch patterns	yes
Remove build platform from machine		no
Recycle powder		no
Post-processing		
Thermal stress relief		yes
Remove parts from build plate		no
Hot Isostatic Pressing		no
Remove support structures		yes
Heat treatment		yes
Shot-peening, surface machining, etc.		no
Inspection		no

Table 1 The main steps in metal AM, and the impact of part design

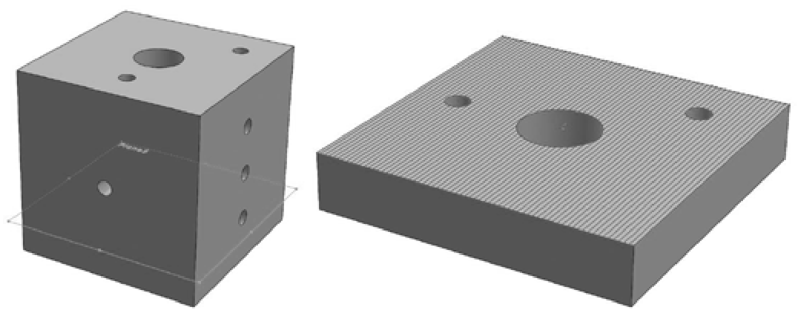

Fig. 1 A hydraulic manifold, left, with an example layer, right

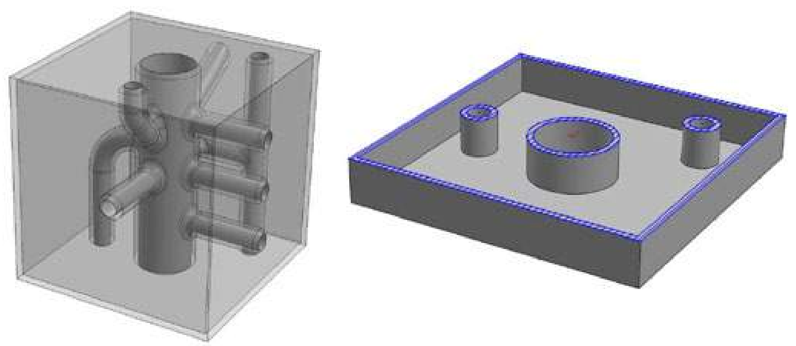

Fig. 2 If the bulk of the material is removed from the part by 'shelling' it to a specified wall thickness, the amount of scanning is greatly reduced, resulting in a faster print time

Bed Fusion (PBF), because the factors discussed here impact it the most. However, the same principles apply to most other metal AM processes.

Recoating times and part design

Some factors in the production of metal AM parts, such as layer recoating time, are not impacted by part design, other than the height of the part. Recoating involves the spreading of a layer of powder before a laser or electron beam can start to melt the layer. Typical recoating times are four to fifteen seconds per layer, depending on the machine. Suppose a part is 100 mm in height and the layer thickness is 50 microns. This part would consist of 2,000 layers, and total recoating time, if the recoating time was eight seconds per layer, would be 16,000 seconds (4.5 hours). Using an average hourly operation cost of $65 per hour, the total cost in recoating time is about $290.

Table 1 shows the main steps involved in metal AM, and the steps from which the total build times are effected by the design of the part. Several design factors can help reduce build time. The amount of powder that needs to be melted is the primary factor that impacts time and cost, and this can be effected through design practices. The operational principle of most metal AM systems is to melt the material in a serial fashion, where the laser or electron beam scans across each layer to fuse the powder. This is referred to as contour lines and hatching patterns, and the process is analogous to cross-hatching a black circle with a pencil; first the outer edge of the circle is drawn, then the pencil is moved back and forth many times to fill in the circle. The larger the surface area, the longer it takes to create each layer of the part.

Suppose a hydraulic manifold is designed for conventional CNC machining. It may consist of a metal block into which many connecting holes are drilled to form interconnecting channels. These channels allow hydraulic fluid to flow to the ports, with valves and pressure sensors attached. The only way to conventionally manufacture internal connecting channels inside the block is to drill holes through from the outside of the block, and then plug them so that only the internal channels remain. If one were to produce such a manifold using AM, a layer of the manifold would look similar to a filled square with a few holes in it, as shown in Fig. 1.

Here, the scanning hatch pattern for each layer requires a long scanning distance. If the manifold measures 100 x 100 mm, and the hatch spacing is set to 0.1 mm, each square will require approximately 100 meters of scanning. In other words, the beam has to travel over 100 meters to create that layer of the part. To relate this to part cost, if the beam is travelling at 330 mm per second, it will take 300 seconds (five minutes), to hatch a layer of the part. In machine time, it would cost $5.41 at $65 per hour.

Reducing material use

In contrast, if the bulk of the material is removed from the same part by 'shelling' it to a specified wall thickness, the amount of scanning is greatly reduced, resulting in a faster print time (Fig. 2). If shell thickness is set to 2 mm and the same hatch spacing parameters are used as before, the total scan distance is about 4.5 meters — a scan distance reduction of more than 95%. If the beam is travelling at 330 mm per second, it will take 13.6 seconds to hatch that layer of the part; $0.24 in machine running cost

When the shelled part is finished, the internal cavities will be filled with unmelted powder, which can remain if weight is not an issue. If weight is a concern, openings can be added to provide access for removing the

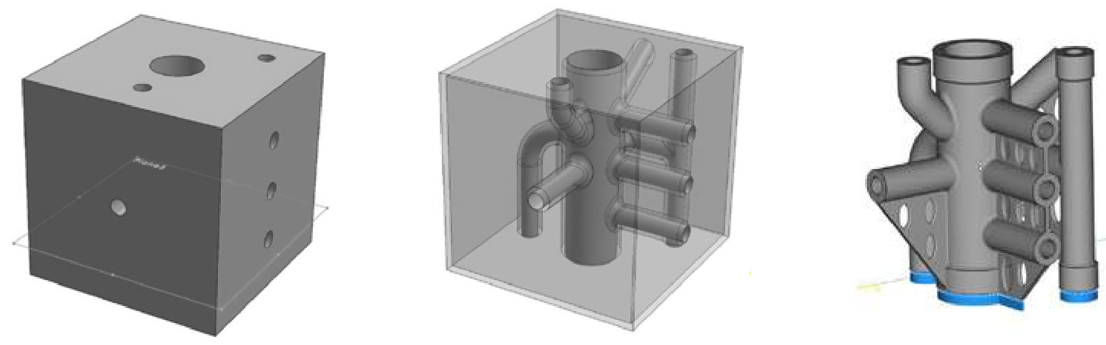

Fig. 3 Three versions of the block manifold: (left) conventionally machined and drilled, (centre) shelled and designed for AM, but with substantial support structures, and (right) fully optimised design

powder. If weight is not an issue, the interior of the part can be filled with support structures.

It is helpful to minimise large volumes of solid material when designing for AM. Similar to a consistent wall thickness in injection moulding, large masses of material usually offer little engineering advantage. They are likely to cause warping of the part and induce residual stress. In addition, they can greatly extend build times. Design techniques are available for eliminating large masses of material, including the shelling method described previously. Another is to fill solid regions with a honey-comb lattice, or porous build structure. Avoiding large masses of material can also reduce thermal stress relief (heat treatment) time. If a part has no large masses of material with a mostly regular wall thickness, it will contain less residual stress from the build process, thus reducing heat treatment time.

Build times and support structures

From a build time perspective, it is best to produce a part in an orientation in which build height is at its lowest. This will result in the fewest number of layers and the fastest build time. Build orientation also plays a role in the mechanical properties of a part, geometric accuracy, surface finish and support material, so these also need to be considered.

One of the important goals in designing for metal AM is to reduce the amount of support material required to build a part. With metal AM, support material is used to anchor the part to the build platform and help support and secure overhanging features. Most importantly, the support material transfers heat away from the part to minimise thermal distortion. In particular, it is important to avoid support material in any internal features, such as inside the manifold channels, as this can be difficult or impossible to remove.

Fig. 3 shows three versions of the block manifold. On the left is a conventionally machined and drilled design, in the centre the manifold is shelled and designed for AM, but with substantial support structures, and on the right is a fully optimised design. The third version can be built with little support material, which anchors it to the build plate. This small amount of support material is relatively easy to remove. Table 2 shows the differing time, cost and weight of the three designs.

The manifold example illustrates the impact that machine cost has on AM part production. It is the most significant factor in overall cost, and can be reduced significantly by avoiding large masses of material and the extended hatching times that come as a result. It quantifiably demonstrates that even a simple strategy of replacing large masses of material with even wall thickness shells can have a substantial impact.

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	Solid block manifold	Shelled block manifold	Fully optimised manifold
Build time	191 h 1 m 33 s	36 h 31 m 21 s	19 h 40 m 39 s
Machine cost at $65 per hour	$12,415	$2,379	$1,261
Material weight	7.411 kg	1.232 kg	0.558 kg
Material cost at $70 / kg plus 10% waste	$570.64	$94.86	$42.96
Service provider quote for part in 316L stainless	$15,294	$3,735	$1,986

Table 2 The time, cost and weight of the three designs and how much they differ

Case Study: Cooling channels for material testing applications using Laser Powder Bed Fusion

Additive Manufacturing continues to gain a reputation as a key technology that will have a major impact on all aspects of mechanical engineering. Under the guidance of Major Ryan O'Hara, the United States Air Force's (USAF) Air Force Institute of Technology (AFIT), based in Dayton, Ohio, has expanded its AM-focused education and R&D capabilities with the purchase of a Laser Powder Bed Fusion system from Germany's Concept Laser. In the following article, AFIT's Benjamin Doane and colleagues highlight work done at the institute to develop AM test bed components to support a high temperature testing programme.

The Air Force Institute of Technology, the United States Air Force's graduate school, recently purchased and installed its first metal Additive Manufacturing system. The addition of this Laser Powder Bed Fusion (LBPF) machine complements AFIT's long history of using polymer-based Additive Manufacturing to enable defence-focused graduate research. As part of AFIT's graduate education mission, it is imperative that students are able to work with cutting edge manufacturing technologies. By utilising the enhanced design benefits of AM, these graduate research students become familiar with the nuances of metal and polymer AM processes. As the private sector rapidly embraces AM, it is vital that government organisations focus on the newest developments in AM processes in order to successfully implement them in current defence applications.

AFIT researchers believe that a hands-on approach to gaining this understanding is required to fully realise the implications of AM technologies. AFIT is focused on process parameter optimisation, material property quantification and qualification, mechanical testing and functional implementation of metal AM. In this article, AFIT researchers present how metal AM components can improve upon currently implemented technology used in mechanical testing.

Fig. 1 Graduates at an AFIT Commencement Ceremony at the National Museum of United States Air Force. AFIT provides defence-focused research-based graduate education (Photo U.S. Air Force / Michelle Gigante)

Motivation for the implementation of AM

In recent years, Additive Manufacturing has been adopted by many industries to enhance their ability to bring innovation to their product offerings. The aerospace and automo-

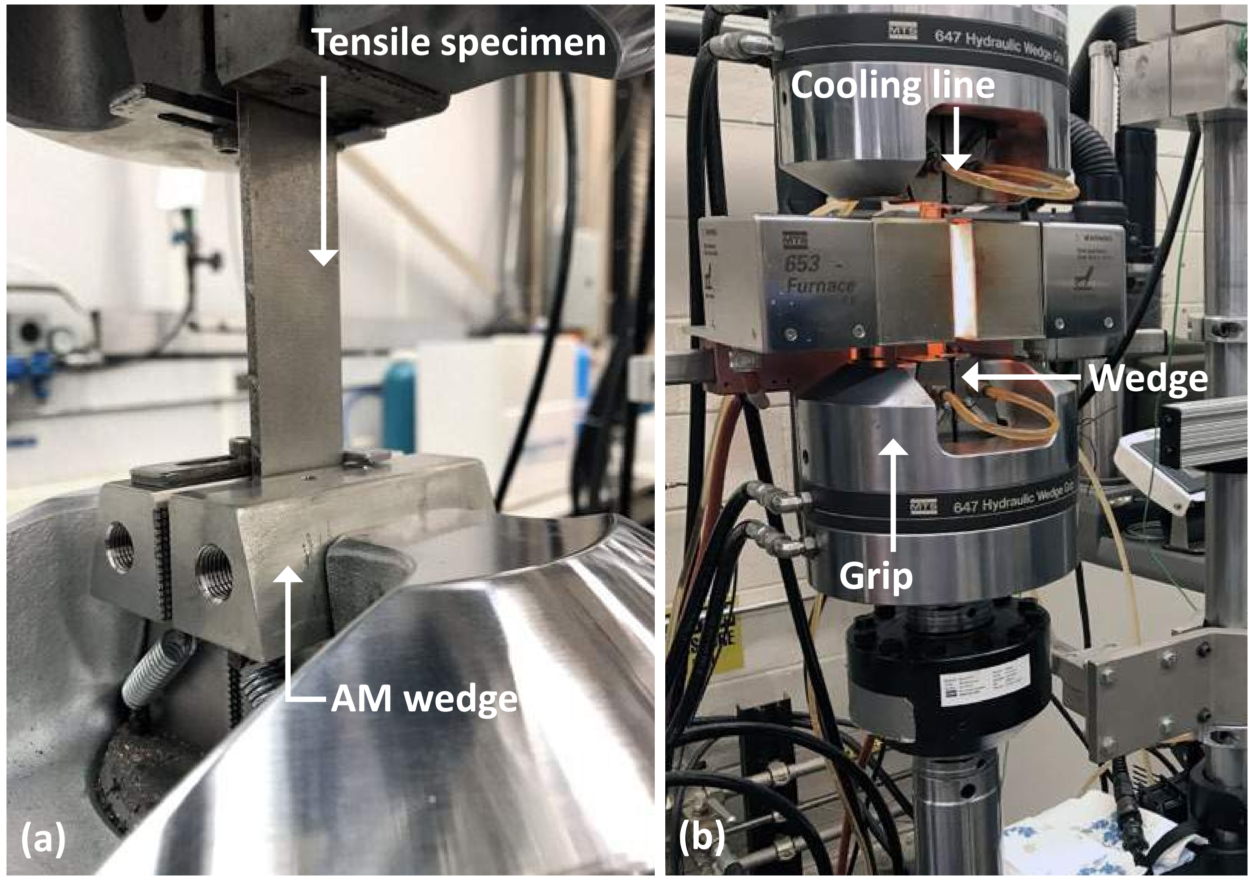

Fig. 2 The creep set-up before (a) and after (b) the furnace and cooling system are installed

tive industries now incorporate AM processes to enable capabilities in their products which were previously unfeasible. It has been shown that AM is an excellent technology for adding internal structures in parts to increase heat transfer [1]. While AM allows for parts with novel capabilities that cannot be replicated with traditional production methods, the consistency of the parts built cannot be guaranteed. It has been shown that AM materials' properties may vary not only from machine to machine, but also from build to build [2]. It is crucial that these variations be identified and quantified. The tests used to quantify this variance include measuring a material's mechanical performance in a variety of standard testing conditions. Material Test Systems (MTS) machines are used to perform these mechanical tests.

> *"AM has enabled an active cooling system that reduces the wedge's thermal stresses and prevents wedge fracture during creep testing. These wedges were successfully manufactured at AFIT using IN718"*

High-temperature mechanical creep testing

The Air Force Institute of Technology is particularly interested in the high temperature creep performance of Inconel 718 (IN718). Due to the high temperatures (700°C) associated with this testing, the standard steel wedges that are employed to grip tensile specimens have fractured. To enable high temperature mechanical creep testing, AFIT researchers designed wedges for production by Additive Manufacturing with internal cooling channels to maximise their performance compared to their traditional subtractive counterparts.

AM has enabled an active cooling system that reduces the wedge's thermal stresses and prevents wedge fracture during creep testing. These wedges were successfully manufactured at AFIT using IN718. Commercial off-the-shelf Computational Fluid Dynamics (CFD) software and

Fig. 3 Initial AM design (left) with 3.0 mm diameter triple loop interior channel; final AM design (right) with 5.0 mm diameter single loop interior channel

thermal imaging methods were used to analyse, compare and validate the performance of the AM optimised wedge versus a conventional wedge. The findings demonstrate that the AM wedge design is three times more efficient at heat transfer compared to the conventional wedge design.

Tension and high temperature creep material tests have traditionally been completed with stainless steel grips in an MTS machine. During creep tests, the MTS machine uses two pairs of wedges to grip a tensile specimen (Fig. 2a). Simultaneously, a furnace heats the tensile specimen and a chiller flows coolant through the wedges to prevent fracture (Fig. 2b). Nevertheless, the coolant has failed to prevent wedge fracture during these tests. This study explores the effects of adding cooling channels to these mechanical wedges using Additive Manufacturing.

CFD analysis and thermal imaging have been used to compare the conventional wedge design with the AM optimised design. Theoretically, the cooling channels in the AM design will increase heat transfer and prevent wedge fracture during creep testing.

Design for AM

This project consisted of two design cycles. The initial design contained a triple loop interior cooling channel with a 3.0 mm diameter. However, the narrow channel in this design made it difficult to remove the powder from the interior and this powder subsequently prevented fluid flow (Fig. 3).

In the second and final iteration, a single loop replaced the triple loop and the diameter of the channel was increased to 5.0 mm. The build orientation was optimised to minimise the use of supports. This design allowed the powder to be removed from the interior channel and provided adequate fluid flow for experimental testing (Fig. 4).

Computational fluid dynamics to determine heat removal

CFD analysis provides qualitative and quantitative prediction of fluid flows and thermal performance by means of mathematical modelling

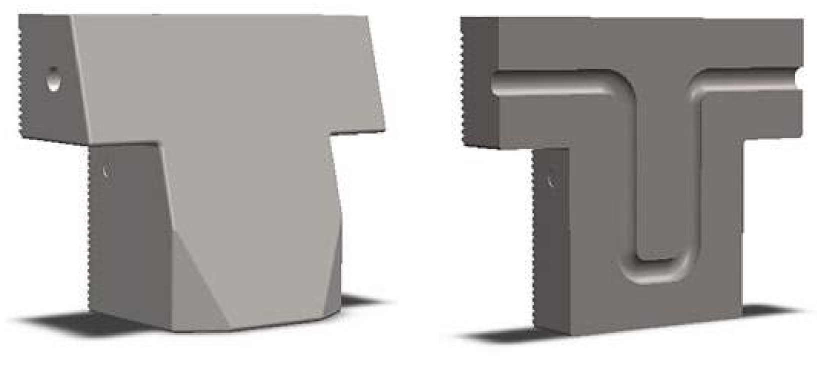

Fig. 4 (a) shows the CAD image of the AM design and (b) shows the sectioned view with the internal cooling passage visible

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AM for a material testing application

Parameters	Conventional model	Additive model
Temperature equation	Advective Diffusive	Advective Diffusive
Turbulence equation	Turbulent	Turbulent
Analysis type	Steady State	Steady State
Convergence tolerance	0.0001	0.0001
Fluid material	Water	Water
Solid material	Steel alloy	Inconel 718
Roughness height	0 m	0 m
Roughness constant	0.5	0.5
Inlet diameter	9.0 mm	5.0 mm
Inflow temperature	16.0°C	16.0°C
Inflow velocity	3.375 mm/s	10.935 mm/s
Outer surface temperature	52.0°C	52.0°C

Table 1 ANSYS™ CFD input parameters

and numerical methods, based on fundamental momentum, energy and continuity equations. The ANSYS™ CFD package was utilised for the computational section of this research. The AM and conventional design files were meshed and imported into ANSYS™ Fluent. Flow conditions were characterised for internal pipe flow using the Reynolds number equation [3]. The Reynolds number identified whether the flow type was laminar or turbulent, which in turn determined the flow equation required for the CFD model. For the purpose of this research, fluid flow was found to be turbulent from the inlet [4] for both models. Table 1 shows the input parameters used in the CFD model. A no-slip condition is applied, which forces the fluid to have zero velocity relative to the solid boundary of the cooling passages. Utilising the results from the CFD analysis (Fig. 5), the total enthalpy at the inlet and outlet of each model was accounted for, where enthalpy is defined as the measurement of energy in a thermodynamic system. This is equal to the internal energy of the system plus the product of pressure and volume [5]. The change in total enthalpy indicates the amount of heat being removed from the system. With this information a quantitative comparison between the conventional and additive designs is possible.

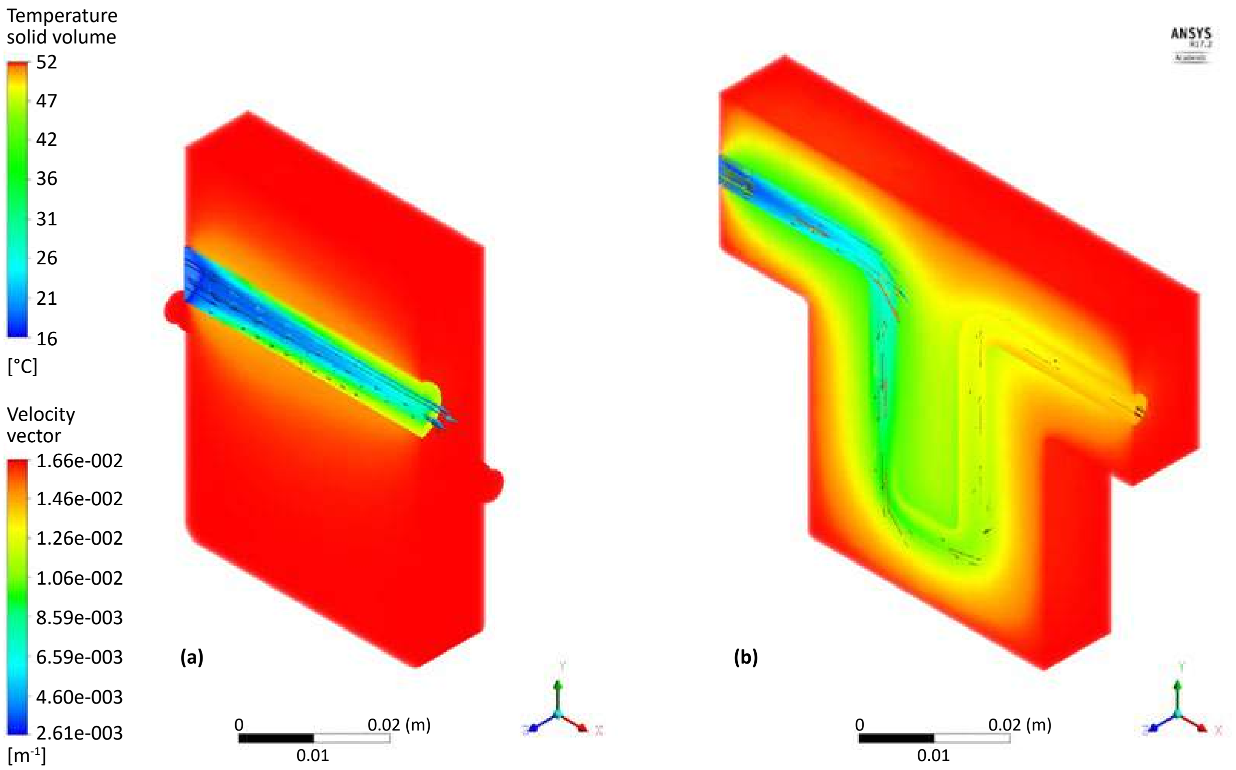

Fig. 5 Side-by-side comparison of the sectioned CFD models of the conventional wedge (a) and the AM optimised wedge (b). The coolant's velocity profile is presented in both models as arrows

Wedge fabrication using Laser Powder Bed Fusion

The AM wedge was printed at AFIT's Additive Manufacturing Laboratory using an M2 Cusing metal Additive Manufacturing system from Concept Laser GmbH (Fig. 6). The LPBF process used in the M2 employs a combination of parameters to control the spot size, power and speed of the laser, which ultimately affect the surface finish and density of the printed parts. These laser settings vary depending on the metal powder being used. The laser scan strategy used for this project was the standard island and skin core parameters developed by Concept Laser GmbH for use with IN718. Fig. 7a shows the island scan pattern strategy on the finished part. This strategy randomly exposes sections of powder in a checkered pattern. Furthermore, the skin core strategy decreases print time by exposing the outer contours (the skin) on every layer and then the surface area (the core) of the part every alternate layer [6]. For this build, the print layer height was set at 0.025 mm with a powder dosage of 0.0375 mm per layer. Materialise Magics was used as the slicing software. Build orientation during the print using Magics software is visible in Fig. 7b.

A filleted 4 mm offset, as seen in Fig. 7a, was added to the base of the part to allow for extra space for post-processing purposes, as well as to provide additional material to assist with heat transfer and build plate adhesion. A one-inch thick steel plate was used as the build platform. All post-processing was completed at AFIT's Model Fabrication Shop. Post-processing included using a wire-cut electrical discharge machine to remove the parts from the build platform, grinding critical surfaces, tapping and threading holes for attachments.

Fig. 6 AFIT's M2 Cusing metal Additive Manufacturing system

Experimental testing

The AM wedges were successfully utilised during a creep test at AFIT. The wedges were installed in a 22 KIP 810 MTS® machine on the lower grips (Fig. 2). An attached MTS 653 furnace was used as the heat source, deionised water was selected as the coolant and the grip pressure was set at 6.8 MPa (1000 psi). A constant force of 1000 N was applied to the tensile specimen and steady state was reached with a furnace

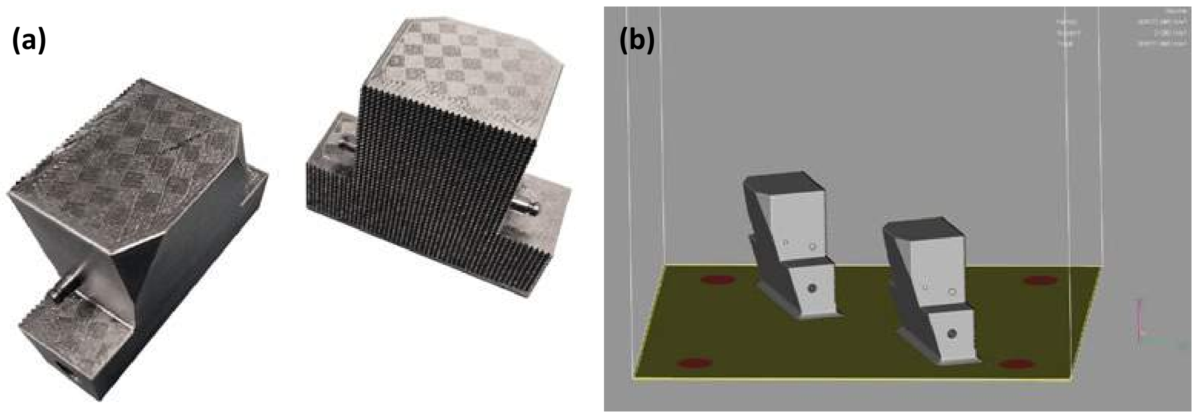

Fig. 7 (a) shows the finished printed parts with the island scan strategy shown as a checkered pattern. Part orientation in Magics build scene on the M2 platform is shown in (b). The red circles on the platform indicate build plate screw hole locations

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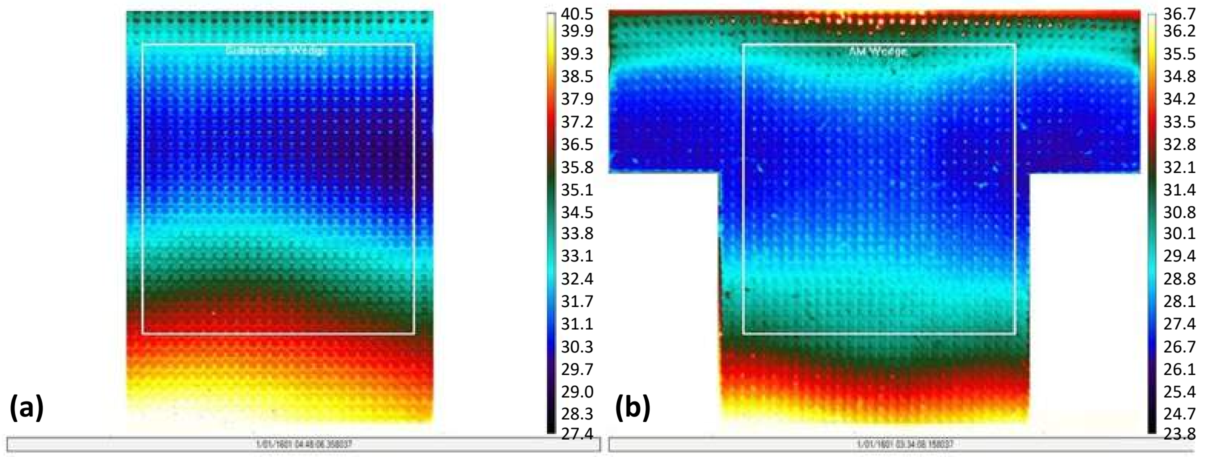

Fig. 8 Side-by-side comparison of the wedge thermal images acquired with the FLIR SC7650. (a) shows the conventional design, while (b) shows the AM design. The white outline on both wedges displays the region of interest. Thermal imaging data indicates that the AM wedge has lower average temperatures compared with the conventional wedge

temperature of 700°C, coolant flow velocity of 13.5 mL/sec and a coolant temperature of 22°C. A FLIR® SC7650 infrared camera was utilised to map the thermal profile of the AM and conventional wedge sets.

Regions of Interest (ROI) on the visible surface of the wedge sets were created using the FLIR® ExaminIR Pro software. The ROI was replicated on both wedge designs and the thermal images were acquired separately. However, it was observed that both the AM and conventional wedge had high percentages of IR reflection, due to the emissivity of the metal surface. Additionally, due to the setup of the MTS machine and attached furnace, it was difficult to observe the grip surface that was expected to receive the highest amount of heat transfer. Nevertheless, the initial experimental setup confirmed the viability of the AM design for use in high temperature creep tests on MTS machines.

In order to accurately map the thermal profile of the wedges with an IR camera, the wedges were coated with Aeroglaze Z306. Aeroglaze Z306 has an emissivity value of 0.91, which means that it will emit most of the heat it absorbs. Coating the wedges mitigated the temperature reading errors caused by the IN718's high IR reflectivity. Next, in order to view the grip surface most likely to experience the greatest amount of cooling, the wedges were removed from the MTS machine and a halogen lamp was used as an external heat source to simulate the furnace. Single AM and conventional wedges coated in Aeroglaze Z306 were heated separately with a halogen lamp, while coolant was passed through the interior channels from left to right at a constant velocity of 13.5 mL/sec and temperature of 16°C. Once steady state was reached, thermal images were acquired with a FLIR® SC7650 for both designs (Fig. 8).

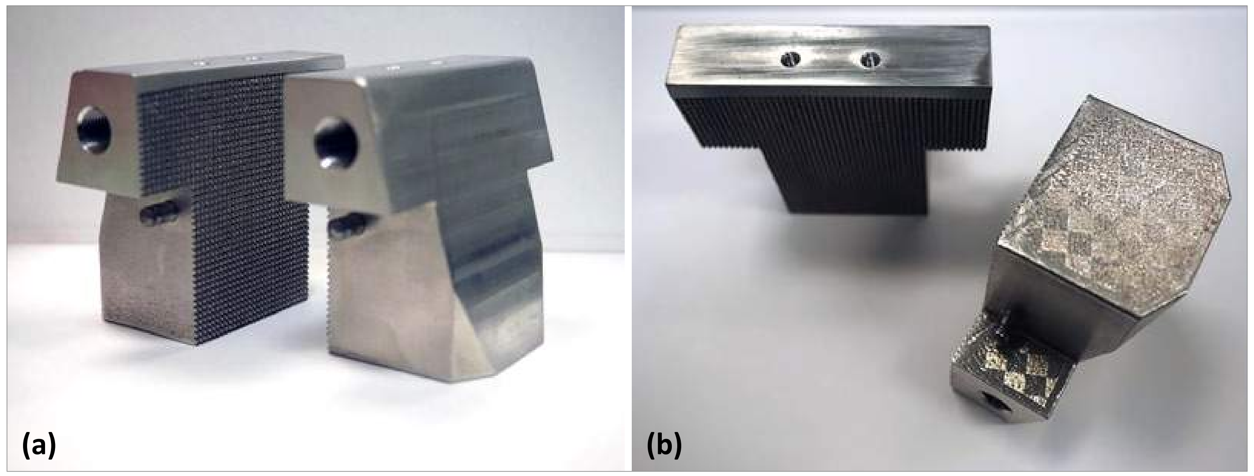

Fig. 9 (a) shows the AM wedges paired together, while in (b) the checkered pattern caused by the island scan strategy is visible on the far right wedge

Results and conclusions

CFD analysis revealed a higher enthalpy change in the AM design. Conduction and forced convections are the dominating heat transfer phenomena as any radiation effect is considered minimal. The forced convection between the fluid flow throughout the body of the wedge is represented using a heat transfer convection equation. As the water flows from the inlet to the outlet in a regenerative cycle, heat energy is transferred from the solid to liquid and taken out of the wedge by the presence of bulk fluid motion [7]. ANSYS™ analysis showed that the AM wedge design was more effective at transferring heat compared with the conventional wedge design and caused a change in enthalpy that was 2.87 times greater than the conventional design. The AM model had a total enthalpy change of 2.017 kJ/kg, while the conventional model had a total enthalpy change of 703 kJ/kg (Table 2).

The thermal images taken with the IR camera indicated that the cooling channel in the AM design removed more heat compared with the conventional design, resulting in a lower average temperature. The temperature of the conventional ROI had an overall average temperature of 31.7°C, while the AM ROI had an average temperature of 27.7°C.

Future work in this area could explore more complex interior channels, such as helical coils with protrusions in the channel that would cause a more turbulent environment and, in turn, increase fluid contact time and heat transfer. These designs could be scaled and applied to similar applications that require fluid cooling channels.

	Conventional model	Additive model
Total enthalpy in [kJ/kg]	2,025	1,217
Total enthalpy out [kJ/kg]	2,728	3,234
Total enthalpy change [kJ/kg]	703	2,017

Table 2 Change in enthalpy comparison

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Evaluation of Sigma Labs' in-situ process control system during Additive Manufacturing

As Additive Manufacturing shifts from process development and characterisation activities into the series production of components for critical applications, in-process quality control, qualification and certification are areas of fundamental importance to widespread adoption of AM [1,2]. In the following report, engineers from Sigma Labs, Inc., present the results of a study to establish a correlation between in-process data collected using the company's PrintRite3D SENSORPAK® system and PrintRite3D INSPECT® software and the results of the metallographic testing of as-built specimens.

Engineers at Sigma Labs Inc., Santa Fe, New Mexico, USA, recently performed an experiment to evaluate Quality Signatures™ using in-situ process control. This experiment was designed to establish a correlation between in-process dependent data mined from in-situ sensor raw trace signals, independent process input variables - for example laser power - and post-process dependent data measured during destructive metallographic testing for the porosity of as-built specimens.

The metal powder used for these experiments was aluminium alloy AlSi10Mg. It had a particle size distribution (PSD) of 15-50 µm and was supplied by Valimet. All builds were performed using a standard EOS M290 Additive Manufacturing system integrated with Sigma's PrintRite3D SENSORPAK® system and PrintRite3D INSPECT® software.

Four in-situ sensors were used during these experiments. The sensor types comprised non-contact, non-imaging optical sensors as well as non-contact thermal sensors. One sensor was a photodetector placed in a fixed, or Eulerian, frame of reference and positioned above the build plate. Its field of view (FOV) was of the entire build plate. A second photodetector was placed in a moving, or Lagrangian, frame of reference within the optics train. Its FOV was restricted to a narrow region immediately surrounding the melt pool. The third sensor was a high-speed, single wave length pyrometer, placed in a fixed frame of reference above the build plate and focused onto a 10 mm, right circular cylinder serving as a Process Control Specimen (PCS). Its FOV was 1 mm. The fourth sensor collects X and Y command signals from the scan head controller and is used to visualise in-process dependent

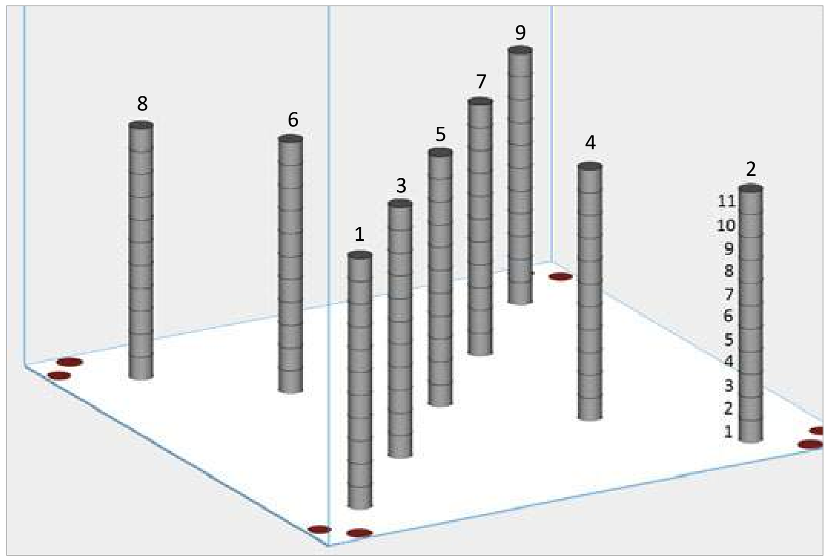

Fig. 1 CAD Image of the build configuration. The PCS cylinder is marked as specimen 2. Individual parametric build segments are numbered 1 to 11 starting directly against the build plate

Build Segment No.	Power Variation (%)	Laser Power (W)	Scan Speed (mm/s)	Hatch Spacing (mm)	Global Energy Density (J/mm²)
1	0	370	1300	0.19	1.49
2	-5	351.5	1300	0.19	1.42
3	-10	333	1300	0.19	1.35
4	-15	314.5	1300	0.19	1.27
5	-20	296	1300	0.19	1.19
6	-25	277.5	1300	0.19	1.12
7	-30	259	1300	0.19	1.05
8	-35	240.5	1300	0.19	0.97
9	-40	222	1300	0.19	0.89
10	-45	203.5	1300	0.19	0.82
11	-50	185	1300	0.19	0.75

Table 1 Independent process input variables

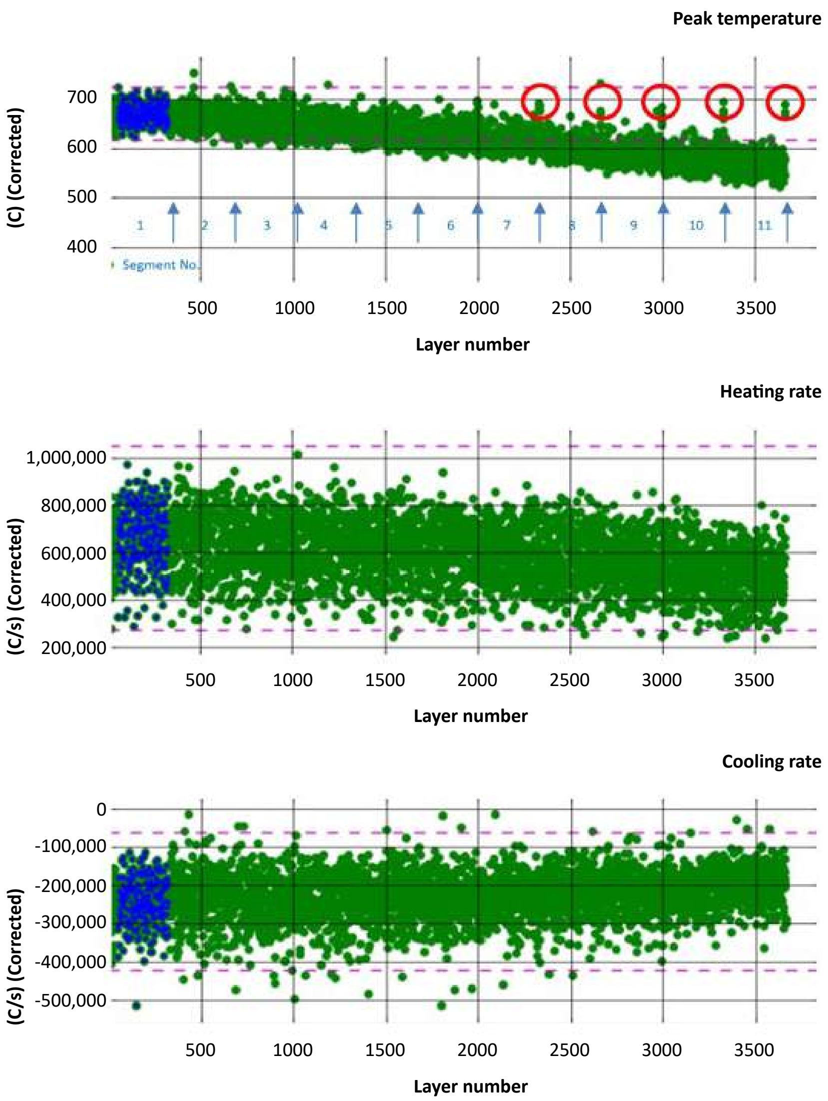

Fig. 2 Melt pool level trend plots for dependent in-process data mined from the pyrometer. The pyrometer was focused on the process control specimen

data or In-Process Quality Metric™ (IPQM®) data in a 3D point cloud. All sensor data was collected using PrintRite3D SENSORPAK's high-speed data acquisition, running at 50kHz per channel, and subsequently analysed using the company's PrintRite3D INSPECT.

Experimental approach

For this experiment, right circular cylinders 10 mm in diameter and 10 mm tall were built using the configuration shown in Fig. 1. A total of nine cylinders were built with one directly beneath the fixed pyrometer. The configuration was intentionally designed to space the specimens across the build plate and allow for the determination of spatial and temporal variation that may exist due to machine or sensor variability.

The starting or control parameters were suitable for lasing Al metal powder. Table 1 lists the control parameters and the ten different sets of processing parameters as well as the calculated Global Energy Density (GED) values. Layer thickness was held constant at 30 µm and each build segment contained 333 layers. The chamber atmosphere was argon and the build plate pre-heat temperature was 170°C.

Results

Data analysis: process control specimen

Univariate trend plots: melt pool level
The trend plots in Figs. 2-3 were generated using Sigma's standard PrintRite3D INSPECT software and algorithms using dependent in-process data mined from the high-speed pyrometer raw trace signal. The control data set (blue markers) used for this analysis was taken from build segment 1, layers 50 to 325. As stated, there were eleven vertical build segments, each containing 333 layers, and identified in Fig. 2 by blue arrows. Each trend plot was reported on a layer by layer basis and included a calculated +/- 3σ upper and lower control limit (UCL, LCL) represented as dashed lines.

Fig. 2 comprises three trend plots of dependent in-process data that individually allowed the melt pool to be tracked according to its peak temperature, heating rate and cooling rate for a given layer. The melt pool dependent in-process data were mined at a fast time scale, e.g., microseconds (µs). By doing so, it was possible to infer changes in the melt pool geometry/volume associated with changes to independent process input variables, namely changes in laser power level. Each data point represents a single laser scan for a given layer. By doing so it is possible to track subtle changes to the melt pool which ultimately would be induced by other process disturbances such as presence of large powder particles or melt pool spatter, not necessarily changes to independent process input variables. Therefore, Sigma's proprietary algorithms would allow for process disturbances to be distinguished from natural process variation.

In all three trend plots the dependent in-process data appeared to be normally distributed. Of interest is the drop in Peak Temperature as the build increased in the Z direction. This corresponded with a decrease in power levels as expected since the melt pool would be expected to reduce in size and maximum temperature with reductions in laser power. Of further note were the apparent natural data breaks (red circles) present because of standard upskin/downskin parametric changes visible around layers 3,300 and 3,700. These upskin/downskin parameter changes were pre-programmed into the EOS M290 and occurred between build segments since each segment was programmed as a separate part. Lastly, it is interesting to note that there was a shift in heating rate and cooling, which was also expected as power levels decreased.

A final comment should be made about the melt pool trend plots in

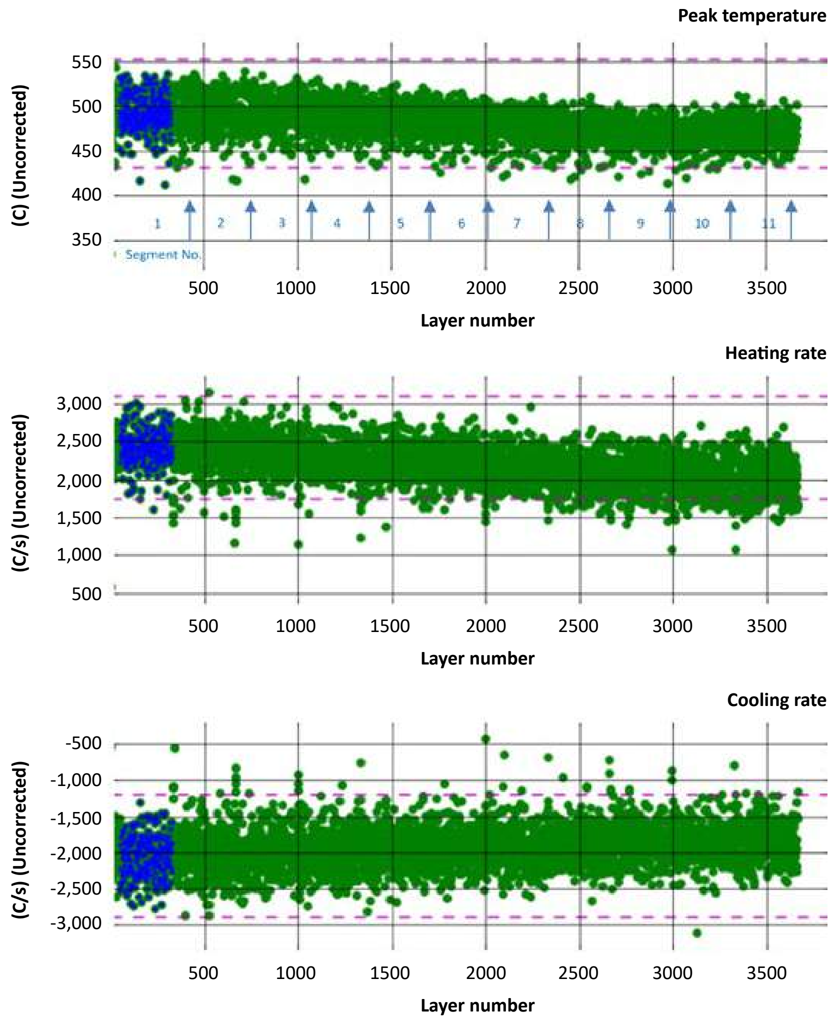

Fig. 3 Layer level trend plots for dependent in-process data from the pyrometer. The pyrometer was focused on the process control specimen

> *"it is possible to track subtle changes to the melt pool which ultimately would be induced by other process disturbances such as presence of large powder particles or melt pool spatter"*

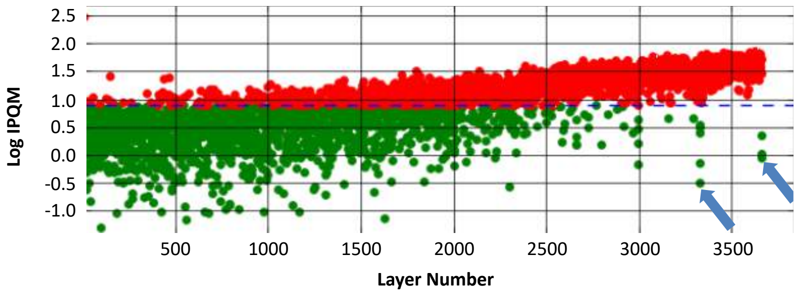

Fig. 4 Multivariate trend plot of melt pool level IPQM pyrometer data collected from the process control specimen

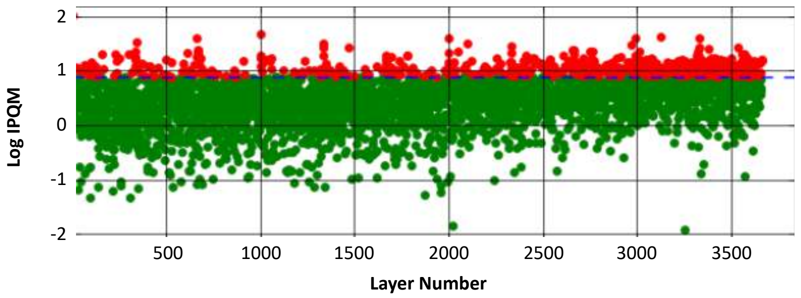

Fig. 5 Multivariate trend plot of layer level IPQM pyrometer data collected from the process control specimen.

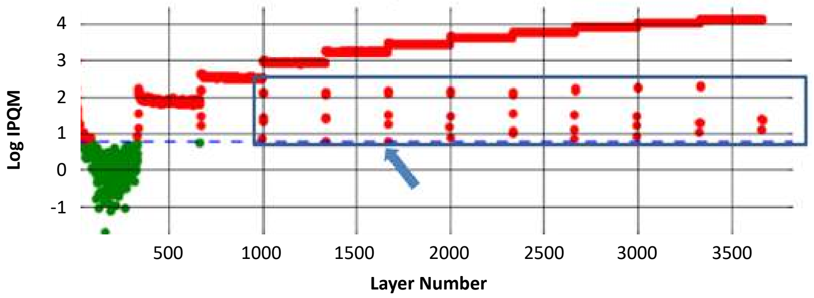

Fig. 6 Multivariate trend plot of IPQM parts graph from photodetector data collected from the entire build layer by layer

Fig. 2. The Y-axes were labeled 'corrected' because the proprietary algorithms used by Sigma incorporated emissivity correction factors for the given material.

Univariate trend plots: layer level
It was also possible to mine the in-process pyrometer raw trace at a slower time scale for additional dependent in-process data and infer information about the bulk material's response to the energy input such as defects associated with lack of fusion (LOF) or spherical porosity associated with keyholing.

In Fig. 3 similar trend plots were generated but this time displayed using thermal history information rolled up for the entire layer from melt pool level information. It is important to note that the layer level trend plots exhibit similar trends to those generated at a melt pool level. For example, there was a decrease in peak temperature, heating rate and cooling rate as the power levels were intentionally decreased.

Multivariate trend plot: melt pool level
It is convenient to represent multiple univariate trend plots in one trend plot while maintaining data continuity without the loss of process sensitivity or data integrity. Therefore, Sigma uses a proprietary multivariate analytics software engine to represent such trend plots. In Fig. 4, a Multi-Variate Statistical Process Control (MVSPC) trend plot combined the results for all univariate trend plots for melt pool information from Fig. 2, i.e., peak temperature, heating rate and cooling rate. This combined dependent in-process data was termed In-Process Quality Metric or IPQM. The Y-axis for the MVSPC trend plot in Fig. 4 is on a log scale because when a data point is flagged as an outlier it may in fact be a significant outlier and far from the normal distribution, hence it is convenient to display such data on a semi-log trend plot. For MVSPC trend plots there is only one control limit (blue dashed line) because the multivariate classifier control data set is defined by a single sided distribution, and it was established using a 95% confidence limit. This means that 95% of the data population lies within the boundary and 5% lies outside the boundary. The control limit is user definable and can be set between 90 and 99%.

For the melt pool MVSPC trend plot in Fig. 4 there was an increasing trend in the IPQM values, which correlated with the parametric changes by segment observed in the univariate trend plots in Fig. 2. The MVSPC trend plot in Fig. 4 is a convenient way for a process engineer to quickly determine if the process is under control. If this were an actual build without intentional changes in laser power the operator would be alerted that the process had trended out of control. Lastly, as a confirmation of data continuity, Fig. 4 upskin/downskin parametric changes were still visible around layers 3,300 and 3,700 (blue arrows).

Multivariate trend plot: layer level
Fig. 5 is also a MVSPC trend plot which combined the results for all univariate trend plots for layer level

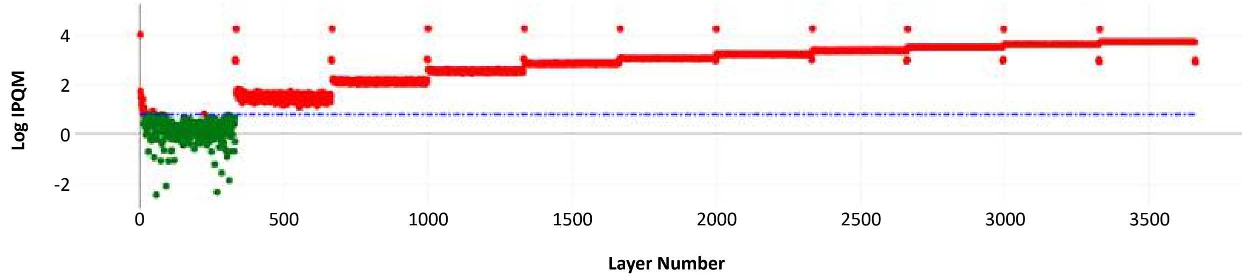

Fig. 7 Multivariate trend plot of the PCS specimen, part 2 generated using in-process photodetector data collected from a build and rolled up

information from Fig. 3, i.e., peak temperature, heating rate and cooling rate. For the layer level MVSPC trend plot in Fig. 5 it was observed that there was a slight increase in the IPQM values starting around layer 2,300 which correlated with the parametric changes by segment observed in the univariate trend plots in Fig. 3.

Data analysis: all specimens

Multivariate trend plots: part level
Fig. 6 contains a trend plot of in-process dependent data collected from both on-axis and off-axis photodetectors for an entire layer; it clearly captured the independent process input parameter changes by layer. All scans, for all parts for a layer are rolled up and plotted as a single data point for that layer. Then each test layer is compared to the control data set (displayed as the control limit/blue dashed line) and the resultant IPQM value is displayed on a log scale for ease of viewing. The results indicate that as the independent input variable (power level) was changed, there was a corresponding change in the in-process dependent variable (IPQM value).

The intermittent points between each build section were the upskin and downskin scans (blue box) that were pre-programmed into the M290 between the completion of one build segment and the start of the next.

Fig. 7 contains a trend plot of the in-process data collected by the photodetectors for part 2, which is the process control specimen. Once again there were clear changes in the dependent in-process IPQM values in response to the intentional process parameter changes to laser power.

Note the individual data points in between each build segment. These represent upskin and downskin parametric changes as compared to control parameter settings. Fig. 8 is a 3D point cloud visualisation of Sigma's proprietary, quantitative In-Process Quality Metric known as Thermal Energy Density™ (TED™). TED comprises proprietary dependent in-process feature data mined from and calculated using

> *"The results indicate that as the independent input variable (power level) was chanced, there was a corresponding change in the in-process dependent variable (IPQM value)"*

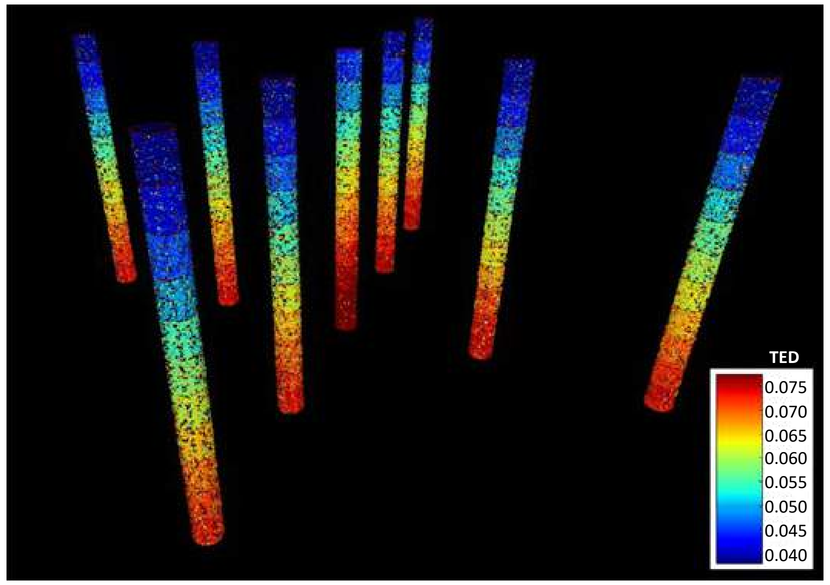

Fig. 8 3D point cloud visualisation of TED

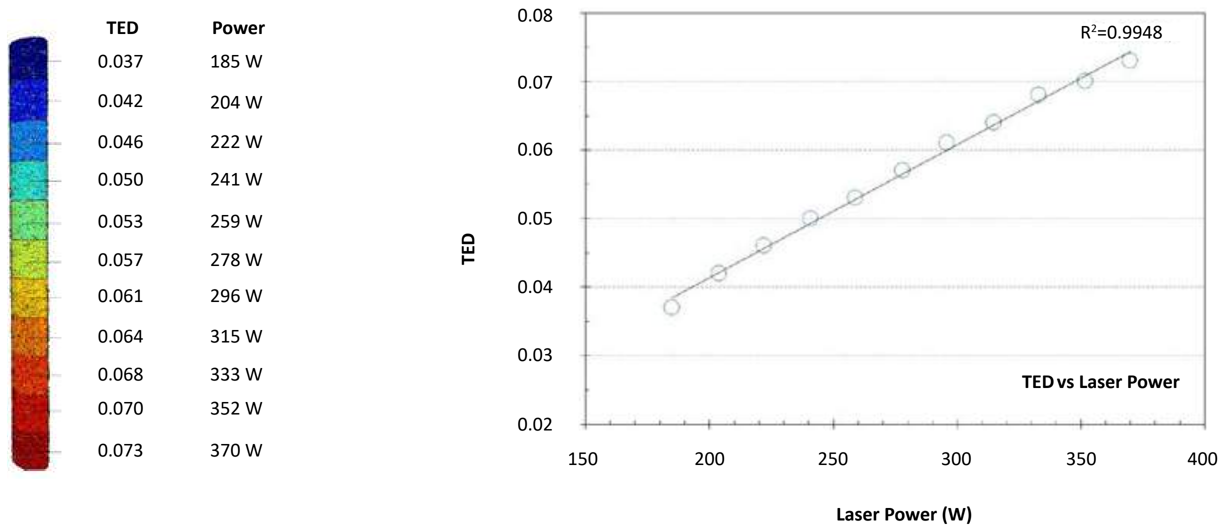

Fig. 9 Trend Plot of TED as a function of laser power, and 3D point cloud of the process control specimen, no. 2, annotated with the TED IPQM and corresponding changes to the independent process input variable, in this case laser power

photodetector raw trace signals from the melt pool. TED from the melt pool is summed over a single scan length, over the area of a layer or over the area of a part, resulting in an areal energy 'density'. So, TED as it is calculated and displayed here corresponds to the part's areal response to the input GED (laser power, travel speed, hatch spacing and overlap). Each vertical build segment has a different TED value assigned to it and correlates with intentional changes to independent process input variables for example changes in laser power level. TED can be expressed in units of power, time and distance.

As a separate verification that Sigma's TED metrics correlated with changes in laser power, Fig. 9 is a trend plot of TED as a function of laser power with visualisation of the process control specimen. It indicated that changes in Sigma's TED metrics correlated with variations in laser power. An R^2 value of 0.9948 for the trendline indicated that the TED data is represented very well by a linear model.

Metallography and analysis

Metallographic services were provided by Metals Engineering and Testing Laboratories, Phoenix, Arizona, USA. Three specimens (parts 2, 5 and 8) were sectioned into two pieces, mounted and polished in accordance with ASTM E3. Once prepared, the specimens were examined in the as-polished condition from 20 to 500X magnification. Photomicrographs were taken at 50X magnification in the centre of each build segment for parts 2, 5 and 8. Image analysis was performed to quantify the (defect density) average areal percent porosity on a build segment basis. Table 2 contains metallographic results for porosity measurements.

Figs. 10, 11 and 12 are photomicrographs taken of cross sections made in the axial or Z direction of parts 2, 5 and 8, segments 1, 7 and 11, respectively.

Build Segment No.	Part No. 2 Porosity (%)	Part No. 5 Porosity (%)	Part No. 8 Porosity (%)
1	0.09	0.02	0.07
2	0.12	0.02	0.1
3	0.04	0.04	0.14
4	0.06	0.03	0.14
5	0.08	0.04	0.11
6	0.11	0.04	0.23
7	0.12	0.14	0.45
8	0.25	0.08	0.89
9	1.22	0.32	1.66
10	2.3	0.45	2.67
11	5.3	1.58	4.77

Table 2 Porosity measurements by part and build segment

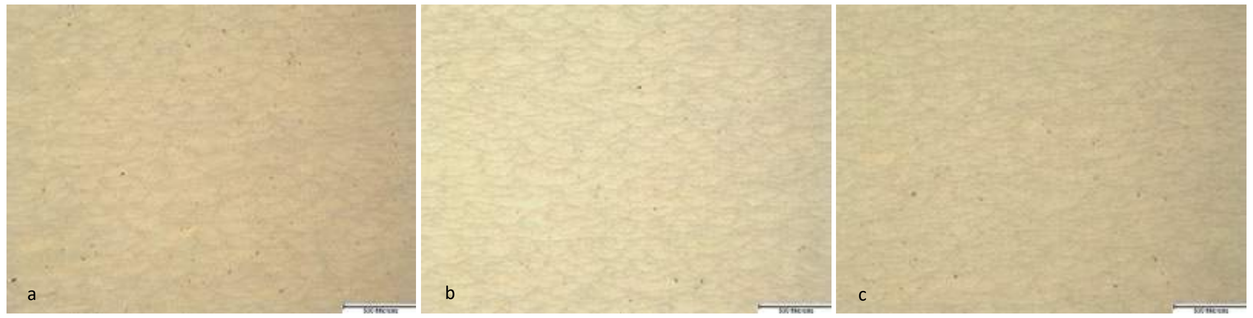

Fig. 10 Photomicrographs of segment 1 (a) part 2, 0.09% porosity, (b) part 5, 0.02% porosity, and (c) part 8, 0.07% porosity

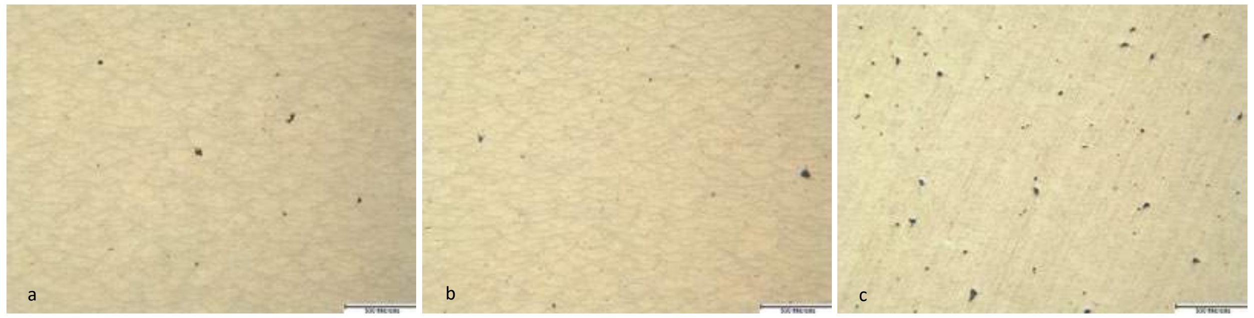

Fig. 11 Photomicrographs of segment 7 (a) part 2, 0.12% porosity, (b) part 5, 0.14% porosity, and (c) Part 8, 0.45% porosity

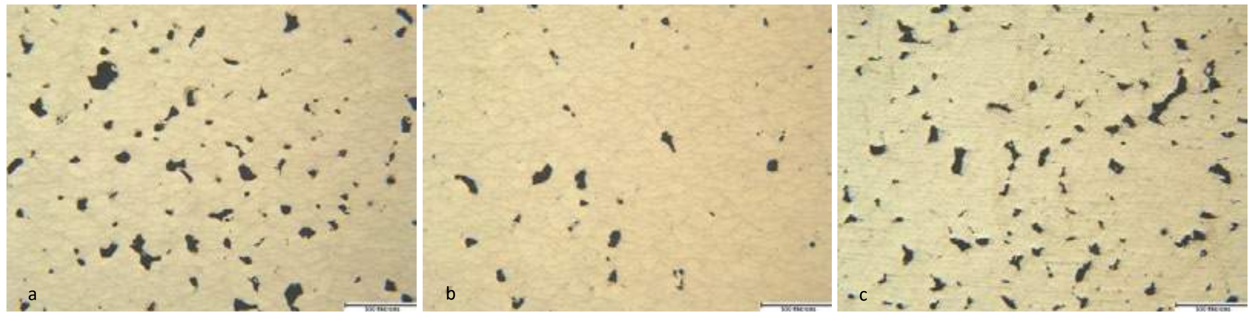

Fig. 12 Photomicrographs of Segment 11 (a) Part 2, 5.3% Porosity, (b) Part 5, 1.58% Porosity, and (c) Part 8, 4.77% Porosity.

Each specimen was etched using Kellers Reagent to reveal individual melt (weld) pool beads.

Fig. 13 is a plot of percent porosity measured versus TED for all 33 segments evaluated. An asymptotic relationship of percent porosity measured as a function of TED is present. Fig. 14 is a plot of laser power and TED as a function of percent porosity measured. An asymptotic relationship of percent porosity measured as a function of TED and power is present. Fig. 15 is a plot of TED and GED versus percent porosity. An asymptotic relationship is also present.

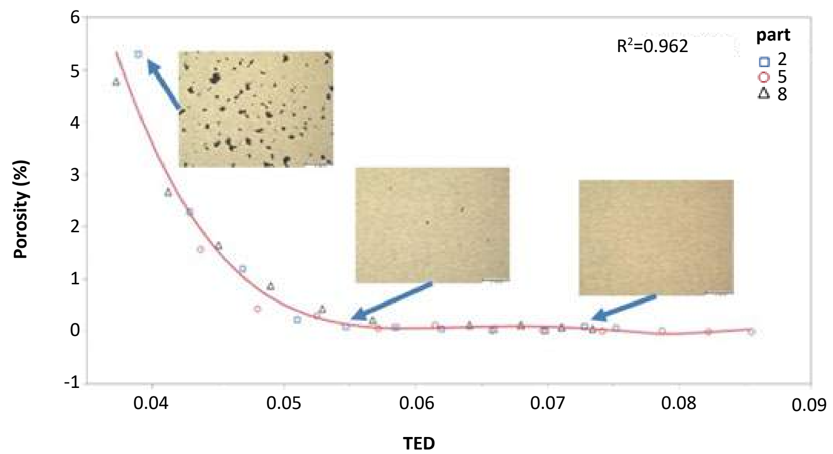

Fig. 13 Graph of porosity as a function of TED for all build segments tested for parts 2, 5 and 8

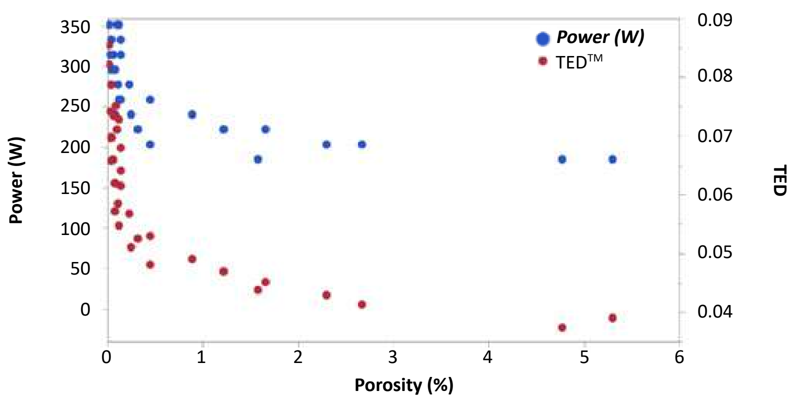

Fig. 14 Graph of porosity as a function of laser power (W) and the TED in-process quality metric

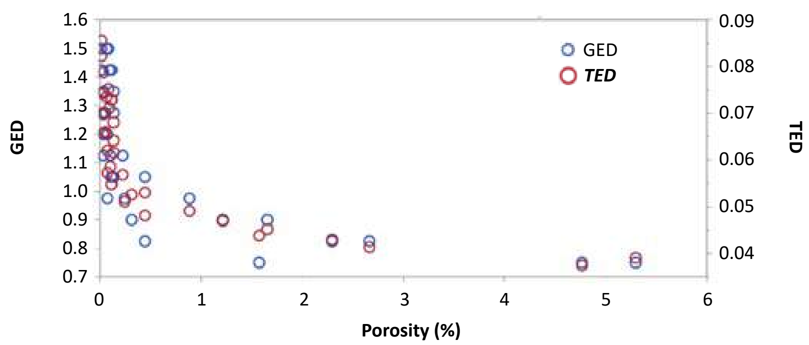

Fig. 15 Graph of porosity as a function of global energy density (J/mm^2) and the TED in-process quality metric

Summary

This experiment evaluated the sensitivity of the PrintRite3D INSPECT software and Sigma's IPQM (TED) metric to changes in the independent process input parameter (laser power) on a layer by layer basis. Using this software and proprietary algorithms, that measure dependent in-process data captured from a pyrometer and photodetector raw trace signals, it is possible to infer effects of process disturbances on melt pool and bulk material thermal responses.

It was observed that thermal in-process dynamical trend data exhibited a Gaussian behaviour when analysed using the software's IPQMs. Trend charts also contained a user defined upper control limit which enabled statistical process control capability on a layer basis. Using the TED IPQM and the on-axis photodetector in-process data for an entire layer, upskin and downskin scan locations were clearly visible. By analysing the TED metric, in relation to laser power and porosity, a strong correlation was observed.

In conclusion, Sigma's IPQM TED metric represents a very good candidate for an In-Process Quality Metric of melt pool process disturbance for metal Additive Manufacturing.

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TCT 2018
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www.tctshow.com

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

IN(3D)USTRY
October 16-18, Barcelona, Spain
www.in3dustry.com

formnext 2018
November 13-16, Frankfurt, Germany
www.formnext.com

Metal Additive Manufacturing Conference
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