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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

GE'S INDUSTRY IN 3D

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INOVAR COMMUNICATIONS

METAL ADDITIVE MANUFACTURING

It's time to pay attention to Additive Manufacturing

This was the message at the heart of GE's 'Industry in 3D' event, held in New York City earlier this year. Given the metal AM industry's dramatic growth over the last few years, and the constant stream of new application stories in the media, the need to send such a 'call to action' to the wider business world may be surprising to some.

The message, however, serves to highlight a very specific challenge faced by the industry. Whilst there is an awareness of the potential of metal AM technology amongst those responsible for innovation within leading global manufacturing firms, there is limited recognition of the fact that the technology is now enabling a move beyond prototyping and one-off builds and into meaningful series production across a range of industries.

That the industry is achieving its current levels of growth with this misconception in place is remarkable. However, as those who currently believe that metal AM is a technology for the future turn to embrace it, then just perhaps we will begin to see growth levels that will truly put metal AM on the manufacturing map.

Nick Williams
Managing Director
Metal Additive Manufacturing

Cover image
GE Additive's Customer Experience Center in Pittsburgh, Pennsylvania, USA (Courtesy GE Additive)

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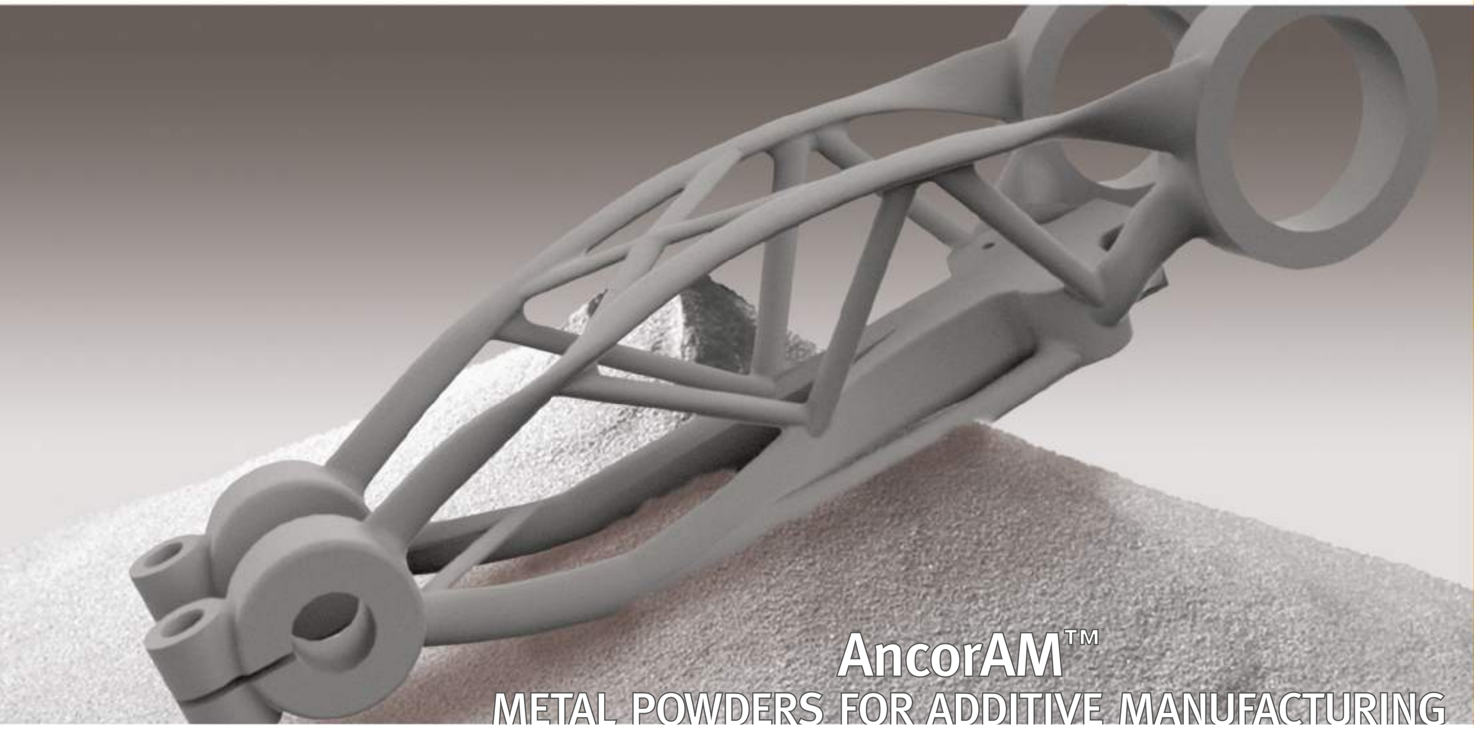

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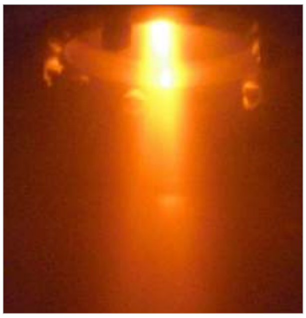

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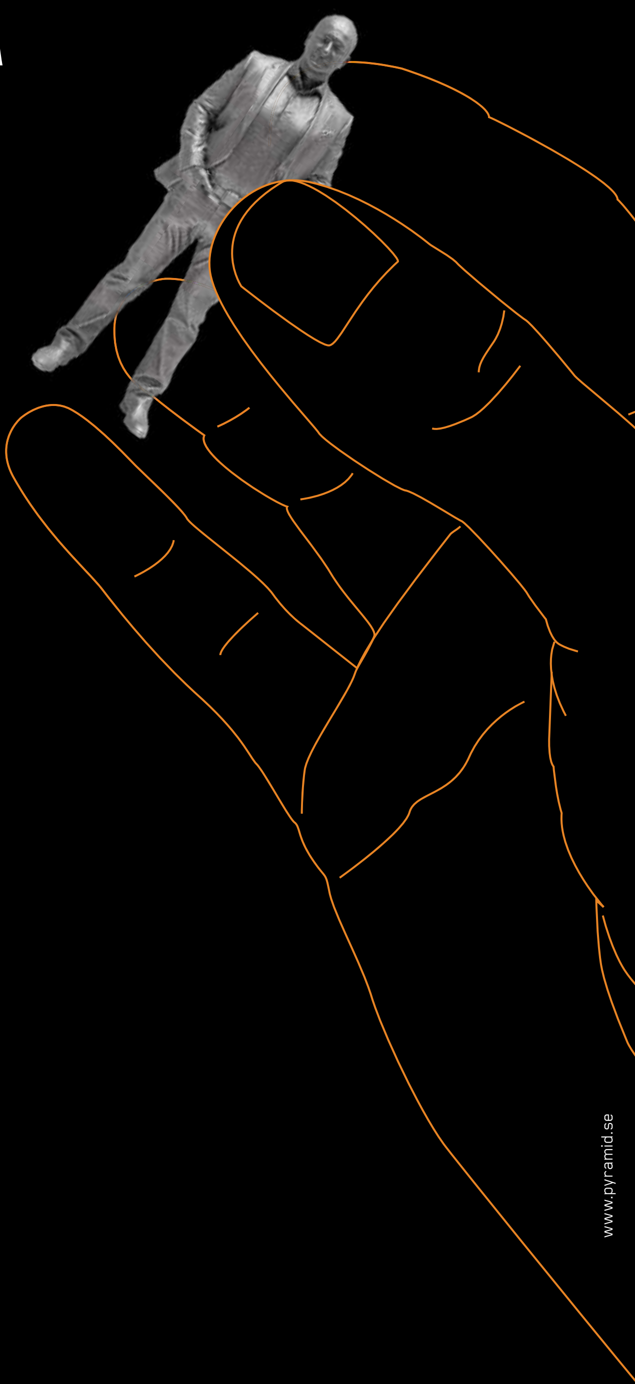

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industry news

Oerlikon and Lufthansa Technik partner to integrate AM into maintenance and repair services for civil aircraft

Oerlikon, Pfäffikon, Switzerland, has signed a Memorandum of Understanding (MoU) with Lufthansa Technik, Hamburg, Germany, to establish robust and repeatable processes for Additive Manufacturing in the aircraft maintenance, repair and overhaul (MRO) industry. The agreement marks an important step towards the integration of AM into the aircraft MRO industry, enabling it to take advantage of flexibility and cost savings in manufacturing, procurement, warehousing and supply chain management.

Under the MoU, the partners will design representative component geometries. These parts will then be manufactured on identical AM systems at three global locations. The same process parameters and powder specifications will be used in order to understand process repeatability. The results of the study will be shared with relevant industry bodies to support defining standards for the qualification and approval of aircraft components.

"We look forward to strengthening our partnership with Lufthansa Technik and joining forces to develop reliable, repeatable and quality-assured Additive Manufacturing processes, standards and products for the MRO industry," stated Dr Roland Fischer, Oerlikon Group CEO.

"Lufthansa Technik is active in areas such as the cabin of the future, 3D printing and Industry 4.0," added Bernhard Krueger-Sprengel, Vice President, Engine Services, Lufthansa Technik. "We see the partnership with Oerlikon's AM team as an exciting opportunity to accelerate Lufthansa Technik's plan of having local AM repair capabilities on a global scale."

The year-long partnership may be extended to other types of AM systems as more data on manufacturing processes is collected.

www.oerlikon.com/am
www.lufthansa-technik.com

Maintenance is undertaken on an Airbus A350 at Lufthansa Technik Munich (Courtesy Gregor Schläger / Lufthansa Technik AG)

Groupe Meloche and FusiA Impression 3D Métal join to offer AM components to aerospace sector

Canada's Groupe Meloche, a supplier of aerostructure and aircraft engine components to OEMs and Tier-1 integrators, and FusiA Impression 3D Métal, a producer of metal AM parts, have signed a partnership agreement to offer Additive Manufacturing of components to prime contractors in the global aerospace sector.

Already well positioned in the supply chain for aerostructure and aircraft engine component manufacturing, Groupe Meloche stated that it will now be able to offer intelligent manufacturing services to all its customers. The company specialises in manufacturing and engineering, complex machining, surface treatment, painting, value-added assemblies, and non-destructive testing. In recent years, Groupe Meloche has made significant investments in automation and advanced machining technologies. "3D printing is part of our goal to deliver world-class performance to our customers in terms of quality, on-time deliveries and manufacturing turnaround times," stated Normand Sauvé, Vice President, Innovation and Infrastructure at Groupe Meloche.

FusiA specialises in the production of metal AM parts for the aeronautics, space and defence sectors in both France and Canada. In Canada, the company offers metal AM services from a production facility in Greater Montréal.

www.melocheinc.com
www.fusia.fr

GE Additive unveils Arcam EBM Spectra H

GE Additive unveiled the Arcam EBM Spectra™ H, a new metal Additive Manufacturing system designed to handle high heat and crack-prone materials, at the recent RAPID + TCT 2018 show, in Fort Worth, Texas, USA. The new system, available to pre-order, will be manufactured at Arcam's plant near Gothenburg, Sweden, with expected delivery from Q4 2018 onwards.

Initially, the new system will support both TiAl and Alloy 718, with additional Ni superalloys supported from 2019. GE Additive's materials science team is currently exploring opportunities for a wider range of high heat materials that includes nickel superalloys, tungsten, CoCr, stainless steel and metal matrix composites.

The Arcam EBM Spectra H incorporates a range of new features and enhancements. An increased build speed of up to 50% has been achieved through the use of a 6 kW HV-unit, resulting in all pre- and post-heating steps taking half the time of current EBM machines. Improved heat management has also been achieved through the incorporation of a moveable heat shield to keep heat in the build area, and an improved layering procedure reduces the need for heating, saving approximately five hours for a full height build. The build volume has also been increased by around 39% compared to previous generation machines to Ø250 x 430 mm.

Further machine enhancements include Arcam xQam™ automatic calibration technology, which, it is claimed, improves the position and focus accuracy and removes the need for manual calibration, reducing the process from three to four hours to fifteen minutes. This innovation will also be incorporated on the Arcam EBM Spectra H and all Qplus systems.

Reducing dependency on operators and incorporating automation technologies to improve accuracy was said to be a major focus during the development of the new machine. As a result, the system offers a significantly improved and automated power handling process. An automated, self-dosing sieve and hopper filling station process has been developed and powder weight is controlled in the powder recovery station and inside the hopper filling station. Only one powder distribution set-up is required for each material and calibration of the fetch position only needs to take place during a material change, no longer before machine start.

The new Arcam EBM Spectra H system (Courtesy GE Additive)

Advanced safety features have also been incorporated into the new machine, including closed powder handling, which also maintains batch integrity and reduces the risk of contamination. As well as protecting the operator from the powder, the dust tight environment in all steps of the process maintains powder batch integrity. Removal of unwanted particles is handled by a thorough process that includes a cyclone for small and low-density particles, a sieve for coarse particles and magnetic traps.

www.ge.com/additive

SLM Solutions reports new twelve-laser machine and new headquarters

SLM Solutions Group AG, Lübeck, Germany, has revealed that it is developing a new twelve-laser Additive Manufacturing machine due for release towards the end of 2019. The company also announced its move to new €25 million headquarters located in Estlandring, on the outskirts of Lübeck.

"The development of our SLM Cube machine with a build chamber of 600 x 600 mm and a minimum of twelve lasers is on track. We are still confident that we will be able to present this machine in November 2019," stated Henner Schöneborn, CTO of SLM Solutions.

Incorporating a minimum of twelve lasers, it is said that the new system will mark a significant step in the evolution of AM technology.

New headquarters

Housing some 340 employees, the company's new headquarters will provide a modern facility with room for further expansion. SLM Solutions has been based with its predecessor companies in Lübeck since 1957.


SLM's new headquarters under construction in Lübeck, Germany

www.slm-solutions.com

3D Systems launches two new metal Additive Manufacturing systems

Multiple concentrically nested stator rings produced on the DMP Flex 100 system (Courtesy 3D Systems)

Metal crown copings produced on the DMP Dental 100 (Courtesy 3D Systems)

3D Systems, Rock Hill, USA, has launched two new metal Additive Manufacturing systems. The company's new DMP Flex 100 is designed for use in R&D, application development and production, with the DMP Dental 100 designed to manufacture metal dental prostheses.

The DMP Flex 100 is reported to provide up to twice the throughput compared to 3D Systems' previous entry-level metal AM system, the ProX DMP 100. With a build volume of 100 x 100 x 80 mm, the system is designed for the production of small, precise metal parts with complex details and thin walls. It is said to be able to achieve a high degree of accuracy, repeatability and a surface finish as fine as Ra 5 µm.

According to 3D Systems, the DMP Flex 100 has the capacity to process a number of metals including some titanium grades and other alloys. At the time of its launch, the company's LaserForm® CoCr (B) and LaserForm 17-4PH (B) materials will be on offer for use with extensively developed, tested and optimised print databases. Additional LaserForm materials for use with the DMP Flex 100 are also in development.

The DMP Dental 100 is reportedly able to build up to ninety crown copings in less than four hours in a single run. The high degree of surface quality offered by the system means minimal post-processing is required, with a typical print accuracy of 50 µm helping to ensure the right fit for patient-specific crown copings, bridges, supra-structures and partial frames. The DMP Dental 100 printer comes with LaserForm CoCr (C) material (ISO 13485, ISO 9001, FDA and CE qualified) and includes 3D Systems' software solution for managing the manufacture of fixed and removable dental prostheses.

Kevin McAlea, EVP Metals and Healthcare, 3D Systems, commented, "3D Systems is demonstrating its commitment to bringing industrial-grade metal Additive Manufacturing to a wider customer base with the launch of the DMP Flex 100 and DMP Dental 100 metal 3D printers. Both solutions feature levels of throughput, print quality, ease of use and material choice that put them in a class by themselves. We believe these 3D printing solutions will further expand the adoption of metal AM by designers and engineers, researchers, manufacturers and dental professionals."

www.3dsystems.com

Coherent acquires AM systems maker O.R. Laser

Coherent, Inc., Santa Clara, California, USA, has acquired O.R. Lasertechnologie GmbH, Dieburg, Germany. O.R. Laser produces a range of compact, high-precision tools for laser-based metal Additive Manufacturing, including Direct Metal Deposition (DMD) and Selective Layer Melting (SLM), as well as systems for cutting, welding, marking and engraving. The company's products are used in diverse applications, including the dental, medical, jewellery, automotive and aerospace industries.

Founded in 1966, Coherent is a provider of lasers and laser-based technology. With headquarters in Silicon Valley, California, and a global network of offices, the company supplies a range of markets and industries, including scientific, commercial and industrial customers

Thomas Merk, Coherent's Executive Vice President and General Manager, Industrial Lasers and Systems, stated, "The acquisition of Rofin-Sinar made Coherent into a major force in laser machine tools, and O.R. Lasertechnologie now gives us a complementary product line that specifically increases our solutions portfolio in Additive Manufacturing."

"Additionally, their products will seamlessly integrate with our current offering because the O.R. Laser approach is congruent with the Coherent philosophy: provide high performance, precision systems which deliver unmatched value and ease of use," he added. "We see this as key to enabling lasers to displace other legacy manufacturing technologies in a variety of industries. For example, these advantages have already allowed O.R. Laser to enjoy success with their solutions for dental and medical device manufacturing."

www.or-laser.com
www.coherent.com


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Updates to Concept Laser M2 cusing range released

GE Additive has released an update to its range of Concept Laser M2 cusing and M2 cusing Multilaser machines, which it states will provide customers with an increased level of productivity and reliability, as well as lower overall operating costs. Concept Laser machines are used across a wide range of industries, such as aerospace, automotive, medical and dental.

The company refers to the M2 cusing family as the 'workhorse' of its Additive Manufacturing product portfolio. Since acquiring a majority stake in Concept Laser in October, 2016, GE Additive has invested aggressively in the future of the company – expanding its headquarters, growing its employee base and support teams and investing in further development of its systems and materials.

"Customers, especially in the aerospace and medical industry, have high expectations," stated Meddah Hadjar, General Manager, Additive Laser Products at GE Additive. "For that reason we continuously review our solutions portfolio to confirm we are offering the right machines and the right materials for an ever-demanding range of applications."

Upgrades to the latest version of the M2 cusing range include a new gas flow system, backed by redundant oxygen monitoring and a closed inert gas circuit for better part quality; a new cooling unit for optical components, offering a temperature controlled environment monitored by multiple new sensors, thus preventing influence from external and internal temperature changes; and a more tightly controlled build environment.

GE Additive's Concept Laser M2 cusing Multilaser machine is one of a range of updated systems (Courtesy GE Additive)

The updated machines are also reported to offer a higher build chamber, with a z-axis of 350 mm (total build volume: 250 x 250 x 350 mm) and a newly designed heating system. Due to the advanced closed-loop control offered by the systems, a higher degree of accuracy is also possible on the z-positioning.

www.ge.com/additive

www.concept-laser.de

Solukon announces new depowdering system for metal AM

Solukon Maschinenbau GmbH, Stadtbergen, Germany, has added a new compact depowdering system to its line of systems for the automated removal and processing of unfused powder from parts built on metal Powder Bed Fusion Additive Manufacturing systems.

The SFM-AT200 small-footprint machine is designed for components or build plates of up to 300 x 300 x 230 mm (11.8 x 11.8 x 9.1 in), and automates the process of removing excess unmelted powder through the systematic rotation and controlled vibration of laser melted metal parts, releasing powder trapped in voids and internal channels around and inside the component.

The system was launched at Rapid. Tech in Erfurt, Germany, June 2018. "The SFM-AT200 incorporates the automatic features that Solukon has developed on its large frame systems into a compact platform, designed for use with small- to medium-sized metal Powder Bed Fusion systems," explained Andreas Hartmann, Solukon Co-founder. "Customers already working with our large frame systems have validated what they require for high-quality parts cleaning and hazard management, and now we are able to meet those needs with an entry-level system incorporating state-of-art solutions for depowdering."

Dominik Schmid, Co–founder, added, "In addition to a smaller footprint, the system also reduces inert gas consumption when used for processing reactive powders such as aluminium or titanium, which pose risks for explosion if not handled correctly. Thanks to our sealed cleaning process, with the safety-monitored infusion of inert protective gas, the systems are certified for the safe processing of these materials."

During depowdering, printed parts including build plates are fixed onto the processing table of the SFM-AT200. The process table then rotates the parts in a pre-planned path to release unused powder. At the same time, a controlled variable-frequency vibration device enables the release of compacted powder from inside the parts. Unfused powder is then collected for further processing or reuse in a specially designed container, or connected to an external sieving device.

www.solukon.de

The SFM-AT200 compact depowdering system (Courtesy Solukon)

AddUp expands its technology offering with BeAM acquisition

AddUp, Clermont-Ferrand, France, a specialist in the design, production and marketing of metal Additive Manufacturing machines and production lines, a joint-venture between Fives and Michelin, today announced its acquisition of BeAM, based in Strasbourg, a leader in the Directed Energy Deposition (DED) technology, an Additive Manufacturing process dedicated to the production of large parts and the repair market.

Formed in 2012 in Strasbourg and with subsidiaries in Cincinnati, Ohio, USA, and Singapore, BeAM is said to serve a broad range of customers both in France and abroad, particularly in the aeronautics, defence and energy sectors. The 100% acquisition of BeAM is expected to enable AddUp to expand its portfolio of metal Additive Manufacturing technologies to better meet the needs of its customers and strengthen its worldwide geographic coverage.

The companies stated that they share the same ambition to support customers in the development of metal Additive Manufacturing solutions which take into account industrial robustness, HSE (Health, Safety & Environment) and certification. Vincent Ferreiro, AddUp CEO, commented, "Together, BeAM and AddUp will be uniquely positioned in the Additive Manufacturing market by offering their customers a comprehensive range of metal AM solutions with, in particular, training and consulting, 3D printing systems and the making of parts for Proof Of Concept."

"BeAM was at a key stage in its development with the broadening of its product line and its geographic expansion," added Vincent Gillet, BeAM's CEO. "The arrival of AddUp and its shareholders, Fives and Michelin, enables us to secure BeAM's development and to benefit from their industrial expertise and the pooling of our respective resources."

The exact terms and conditions of the transaction have not yet been disclosed.

www.addupsolutions.com
www.beam-machines.com

Ilan Levin steps down as CEO and Director of Stratasys

Stratasys Ltd, based in Minneapolis, USA, and Rehovot, Israel, has announced that Ilan Levin has resigned from his position as Chief Executive Officer and Director of the company effective June 1, 2018. Elchanan (Elan) Jaglom, the company's current Chairman of the Board, will serve as interim CEO until a successor can be appointed.

In accordance with Israeli law, Jaglom's service in the position of Chairman and CEO will require shareholder approval and to this effect, Stratasys plans to call a shareholder meeting. Levin will reportedly provide ongoing consultancy services to the company following his resignation.

The company's Board of Directors has also appointed an Oversight Committee to help support the management of the company during the interim period. This committee is comprised of David Reis, the company's Vice Chairman of the Board, Executive Director and former CEO, along with Directors Scott Crump, previous Chairman and Founder, and Dov Ofer.

The Board of Directors has also established an Executive Search Committee, composed of Jaglom and Victor Leventhal, the Chairman of the Compensation Committee of the Company's Board of Directors, to oversee the engagement of an international executive search firm to help identify a new Chief Executive Officer.

On Levin's resignation, Jaglom stated, "The Board of Directors is appreciative of Ilan's contributions to Stratasys and Objet for over fifteen years. Ilan has implemented a number of key decisions as CEO that have kept the company strong and ready for future expansion. We thank Ilan for his dedicated leadership of our company during this phase in Stratasys' history."

www.stratasys.com

ExOne announces leadership change

ExOne, North Huntingdon, Pennsylvania, USA, has announced that CEO James L McCarley will be leaving the company effective immediately to pursue other interests and opportunities. He will be succeeded by S Kent Rockwell, who previously served as ExOne CEO from January 2013–August 2016.

For the past two years, Rockwell has served as the company's Executive Chairman. On his reappointment to the position of CEO, he stated, "On behalf of our board and management team, I would like to thank Jim for his efforts and wish him all the best in his future endeavours."

Prior to his initial appointment as CEO in 2013, Rockwell served as the Managing Member of Ex One Company, LLP, the company's predecessor, from 2008. He is also the Chairman and CEO of Rockwell Venture Capital, Inc., a private venture capital company, and of Appalachian Timber Services, a supplier of timber products for railroads.

www.exone.com

Xact Metal introduces two new metal Additive Manufacturing systems

Xact Metal's XM200C (left) and XM200S (right) (Courtesy Xact Metal)

Xact Metal, State College, Pennsylvania, USA, has launched two new metal Additive Manufacturing systems, the XM200C and the XMS200S. Both systems are based on a metal Powder Bed Fusion (PBF) process and both have a build volume of 2048 cm^3 (127 x 127 x 127 mm) / 125 in^3 (5 x 5 x 5 in).

The XM200C features a 100 W Yb fibre laser and a patent-pending scanner which fuses at speeds up to 500 mm/sec. The system has a small footprint which is said to allow for simple integration into the lab or manufacturing floor. Priced at $80,000, the XM200C can be used with a range of metals including stainless steel, superalloys and tooling steels.

"The XM200C makes metal powder-bed fusion available for universities, labs and small-to-medium businesses who need prototyping, casting, tooling and printing of small parts, and who could not afford these systems in the past," stated Juan Mario Gomez, CEO of Xact Metal. "In addition, when compared to bound metal deposition, atomic deposition additive manufacturing or other FDM-like metal 3D printers, metal powder-bed fusion provides high-quality and complex parts, reduces total cycle time by about 50%, and removes the need for wash/debinder and sintering/oven equipment."

Xact Metal's XM200S incorporates a 200W Yb fibre laser and a digital galvanometer mirror scanner which has a jogging speed of 12 m/sec. The system can be used with a wide range of metals including aluminium, stainless and tooling steel, super alloys and titanium.

"Priced at $130,000, the XM200S is ideal for printing of small parts where high-performance applications and print speed are critical," explained Gomez. "The introduction of the XM200S is another example of how Xact Metal continues to combine the requirements of metal Powder Bed Fusion and breakthrough technology to establish a new level of price and performance for Additive Manufacturing."

Matt Woods, Xact Metal's CTO, stated, "The XM200S uses state-of-the-art technology. Precision digital optical systems provide active thermal drift compensation which eliminates warm-up times and minimises long-term drift during printing operations. The 24-bit command resolution gives industry leading positional accuracy."

"In addition, the patent-pending recoater uses a unique 'bulb' shape element to spread powder like a blade, yet provides compaction similar to a rolling element, and the compliant design allows the recoater to negotiate out-of-plane growth and continue printing."

Shipments of the XM200C were expected to start in June 2018, while shipments of the XM200S are expected to begin in September 2018.

www.xactmetal.com

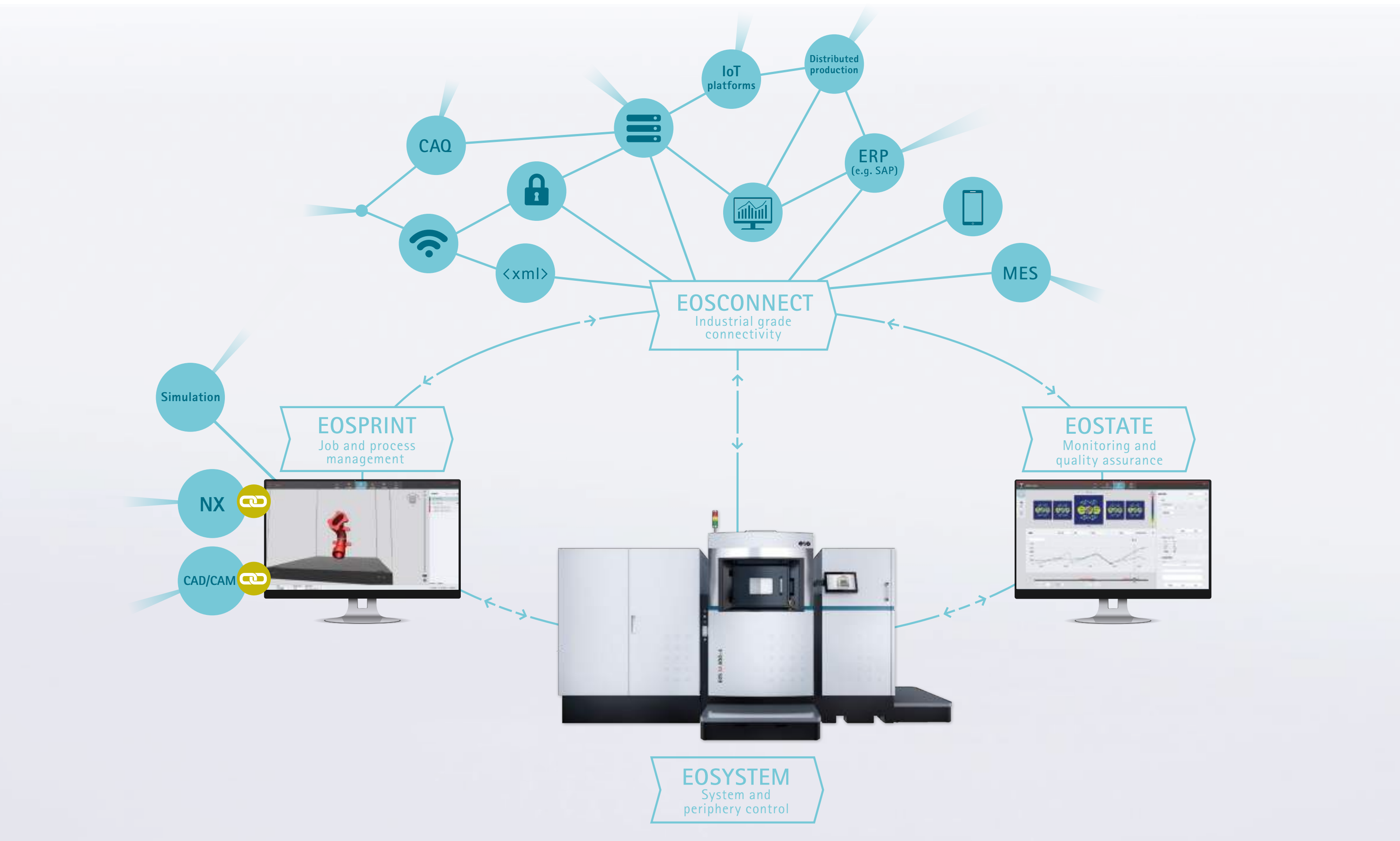
ASTM International to publish new standard for Powder Bed Fusion AM

ASTM International states that it will publish a new standard (F3303) for manufacturing using laser and electron beam-based Powder Bed Fusion (PBF) technologies. The standard has been developed to support the growing use of metal Additive Manufacturing for the production of quality aerospace parts, medical devices and more. Specifically, the standardised practice will outline ways to qualify machines and processes used for PBF-based Additive Manufacturing, according to ASTM member Amir Farzadfar, Materials and Process Engineer for Additive Manufacturing at Corning Inc. In addition, it will cover the required steps related for the configuring and control of digital data.

The standard was developed by ASTM International's subcommittee on materials and processes, part of its larger committee on Additive Manufacturing technologies (F42). By ensuring that Additive Manufacturing steps are fixed and repeatable throughout the industry, the committee hopes that customers can be more assured of part quality in future.

"An additional standard is underway to support part qualification, quality assurance and post-processing of Powder Bed Fusion parts," added Farzadfar.

www.astm.org



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Leading MIM furnace manufacturer reports strong demand from the metal AM sector

Leading Metal Injection Moulding (MIM) furnace manufacturer Elnik Systems LLC, Cedar Grove, New Jersey, USA, is reporting strong sales growth to the metal Additive Manufacturing industry. The company specialises in laboratory and production-scale vacuum debinding and sintering furnaces that have been specifically developed for the processing of MIM parts. As such, its systems are well suited to the thermal processing of parts produced using the new generation of MIM-like processes.

The company told *Metal AM* magazine that it has now supplied nine systems to the metal AM industry, with usable volumes ranging from 27 to 117 litres.

Stefan Joens, Vice President of Elnik Systems, commented, "There are multiple reasons for our success in the metal binder jetting and filament-based AM sector. The most important is the ability for potential customers to experiment with the furnaces at our on-site development partner, DSH Technologies, LLC."

"This service has helped part makers to understand the quality of our furnace systems, the consistent results that can be achieved, and their flexibility of use before committing to a purchase. Our reputation in the debinding and sintering industry is also a strong attraction – we have demonstrated our value to the MIM industry over several decades, and now the metal AM industry is doing its homework before investing."

Contract debinding and sintering services expanded

Elnik Systems and DSH have for many years offered toll debinding and sintering services from the New Jersey facility, enabling companies to process small-to-medium volumes of MIM and MIM-like AM parts before investing in their own furnaces, or as part of a component development programme.

This service is now also being offered to the European market from a new facility in Waldachtal, Germany. Elnik Systems GmbH has the capability of processing first stage debinding via the catalytic process, and second stage debinding and sintering services in an Elnik MIM3045 furnace. This large furnace has a 117 litre usable volume, is high vacuum capable, features argon purification, allows survey thermocouples to be used as needed and the furnace can process any binder-containing metal powder part, be it from a binder jetting, filament-based or pellet-based metal AM process.

www.elnik.com
www.dshtech.com

Vacuum debinding and sintering furnaces for MIM and MIM-like processes at Elnik Systems/DSH in Cedar Grove, New Jersey, USA

Hot Isostatic Press from Quintus installed at Pankl Racing Systems' AM Competence Center

Quintus Technologies, Västerås, Sweden, has supplied a Hot Isostatic Press (HIP) to Pankl Racing Systems for installation in its new Pankl Additive Manufacturing Competence Center (PAMCC) in Kapfenberg, Austria. The QIH48 is expected to complement Pankl's facilities for the HIPing of AM parts for high-performance automotive and aviation customers.

The PAMCC is an initiative of Pankl Racing Systems in collaboration with Voestalpine/Böhler Edelstahl, EOS and Quintus. "As market leaders in our industry, we need the best equipment and best partners for our advanced AM production," stated Stefan Seidel, CTO of Pankl Racing Systems. The press is equipped with Quintus' patented Uniform Rapid Cooling (URC®) and Uniform Rapid Quenching (URQ®) technologies for cost-effective production and combined HIP and heat treatment, making it suitable for advanced AM process development.

Jan Söderström, CEO of Quintus Technologies, commented, "High-speed, high-tech, high-quality–we are impressed with this commitment of Pankl to their customers and their own objectives and happy to become part of their effort to broaden the application fields for AM in the racing car industry."

"Quintus' capability to deliver an easy-to-install, compact HIP system in a very fast time is very important for rolling out our AM strategy and business plan. We are looking forward to adding the Quintus HIP to our production portfolio," concluded Wolfgang Plasser, Pankl Racing Systems CEO.

www.quintustechnologies.com
www.pankl.com

ExOne launches Innovent+ metal Additive Manufacturing machine

The ExOne Company, North Huntingdon, Pennsylvania, USA, has released its newest binder jet metal Additive Manufacturing system, the Innovent+. The new system is based on the company's previous Innovent range and offers increased powder handling capabilities and the company's new Ultrasonic recoater, designed to enable greater material flexibility and ease of use.

According to ExOne, the Ultrasonic recoater is the most advanced powder dispensing technology on the market. The recoater can be quickly removed for system cleaning or powder changeover, and comes with four screen configurations for greater material compatibility.

The Innovent+ has been designed for small-scale research and laboratory environments and offers a compact footprint of 1203 x 887 x 1434 mm. The machine has a build volume of 160 x 65 x 65 mm and a production speed of 45–60 seconds/layer at a layer thickness of 50 μm.

The new system also offers expanded dust collection options. Dust collection has been localised to remove powder from around the buildbox, using a dust particulate remover with a variable control knob to allow the user to adjust the CFM units removed. These options are now available for both the Innovent+ and the original Innovent system.

ExOne's new Innovent+ Additive Manufacturing system is designed for small-scale research and laboratory environments (Courtesy ExOne)

www.exone.com

Premium Aerotec acquires APWorks

The aerostructures supplier Premium Aerotec, based in Augsburg, Germany, has reinforced its position in the Additive Manufacturing sector through the takeover of APWorks, an AM specialist based in Munich, Germany. It was stated that both partners complement the other's capabilities and aim to profit from the fast-paced growth in the Additive Manufacturing market together. Premium Aerotec and Airbus, the previous owner of APWorks, did not reveal the purchase price.

Premium Aerotec numbers among the world's leading Tier 1 suppliers of commercial and military aircraft structures and is a partner in major European and international aerospace programmes. The company is stated to have been the first aviation supplier to introduce AM titanium components into the structure of aircraft and has full capability throughout the entire Additive Manufacturing process chain, from product conception to development and the actual manufacturing process through to the downstream process steps.

APWorks was founded as an Airbus Group spin-off in 2013 and has since positioned itself as a technology driver for manufacturing methods for the future, with a clear focus on metal Additive Manufacturing.

"Our investment has created a powerful alliance between Premium Aerotec and APWorks which opens up all of the opportunities in Additive Manufacturing for both actual and future clients," stated Dr Thomas Ehm, Chairman of the Executive Board at Premium Aerotec. "We want to actively support APWorks on its dynamic growth journey. With our experience as a pioneer in metal 3D printing and our knowledge of the tried and trusted quality standards in aerospace, we are the industrial reference point for APWorks' innovative ideas."

Joachim Zettler, Managing Director of APWorks, stated, "With Premium Aerotec coming on board, we can take a huge step closer to our vision of industrial mass production using Additive Manufacturing technology. The aim is to combine APWorks' highly dynamic approach in solving the issues posed by our clients' additive manufacturing questions with Premium Aerotec's decades of production experience to elicit maximum benefit for our clients from each and every industry, throughout the entire Additive Manufacturing value added chain."

APWorks developed the Light Rider electric motorcycle, with its frame additively manufactured from Scalmalloy® aluminium alloy

www.premium-aerotec.com

www.apworks.de

World's largest contract manufacturer of medical devices and implants adds metal Additive Manufacturing

US-based Norman Noble, the world's largest contract manufacturer of medical devices and implants, has taken delivery of its first Additive Manufacturing machine from GE Additive's Concept Laser division at its plant in Highlands Heights, Ohio.

Following the installation of the new Mlab cusing R machine, the team at Norman Noble plans to develop shape-set tooling for processing nitinol based rapid prototypes for a number of applications. The company states it will build on its existing implant manufacturing capabilities by exploring the potential of producing metal AM vascular stents and orthopaedic implants.

"Norman Noble will utilise this new 3D printing technology to support rapid prototyping capabilities for nitinol parts, and as a manufacturing solution for prototype-to-production of our customers' next-gen vascular and orthopaedic implant designs," stated Brian Hrouda, Director Global Sales and Marketing at Norman Noble.

Additive manufactured parts often include complex geometries and internal features. To support its Additive Manufacturing capabilities, Norman Noble also purchased a state-of-the-art Computerised Tomography Inspection system that provides complete dimensional analysis of all internal and external part features. In addition, this technology enables the dimensional inspection of very complex geometries that conventional systems are unable to perform.

"Norman Noble's plans to use metal-based additive technologies to explore stent production are really exciting. Until now Additive Manufacturing applications in cardiology have been polymer models for preoperational training and visualisation, so it will be interesting to see how things progress over the coming years," said Stephan Zeidler, Business Development Manager for the medical sector at Concept Laser.

www.nnoble.com

www.ge.com/additive

Norman Noble has installed a Concept Laser Mlab cusing R (Courtesy GE Additive)

LLNL collaborates with U.S. Navy on replacement parts by metal AM

Researchers at Lawrence Livermore National Laboratory (LLNL), California, USA, have joined a collaboration with the U.S. Navy aimed at producing critical replacement parts using metal Additive Manufacturing. The Office of Naval Research recently announced an award of $9 million to fund the collaboration, which is led by GE Global Research and aimed at developing a rapid process for creating exact digital models of replacement or newly designed parts for naval, marine and aviation assets.

The collaboration involves scientists and engineers from LLNL, GE's Aviation and Additive divisions, Honeywell, Penn State University, the Nuclear National Lab (NNL) and the National Center for Defense Manufacturing and Machining (NCDMM). The goal over the four-year project will be to build 'digital twins' from model and sensor-based data, enabling scientists and engineers to dramatically speed up the qualification and certification process of for metal AM parts. The partners stated that researchers hope to eventually replace traditional manufacturing processes with Additive Manufacturing, and produce legacy replacement parts no longer manufactured by conventional methods.

Under the collaboration, LLNL reported that it will contribute its ongoing development of an intelligent, computational 'feed forward' design process, which relies heavily on advanced modelling and simulation as well as experimental analysis to predict and teach AM systems to efficiently create parts without defects. "We've come up with a methodology and we think we've made some significant progress in part qualification," explained Wayne King, head of LLNL's Accelerated Certification of Additively Manufactured Metals (ACAMM) project. "We're training the machines to build parts right the first time, every time, and building the confidence of our physicists and project engineers that they are high-quality."

The four-year 'Quality Made' programme will initially focus on underlying software and hardware developments, before moving toward the development of a complete system demonstrating rapid and robust creation of a part's digital model or digital twin. The project is expected to culminate in the production of parts for the U.S. Navy using a Direct Metal Laser Melting (DMLM) AM system.

www.llnl.gov

Metal AM could be used for the replacement of critical parts in the U.S. Navy (Courtesy LLNL)

Vader Systems introduces new liquid metal AM technology

Vader Systems, Buffalo, New York, USA, has announced three new Additive Manufacturing systems based on its patented Magnet-o-Jet™ technology. The machines include the Vader Polaris™ liquid metal AM system, the Magnet-o-Jet™ Subsystem for hybrid manufacturing equipment integration and the Ares™ Powder System.

Vader's Magnet-o-Jet technology utilises the control and precision of an electromagnetic field to propel liquefied metals to produce high integrity parts. The system is said to deliver 1000 droplets per second with micron level accuracy, while doubling the speed of conventional powder bed metal systems. It can process many aluminium alloys, including 4043, 4047 and 1100, as well as the sought-after 6061 and 7075 alloys "Our new technology platforms emphasise Vader's unique ability to be the agile additive solution for the market," stated Scott Vader, President of Vader Systems.

The Vader Polaris is a turnkey AM system using Vader's patented liquid metal process. Its reliance on wire feedstock rather than powders is said to offer significantly reduced operating expenses and dramatically reduced time for near net shape parts. It offers a build volume of 305 x 305 x 305 mm (12" x 12" x 12") and optimised parameters yield 99.5% dense parts, with low residual stress and less warping.

The Magnet-o-Jet Subsystem is designed to integrate into hybrid manufacturing systems such as CNC and machine centre equipment. The company claims that the Magnet-o-Jet system allows manufacturers to produce parts and precisely finish them all in one system.

The Ares™ Powder System is reported to produce highly uniform and consistent metal powders for powder-based AM systems. Known as Vaderite™ Microspheres, the Ares is suited to on-demand, small batch production. It is said to eliminate the need to carry powder inventory and enables companies to produce a wide variety of small batch applications.

www.vadersystems.com

The Polaris system is the new turnkey liquid metal AM system from Vader (Courtesy Vader Systems)

Bohler-Uddeholm becomes voestalpine High Performance Metals

Bohler-Uddeholm Corporation, USA, has been rebranded as voestalpine High Performance Metals Corporation. According to voestalpine, the decision was taken to reflect the ownership structure of the company, which has been in place since 2007 when voestalpine AG acquired Bohler-Uddeholm AG. The name change is said to align the United States brand globally with each of its sister companies. voestalpine AG owns a number of global brands alongside Bohler-Uddeholm, including eifeler and ASSAB.

voestalpine's High Performance Metals Division is a global leader for tool steel and a leading provider of high-speed steel, valve steel, and other products made of special steels, as well as powder materials, nickel-based alloys and titanium. It is focused on producing and processing high-performance materials and customer-specific services including heat treatment, high-tech surface treatments and Additive Manufacturing processes.

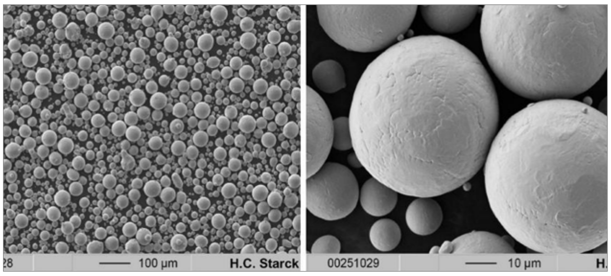
voestalpine AG added that eifeler Coatings Technology will be rebranded as voestalpine eifeler Coatings in the coming months.

www.bucorp.com

H.C. Starck Tantalum and Niobium offers highly biocompatible alloys for medical applications

H.C. Starck Tantalum and Niobium GmbH, Munich, Germany, has released a short report on the advantages offered by its biocompatible alloys for metal Additive Manufacturing. Among its materials product range, the company offers titanium, tantalum and niobium based alloys designed to meet the latest standards for medical technology.

Orthopaedic and dental implants are exposed to high mechanical loads during their lifetime. Though many of the materials currently used in Additive Manufacturing, including stainless steel and cobalt-chrome alloys, are able to cope with these mechanical stresses, there are some concerns regarding their release of toxic or allergenic elements which could result in inflammation of surrounding tissue and rejection of the implant. An important prerequisite of all medical implants is their biocompatibility. As they are designed to remain in the body for a long period of time, the materials used in their production cannot have any effect on living organisms, regardless of the technology used to produce the implant. Proof of the biocompatibility of the materials used in medical implants is a primary approval criterion for their official regulatory approval.



SEM images of gas-atomised AMPERTEC Spherical Ti-42Nb powders at 100 x (left) and 1000 x (right) magnification (Courtesy H.C. Starck Tantalum and Niobium GmbH)

Among its biocompatible alloys, the company offers AMPERTEC Spherical Ti-42Nb powders as well as tantalum alloys. These are produced using an electrode induction-melting gas atomisation process, and are said to be fully spherical with a negligible amount of satellites. The spheroidal shape of the powders improves their AM processability. Because of their processing properties, AMPERTEC Spherical Ti-42Nb powders can be additively manufactured to almost full density (99.95%) using the Selective Laser Melting process. This results in a low level of internal stress, meaning that thermal post-processing steps such as diffusion annealing or Hot Isostatic Pressing (HIP) are not typically required.

In addition, the phase composition of these materials is not affected by the laser melting process; similar to the atomised powders, the additively manufactured Ti-42Nb is pure β-phase. Additively manufactured parts also have a fine-grained microstructure with extremely homogeneous elemental distribution, and scanning electron microscopy with energy dispersive X-ray spectroscopy investigations is said to confirm that there is no segregation of Ti or Nb-rich phases in the powders.

Using mechanical analysis by means of tensile and compression tests, the company stated that the processed materials exhibit a combination of high elasticity and strength. Because Ti-42Nb is similar in its tensile elasticity to cortical bone, the use of this material is capable of reducing stress shielding between bone and implant, as well as the associated inflammation or implant loosening due to mechanical mismatches.

"The materials we have developed show excellent biocompatibility in comparison to commonly used alloys. Moreover, they have better mechanical properties, particularly regarding the higher elasticity, near to that of cortical bone, in comparison to conventionally applied implant materials," stated Dr Melanie Stenzel, Head of Marketing & New Business Development at H.C. Starck Tantalum and Niobium GmbH. "Our new AMPERTEC Spherical Ti-42Nb powders represent the new generation of powders with excellent properties, best suited for these demanding medical applications."

www.hcstarck.com

TU Munich's student racing team uses GKN's metal AM to boost vehicle performance

Students from Team TUfast, the Formula Student racing team at the Technical University of Munich (TU Munich), Germany, have partnered with GKN Powder Metallurgy's Additive Manufacturing business to produce a metal AM motor housing for its electric race car. The annual Formula SAE and Formula Student competitions challenge students to build electric race cars, which compete and are ranked based on their design, acceleration, electrical efficiency, endurance, cost and manufacturing analysis. This year's Formula Student will comprise of three races, beginning at Silverstone, UK, and continuing at Hockenheim, Germany and Barcelona, Spain.

In previous years, Team TUfast's vehicle has been powered by a small, power-dense motor forced into the wheel hub. This operated at very high temperatures, damaging the motor, the team's race performance and the endurance points earned. By using metal AM, the team was able to produce a metal housing small enough to fit precisely into the wheel hub (Fig. 2), while incorporating a system of cooling channels (Fig. 3) to enhance the vehicle's performance. The TUfast racing team also topographically-optimised its parts, reducing the wheel-packaged weight by around 0.6 kg.

In an article published by GKN Sinter Metals, GKN Powder Metallurgy's Dr Simon Höges, Manager Additive Manufacturing, spoke to Team TUfast's Marco Tönjes, responsible for the development of the electric motor and its components, about the decision to move to AM. "The electric motor is typically not part of the chassis, but here it is because it has a wheel hub drive," stated Tönjes. "And since it has a wheel hub drive, it has many interfaces to the chassis. I'm in charge of the design and construction of the components that comprise the electric motor. Several of the other teams that we compete against buy their motors. We prefer to build ours."

"The all-wheel drive wheel hub of this year's vehicle combines the different drive components, and its functions are integrated in a compact and lightweight-optimised design for the lowest amount of space. Next to the topology optimised upright, the gearbox and the braking system is the electric motor. The laser sintered aluminium body with the new integrated cooling structure is the centerpiece of the powertrain."

According to Tönjes, this year's cooling system is fundamentally different from that used in 2017's motor, which did not perform as desired. In 2018, the team integrated a cooling structure which encloses the motor like a jacket, and is fluid-dynamically optimised to maximise heat transfer; essential to enable the electric motor to deliver a constant, high level of power (Fig. 4). "The structure consists of an inner cooling channel with a special optimised pin structure. The cooling channel is directly integrated in the housing, in which the stator is cast," stated Tönjes. "The manufacturing of this structure with its closed jacket structure is not realisable with conventional methods. Additive Manufacturing, or more precisely, laser sintering, is the only process that makes it possible to manufacture this component."

Fig. 1 Team TUfast and its Formula SAE/Student race cars (Courtesy TUfast Racing Team)

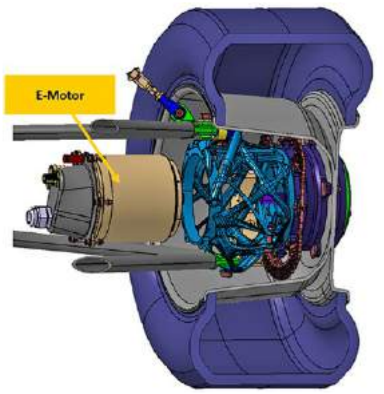


Fig. 2 The 2018 wheel hub drive package has been designed to fit into the lowest amount of space (Courtesy TUfast Racing Team)

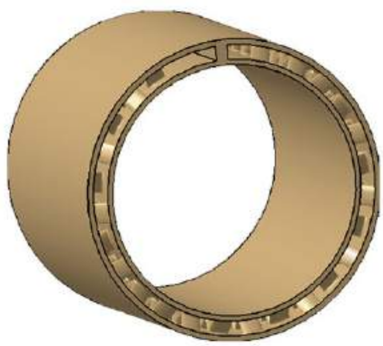


Fig. 3 The cooling structure has integrated cooling channels (Courtesy TUfast Racing Team)

Fig. 4 Step-by-step assembly of the wheel-hub-drive (Courtesy TUfast Racing Team)

The new cooling geometry is said to have increased heat conduction by 2%, with the same mass flow, compared to the previous structure, while the decreased pressure drop across the entire cooling system of the four-wheel-driven electric vehicle is said to have increased total mass flow by 31%. The result is a total heat conduction and efficiency increase of almost 20%.

With the help of GKN Powder Metallurgy, the team was able to further optimise the housing. "We originally wanted to implement the adapter for the cooling connections as an integral part with the housing. However, GKN's engineers had a different approach," explained Tönjes. "They suggested that we should separate the housing and connection adapter, as this significantly reduces the support structures required for production. The adapter, which is also laser-sintered by the additive business of GKN Powder Metallurgy, is now screwed to the housing with two screws."

Tönjes added that the team hopes to make further use of metal AM components in the next season, stating, "Compared to the normal automotive sector, metal 3D printing is particularly versatile in racing. Especially for small quantities, it is a fascinating technology. You can do everything without needing a mould or a tool."

https://tufast-racingteam.de
www.gkn.com/additive

Burloak investing $104 million in new AM Technology centre

Burloak Technologies, a division of Samuel, Son & Co., Dundas, Ontario, Canada, is investing a total of C$104 million (approx. $81.5 million) in a new Additive Manufacturing Technology Center in Oakville, Ontario. Burloak designs and manufactures metal and plastic AM parts for a range of industries including aerospace, defence, energy, medical, automotive and transportation.

Assisted by C$7 million in support from Ontario's Jobs and Prosperity Fund, Burloak Technologies' new facility is expected to enable the company to scale up and reach new markets by developing innovative designs, improving its manufacturing processes and introducing new products.

"Additive Manufacturing is a rapidly developing technology that is destined to become a multi-billion-dollar industry," stated Peter Adams, President and Co-founder, Burloak Technologies. "Through its investment in the Burloak Technologies Advanced Manufacturing Center, the provincial government is showing its leadership and support for innovation in the manufacturing sector and is helping to establish world-class 3D printing capabilities right here in Ontario."

"This is great news for Burlington and for Canada's advanced manufacturing industry," added The Honorable Karina Gould, Canada's Minister of Democratic Institutions. "Advanced manufacturing is an important and growing sector that is contributing to our economy and creating well-paying middle class jobs. Our government's investment in Burloak's project will help ensure Canada remains at the forefront of advanced manufacturing technology and a globally competitive centre for innovation. "

In addition to the support granted to the project by Ontario's Jobs and Prosperity Fund, the investment was said to have been made possible through the Canadian Strategic Innovation Fund, a programme designed to attract and support high-quality business investments across all sectors of the economy, by encouraging R&D that will accelerate technology transfer and the commercialisation of innovative products, processes and services, and facilitate the growth of innovative firms.

"The announcement by Burloak is a huge step for Canada's Additive Manufacturing sector," added Frank Defalco, Manager of Canada Makes. "We applaud the two levels of government for coming together and supporting Canada's emerging additive sector and we look to keep working with Burloak to make Canada's industries leaders in the adoption of additive manufacturing."

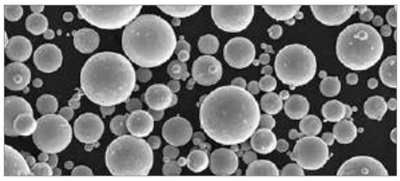
Samuel, Son & Co. is one of North America's largest metal manufacturing, processing and distribution companies. The company employs more than 5,200 people at over 100 facilities worldwide.

www.burloaktech.com

Metal AM parts produced by Burloak (Courtesy Burloak Technologies)


Arcam EBM
a GE Additive company
Arcam EBM
Spectra H
The evolution of a revolution
GE Additive is leading a transformation into a whole new phase of high-volume production. Introducing the Arcam EBM® Spectra H, a machine capable of quickly producing parts at temperatures exceeding 1000°C within an extended build platform. Now manufacturers can produce the largest additive TiAl components ever made. See how the Spectra H is advancing the industry at **ge.com/additive/spectra.**

PyroGenesis signs major deal for sale of titanium powders to Asia



PyroGenesis uses plasma atomisation to produce high-purity spherical metal powders (Courtesy PyroGenesis Canada Inc.)

PyroGenesis Canada Inc., based in Montreal, Quebec, Canada, has signed its first major exclusive commercial agreement for the sale of its titanium (Ti-6Al-4V) powders for use in metal Additive Manufacturing. The deal follows the qualification of its titanium powder by an unnamed client in Asia, and will result in a minimum sales volume of 10,000 kg to the client over two years.

It is anticipated that the agreement will be extended for further terms at the conclusion of the first two-year term. The client is said to specialise in advanced alloy powders for metal AM, as well as other industries, and also produces metal powders and speciality parts.

The client is reportedly well established within the region, which is seeing one of the fastest growing demands for metal powders for AM. P Peter Pascali, President and CEO of PyroGenesis, stated, "This agreement is significant because (i) of the magnitude of the order when compared to previous years revenues, (ii) it validates our strategy as a powder supplier to the AM industry, and (iii) the potential additional growth that can develop from this relationship alone."

"We did not expect to make such inroads into this particular geographic region before 2019, or even 2020," he added. "Although important, we did not see this as being what we call 'low hanging fruit', as we thought it would take a lot more time and effort before we could announce results like we have today. This agreement complements our Asian strategy nicely and was structured in such a way as not to impede other discussions taking place with others in the industry."

Massimo Dattilo, Vice President, Sales, PyroGenesis, commented, "We believe that this is the beginning of a developing partnership as this is only the guaranteed minimum sales volume committed to by the client. Of note, this agreement is for titanium powders only. The client also has a need for nickel alloy powders (such as Inconel) which we have already successfully produced, as well as aluminium alloy powders which we can also produce. We expect to gain traction with respect to these other powders as well."

www.pyrogenesis.com

Formalloy launches new X-series metal Additive Manufacturing system

Formalloy, San Diego, California, USA, launched its new X-series Laser Metal Deposition (LMD) machine during Rapid+TCT, Texas, USA, April, 2018. The metal Additive Manufacturing offers closed-loop control, variable-wavelength lasers and custom powder feeders for the production of gradient/bi-metallic structures.

According to the company, the X-series offers improved quality, better powder efficiency and the ability to process a comprehensive list of metal alloys. Each machine incorporates the company's Formax Metal Deposition Head, a customisable build volume and five-axis capability.

Unlike powder-bed technologies such as Powder Bed Fusion (PBF), Formalloy's LMD process deposits metal with a coaxially aligned laser/powder nozzle. The process is said to achieve much faster build times, improved material properties and a larger build envelope when compared with powder-bed systems. LMD can produce parts with dimensions from less than 1 mm to greater than 1 metre, with bead widths from 250 micron and up.

The X-series uses scanning technology to monitor build quality and accuracy in real-time, and is said to be capable of auto-correcting errors during the build to achieve an end part which is free of defects. Formalloy's components and systems are designed using open standards for powder supply, allowing manufacturers to use their own powders if desired.

Formalloy's LMD technology can be used across a number of industries including aerospace, defence, energy, automotive, chemical and heavy industry. The process is said to have demonstrated capabilities with titanium, Inconel, stainless steels, copper-alloys and other metals, and can be used for part repair and cladding in addition to Additive Manufacturing.

www.formalloy.com

Formalloy's X-Series laser metal deposition systems start at $200K (Courtesy Formalloy)

Huisman and RAMLAB to produce 'world's heaviest' wire-arc additively manufactured crane hook

A 400 mt offshore mast crane aboard a subsea vessel (Courtesy Huisman Equipment)

Netherlands-based companies Huisman Equipment, Schiedam, and Rotterdam Additive Manufacturing Lab (RAMLAB), Rotterdam, have initiated a project to produce a large offshore crane hook using Wire & Arc Additive Manufacturing (WAAM). The hook, which is based on a Huisman 4-prong hook design, will reportedly take advantage of the weight and material savings offered by metal Additive Manufacturing by incorporating a hollow design.

The final product is expected to measure over 1 x 1 m and weigh close to 1000 kg, making it what is thought to be the world's largest steel additively manufactured structure in terms of weight. It will have a Safe Working Load (SWL) of 325 mt, significantly higher than that of a previous WAAM offshore crane hook successfully load tested by Huisman in January 2018, which was said to have a SWL of 80 mt.

RAMLAB is thought to be the first laboratory focused specifically on Additive Manufacturing offshore and marine applications. The laboratory was initiated by the Port of Rotterdam Authority, InnovationQuarter and RDM Makerspace and, in 2017, produced the world's first additively manufactured ship propeller: the 1,350 mm diameter, 400 kg, triple-bladed WAAMpeller. RAMLAB was recently awarded the Manufacturing Leadership Council's Engineering and Production Technology Leadership Award 2018.

By producing a class-certified offshore crane hook using WAAM, Huisman and RAMLAB stated that their goal is to advance common rules and guidelines for the use of WAAM in offshore/maritime engineering.

DNV GL, Bureau Veritas and ABS, three of the leading classification societies for the maritime and offshore industry, are also said to have joined the project, enabling the WAAM offshore crane hook to receive triple certification following its production and successful testing, marking a significant step in the adoption of rules for the AM of structures for the maritime and offshore industry.

In addition, voestalpine Böhler Welding will provide feedstock and materials expertise for the project, while Autodesk will provide support by means of its Additive Manufacturing software.

www.huismanequipment.com
www.ramlab.com

DMG Mori debuts its first additive-only metal AM system in Chicago

Parts produced on the DMG Mori Lasertec 30 SLM metal Additive Manufacturing system (Courtesy DMG Mori Co., Ltd.)

DMG Mori Co., Ltd., Nagoya City, Japan, debuted its new Lasertec 30 SLM metal Additive Manufacturing machine during its Innovation Days in Chicago, Illinois, USA, May 7-10, 2018. The system was developed in collaboration with German-based AM company Realizer GmbH, which joined DMG Mori Group in February 2017.

While it has previously manufactured two hybrid additive and subtractive manufacturing systems, the Lasertec 4300 3D and Lasertec 65 3D, the Lasertec 30 SLM is the company's first additive-only system, and its first to use Powder Bed Fusion technology instead of material deposition.

The Lasertec 30 SLM has a build volume of 300 × 300 × 300 mm and a layer thickness of 20–100 μm, enabling users to manufacture small workpieces such as impellers and dental crowns. The machine is said to be especially suitable for the production of high-mix, low-volume parts or complex-shaped workpieces.

As well as being the company's first additive-only system, this is also DMG Mori's smallest AM machine to date. Its small footprint was reportedly achieved by incorporating fewer movable axes and simplifying overall machine construction. It is also said to incorporate powder recycling for further efficiency and improved powder handling, using a closed powder loop and a removable powder handling unit for contamination-free powder changes between builds.

www.dmgmori.co.jp

Lockheed Martin announces further investments in Additive Manufacturing

Lockheed Martin, Bethesda, Maryland, USA, has announced further investments in the Additive Manufacturing sector. The company recently reported it has added $100 million to its venture capital fund and, as part of its latest wave of investments, has expanded its relationship with nTopology, a New York City based software company and the creator of Element, an advanced CAD software which offers generative, function-based design for engineering, including AM.

"Our investment in nTopology will bring strategic advantages in Lockheed Martin's computational design processes and help shorten the periods between the design and manufacturing phase," stated Chris Moran, VP and General Manager of Lockheed Martin Ventures.

"Our focus is on finding and investing in companies developing cutting-edge technologies that will grow our business and disrupt our industry," he continued. "We're developing long-term strategic partnerships with companies and helping them navigate through the early stages of product development while leveraging our decades of experience working with government customers."

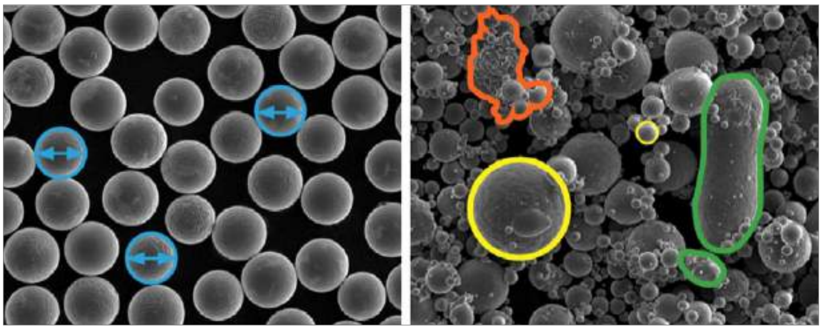
Lockheed Martin is also reported to have invested $5 million in Equispheres, a materials science company based in Ottawa, Canada. The investment is intended to enable Equispheres accelerate its growth in the provision of high-quality spherical metal powders required for technologies such as AM and cold spray deposition.

Equispheres is said to have created a unique technology for producing perfectly spherical metal powder with the specific characteristics desired within the aerospace and automotive industries. Lockheed Martin's investment is expected to allow Equispheres to grow from its existing workforce of twenty to more than 200 employees over the next five years.

"We are very excited to have developed this relationship with Lockheed Martin and secured this investment as it enables Equispheres to offer a broader range of products to the metal powder market, which is doubling in size every 12 to 18 months," stated Kevin Nicholds, CEO of Equispheres.

Charles Bouchard, Chief Executive of Lockheed Martin Canada, commented, "We are very pleased to see our Investment Framework grant going to such an innovative industry leader like Equispheres. The success of this investment is another great example of how large international aerospace companies such as Lockheed Martin can collaborate with smaller businesses in Canada to create opportunities for lasting growth in the Canadian economy."

www.ntopology.com
www.equispheres.com
www.lockheedmartin.com



Equispheres' powder is virtually spherical (left) when compared to conventionally atomised powder (right) (Courtesy Equispheres)

Boeing and Assembrix to collaborate on secure Additive Manufacturing

Boeing and Israel's Assembrix Ltd have signed a Memorandum of Agreement that will enable Boeing to use Assembrix software to manage and protect intellectual property shared with vendors during design and manufacturing.

Assembrix's software will enable Boeing to transmit Additive Manufacturing design information using secure distribution methods to protect data from being intercepted, corrupted or decrypted throughout the distribution and manufacturing processes.

"This agreement expands Boeing's ties to Israeli industry while helping companies like Assembrix expand their business," said David Ivry, President, Boeing Israel. "Boeing seeks suppliers globally who meet stringent quality, schedule, cost and intellectual capital standards, and Assembrix does all of that."

Boeing is focused on leveraging and accelerating Additive Manufacturing to transform its production system and support the company's growth. The company currently has AM capabilities at twenty sites worldwide and partners with suppliers across the globe to deliver AM parts across its commercial, space and defence platforms.

"We are pleased to partner with Boeing and value its confidence in us and in our capabilities," said Lior Polak, Assembrix CEO. "This collaboration supports our vision to develop and implement innovative solutions that connect the world and take the Additive Manufacturing digital thread one step forward."

www.boeing.com
www.assembrix.com


ADDITIVE MANUFACTURING
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▪ No oxygen entry – no loss of inert gas
▪ Prevention of oxidation and lack-of-fusion defects
▪ Frequency inverter control for optimized adaption to variable process conditions
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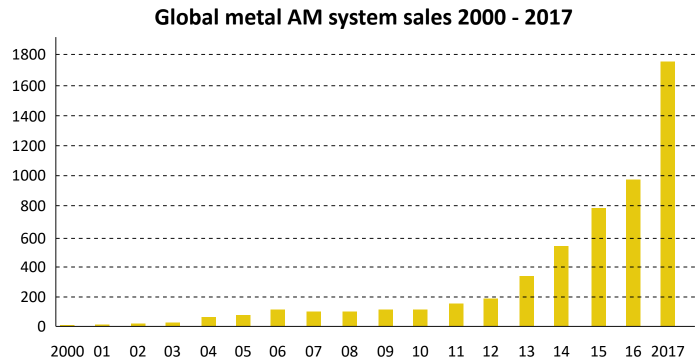
Wohlers Report 2018 reflects major increase in metal Additive Manufacturing systems



Wohlers Report 2018 reflects significant rise in yearly metal AM system sales (Courtesy Wohlers Associates Inc.)

Wohlers Associates, Inc., Fort Collins, Colorado, USA, has released its latest industry report, *Wohlers Report 2018*. *Wohlers Report* is a leading global review of the state of the Additive Manufacturing industry and has been published for twenty-three consecutive years.

According to the new 343 page report, sales of metal AM systems saw an increase of nearly 80% in 2017, with an estimated 1,768 metal AM systems sold throughout the year compared to 983 systems in 2016. This dramatic rise in metal AM system installations accompanies improved process monitoring and quality assurance measures in metal AM. Increasingly, the report stated, global manufacturers are becoming aware of the benefits of producing metal parts by Additive Manufacturing.

Wohlers Associates found that 135 companies around the world produced and sold industrial AM systems (defined as machines that sell for more than $5000) in 2017, up from 97 companies in 2016. New system manufacturers continued to enter the AM market at a rapid rate, releasing machines with open material platforms, faster print speeds and lower pricing. Seventy-six co-authors and contributors from thirty-two countries are said to have provided their data and expertise to the compiling of *Wohlers Report 2018*. The report includes new and expanded sections on design for Additive Manufacturing, post-processing, and a range of start-up companies and research initiatives.

www.wohlersassociates.com

Boeing adds Norsk Titanium's PDQC to its official Qualified Producers List

Norsk Titanium's Development and Qualification Center in Plattsburgh, New York (Courtesy Norsk Titanium)

Norsk Titanium (NTi), New York, USA, a supplier of aerospace-grade, additively manufactured structural titanium components, has announced that its Development and Qualification Center (PDQC) in Plattsburgh, New York, has been added to Boeing's official Qualified Producers List (QPL).

The PDQC reportedly initiated qualified production on May 15 by manufacturing its first part under the Boeing contract. This achievement is said to be a culmination of recent company successes, including NTi's certification under AS9100D.

"We could not be prouder of our Plattsburgh, New York production operations as they put another stake in the ground for the continued success of Norsk Titanium and the state of New York," stated Tamara Morytko, NTi's Chief Operating Officer. "Receiving this qualification from Boeing, now qualifying two NTi sites for production across the globe, is a true vote of confidence in our service, quality and disruptive RPD™ technology."

PDQC will produce aerospace components for Boeing and other aerospace manufacturers. It currently houses nine of NTi's proprietary Rapid Plasma Deposition (RPD) titanium Additive Manufacturing machines, developed at Norsk's Engineering and Technology Center in Norway. The Norwegian facility continues to operate qualified and approved RPD Machines.

In 2017, Norsk announced its first production order from Boeing Commercial Airplanes for the manufacture of AM structural titanium components for the 787 Dreamliner. The company later announced a 60% expansion of the PDQC facility, located near the future site of the planned Norsk Titanium Production Center.

Norsk RPD uses titanium wire with plasma torches to manufacture titanium structural components on an industrial scale, and can be used to produce large structural parts weighing over 45 kg. It is also said to be 50-100 times faster than powder-based systems and use 25-50% less titanium than incumbent forging processes. It has current and potential applications in aviation, space, transportation, oil & gas and maritime.

www.norsktitanium.com

MELD to offer unique metal Additive Manufacturing process

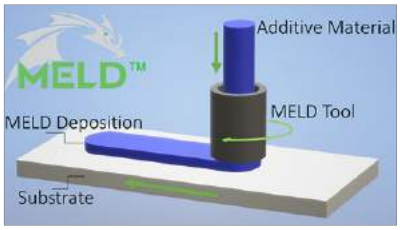
Aeroprobe Corporation, Christiansburg, USA, reports that it is to commercialise its patented MELD manufacturing process after over a decade of research and development. The commercialisation process will include the establishment of a spin-off venture, MELD Manufacturing Corporation.

The company holds more than a dozen patents for MELD, a solid-state process which can be used to manufacture parts in a wide range of materials, including metal powders and rods. It can also be used with metal chips generated as the waste material in other manufacturing processes. "We identified an area in the Additive Manufacturing industry that could be improved upon and put a lot of time and effort into making it happen. The MELD process is a game changer in the AM field and beyond," stated Nanci Hardwick, MELD CEO.

Chase Cox, Additive Manufacturing Manager at MELD, explained, "What sets us apart from other technologies is that we aren't melting. When you melt, you introduce weakness and other issues. By taking the material up to a point where it is malleable but not melted, we end up with properties that meet or exceed similar processes and, in some cases, even those of the original material."

While there are other AM processes which do not require melting of the feedstock material, MELD is said to be further differentiated by the fact that it is an open atmosphere process, meaning that no special chambers or vacuums are needed to operate a MELD machine.

"Being open atmosphere means less equipment and fewer headaches," continued Cox. "From a manufacturing standpoint, it also means that MELD isn't limited in the size of the parts it can make. Compared to similar processes, we can make parts that are not only bigger, but also superior in quality and material options."



MELD is a solid-state process which can be used to manufacture parts in a wide range of materials (Courtesy MELD Manufacturing)

As well as being used to additively manufacture components, the MELD process can be used to repair, coat and join materials, and could make it possible to weld previously unweldable materials. The process is reported to deposit material at least ten times faster than fusion-based metal AM processes.

www.meldmanufacturing.com

SAE International issues new technical standards for aerospace AM

SAE International has released its first suite of Aerospace Material Specifications (AMS) for materials and processes used in the metal Additive Manufacturing of aircraft and spacecraft critical parts. The new standards are expected to aid the certification of metal AM parts for aerospace by providing a framework to protect the integrity of material property data and provide traceability within the supply chain. The four new standards are:

- AMS7000: Laser-Powder Bed Fusion (LPBF) Produced Parts, Nickel Alloy, Corrosion and Heat-Resistant, 62Ni – 21.5Cr – 9.0Mo – 3.65Nb Stress Relieved, HIP and Solution Annealed
- AMS7001: Nickel Alloy, Corrosion and Heat-Resistant, Powder for Additive Manufacturing, 62Ni – 21.5Cr – 9.0Mo – 3.65Nb
- AMS7002: Process Requirements for Production of Metal Powder Feedstock for Use in AM of Aerospace Parts
- AMS7003: Laser Powder Bed Fusion Process

"Given that advanced materials and advanced manufacturing are strategic focus areas for SAE International, we are committed to supporting the aerospace industry's adoption of Additive Manufacturing technologies," stated David Alexander, Director, Aerospace Standards, SAE International.

"Tremendous effort was expended by industry and regulatory stakeholders from North America, Europe and beyond to develop this initial suite of material and process specifications which help address the regulatory authorities' request for guidance material for this emerging technology," he continued.

"SAE looks forward to assisting with the migration from point design to material qualification by continuing to develop additive manufacturing aerospace material and process documents containing statistically validated specification minimum values."

Established in 2015 and supported by a Federal Aviation Administration tasking letter to assist regulatory authorities in developing guidance materials for AM certification, SAE International's AMS-AM Additive Manufacturing Committee continues to develop AMS specifications for metal and polymer AM to support the needs of the aerospace industry.

Over 350 global participants from more than fifteen countries representing aircraft, spacecraft, and engine OEMs, material suppliers, operators, equipment/system suppliers, service providers, regulatory authorities and defence agencies are said to be active on the committee.

www.sae.org/standards

Italian AM dental implant business Yndetech reports success with 3D Systems

3D Systems, Rock Hill, South Carolina, USA, has reported that Yndetech, a supplier to the dental market based in Fano, Italy, recently celebrated its 700th customer, just two years after it launched. The company acquired its first ProX® DMP 100 metal Additive Manufacturing machine from 3D Systems shortly after it opened its doors in June 2016 and today has four of the ProX® DMP 100 systems installed, producing high-quality dental implants and other dental devices for the Italian market.

Emidio Cennerilli, President and CEO of Yndetech, stated, "My partner, Francesco Grande, and I realised that the quality of the pieces we were seeing from the DMP 100 was absolutely outstanding. We shared these results with the dental technicians in the area and the feedback was very positive."

The quality and throughput of its metal Additive Manufacturing systems enabled Yndetech to provide its customers – predominantly dental technicians – with a twenty-four hour turnaround service.

"Today we are printing a complete portfolio of dental devices with this laser melting technology using 3D Systems' cobalt-chrome material, including bridges, abutments, and implant bars," explained Cennerilli. "Cobalt-chrome has many advantages for dental applications such as biocompatibility, high wear resistance, easy to polish, chrome makes it more resistant to corrosion, and the very smooth surface finish makes it difficult for bacteria to attach to it."

Yndetech is supported on-site by 3D Systems' channel partner 3DZ Italy. 3DZ provides application expertise together with technical support for all of Yndetech's ProX DMP 100 systems, while ensuring that materials are delivered on time to maintain high customer satisfaction.

The 3D Systems workflow supports 24-hour turnaround

Dental technicians upload their dental CAD files to the Yndetech site or send them via email by 3pm. Using 3D Systems' Phenix dental software, the Yndetech operator nests the various devices for printing on the ProX DMP 100's plate. Within three hours, the files are ready to build overnight. The next morning, the parts undergo post-processing and are sent to customers by courier by 5pm. Five to six hundred dental elements are produced this way each day.

"Since I first became acquainted with Yndetech and their 3D Systems laser melting solution, I could no longer work without them. Compared to the other types of manufacturing processes and other milling centers, Yndetech has allowed me to produce dental elements with very high quality and precision – making my job easier and more accurate at the same time," said Graziano Bruni, Laboratorio Odontotecnico Bruni & Pellanera. "The cobalt-chrome implants with the easily–removed, thin support structures are my favourite, and competitively priced for the truly excellent quality we receive."

ISO certifications

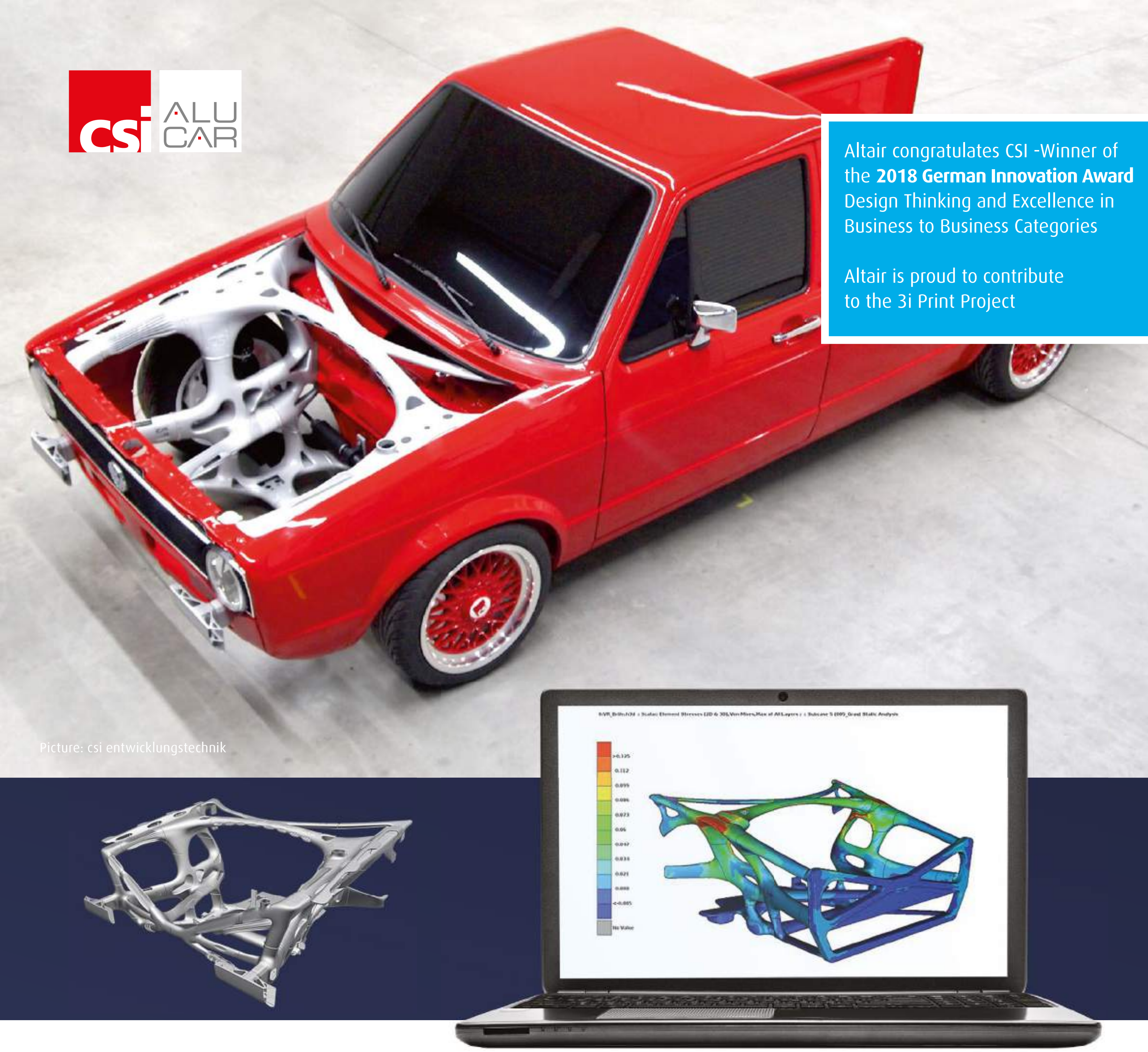
Yndetech is certified to ISO 9001 and ISO 13485 to manufacture medical and dental parts. "This level of certification is important to Yndetech's customers to give them the peace of mind that they are receiving the level of quality and service they expect for dental implants," stated Cennerilli.

"The quality of the parts in terms of the surface finish is the reason we were able to build this business so quickly. Another important factor is the price/performance ratio of the materials, which is quite attractive. The reaction from the Italian market has been so strong, now we are looking to expand our business to other countries."

"We are pleased to see a young company like Yndetech succeed so rapidly in a competitive environment where absolute accuracy and predictability are expected," added Wayne Davey, General Manager, EMEA & India, 3D Systems. "Their success confirms the quality of our complete digital dentistry solutions, which include software, plastic and metal materials, 3D printers and on demand manufacturing – supported by the dedication and experience of our local channel partner 3DZ. We encourage all dental labs, clinics and service providers to compare the quality and precision of our regulatory-approved solutions for the complete range of dental applications."

www.yndetech.com
www.3dsystems.com

Yndetech produces AM dental implants and related devices (Courtesy Yndetech)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Altair congratulates CSI -Winner of the **2018 German Innovation Award** Design Thinking and Excellence in Business to Business Categories
Altair is proud to contribute to the 3i Print Project
Picture: csi entwicklungstechnik


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AM PROCESS TECHNOLOGIES
MANUFACTURING EXCELLENCE
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Researchers use X-ray imaging to probe metal AM process

A team of researchers at Lawrence Livermore National Laboratory (LLNL), California, USA, has successfully designed, built and tested a portable diagnostic machine which uses X-ray imaging to 'probe' the inside of metal parts during laser Powder Bed Fusion (PBF), revealing many of the complex mechanisms that can drive defect formation and limit part quality in metal Additive Manufacturing. The research is being carried out in partnership with SLAC National Accelerator Laboratory and Ames Laboratory, funded by the USA Department of Energy's Energy Efficiency and Renewable Energy (EERE) Advanced Manufacturing Office.

The portable diagnostic machine, capable of probing the melt pool, was developed and designed by LLNL researcher Nick Calta and his team. At the Stanford Synchrotron Radiation Lightsource at SLAC, researchers were then able to evaluate the method and successfully observe melt pool dynamics beneath the surface, providing researchers with new insights into the process. The research was published earlier this month in the Review of Scientific Instruments.

The instrument provides data on a combination of imaging and X-ray diffraction, allowing researchers to see how the metal solidifies, a key determiner of a part's strength. The team was immediately able to glean meaningful data which they are reportedly still in the process of analysing. "A vast majority of diagnostics use visible light, which are extremely useful but also limited to analysing the surface of the part," explained Calta. "If we're going to really understand the process and see what causes flaws, we need a way to penetrate through the sample. This instrument allows us to do that."

"We're getting information about the melt pool structure and what can go wrong during a build," added LLNL physicist and Laser Materials Science group leader Ibo Matthews, who in recent years has been developing experimental methods to understand the physics behind the laser fusion process. "The vapour plume created by laser heating the melt pool can create pockets and pores. These pore defects can serve as stress concentrators and compromise the mechanical properties of the part."

Matthews explained that the ability to see the layers formed at the melt pool and compare the X-ray images to simulations is confirming predictions of how the laser's path, heat build-up and the gas plume caused by the laser can create defects. Combining this understanding with modelling and detailed experiments could help accelerate improvements and confidence in parts produced using metal AM.

"Success would be learning more about the physics in ways that let us modify the process to avoid defects," Calta continued. "So far we're getting promising results. We want to continue to optimise the instrument and apply it to different material systems. We already have a big body of knowledge based on optical data, this lets us branch out and complement that knowledge."

While the collaboration is still in its initial stages, Calta stated that researchers have already begun mapping pore formation and extracting information on cooling rates. Eventually, the researchers want to exploit their flexibility to add optical diagnostics typically used on commercial machines to correlate with the X-ray imaging.

"You can't tell what's inside the box by looking outside the box," Van Buuren stated. "The purpose of this project is to accelerate the adoption of AM for metallic components across the manufacturing sector by developing sophisticated in-situ tools to enable rapid process development of the AM components. With new materials, we don't yet understand the properties and we need to be able to look at the process in real-time. It's a bit different focus than what we usually do at the lab. We want to build up a capacity that industry would come in and use."

www.llnl.gov

Researchers (from left) Phil Depond, Nick Calta, Aiden Martin and Jenny Wang are part of a multi-lab team that has successfully designed, built and tested a portable diagnostic machine capable of probing inside metal parts during AM (Courtesy Julie Russell/LLNL)

Innovation by Matsuura

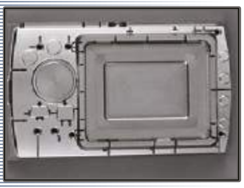
Hybrid Additive Manufacturing

Seamless Metal Laser Sintering & Milling Process

LUMEX Avance-25

Build Volume:

(D)250mm x (W)250mm x (H)185m
(D)250mm x (W)250mm x (H)300m *
(* Option)



HOLLOW — **COMPLEX GEOMETRY**
3D Cooling Channels
Internal Features

POROUS — **VARIABLE DENSITY**
Gas Venting
Gas Assist

NO EDM — **LAYER MACHINING**
High Aspect Features
Reduce EDM Processing

MILLING — **PROFILE MACHINING**
High Accuracy
Precision Finished Parts

TIME — **TIME SAVING**
One Process Manufacture
Reduced Lead Times

The ***Matsuura LUMEX Avance-25*** is the world's first hybrid powder bed fusion machine. The combination of additive technology and ***Matsuura's*** 80 years of subtractive high speed milling technology into one seamless process, enables the production of complex, high accuracy molds and parts in a method that has never been possible, nor imagined. Further adding to ***Matsuura's*** expertise in the Hybrid metal AM field, this technology is now available on the new ***Matsuura LUMEX Avance-60*** possessing the largest powder bed platform available on the market.

LUMEX Avance-60

Build Volume:

(D)600mm x (W)600mm x (H)500m

See the newly released Matsuura Avance-60 with the largest powder bed platform available on the market.

More information at lumex-matsuura.com and matsuurausa.com

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Centinel Spine granted FDA clearance for its metal AM spinal implants

Centinel Spine, LLC, West Chester, Pennsylvania, USA, has received 510(k) clearance from the US Food and Drug Administration (FDA) to market its FLX™ Platform of Integrated Interbody™ and non-integrated interbody fusion devices. Centinel is said to be the largest privately-held spine company, and is focused on the manufacture of devices for reconstructing the anterior column (the pronounced, ventrally oriented ridge of grey matter in each half of the spinal cord).

The FLX range comprises a number of all-titanium additively manufactured devices which feature a combination of solid and porous radiolucent sections (transparent under X-rays) designed to reduce mechanical stiffness and improve visibility compared to solid titanium implants. The devices also feature the company's proprietary FUSE-THRU™ trabecular scaffold, designed to allow for bony in-growth and on-growth throughout the implant.

"We are excited to announce the clearance of the FLX Platform, which represents the next evolution in STALIF technology," stated John Viscogliosi, Centinel Spine Chairman & CEO. "Utilising AM, we are able to offer the proven benefits of the STALIF design in a truly novel, all-titanium lattice option. This allows our surgeons the flexibility to use multiple implant material options through a single set of instruments to address each patient's unique pathology."

STALIF FLX Integrated Interbody devices are said to offer a unique advantage over other all-titanium implants as they are indicated for use at one or two contiguous levels, with both autograft bone grafts, using the patient's own bone, and allogenic bone grafts, using donated or harvested bone from a second individual.

www.centinelspine.com

Centinel's proprietary FUSE-THRU trabecular scaffold allows for bony in-growth and on-growth throughout the implant (Courtesy Centinel Spine, LLC)

MTU Aero Engines establishes new team to focus on AM for aerospace

MTU Aero Engines, Munich, Germany, has established a new department dedicated to Additive Manufacturing for aerospace applications. Led by Dr Jürgen Kraus, the department is staffed by around thirty professionals from various technical disciplines including design engineers, structural mechanics engineers, process specialists and operations scheduling experts.

According to Lars Wagner, MTU's Chief Operating Officer, the department aims to "maintain and build [the company's] competitive edge," and accelerate the development of AM technologies "by pulling all activities – from design to technology development and all the way to production – together in one unit." The team is said to be looking into new conceptual designs for applications and constructions from a bionics viewpoint, with the aim of pushing the development of the production technology forward and industrialising the entire process chain.

"With the development of new machine types and improved online process control, it will be possible to produce an increasing number of components by Additive Manufacturing in a cost-effective manner," explained Dr Jörg Henne, Senior Vice President, Engineering and Technology. MTU uses Selective Laser Melting in the production of its borescope bosses for the PurePower®PW1100G-JM geared turbofan engine, which has powered Airbus's A320neo jetliner since 2013.

As part of Clean Sky, thought to be the largest technology initiative ever launched in Europe, MTU is currently working on a seal carrier manufactured using AM processes. The inner ring, featuring an integral honeycomb structure, will be installed in the high-pressure compressor and is expected to contribute to improving clearance control, and hence increasing efficiency. Additional components, such as bearing housings, brackets and struts, will follow. The company stated that it also plans to further enhance the process monitoring system and improve the surface finish.

MTU first began developing its Additive Manufacturing capabilities more than ten years ago, "making tools, such as spray nozzles and grinding wheels, as well as parts with a simple geometry for experimental testing," explained Kraus. Later, castings and milled parts were replaced using AM parts, and work on the turbofan engine's borescope bosses began to pick up speed. Now, MTU stated that it plans to redesign and produce a number of lightweight components across its product offering.

www.mtu.de

New air classifier helps optimise metal powder particle size distribution

Blue Power Casting Systems GmbH, Walzbachtal, Germany, has introduced a new version of its AC 1000 air classifier for metal powders. The AC 1000 has been specially developed for the economic and flexible separation of small powder batches into fine and coarse fractions, especially those in the <25 µm range, where conventional screening methods no longer work. The company states that it is suited for use in research and development as well as for demanding PIM and AM projects with special requirements for particle size distribution.

Specifically designed for small powder quantities and for frequent changes of alloys or desired particle sizes, the company stated that the development focus of the system was on simple handling, precisely controllable classification, high process stability and above all the fastest, safest cleaning possible to avoid metal losses and cross-contamination by powder residues.

Air flow has been optimised to be able to define the size distribution even more precisely and a central layout of the operating touch screen, optimal accessibility of the components and simplified cleaning has improved the ergonomics of the system. The turbine unit can now be selectively raised by means of an integrated crane with pulley and cleaned of powder residues.

Blue Power Casting Systems stated the most significant advances are the optionally available or GS versions. The AC 1000 G enables separation under a protective gas atmosphere, greatly reducing potential oxidation in reactive metals. In addition, the GS version is an explosion-proof version that can be used to safely process explosive metals such as aluminium, magnesium, zirconium or titanium alloys.

www.bluepower-casting.com

The AC 1000 air classifier from Blue Power Casting Systems

Medtronic launches platform for Additive Manufacturing of complex titanium spinal implants

The ARTiC-L Spinal System incorporates a honeycomb structure to encourage osseointegration of the surrounding bone (Courtesy Medtronic plc)

Medtronic plc, Dublin, Ireland, has launched a titanium Additive Manufacturing platform which it states enables more complex designs and integrated surface technologies for spinal surgical implants. The announcement was made during the American Association of Neurological Surgeons (AANS) annual meeting in New Orleans, Louisiana, USA.

The new platform, titled TiONIC™ Technology, is an Additive Manufacturing technique said to create enhanced surface textures using a differentiated laser method. This enables the production of implants with rough three-dimensional surface structures which imitate natural trabecular bone morphology, increasing osteoconductivity and promote bone in-growth (osseointegration).

The first implant to be manufactured using the TiONIC process is its ARTiC-L™ spinal system, which incorporates a 'honeycomb' structure. The titanium implant is designed for use in transforaminal lumbar interbody fusion spinal surgery. As well as encouraging osseointegration of the surrounding bone, the honeycomb structure reportedly provides improved mechanical load distribution across the implant.

"ARTiC-L is an important component of Medtronic's portfolio of reproducible solutions for minimally invasive procedures," stated Doug King, Senior Vice President and President of Medtronic's Spine Division, which is part of the Restorative Therapies Group at Medtronic. "Our 3D printed TiONIC Technology allows devices such as ARTiC-L – and our future interbody implant portfolio – to offer surgical advantages not traditionally possible."

Dr Colin C Buchanan, a neurosurgeon at the Colorado Brain and Spine Institute, USA, commented, "Surface advancements, like TiONIC Technology, have emerged as a paradigm shift in interbody fusion implants. Implants utilising newer surface technology can help stimulate a cellular response and give me greater confidence that the patient will have a successful fusion."

www.medtronic.com

Javelin Technologies and Cimetrix Solutions merger

Javelin Technologies, Oakville, Ontario, and Cimetrix Solutions, Oshawa, Ontario, have merged with the aim of providing an enhanced service offering to a combined total of around six thousand customers in Canada.

Javelin Technologies provides AM design engineering, product data management, automation and industrial metal and plastic Additive Manufacturing and is a trusted reseller for Solidworks software and Desktop Metal machines. Cimetrix offers Additive Manufacturing and laser scanning solutions for both industry and education, in fields as varied as automotive, aerospace and medicine.

The senior management team for the integrated company will consist of John Carlan and Ted Lee, Javelin's co-founders and Owners, and James Janeteas, founder, CEO and President of Cimetrix. Javelin will continue to be known as Javelin Technologies, while Cimetrix will now be referred to as 'Cimetrix Solutions, a division of Javelin Technologies.' "Our focus has always been on taking care of our customers by understanding what drives their business and providing solutions that affect the bottom line," Janeteas stated. "I'm excited because by combining our expertise and resources, we can be even more responsive and provide even deeper application knowledge and advice."

"We shorten the distance between idea and production," added Lee. "We help people and businesses execute well, and that's never been more important. Joining Javelin and Cimetrix means we're putting ourselves exactly where our customers will be and will need us to be."

Javelin and Cimetrix are already said to be highly involved in rapidly changing, high-growth sectors such as manufacturing, energy and healthcare. In addition, Javelin reported that it has a new investment partner – CAI Capital Partners, a private equity firm based in Vancouver, British Columbia. CAI has a long history of partnering with Canadian founder-led businesses to support growth initiatives and build upon their past success

Rich Garrity, President, Americas for Stratasys, commented that the Stratasys team sees the merger as a positive step. "For the past seventeen years, Stratasys has had strong representation in the Canadian market with our veteran partners Cimetrix Solutions and Javelin Technologies. The Additive Manufacturing landscape is changing at an ever-increasing rate and we value and need strong, industry-defining partnerships to help customers navigate."

www.javelin-cimetrix.com

中航迈特
AMC POWDERS

ISO 9001
ISO 13485:2016

Powder Solutions for Metal AM

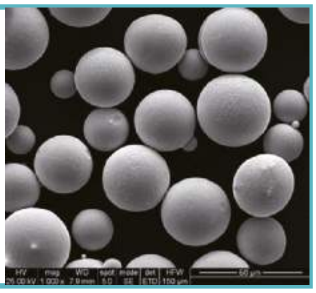
Main Powders

Titanium: Ti CP, Ti64 Gr5/Gr23, BT9, BT20, Ti6242, Ti4822, Ti2AINb, NiTi50
Nickel: IN718, IN625, IN713, Hastelloy X, Hastelloy C276, Waspaloy
Cobalt: CoCrMoW, CoCrMo, CoCrW, HA 188
Stainless Steel: 316L, 17-4PH, 15-5PH
Die Steel: 1.2709(MS1), Corrax, H13, S136
Aluminium: AISi10Mg, AISi7Mg
Refractory Metal: W,Mo, Ta, Nb, Cr, Zr

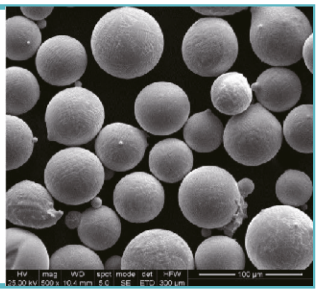
Additional alloys are available upon request

Advanced Atomization System for Metal Powder Production

Ti64 Gr5
15-45μm



IN718
15-45μm



Powder Characteristics

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

Capacity

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

Particle size range(min/max)

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

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Aurora Labs produces its first metal powders for Additive Manufacturing

Aurora Labs Ltd, Bibra Lake, Western Australia, has produced the first batch of laboratory test-scale powder from its prototype powder production unit. According to the company, the prototype system is intended to test and demonstrate its technology for producing high-quality powders for use in metal Additive Manufacturing.

It is reported that Aurora's process allows AM-suitable metal powders to be produced at substantially lower costs than is possible with existing processes. Now, the company will seek to prove its capacity for high-volume powder production, confirming yields and quality parameters.

David Budge, Managing Director, Aurora Labs, stated, "The result for producing our first powder is an outstanding achievement for the company. The process of going from concept through to patenting and production of a product is at times an arduous one, but the team has worked extremely hard, determined to achieve this outcome."

"Seeing a result where we have produced high-quality spherical powder where almost all of the powder produced is within a very narrow size range is a remarkable result and one that the company and its staff can be proud of," he continued. "This development opens up significant new opportunities for the company. We hope that this result will pave the way for Aurora Labs to become a global player in a highly compelling industry."

In addition to its powder development efforts, Aurora manufactures the S-Titanium Pro small format metal Additive Manufacturing machine. Priced at around $50,000, this is thought to be one of the most affordable metal AM systems on the market.

Aurora is also continuing to develop its large format Additive Manufacturing technology, and has reportedly produced a significant number of parts and shapes with its prototype. Recently, the company stated that it has achieved the goal of additively manufacturing simple parts at a rate comparable to existing technologies on the market.

It is intended that the powders produced from Aurora's powder production unit will support part of the projected high utilisation of consumables from the company's large format printers.

www.auroralabs3d.com

Australian researchers explore use of AM for aircraft repairs

A team of researchers at the Royal Melbourne Institute of Technology (RMIT), Melbourne, Australia, is exploring the use of Laser Metal Deposition (LMD) Additive Manufacturing to build and repair steel and titanium parts for Australian Defence Force aircraft in collaboration with RUAG Australia and the Innovative Manufacturing Cooperative Research Centre (IMCRC).

LMD is an Additive Manufacturing process in which metal powder is fed into a laser beam, which is scanned across a surface to deposit the material in a precise, web-like formation. It can be used to produce parts from scratch or to repair existing parts with a bond that is as strong as, or in some cases stronger, than the original. "It's basically a very high-tech welding process where we make or rebuild metal parts layer by layer," explained Professor Milan Brandt, the research team lead, who says the concept is proven and that prospects for its successful development are positive.

Neil Matthews, Head of Research and Technology at RUAG Australia, stated that the technology has the potential to transform the concept of warehousing and transporting for defence and other industries. Currently, replacement parts must be stored in warehouses before being transported to customers as needed, but this technology means parts could be built or repaired onsite. "Instead of waiting for spare parts to arrive from a warehouse, an effective solution will now be on-site," he commented. "For defence forces this means less down-time for repairs and a dramatic increase in the availability and readiness of aircraft."

The technology will apply to existing legacy aircraft as well as the new F35 fleet, and the move to locally additively manufactured components is expected to offer cost savings on maintenance and spare part purchasing, scrap metal management, warehousing and shipping costs. An independent review, commissioned by BAE Systems, estimated the cost of replacing damaged aircraft parts to be more than $230 million a year for the Australian Air Force.

CEO and Managing Director of the IMCRC, David Chuter, believes the technology also has applications in many other industries. "The project's benefits to Australian industry are significant," he stated. "Although the current project focuses on military aircraft, it is potentially transferable to the civil aircraft, marine, rail, mining, and oil & gas industries. In fact, this could potentially be applied in any industry where metal degradation or remanufacture of parts is an issue."

The two-year project is the latest in a series of collaborations between RUAG Australia and RMIT's Prof Brandt.

www.rmit.edu.au
www.ruag.com.au
www.imcrc.org

Titomic and Fincantieri work to develop titanium AM for shipbuilding

Titomic Ltd, Melbourne, Australia, has entered into a Memorandum of Understanding with Fincantieri Australia PTY LTD, Adelaide, the Australian division of Italy's Fincantieri S.p.A, Europe's largest shipbuilder. The twelve-month agreement is Titomic's first for the marine sector, and will enable the company to evaluate the potential for its Titomic Kinetic Fusion AM technology in Fincantieri's manufacturing activities.

Titomic Kinetic Fusion (TKF) is a proprietary and patented process co-developed with Australia's CSIRO for the application of cold-gas dynamic spraying of titanium or titanium alloy particles onto a scaffold to produce a load-bearing structure. The process is said to allow dissimilar metals, alloys, composites and hybrid materials to be fused together, creating new advanced materials and parts with engineered properties not available with any other manufacturing technology.

The shipbuilding sector is said to be a very traditional and cost-oriented industry. By signing with Fincantieri, the fourth largest shipbuilder in the world with twenty shipyards across four continents, Titomic will have the opportunity to use its proprietary processes to complement and improve existing manufacturing process.

"This agreement with Fincantieri marks a significant milestone for future shipbuilding and industrial scale Additive Manufacturing. Titomic's signing with Fincantieri to evaluate our Titomic Kinetic Fusion process will not only add value to existing manufacturing and repair activities, it will lead to the creation of next generation high-tech vessels," stated Jeff Lang, CEO & CTO of Titomic.

Fincantieri, reported to be the leader in cruise ship design and construction, is involved in many shipbuilding industry sectors including naval and offshore vessels, ferries, mega-yachts, ship repairs and conversions, systems and equipment production and after-sales services. Fincantieri also carries out maintenance and refurbishment of cruise ships, said to be a major and growing international industry.

Dario Deste, Chairman of Fincantieri Australia, stated, "We are pleased to partner with Titomic, an innovative advanced manufacturing company, to pursue new technological development, continuous improvement and value creation for all our stakeholders."

The project's initial R&D phase will be run from Titomic's Melbourne facility, which was opened officially on May 16, 2018. The site is said to house a TKF system with a 40.5 m^3 build area, which the company believes makes it the largest Additive Manufacturing machine in the world.

www.titomic.com
www.fincantieri.com

Fincantieri is a key figure in cruise ship design and construction (Courtesy Fincantieri)

3D Systems partners with shipbuilder Huntington Ingalls

3D Systems, Rock Hill, South Carolina, USA, announced a collaboration with Huntington Ingalls Industries' Newport News Shipbuilding (NNS) division in Virginia, USA, on the qualification of metal Additive Manufacturing technologies for the construction of naval warships. NNS is the sole designer, builder and refueller of US Navy aircraft carriers and one of two providers of US Navy submarines.

Under the agreement, the shipbuilder stated that it will move portions of its manufacturing process from traditional methods to AM, and sees the potential for enhanced production rates of high-accuracy parts, reduced material waste and significant cost savings. 3D Systems reports it has already delivered and installed one of its ProX® DMP 320 metal AM systems at NNS's site, where it plans to use the system to produce alloy replacement parts for castings as well as valves, housings and brackets for future nuclear-powered warships. The companies reported that they are also developing new AM technologies to further enhance part production.

The collaboration with NNS marks the culmination of longstanding joint R&D efforts to qualify metal AM for the production of components for nuclear-powered naval vessels. Charles Southall, Vice President of Engineering and Design at NNS, added, "Newport News Shipbuilding is leading the digital transformation to further revolutionise how shipbuilders build the next generation of warships. With the inclusion of the ProX DMP 320 into our manufacturing workflow, this marks the first metal 3D printer installed at a major US Navy shipyard. With this disruptive technology, Newport News has the potential to reinvent shipbuilding."

www.3dsystems.com
www.huntingtoningalls.com

voestalpine begins construction of advanced special steel plant in Austria

A recent ground-breaking ceremony has marked the official start of a three-year construction phase for the new €350 million voestalpine special steel plant in Kapfenberg, Austria. From 2021 onwards, the plant will produce around 205,000 tons of high-performance steels a year.

Once operational, the new high-tech special steel plant is intended to replace the existing voestalpine Böhler Edelstahl GmbH & Co KG plant in Kapfenberg and is designed to produce premium quality pre-materials for aircraft components, tools for the automotive industry, equipment for oil & gas extraction, and for the Additive Manufacturing of highly complex metal parts.

"Today's ground-breaking ceremony for the new plant is not only a milestone for our group, and Kapfenberg as a location, but also a positive signal for European industry, as this is the first investment in a completely new steel plant in decades," stated Wolfgang Eder, Chairman of the Management Board of voestalpine AG.

voestalpine's High Performance Metals Division is the global market leader for tool steel and a leading provider of high-speed steel, valve steel, and other products made of special steels, as well as powder materials, nickel-based alloys, and titanium. It is focused on producing and processing high-performance materials and customer-specific services including heat treatment, high-tech surface treatments, and Additive Manufacturing processes.

"This investment provides voestalpine with a global technological lead and cost advantage in manufacturing high-performance steels, and allows us to remain globally competitive over the long term, even when producing at a traditional European location," added Eder.

The voestalpine Group has around 50,000 employees worldwide, with the High Performance Metals Division accounting for 13,700 employees.

www.voestalpine.com

The ground-breaking ceremony marked the official start of construction (Courtesy voestalpine)

Sigma Labs demonstrates closed-loop quality control

Sigma Labs, Inc., Santa Fe, New Mexico, USA, a provider of quality assurance software, has developed and demonstrated closed-loop feedback control of the metal laser Powder Bed Fusion Additive Manufacturing process. Using Sigma's PrintRite3D® technology, the system reportedly operates by monitoring the process output and extracting process metrics.

These process metrics are then compared to baseline metrics. The system determines what process input parameter values need to be changed and implements those remedial changes in real time by signaling a change in laser power in order to maintain process control.

Mark Cola, Chief Technology Officer of Sigma Labs, stated, "Automatic feedback process control was the next step in completing Sigma Labs' suite of sensing, monitoring and control capabilities of metal Additive Manufacturing processes. Our addition of real-time process control clearly sets Sigma as the leader in AM process quality assurance."

The company has patents pending covering its closed loop control of melt pool quality during metal AM and is said to be planning beta testing with select end-user customers across various market segments.

www.sigmalabsinc.com

China's MTI receives enterprise award and certification for its cobalt dental alloys

CoCrMoW alloy is used for numerous dental applications due to its high strength, corrosion resistance (Courtesy MTI)

Since its establishment in 2014, Material Technology Innovations Co., Ltd (MTI), Guangzhou, China, reports that it has seen ongoing growth in the Additive Manufacturing sector. The company manufactures metal powders for Additive Manufacturing, thermal spray and Metal Injection Moulding applications and currently operates out of a 1,200 m^2 facility equipped with gas and water atomisation systems.

MTI's metal powder portfolio includes cobalt based alloys, stainless steels, titanium alloys and nickel alloys. In addition, the company works with partners on customised alloy development, and operates an ongoing programme of research and development, using state-of-art equipment to study the properties of metals and their performance.

The company recently won a 'High-tech Enterprise' award, issued jointly by the Government Science and Technology Department of Guangdong Province, Guangdong Provincial Department of Finance, National Taxation of Guangdong Province and Local Taxation Bureau of Guangdong Province. This award recognises the company's performance in materials science and new materials technology, as well as its "tenacious spirit of independent innovation."

In addition, in March 2018, MTI achieved both ISO 13485:2012 Certification and the CE Certificate for Cobalt Based Dental Alloy for 3D Printing, reportedly becoming the one of the first companies to obtain CE certification for this type of product. The company stated that receiving CE Certification marks the products of Material Technology Innovations as having reached an internationally advanced level in terms of quality and safety performance, and expects this to help accelerate the pace at which it is able to gain entry into overseas markets.

www.mt-innov.com

Sintavia achieves NADCAP accreditation for its laser and electron beam metal AM

Sintavia, LLC, Davie, Florida, USA, a tier-one metal Additive Manufacturing parts maker, has achieved National Aerospace and Defense Contractors Accreditation Program (NADCAP) approval for its laser and electron beam Powder Bed Fusion production.

The NADCAP accreditation is the latest quality certification achieved by the company, and is the result of a year-long application process. Doug Hedges, Sintavia's President, stated, "As the only Tier One additive manufacturer with NADCAP, AS9100 Rev. D, and ISO 17025 accreditations, we are understandably proud of this major quality achievement."

"Sintavia has long differentiated itself with aerospace OEMs through its vertically aligned aerospace quality system," he added. "Our customers know that we offer high-quality, cost-effective metal AM production, and the NADCAP accreditation is an outstanding third-party validation of this."

The company stated that it expects to pursue additional NADCAP certifications in the coming months for its other in-house capabilities, including heat treatment, machining and non-destructive testing.

www.sintavia.com

IMTS 2018 to showcase its largest ever AM Pavilion


IMTS is the largest manufacturing event in North America (Courtesy IMTS)

The Association For Manufacturing Technology's International Manufacturing Technology Show (IMTS) 2018, set to take place at McCormick Place in Chicago, Illinois, USA, September 10–15, will host nearly triple the number of exhibitors at its Additive Manufacturing Pavilion compared to the most recent event in 2016. This year's AM Pavilion will host fifty-six exhibitors, giving visitors access to a wide range of experts on the technology, equipment and materials.

The AM Pavilion will be located on Level 3 of the West Building during the event. At the centre of the entrance will be the premier AMT's Emerging Technology Center focused on AM.

One of two ETCs, this one will offer visitors an overview of AM and demonstrations of the latest breakthroughs in materials, speeds and technologies as recently developed by Oak Ridge National Laboratory (ORNL), public-private collaborations and exhibiting additive manufacturers.

AM-related technology will also be featured in other pavilions, including within the Methods Machine Tools exhibit in the Metal Cutting Pavilion and as part of AM-specific software exhibits in the Controls & CAD-CAM Pavilion. In addition to these exhibits, IMTS 2018 will feature two events dedicated to Additive Manufacturing: the Additive Manufacturing Conference, presented by Gardner Business Media, September 11-12, and AppliedAM – Where Additive Minds Meet symposium, presented by EOS North America, September 11-12. Six technical sessions presented as part of the IMTS Conference will also focus on AM technology.

Registration is now open. International visitors may attend the exhibition free of charge and all visitors can save 25% on conference registrations using promotion code 25IMTSCONF.

www.imts.com/intl

Global Advanced Metals to manufacture tantalum powders for AM and MIM

Global Advanced Metals Pty Ltd (GAM), a producer of tantalum products, has commissioned a Tekna TEKSPHERO plasma spheroidisation system for installation at its facility in Boyertown, Pennsylvania, USA. The equipment is part of a new process development facility for the manufacture of spherical tantalum and other refractory metal powders for Additive Manufacturing and Metal Injection Moulding.

The TEKSPHERO equipment produces spherical powders from a variety of tantalum feed materials. Particle sizes range from 10–100 μm, in narrow or broad particle size distributions. Standard oxygen content is in the range of 600–1000 ppm, but low oxygen (< 250 ppm) powders remain an option.

Andrew O'Donovan, Chief Executive Officer, Global Advanced Metals, stated, "Our new process development facility enables us to create spherical tantalum powders that can be used for the 3D printing of prototypes and commercial parts. The ability to rapidly prototype and produce complex tantalum parts via AM offers designers new materials choices for applications in military, aerospace, medical and other demanding industries."

www.globaladvancedmetals.com

Sigma Labs granted US patent for process control systems during AM

Sigma Labs, Inc, Santa Fe, New Mexico, USA, has been granted a seminal patent that provides protection for methods of assuring part quality using real time data from multiple sensor types. The patent enables serial production applications through real time tracking and reporting of process consistency and part repeatability.

Titled 'Method and System for Monitoring Additive Manufacturing Processes,' the patent is the first application filed in a series of eighteen patent applications submitted by Sigma over the past five years in the general domain of process quality assurance. Mark Cola, Sigma Co-Founder, President and Chief Technology Officer, stated "Our PrintRite3D® technology can be used in many AM applications and helps our customers to decrease their product time to market through a better understanding of their process variance and means by which to control it. Looking to the future, PrintRite3D will allow our customers to achieve product yield improvements during serial production through use of our proprietary software algorithms."

www.sigmalabsinc.com

BMW displays range of metal Additive Manufacturing during Digital Day

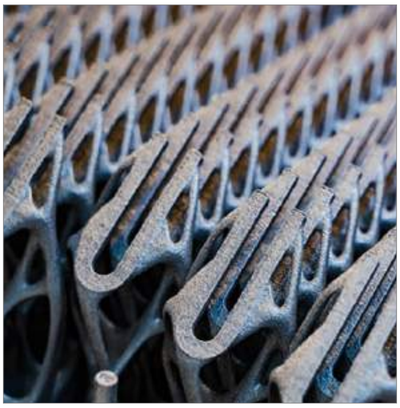
The BMW Group provided an insight into current product developments, technological concepts, innovations and manufacturing processes at its Digital Day 2018 event. On show were a range of technologies that also included a number of components from the company's metal Additive Manufacturing activities.

BMW has been utilising Additive Manufacturing in production applications since it began using the process to make water pump wheels for its DTM racing cars in 2010. On display was the latest AM series component found in its new BMW i8 Roadster, an aluminium bracket made using metal powder laser melting for use in the soft-top cover mechanism. The mounting's standout characteristics are said to include its optimised geometry, lower weight and higher rigidity.

"Additive Manufacturing is an integral element of the BMW Group's production system. The BMW Group considers it one of the key manufacturing methods of the future and a highly promising one. A great deal of its potential lies in series production," the company stated.

Also on display was a prototype motorcycle frame made by metal Additive Manufacturing. Although no plans were announced to put the frame into production, BMW expressed the importance of metal AM in the development of new components.

"The Additive Manufacturing Centre housed in the BMW Group's Research and Innovation Centre in Munich already supplies around 140,000 prototype parts a year to the company's various development departments," the company reported.



BMW's new i8 Roadster features a lightweight metal additively manufactured cover carrier bracket

"These range from design samples to plastic mounts and chassis components made from metal. The primary benefit for the developers is that the requested parts are usually available within the space of a few days once the relevant design data have been provided."

www.bmwgroup.com

Researchers use metal AM to accelerate search for cheaper permanent magnets

Researchers at the U.S. Department of Energy's Critical Materials Institute (CMI), operated by Ames Laboratory, Iowa, USA, report that they have used metal Additive Manufacturing to accelerate their search for a permanent magnet material which could offer a cheaper alternative to more expensive rare-earth neodymium iron boron (NdFeB) magnets for some applications.

The magnetic alloy is composed of cerium – a less expensive and more plentiful rare earth – cobalt, iron and copper. The researchers produced a range of alloy compositions, which were then used to produce additively manufactured samples on a laser powder bed AM system.

Ryan Ott, one of the CMI's researchers, stated, "This was a known magnet material, but we wanted to revisit it to see if we could find exceptional magnetic properties. With four elements, there is a vast space of compositions to hunt around in. Using 3D printing greatly accelerates the search process."

While it would have taken multiple weeks to produce these samples using conventional production techniques, the research team reported that using AM enabled the production of a range of magnetic samples in just two hours. The samples with the most promising properties were then identified and a second set of samples produced by conventional casting methods and compared to the originals, confirming the findings of the AM samples.

"It is very challenging to use laser printing to identify potential permanent magnet phases for bulk materials because of the need to develop the necessary microstructure," added Ikenna Nlebedim, another CMI researcher. "But this research shows that Additive Manufacturing can be used as an effective tool for rapidly and economically identifying promising permanent magnet alloys."

The Critical Materials Institute is a Department of Energy Innovation Hub and is supported by the Office of Energy Efficiency and Renewable Energy's Advanced Manufacturing Office, which supports early-stage research to advance innovation in US manufacturing and promote American economic growth and energy security. CMI seeks ways to eliminate and reduce reliance on rare-earth metals and other materials critical to the success of clean energy technologies.

www.science.energy.gov

Metal Additive Manufacturing enables development of automated suturing devices

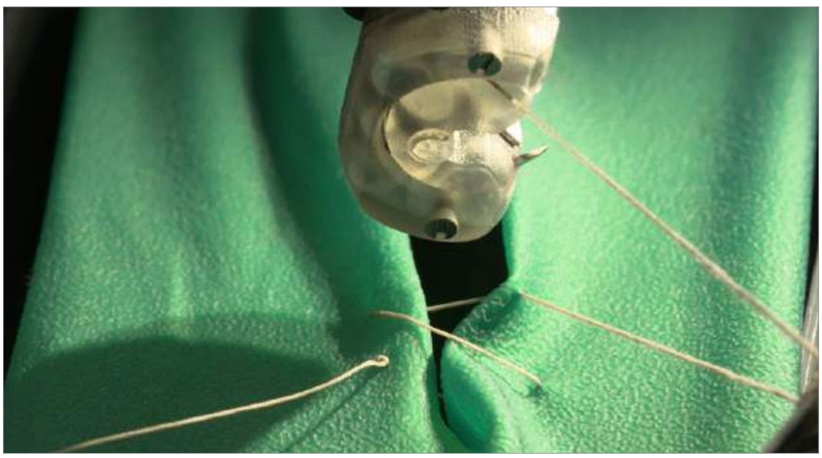
UK-based medical research company Sutrue has successfully developed and patented two new automated suturing devices featuring metal additively manufactured components. The two devices – a handheld suturing device and an endoscopic/robotic suturing device – are the product of more than eight years of development between Sutrue and Richard Trimlett (Cardiothoracic Surgeon and Head of Mechanical Support at the Royal Brompton Hospital), as well as a number of other medical professionals including Professor John Pepper OBE, Professor in Cardiothoracic Surgery at the National Heart and Lung Institute.

Medical stitching by hand can sometimes be problematic, as it relies on the ability, dexterity, training and alertness of a practitioner. According to Sutrue, its two devices have the potential to transform the manual process of stitching into a far simpler, quicker and more accurate automated process, thus reducing the margin for human error. There have been over 10,000 patent attempts to produce a device that sutures wounds, including one in 1908, but Sutrue is said to be the first to successfully achieve it.

Device development

To create its suturing mechanism, the company produced thirty-eight prototypes and designed and tested more than 1,500 parts. The result was a patented automated suturing mechanism with the ability to produce a row of sutures, tie a knot and sew around corners. These capabilities offer significant benefits within medicine and – in the case of the handheld device – even industrial applications.

Sutrue has been working with with Concept Laser, a GE Additive company, for the past three years to additively manufacture the small, detailed parts used in the automated suturing devices on an Mlab Cusing R system. Alex Berry, Sutrue's Managing Director, stated, "Rapid prototyping has significantly reduced the cost of the creation of the devices, probably by a factor of fifty. It has also shaved years off the time it would have otherwise taken. We've taken a 'create, print, test, tweak, reprint' approach to solving the problem. We even coined our own term for the working process and called it 'Multi-typing', which is the ability to loosely design the same component in three or four different ways, have them printed within a few hours and then test and learn from each prototype. This approach has been instrumental in allowing a small start-up company like ours to maximise our output in terms of creativity and problem solving."



A knot is tied by one of Sutrue's automated suturing devices (Courtesy Sutrue)

Stephan Zeidler, Business Development Manager for the Medical Sector at Concept Laser, stated, "Once designed by Sutrue, the structurally superior parts were printed by our team before Sutrue assembled them into numerous medical prototypes – sometimes straight from our printer with minimal post-processing. This in turn saved considerable time and cost and has resulted in the completion of a series of fully-functioning medical prototypes. Sutrue's success in having achieved this is a fantastic example of what is possible with our DMLM machines and AM technology. We are delighted that both devices are now mechanically sound and are ready for testing within the medical industry."

Benefits and applications

Richard Trimlett believes that the robotic/endoscopic suturing device could be influential to the future of robotic surgery, significantly reducing the number of open operations undertaken in the future. "The majority of operations we're doing today are still open and that's not because the patient wants them open, it's because of the limitations of the technology," he explained. "There are many improvements to technology that we need to get to the point where we can do everything as a keyhole operation, and I see [Sutrue's device] as one of them."

As well as reducing the number of open surgeries performed, the benefits offered by using this device instead of forceps include increased suturing speed (an experienced endoscopic surgeon can take up to twenty-five seconds per stitch, whereas the device takes 1/3 of a second), increased access to hard-to-reach places using the articulation of the device, increased accuracy and a reduction in human error.

The handheld suturing device is expected to benefit inexperienced medical staff when closing wounds, as well as having applications in veterinary practice, dentistry, in extreme environments such as field hospitals and in space, and potentially in the manufacturing and textiles industries.

www.sutrue.com

www.concept-laser.de

Boeing HorizonX invests in metal AM service bureau Morf3D

Boeing has announced its investment in Morf3D, an Additive Manufacturing design and production service bureau based in El Segundo, California, USA. Established in 2015, Morf3D has produced a range of titanium and aluminium AM components for Boeing satellites and helicopters.

"Developing standard Additive Manufacturing processes for aerospace components benefits both companies and empowers us to fully unleash the value of this transformative technology," stated Kim Smith, VP and General Manager of Fabrication for Boeing Commercial Airplanes and Boeing Additive Manufacturing leader.

Morf3D's metallurgy experts utilise state-of-the-art software combined with engineering expertise to significantly reduce mass and increase the performance and functionality of manufactured parts. "We are excited to be a distinguished and trusted partner of Boeing's Additive Manufacturing supplier base, as we continue to industrialise our processes for the high-rate production of flight-worthy additively manufactured components," stated Ivan Madera, CEO of Morf3D. "This investment will enable us to increase our engineering staff and expand our technology footprint of EOS M400-4 DMLS systems."

Boeing HorizonX Ventures co-led this Series A funding round. The Boeing HorizonX Ventures investment portfolio is made up of companies specialising in technologies for aerospace and manufacturing innovations, including autonomous systems, energy storage, advanced materials, augmented reality systems and software, machine learning, hybrid-electric and hypersonic propulsion, and Internet of Things connectivity.

"As innovative companies continue to revolutionise technologies and methods, we are proud to invest in the rapidly growing and competitive Additive Manufacturing landscape," added Steve Nordlund, VP of Boeing HorizonX.

Boeing's investment in Morf3D is the latest example of the company's involvement with Additive Manufacturing partners worldwide. In March 2018, Boeing and Norsk Titanium received the Aviation Week Laureate Award for Commercial Supplier Innovation for qualifying the first AM structural titanium parts on a commercial airplane. In February 2018, Boeing announced a five-year research agreement with Oerlikon to develop standard materials and processes for titanium powder bed AM.

www.morf3d.com
www.boeing.com

Siemens produces its first metal AM replacement part for steam turbine

Siemens reports that it has produced its first metal additively manufactured replacement part for an industrial steam turbine, reducing lead time by as much as 40%. The parts produced are two oil sealing rings, used to keep oil separated from steam inside the steam turbine using pressurised air. The rings will be installed as replacement parts on an SST-300 industrial steam turbine, operating at the JSW Steel Ltd. plant in Salem, India.

Siemens engineered, designed and developed the components as part of a collaborative project between its teams in Germany and India, as well as in Sweden, where the company operates an Additive Manufacturing centre of expertise. It stated that Additive Manufacturing has opened up new possibilities by which small, high-impact changes can be made to further adapt the components to the client's challenging environment and needs; adding functional enhancements that could not have been made using traditional manufacturing processes.

"This latest breakthrough is a game changer as it significantly reduces the lead time needed to produce these spare parts, enabling us to meet our customers' needs even more quickly," stated Thorbjoern Fors, CEO of Siemens Power Generation Services, Distributed Generation and Oil & Gas. "With this latest achievement, it's evident that the investments and innovative advancements we are making in Additive Manufacturing are positively impacting the energy industry in this new and exciting digital age, just as we had anticipated."

An oil sealing ring for an industrial steam turbine, designed and produced by Siemens using metal AM (Courtesy Siemens)

In 2017, Siemens successfully completed the first full-load engine tests for its metal AM gas turbine blades. During testing, the company validated multiple AM turbine blades with a conventional blade design at full engine conditions, reaching 13,000 rpm and temperatures beyond 1,250°C.

www.siemens.com

TopologX looks to offer in-house metal powder production from scrap chippings

A new Netherlands-based start-up is planning to enhance the sustainability of metal Additive Manufacturing processes by producing AM powders from metal chippings. TopologX was established by business partners Pedro Sterken and Hans Ingeveld in Eindhoven. In its first year, the company has participated in the Incubator Program of Brightlands Innovation Factory and produced its first batch of powder.

As Additive Manufacturing begins to compete with conventional metal-based manufacturing processes, an increasing number of companies require metal powder feedstock. By converting metal chippings into powder, TopologX stated that it could help make the metal AM industry more circular by taking advantage of material waste from machining processes to produce powders for AM processes.

TopologX stated that it brings the waste stream closer to the production stream. Sterken stated, "Just imagine: an industrial site where one production facility converts all the scrap metal into metal powder, rather than having several trucks arrive and leave every day. This saves on transport, storage space, transport volume and energy. It creates a first step towards a circular production process. It's sustainable and cost-effective."

TopologX is currently working on a powder production system which it refers to as 'the Picasso' due to its ability to 'modify the image of objects.' "TopologX does something similar," added Sterken. "we do the same with scrap metal. It starts by looking at things differently. [...] The machining process creates the object and scrap. TopologX shows that you can retain value by cleaning the chippings and converting them into powder. We are now looking for companies that process titanium and where the TopologX system creates added value."

"The industry for which TopologX is disruptive," he continued, "is the trade in scrap metal and iron. In Deurne, close to where I live, you pass by mounds of metal several meters high when you travel to the village. This metal is rusting away here until the price per kilogram is good enough and it is sold and melted down. We are a huge threat to that trade; if we are active next to or within a metal processing company, intermediate trade becomes superfluous. Scrap metal is converted into metal powder on site."

As a result, he explained, "The scrap dealer who now gives two dimes for a kilogram of titanium is basically our biggest competitor. This has always been our business case: turning those two dimes into something valuable, €300 per kilogram. High added value, high gross margins," explains Pedro.

The start-up's first 20 kg metal powder batch is said to be ready for delivery to Xilloc, an Additive Manufacturing specialist which uses EOS AM systems provided by Brightlands Chemelot Campus. TopologX is said to be engaged in helping Xilloc to handle materials more efficiently. In future, the start-up stated that it expects its metal powder production system to provide a valuable tool to major machining companies, from aerospace to automotive.

"We provide the system plus consultancy," added Sterken. "The repeatability and reproducibility of the correct material quality is the basis of a controlled Additive Manufacturing process. TopologX views everything that deviates from this norm as waste and strives to achieve zero waste. A controlled AM process is achieved by handling materials smartly, but also by handling the other processes smartly."

www.brightlands.com
www.topologx.com

NATEP to fund development of advanced aluminium powder for metal Additive Manufacturing

A group of companies led by Aeromet International has been awarded funding from the UK's National Aerospace Technology Exploitation Programme (NATEP) for the further development of A20X, an aluminium powder for metal Additive Manufacturing.

As part of the High Strength Aluminium Powder for Additive Manufacture (HighSAP) project, Aeromet, along with partners Renishaw, Rolls-Royce and PSI, are currently working to further develop A20X alloy for use in AM and to produce a set of demonstrator parts.

NATEP, an Aerospace Growth Partnership initiative, is an industry-led programme which aims to support British companies in the aerospace supply chain to develop innovative technologies.

Mike Bond, Director of Advanced Material Technology at Aeromet, stated, "We are very pleased to have been awarded NATEP funding for this exciting project. By working with our partners, we hope to further develop our powder technology and create a new option for high strength additive manufactured parts. NATEP is a great way for innovative companies to come together to develop cutting edge technologies."

A20X is a family of high-strength aluminium alloy technologies developed and patented by Aeromet. A20X is an aluminium-copper alloy with a highly-refined microstructure and a unique solidification mechanism, which is said to give it greater strength, fatigue and thermal characteristics compared to other alloys.

www.a20x.com/powder

CASCADE project seeks to establish advanced manufacturing supply chain in UK

The CASCADE project, supported by the UK Government's Advanced Manufacturing Supply Chain Initiative (AMSCI), enters its third year focused on establishing an advanced manufacturing supply chain for Net Shape and Additive Manufactured (NSAM) parts. The project, led by Liberty Steel in Sheffield, UK, aims to bring together world-class expertise in metal powder atomisation, metallurgy, net-shape and Additive Manufacturing. Its participants include industrial partners Johnson Matthey, Renishaw plc, Atomising Systems Ltd (ASL), Hybrid Manufacturing Technologies (HMT) and Farleygreene, as well as research and academic partners at the Manufacturing Technology Centre (MTC), Advanced Manufacturing Research Centre (AMRC), the University of Birmingham and the Warwick Manufacturing Group (WMG), University of Warwick via a subcontract.

Metal AM magazine spoke to Gill Thornton, Senior Project Manager at Liberty Speciality Steel (LSS), about some of the key topics under investigation by CASCADE, along with a selection of the project's technical achievements to-date. "It is well-known that there is a huge potential for manufacturing using advanced powders," she explained, "however, the industrial application of many processes is being held back by some fundamental science and engineering challenges, where government funding of projects like CASCADE can help."

Key topics under investigation by the project's partners include particle size distribution and powder production yields – specifically, aiming to achieve full utilisation of powder batches by expanding existing powder size distribution specifications and supplying a range of markets, thereby reducing production costs and increasing industry uptake. CASCADE is also involved in designing next generation alloys for NSAM, through a combination of process modelling and alloy development, and in optimising the atomisation process for stainless steels and nickel super-alloys.

The CASCADE team with a Romi 'AMBIT'-enabled machine tool. (From left to right: Hugh Hamilton (Johnson Matthey), Tom Williamson (ASL), Usama Attia (MTC), Alex Selby (HMT), Kristina Parry (AMRC), Gill Thornton (LSS), Peter-Jon Solomon (HMT), James Ashby (LSS), Stuart Christie (Renishaw) and Xinjiang Hao (LSS) (Courtesy Liberty Speciality Steels)

Contributing to industry development

Through its industrial partners, the project also seeks to create what it calls the 'next generation' of Additive Manufacturing and hybrid AM systems. At formnext in November 2017, Renishaw debuted its RenAM 500Q multi-laser AM system, developed using CASCADE funding. Through CASCADE, next-generation hybrid AM blown powder deposition and deep inspection tool heads have also been developed at HMT.

CASCADE, using a state-of-the-art automated scanning electron microscope (SEM) system at WMG, is involved in the development and enhancement of a number of metal powder quality control concepts including; powder handling, in-line characterisation and the detection and understanding of the influence of contaminants and inclusions in metal powder. The Sievgen 04, an automated powder screening solution launched by Farleygreene in April 2017, was also developed in partnership with the project.

Comparison with traditional production methods

The project aims to develop a through-process metallurgical understanding of quality parameters on end-user components – from raw material to finished parts. The partners are currently involved in the production of a number of Hot Isostatically Pressed (HIP), AM, Metal Injection Moulded (MIM) and hybrid AM demonstrator components, produced from fully characterised stainless steel and nickel super-alloy metal powders. These are to be sent for metallurgical and mechanical assessment across multiple partners for comparison against components made using traditional production methods.

Novel materials development

One novel area under investigation by CASCADE is the use of platinum group metal dopants to enhance the corrosion resistance of net shape and additively manufactured components, led by Johnson Matthey. If successful, this could make it possible to extend the lifespan of NSAM components without the need for cladding or coating.

Creating an Additive Manufacturing supply chain

Central to the project is the establishment of a full net shape and Additive Manufacturing supply chain within the UK, with Liberty Steel proposing to acquire a vacuum atomisation system and a range of NSAM capabilities. In 2017, Liberty Speciality Steels (then Tata) reported that it had identified metal powder production as a key strategic future product range in the sectors of oil & gas, automotive, and aerospace, a view upheld by the new leadership team.

Under CASCADE, the company plans to establish a medium-term development programme to construct a large-scale atomising facility with annual production capacity of 400 tonnes per year, with a planned increase to 1200 tonnes annually. Liberty Steel believes that it has an advantage over most other potential vacuum powder suppliers, in that it is already experienced in the aerospace, automotive and nuclear supply chains, and the company stated that it will produce both powder and components depending on end-user requirements.

Liberty Steel commented that currently, vacuum atomised powders are produced in the USA, mainly by Carpenter and Allegheny Technologies Inc, and in Japan by JFE Steel Corporation and Sanyo Special Steels. It was also stated that there are few vacuum atomisation facilities available to customers in Europe, aside from small facilities aimed at the production of powders in quantities suitable for fundamental research and development.

According to Liberty Steel, early stage discussions with a range of end-user partners within CASCADE suggest that if a pilot scale facility is established prior to completion of CASCADE there is a high likelihood of commercial supply opportunities even in the short term.

"This project is moving fast with developing powder metals technology, and has already led to the creation of seventy-two new jobs across the CASCADE partners in the industry in England," stated Thornton. CASCADE is currently seeking further input from end users who would benefit from having a prototype demonstrator manufactured by the project partners.

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www.libertyhousegroup.com

H.C. Starck launches niobium C-103 alloy for rocket and jet propulsion applications

H.C. Starck's Fabricated Products Division (FPR), Newton, Massachusetts, USA, has introduced niobium C-103 for rocket and jet propulsion applications, typically used in spacecraft and launch vehicles. The new alloy will be available in a range of forms, including powder for metal Additive Manufacturing, and is said to offer excellent resistance to the high-frequency vibrations and cryogenic temperatures which occur in satellites and high-performance rocket nozzle applications.

"H.C. Starck's niobium C-103 alloy is part of our alloy development programme to extend our fabricated products portfolio, allowing customers to take advantage of the unique characteristics of our alloyed materials. We are working with customers in space exploration to design the highest quality and performance products with the prospects of more advanced space exploration in mind," stated Andreas Mader, CEO, Fabricated Products Division.

The company stated that it will collaborate with customers to produce niobium C-103 alloy components for aerospace. The alloy meets ASTM B652, B653, B654, AMS7852 and AMS7857 specifications and, as well as having a high resistance to cryogenic temperatures, is said to be capable of withstanding high stresses at elevated temperatures.

Partnering with its customers, H.C. Starck Group develops and optimises materials, products and processes, having decades of Powder Metallurgy experience and the chemical expertise to formulate powders which can be fabricated into products for the most challenging applications. The company has extensive in-house state-of-the-art labs equipped with analytical tools, testing equipment, modeling and simulation software, and has the capacity to evaluate product performance for the most critical applications.

www.hcstarck.com

Niobium C-103 can be used for rocket and jet propulsion applications (Courtesy H.C. Starck)

Xi'an Sailong produces its first tantalum surgical implant by Selective Electron Beam Melting

The custom, lattice-structured tantalum knee support component was produced for a knee surgery on an 83 year old patient (Courtesy Xi'an Sailong)

Xi'an Sailong Metal Materials Co., Ltd., based in Xi'an, China, has recently designed and manufactured a custom, lattice-structured tantalum knee support component for a revision surgery on an eighty-three year old female patient. The production of this implant comes after the company first reported its success in the Additive Manufacturing of tantalum components using its Selective Electron Beam Melting (SEBM) system in February, 2018.

Porous tantalum offers highly desired biocompatibility for use in surgical implants. However, it can be challenging to additively manufacture intricate tantalum implants due to the material's high melting point (2996°C) and reactivity.

This first tantalum knee support was developed with support from the Ministry of Science and Technology of China under a major research programme titled 'Custom-printed tantalum implants by Selective Electron Beam Melting and clinical applications,' and manufactured using a Sailong Y150 SEBM system.

The project was led by Professor Liu Yang of Southwest Hospital and Professor Huiping Tang of Xi'an Sailong Metal Materials Co., Ltd. and State Key Laboratory of Porous Metal Materials, Northwest Institute for Nonferrous Metal Research, China. The surgery, lasting two hours, was completed in April 2018 and a recent post-surgical review suggests that the surgery was successful and the patient is recovering well.

www.slmetal.com

BMW Group to invest €10 million in Additive Manufacturing Campus

The BMW Group has announced that it will invest more than €10 million in a new Additive Manufacturing Campus in Oberschleissheim, just north of Munich, Germany. The new facility is expected to allow the company to develop its AM expertise, having begun series production of a metal additively manufactured cover carrier for its i8 Roadster in December 2017.

According to BMW, the Additive Manufacturing Campus will foster the latest AM technologies in the same way as a pilot plant, with the end goal of making them available for use within the auto maker's manufacturing network. Much of the work carried out at the plant is expected to focus on manufacturing techniques for prototype construction, series production and customised solutions.

The AM Campus will also act as an interdisciplinary training and project area for BMW staff such as development engineers. Located in an existing building with a footprint of over 6,000 m^2, it will reportedly accommodate up to eighty associates and over thirty industrial systems for metal and plastic AM. The campus is expected to begin operation in early 2019.

Udo Hänle, Head of Production Integration and Pilot Plant at BMW Group, stated, "Our new Additive Manufacturing Campus will concentrate the full spectrum of the BMW Group's 3D printing expertise at a single location. This will allow us to test new technologies early on and continue developing our pioneering role."

Investments in AM companies through BMW i Ventures, BMW Group's venture capital arm, have also formed an important part of the company's approach to AM adoption. According to the group, investments in start-ups have proved promising not only in strategic but also in commercial terms. The company has invested in a number of AM start-ups, including metal Additive Manufacturing systems producer Desktop Metal in February 2017, and reports that it is working closely with such companies now.

Using AM, the group stated that it believes it will eventually become possible to produce components directly where they are needed. "The 3D printers that are currently operating across our production network represent a first step towards local part production. We are already using Additive Manufacturing to make prototype components on location in Spartanburg (US), Shenyang (China) and Rayong (Thailand)," stated Jens Ertel, Head of the BMW Group's Additive Manufacturing Center and the future campus director. "Going forward, we could well imagine integrating it more fully into local production structures to allow small production runs, country-specific editions and customisable components – provided it represents a profitable solution."

www.bmwgroup.com

Barnes Group Advisors to provide AM training under ADDvisor Services

The Barnes Group Advisors (TBGA), Pittsburgh, Pennsylvania, USA, will now provide training for Additive Manufacturing as part of its ADDvisor℠ Services offering. According to the group, the training on offer will range from online courses to short introductory workshops to intensive, hands-on experiences using innovative technical and training tools.

TBGA appointed Alison Wyrick Mendoza to lead this segment of the business in March. Rob Higham, Senior ADDvisor at TBGA, stated, "Our industry contacts expressed interest in having training in the Additive Manufacturing space available. We feel we're in a position to leverage our team experience to do so. We plan to place a premium on accurate, robust technical content."

John Barnes, Managing Director at TBGA, added, "TBGA is uniquely situated to provide high quality training for several reasons. We're aerospace OEM trained engineers with hands on, practical experience using various machines, and we understand what it takes to qualify parts for production. We bring that approach, requirements driven manufacturing, to bear for what people need to know."

www.thebarnes.group

Euro PM2018 technical conference programme published

The European Powder Metallurgy Association (EPMA) has announced the publication of the conference programme for its Euro PM2018 International Conference and Exhibition. Taking place in Bilbao, Spain, October 14-18, 2018 at the Bilbao Exhibition Centre (BEC), the event will cover all aspects of Powder Metallurgy, including numerous sessions on metal Additive Manufacturing.

Now available online, the congress programme includes over 300 technical papers presented in oral and poster sessions. In addition to the main technical programme, a number of EPMA Keynote Paper Award presentations and special interest seminars will be held covering the main sectors of the Powder Metallurgy industry. EPMA working group meetings and workshops on key topics will also be held in Bilbao.

The Euro PM2018 exhibition will take place in parallel to the technical sessions and will provide a showcase for the global Powder Metallurgy industry. Euro PM2018 will also include a number of social events. Registration for the congress and exhibition is now open and will be available at discounted rate until September 5, 2018.

www.europm2018.com

A guide to debinding and sintering 17-4 PH stainless steel for MIM and MIM-like AM processes

In the Metal Injection Moulding (MIM) industry, 17-4 PH stainless steel is one of the most popular materials thanks to its combination of strength, hardness and corrosion resistance. Although it is not the best stainless steel in any one of these categories, after heat treatment the property combination is attractive for aerospace, medical, dental, nuclear and consumer products. As a result of its success in MIM, it is also attracting interest for use in the growing number of 'MIM-like' Additive Manufacturing processes, including binder jetting and feedstock extrusion.

Much progress has taken place over the years since sintered 17-4 PH stainless steel first gained attention. When a Metal Injection Moulded aerospace component with a tensile strength of 1068 MPa was given "part of the year" designation, sintered 17-4 PH jumped to the forefront of the MIM industry. That platform is now an important basis for Additive Manufacturing and other binder-assisted forming approaches, all relying on this strong technology base.

The sintering behaviour of 17-4 PH stainless steel depends on particle size, peak temperature, heating rate, atmosphere and hold time. Despite the alloy's popularity, there remain limited data on the final properties that can be expected, as well as data relating to dimensional control and the impact of Hot Isostatic Pressing.

In a major 28-page report published in the June 2018 issue of *PIM International*, Prof Randall German highlights best practice in the debinding and sintering of 17-4 PH, as well as presenting an in-depth analysis of published data. Sections of this free-to-access report include:

- An introduction to 17-4 PH
- Binder and debinding effects
- Powder characteristics
- Sintering parameter effects
- Additives
- Carbon control
- Hot Isostatic Pressing
- Heat treatment
- Microstructure
- Mechanical properties
- Corrosion, wear and biocompatibility
- Dimensional control

The full report can be read or downloaded for free via the *PIM International* website.

www.pim-international.com

Höganäs forms Customization Technologies for Additive Manufacturing and MIM services

Sweden's Höganäs AB has announced the formation of a new product area to meet growing market demands within Additive Manufacturing and Metal Injection Moulding (MIM). The new venture, Customization Technologies, is part of Höganäs's Industrial business area and will cover the entire value chain for AM and MIM, from application development and technology support to market development and global sales.

Kennet Almkvist, currently Senior Vice President Commercial at Höganäs, has been selected as head of the new area and is expected to continue in both roles. On the formation of Customization Technologies, he stated, "With this new venture, Höganäs becomes a strong global supplier of products and services within these fields on an international, expanding market."

Fredrik Emilsson, CEO of Höganäs AB, added, "Höganäs already has a number of successful metal powders in AM and we see further opportunities to grow rapidly within both AM and MIM, not least through our recent acquisitions of Metasphere Technology and H.C. Starck Surface Technology and Ceramic Powder."

www.hoganas.com

Engine producer looks to cut product development time by 25% using AM

In order to help reduce time to market, internal combustion engine developer Lumenium LLC, Virginia, USA, has been collaborating with Desktop Metal to evaluate the use of its metal Additive Manufacturing Studio System™ in the product development stage. For Lumenium, rapid prototyping is particularly important to enable the quick iteration of part features and designs required to continually improve engine performance. To produce prototype parts for its Inverse Displacement Asymmetrical Rotational (IDAR) engine, for example, the company currently uses an in-house CNC machine and wire electrical discharge machining (EDM). This makes the process of prototyping relatively time consuming and costly, with the full development cycle taking between three and five years.

Lumenium produces approximately twenty prototype parts per month, around 95% of which are manufactured in-house. To manufacture each new design, a CNC machine requires reprogramming, which often involves custom fixturing and part realignment by an operator; for more complex jobs this may take weeks. Some machined parts also require post-processing by external vendors, which can add up to three weeks to the fabrication timescale. The remaining 5% of prototype parts are sent to an outside machine shop for production, where lead times average around three weeks, limiting Lumenium's ability to refine and quickly iterate each design.

In seeking a faster and more cost-effective approach, Lumenium has been collaborating with Desktop Metal for several months, and was one of the first wave of customers to receive a Studio System in December 2017. To compare the production of a steel prototype engine part made using a traditional CNC machine, to one made using Additive Manufacturing, Lumenium identified three components for initial benchmark testing: a saddle carrier, swing arm and connecting rod (Fig. 1). The components fit together to form part of a sub-assembly of the IDAR engine.

To illustrate the fabrication process, Desktop Metal and Lumenium reported on the saddle carrier. The component required a serrated design along the top and bottom edges, which mate with the swing arms. To ensure a smooth and accurate mating surface, the serrations must be machined even on an AM part. Using specialised design software, Lumenium was able to adjust the part's shell thickness selectively by 5.2 mm on its serrated surfaces (Fig. 2), thereby accounting for material which would be removed during machining while maintaining the part's dimensions. Once the prototype had been built on the Studio System, Lumenium performed the required post-processing steps, including CNC machining and wire EDM. The company found that, compared to the traditionally machined part, fewer post-processing steps were required, and those required were easier to perform because less fixturing and programming was required. Total fabrication time for the AM prototype was four days, with a cost-per-part of $148 – a significant reduction from seven days' fabrication time at a cost-per-part of $990 using CNC machining. In this example, AM provided cost savings of 74%, time savings of 43% and a weight reduction of 39%.

For each of the three parts, Desktop Metal's Studio System was reported to be a faster and less expensive solution than the CNC machined alternative. With the design and function of each part within the assembly being critical, the ability to refine and iterate quickly has a direct impact on the overall engine performance. It was stated that in house AM could cut the concept phase by 25%, design phase by 33% and the fabrication/iteration phase by 50%, this approach could therefore cut the overall product development cycle by 25%.

www.lumenium.com
www.desktopmetal.com

Fig. 1 Three components were chosen for initial benchmark testing: a saddle carrier, swing arm and connecting rod (Courtesy Desktop Metal)

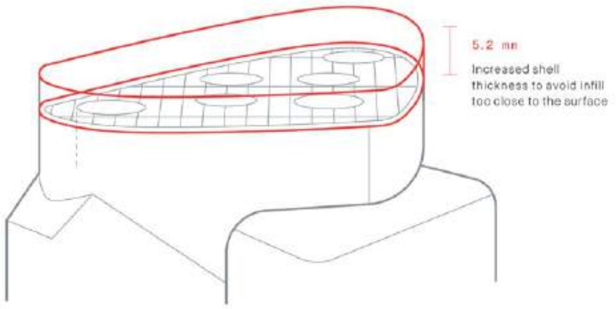

Fig. 2 Lumenium was able to adjust the part's shell thickness selectively by 5.2 mm on its serrated surfaces (Courtesy Desktop Metal)


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GE's Industry in 3D: It's time to pay attention to Additive Manufacturing

In May this year, GE held its first 'Industry in 3D' event, gathering several hundred international participants from the world of business to discover the current status of Additive Manufacturing and the opportunities that it presents to industry. Whilst the technology has come on rapidly in recent years, GE recognises that there is still a long way to go to convince many business leaders that 'the time is now' for its wider adoption. As *Metal Additive Manufacturing* magazine's Nick Williams reports, this event sought, through GE's story and those of its partners and customers, to make the case for AM.

At its inaugural 'Industry in 3D' event in New York, USA, on May 3, 2018, GE invited leaders from across industry to make the case for Additive Manufacturing as a technology that can no longer be ignored. The event, which attracted more than three hundred international participants from across the business world, took place in Industria, a historic West Village venue that, when filled with an impressive exhibit area containing state of the art AM machines and applications, served to emphasise just how dramatically the world of engineering has changed since the building's construction in 1924.

Whilst the tremendous growth of AM over the last decade has been clear for those within the industry to see, in organising this event, GE responded to the fact that not only is there a pressing need to further educate the wider industrial community about AM, but that as a company it is in a unique position to drive this effort.

GE has rarely been out of the news over the last year, in large part as the result of a challenging period for the business which culminated in its recent decision to spin-off its Healthcare division and sell its stake in Baker Hughes, allowing it to instead focus on its core industrial businesses such as aviation, power and renewable energy. Its activities in Additive Manufacturing, which are of course inextricably intertwined with these core industrial areas, have made a significant contribution to the development of the wider AM industry and, as a result, positioned GE firmly at its heart.

Fig. 1 GE's inaugural Industry in 3D event featured keynote presentations and panel discussions with industry experts and end-users

Fig. 2 Left; Mohammad Ehteshami, Vice President and General Manager, GE Additive, with Jason Oliver, CEO and Vice President, GE Additive. Top right; GE's Chairman and CEO John Flannery interviewed by Bob Safian (Courtesy GE)

The company's leading position in the burgeoning AM industry has had two key benefits: firstly, GE now understands better than anyone how AM can bring major cost savings to its businesses, enabling technical innovations that are dramatically improving manufacturability and operational efficiency. Secondly, GE is now firmly established as one of the leading suppliers of AM production equipment and metal powders, thanks to its acquisitions of Germany's Concept Laser GmbH and Sweden's Arcam AB in 2016, and AM software specialist GeonX in 2017. These bold moves, and the subsequent establishment of GE Additive, have also served to secure the availability of the production equipment and materials that have become so strategically vital to the company's core divisions. Further, they have given GE the freedom to exert a greater influence on the development of AM production technology to meet its own evolving requirements. As an example, GE Additive's Project A.T.L.A.S. (Additive Technology Large Area System) metre-class AM machine is enabling the development of ever larger parts for the next generation of aviation, space, energy and automotive applications.

"GE now understands better than anyone how AM can bring major cost savings to its businesses, enabling technical innovations that are dramatically improving manufacturability and operational efficiency"

Understanding industry's perceptions of AM

Some of the driving factors behind the need to 'make the case' for AM were highlighted earlier in the year in the *GE Global Innovation Barometer 2018*, published in February [1]. The report is based on a survey of more than two thousand international business executives whose line of work involves taking part in their company's innovation process/policies and who have responsibility for making decisions related to innovation, product development or R&D activities.

Some of the report's key findings relate to the potential of Additive Manufacturing. Whilst global executives are excited about the potential of AM, believing it will have a positive impact on business (63%), increase creativity (91%) and get goods to market faster (89%), 53% believe AM has yet to reach its full potential, requiring more 'education and reassurance'.

Of greater concern is the fact that only four in ten business executives described themselves as being 'very familiar' with Additive Manufacturing, suggesting there is work to be done to encourage the majority of business executives to gain a better understanding of AM and increase their willingness to adopt the technology (Fig. 3).

Also highlighted in the *GE Global Innovation Barometer* was the perception of AM's current level of maturity, with 53% of respondents believing that AM will not impact businesses for several years (32%), that it is not a reality yet (21%) or that it isn't even talked about (5%) (Fig. 4).

In welcoming participants to Industry in 3D, GE Additive's CEO and Vice President, Jason Oliver, stated that even with AM's limited familiarity to-date amongst business executives, "the technology is already changing the world that we thought we knew," and went on to explain that what has been seen to-date in AM "is the tip of the iceberg." He stated that what has been achieved thus far has been, in large part, based on designers coming at AM product development from a conventional, subtractive point of view. "What this does is fail to unlock the full creative capability of Additive Manufacturing. When we think about 3D from a subtractive point of view we're just limiting ourselves," emphasising that the next phase of industry growth will come as more designers "think about 3D printing from a 3D point of view."

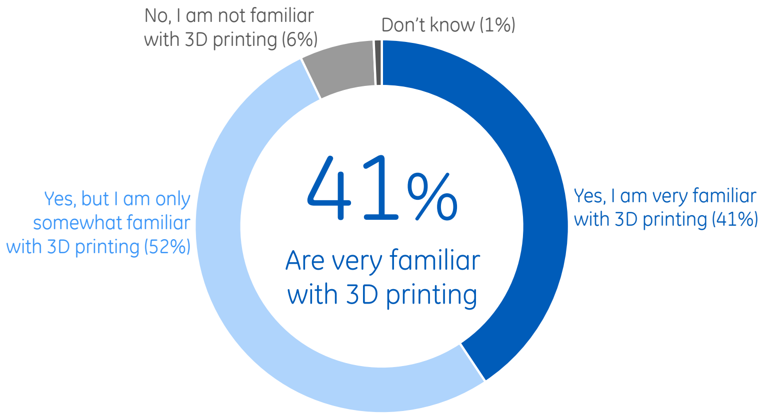

Fig. 3 Only four in ten business executives described themselves as being 'very familiar' with Additive Manufacturing, according to GE [1]

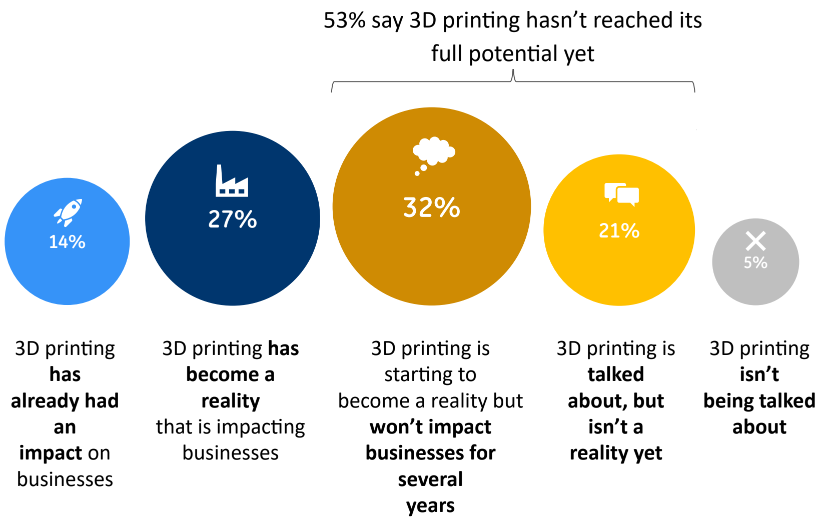

Fig. 4 Gauging the perception of AM's current level of maturity. 53% of respondents believe that AM will not impact businesses for several years [1]

Through presentations from both AM industry leaders and end-users, combined with high-level panel discussions, the Industry in 3D programme was tailored to educate and inform about how AM is driving developments across a range of sectors, including aviation, automotive, medical, space, power generation and transportation.

Exponential growth? Forecasting AM's future

In his opening keynote the futurist Paul Saffo considered the exponential potential of the Additive Manufacturing industry, placing the growth of the technology in the context of other transformational advances in science and engineering. What became clear was his conviction that Additive Manufacturing is at a point of tremendous growth. "We are in an exponential age," he stated. "It's a really interesting moment [for AM], things are out on the horizon, they are just about to change and about to get really interesting."

There is no doubt that the Additive Manufacturing industry is still in its nascent stages, but data from AM market experts gives credibility to predictions of AM's exponential growth potential. An example cited by GE Additive from *The Wohlers Report 2018* stated that metal machine unit

Fig. 5 The accompanying exhibit area at Industry in 3D featured production equipment and application examples, such as these dental parts prior to removal from the build plate (Courtesy GE)

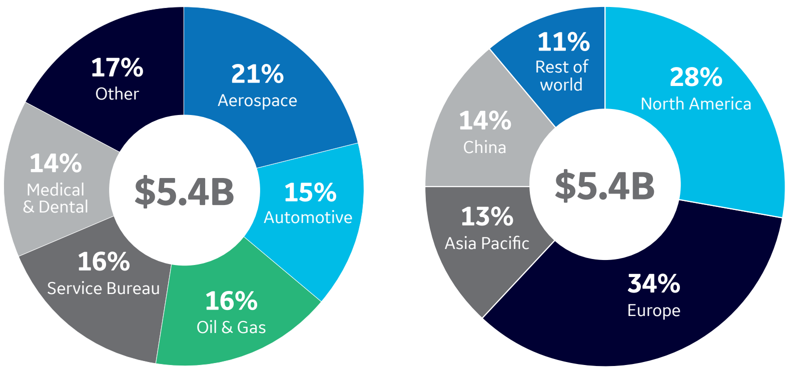

Fig. 6 Left; Estimated metal AM production system revenue by industry, 2027. Right; metal AM production system revenue by region, 2027 [3]

sales grew 79.9% from 2016 to 2017, from 983 to 1,768 systems [2].

In a white paper published by GE Additive in conjunction with AM market analysts at SmarTech [3] to coincide with Industry in 3D, it was estimated that approximately $13 billion has been spent on AM production equipment, materials, software and services over the past four years, half of that during 2017 alone. The white paper's authors then projected that more than $280 billion will be invested in Additive Manufacturing over the next ten years.

AM machinery sales are of course indicative of industry adoption rates and it was estimated that by 2027 metal AM machine sales revenue will be $5.4 billion, with 52% of metal AM machines operating in heavy machinery industries, including aerospace, automotive, oil & gas and energy (Fig. 6).North America and Europe, it was suggested, will together account for more than 60% of this revenue.

Flannery on GE Additive's mission

The need to convince industry that "it's time to pay attention to AM" was the major theme of comments made by GE's Chairman and CEO John Flannery when interviewed on-stage by the Flux Group's Bob Safian. Flannery stated following the event, "I am more convinced than ever that this technology will fundamentally transform industry. It will deliver higher productivity and better outcomes for customers in aerospace, medical, automotive, energy and beyond. But like any transformation, change takes time, perseverance and requires people to operate outside their comfort zones." He believes that when it comes to AM, businesses are excited about its promise, but he recognises that the prospect of the transformation is overwhelming. "The gap between the promise of additive, and the widespread adoption of these technologies, is real."

"We know that it's not enough to build our own additive facilities and implement technology within our businesses: it's up to us to guide our customers in this transformation as well. That is why we set up GE Additive, selling additive machines, materials and consulting services to customers outside GE." As part of this mission, GE Additive has opened Customer Experience Centres in Munich, Germany, and Pittsburgh, USA, enabling the company to fully support customers on the journey from evaluating an application to starting commercial production. "Here, we lend our knowledge that spans more than a decade and domain expertise

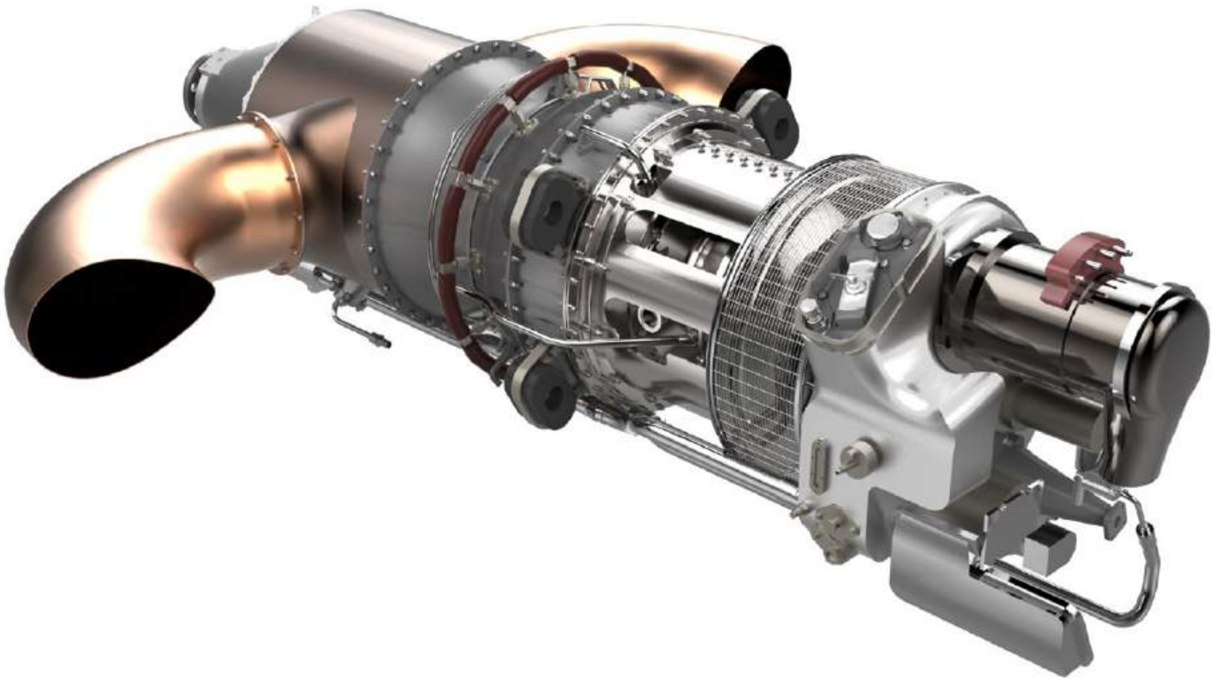

Fig. 7 GE Aviation's new Catalyst turboprop engine, known during its development phase as the Advanced Turboprop Engine (ATP), is an invaluable case study on how AM can transform a new product's design and manufacture (Courtesy GE)

in additive to help customers determine how and where it makes the most sense for them to bring additive technologies into their own businesses. In these centres, customers are trained in the technology, are able to collaborate and redesign their product portfolio, learn how to select the right materials for their products and get help building their entire additive operations," stated Flannery.

How AM has transformed production within GE

The story of GE's AM journey, from its purchase of Morris Technologies in 2012 to the LEAP fuel nozzle's move to series production and beyond, is today widely known. More recent updates on how the company has benefited from its use of AM continue to impress and attract extensive media coverage.

GE Aviation's new Catalyst turboprop engine, known during its development phase as the Advanced Turboprop Engine (ATP), is an invaluable case study on how AM can transform a new product's design and manufacture (Fig. 7). 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, around a quarter of the engine is metal additively manufactured from advanced alloys.

In using metal AM the development team was able to consolidate the number of separate components in the engine from 855 to twelve, reduce the engine weight by more than 45 kg, improve fuel burn by up to 20%, increase power by 10% and simplify engine maintenance. GE's Oliver stressed that this use of AM also has a dramatic effect on the supply chain, stating, "If the company were to source the 855 parts individually, they would have to travel a combined 60,000 miles to the assembly shop. Now they travel across the parking lot."

GE Aviation achieved Federal Aviation Administration (FAA) certification of its first AM part in April 2015 and, since then, two more AM parts have been FAA certified and more than twenty additional parts are in active certification projects. GE Aviation has already produced over 23,000 flight-quality additive parts.

When taking a broad view of the cost benefits of AM across the whole of GE, Flannery stated, "We have a target of removing US$3–5 billion cost out across GE and we couldn't do this without additive. Today, we make parts using additive technologies that we never would have dreamed of just a few years ago. So, our own journey continues to be an amazing one."

Fig. 8 GE Additive's Customer Experience Center (CEC) in Pittsburgh, Pennsylvania, USA, is designed to accelerate the use of Additive Manufacturing with GE customers across several industries (Courtesy GE)

Other high-volume AM successes highlighted

Many of the invited speakers at Industry in 3D highlighted the fact that, for their businesses, AM is very much in the here and now. Kim Smith, Additive Manufacturing leader at Boeing, told the audience that her company has manufactured and delivered 60,000 additively manufactured parts, including components for passenger and military aircraft as well as the International Space Station.

Stryker Corporation, which uses GE Additive machines to produce titanium medical implants with uniquely engineered surfaces that foster bone in-growth or osseointegration, also highlighted how AM is now in high-volume production within the business. John Haller, VP Global Supply at Stryker, explained to participants that investments in AM have enabled the company to focus on the development of innovative new products that would be impossible with traditional manufacturing methods, and it was revealed that Stryker has already supplied hundreds of thousands of these AM titanium implants. These are produced at the company's AM manufacturing hub in Carrigtohill, County Cork, Ireland, reported to be one of the world's largest and most sophisticated metal AM manufacturing facilities. Commenting on the further potential of AM, Haller stated, "When designers can think differently without restraints, that's when additive can really take off."

GE's mission to educate the designers of the future

GE Additive's drive to raise awareness of AM through Industry in 3D is part of a wider mission to ensure that AM is firmly on the agenda of the current generation of design and engineering students. Through its Additive Education Program (AEP) the company has made a significant financial commitment to, over a five year period, invest in educational programmes to deliver AM systems to colleges and universities around the world. Now in its second year, the AEP has awarded polymer 3D printers and curricula to more than 1,000 primary and secondary schools in fifty US states and more than thirty countries, and metal Additive Manufacturing systems to a total of thirteen colleges and universities worldwide.

The company recently concluded its AEP for 2018/19 by announcing the five universities in Europe and the United States that will each receive a Concept Laser Mlab 200R metal AM machine. These laser-based systems, worth a combined total of more than $1.25 million, will be delivered in the first quarter of 2019 to Coburg University of Applied Sciences and Arts, Germany, University of Limerick, Republic of Ireland, Calhoun Community College, Alabama, USA, University of Illinois at Urbana-Champaign, USA, and West Virginia University, USA.

Fig. 9 Industry in 3D participants had the opportunity to meet with experts in a range of industries, from aerospace to power generation, in a busy exhibit area (Courtesy GE)

"For additive to fulfil its potential, we need to attract as many engineers and materials scientists as possible to build their careers in our industry," stated Jason Oliver. "Getting machines onto campus and into the hands of undergraduates, researchers and faculty members is a sure-fire way of getting them as excited about additive as we are." More than 400,000 students worldwide will now have access to AM machines thanks to the GE Additive Education Program.

Future directions

"Going forward, GE Additive will continue to bring together the best in the world of Additive Manufacturing, all under one roof," stated Oliver at Industry in 3D. This includes continuing to innovate and introduce new machines under the Arcam and Concept Laser brands, as well as metal powders through its AP&C business. There is also a move to broaden the range of technologies that it offers. "Binder jetting is a technology that GE is taking to the next level and we will be releasing a system in the very near future that can print a hundred times faster than current metal additive technologies. So anyone here in one of the high-volume markets, standing back and waiting to step into Additive Manufacturing, pay attention, because binder jetting is going to dramatically disrupt the world that we thought we knew."

Commenting in relation to the announcement about the recent restructuring of the company, Flannery made it clear that AM remained a core focus, stating, "GE will continue to invest for the future and lead in innovative technologies like Additive Manufacturing and digital to lead the next wave of industrial productivity."

Industry in 3D participants were left in no doubt that GE Additive and its partners and customers see a bright future for metal AM technology, and, whilst its technology and experience places it in a strong position to compete in its core fields of aviation, power and renewable energy, its continuing efforts to promote the technology to a wide audience can only be of benefit to the industry as a whole.

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Presentations from Industry in 3D are available to view on Youtube via this short link: https://goo.gl/bRJSWF


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Poly-Shape: Metal Additive Manufacturing for the high-performance motorsport industry

In a little over ten years, France's Poly-Shape has grown into one of Europe's leading manufacturers of AM components. With more than thirty metal AM systems installed across four plants, the company is a key supplier to top-tier motorsports, from Formula 1 and IndyCar to World Rallycross and the Pikes Peak International Hill Climb. In the following article, the company presents a series of case studies highlighting the use of metal AM in this sector, and reveals its approach to the technology and plans for the future.

In terms of the metal Additive Manufacturing industry, Poly-Shape, at more than ten years old, is one of the more experienced companies operating within the sector. Founded in 2007 near Paris, France, by its CEO Dr Stéphane Abed, the company offers a depth and breadth of experience in metal AM to international customers in a range of high-tech industries, including aerospace, energy, industrial and motorsports, and is involved in both the prototyping and series production of parts.

As well as offering a high level of expertise in powder bed Additive Manufacturing for the production of geometrically complex parts, the company also uses Directed Energy Deposition systems for the production of simpler components from both powder and wire feedstock. Currently, it operates more than thirty metal AM production systems across its four European plants, aided by in-house capabilities covering the full component life-cycle, from conception through design to eventual manufacture.

A heritage in high-performance motorsport

Poly-Shape's motor racing roots date back to the establishment of its original facility, situated close to Renault Sport's Formula 1 engine development site in Viry-Châtillon, France, where initial collaboration between the companies quickly identified a range of applications for metal AM within the automotive industry. Continued growth in this and other areas soon saw Poly-Shape launch its first R&D facility in Salon-de-Provence, close to one of Formula 1's most famous circuits, the Circuit Automobile Paul Ricard at Le

Fig. 1 In one of its earliest motorsport projects, Poly-Shape collaborated with Lotus to explore the use of the Coanda effect on the E20 Formula 1 car (Photo courtesy Nic Redhead)

Fig. 2 The Norma MXX RD Limited at Pikes Peak. Taking place in Colorado, USA, the Pikes Peak International Hill Climb is believed to be the third oldest official automobile race still active in the country (Courtesy Poly-Shape)

Castellet. It was out of this facility that the company produced its first parts for the motor racing industry.

In 2011, the company began a research programme in collaboration with Renault F1 to explore the use of hot exhaust gases directed upwards to help 'suck' its R31 vehicle to the track. The following year Team Lotus – then the F1 team of English sports car manufacturer Lotus Cars – engaged Poly-Shape as it investigated the use of the Coanda effect to augment the effectiveness of the rear wing on its E20 car (Fig. 1). The Coanda effect is a phenomenon in which a jet flow attaches itself to a nearby surface and remains attached even when the surface curves away from the initial jet direction. Both parts required a complex three-dimensional geometry and very thin walls for weight-saving, making them impossible to produce by conventional manufacturing methods and thus ideal candidates for metal AM.

Around the same time, a number of teams began to turn to metal AM to manufacture multiple iterations of components for use in dynamometer (dyno) and wind tunnel testing. As confidence in the technology grew through the testing process, an increasing number of parts were designed and manufactured specifically for race conditions. Poly-Shape has since seen revenue from the F1 industry grow dramatically and states that it has manufactured parts for engines, chassis, suspension, exhaust systems and accessories for the majority of teams active in the sport. Today, four engine manufacturers across eight F1 teams have used metal AM parts produced by Poly-Shape, including complex components such as roll hoops, cooling plates, hydraulic blocks, pump housings, cooling pipes, wing support structures, turbine and compressor casings and other areas in which strength and temperature resistance may be critical.

Expertise in converting components to AM

One of the key strengths which Poly-Shape believes has helped it to achieve such success in the high-performance motorsport industry is its ability to take existing, traditionally manufactured components and apply the principles of Design for Additive Manufacturing (DfAM) to optimise their weight, functionality and suitability for metal AM. A vital part of DfAM is topological optimisation – a mathematical iterative method able to calculate the very minimum mass required in a component based on a material's mechanical properties within the volumetric constraints of the part. This enables the designer to build a part with the right amount of the right material at the right place for the right reason.

Using this expertise, the company now co-designs and produces parts not just for F1 cars but for a range

Fig. 3 The redesigned upright for the Norma MXX RD Limited was produced in Ti-Al-6V on an EOS M290 machine (Courtesy Poly-Shape)

of performance racing vehicles for hill climbing, open wheel racing, rallycross and more. In 2016, it launched Poly-Shape Italia, a new facility dedicated to the manufacture of components for motorsports vehicles in Carpi, Modena, Italy.

"Thanks to our training sessions and through our motorsport-dedicated designers, who are going to customers' design offices to work side-by-side with engineers, more and more of the components we are producing are now designed for AM," states Frédéric Impellizzeri, Business Unit Manager Motorsport/Ground Vehicles at Poly-Shape. "The most important step to reach for our customers is for them to accept that, once a part has been redesigned for AM, they will not be able to return to a conventional manufacturing method, and this acceptance is only possible once the customer feels very comfortable with the technology in terms of reliability and consistency."

As an approach to AM, Impellizzeri suggests, "Forget all that you learnt about process limitations, focus on the function of the system you are designing and open the box to give freedom to your mindset."

The following case studies demonstrate some of the ways in which the motorsport industry, supported by Poly-Shape's designers, is embracing new approaches to redesigning and optimising critical components for a range of performance vehicles.

Norma Auto Concept and Romain Dumas: Pikes Peak International Hill Climb

In 2017, Poly-Shape was approached by Norma Auto Concept for design and manufacturing input on its Norma MXX RD Limited vehicle, intended to be driven by Romain Dumas in the annual Pikes Peak International Hill Climb, Colorado, USA (Fig. 2). Known as the 'Race to the Clouds', this is said to be the third oldest official automobile race still active in the USA, having begun in 1916. The course consists of 156 corners over 12.42 miles, with an average gradient of 7.2%, finishing at an elevation of 14,110 ft.

Norma Auto Concept had previously developed the M20 RD Limited prototype, also for Romain Dumas. Equipped with alloy steel 15CDV6 mechanically welded uprights and 13-inch wheels, the car had won the event in 2014 and 2016. In order to challenge for a third win, the company began work on the Norma MXX RD, with a new aerodynamic package and tyres specifically designed for 18-inch wheels.

On finding that these modifications created a 30% increase in load, the company identified the need to create new uprights which would be able to withstand the new load while limiting any increase to the vehicle's mass (Fig. 3). Due to its proven track record in the topological optimisation of

Original part	Substitute part	Optimised part
Welded fabrication	Machined from block	Design for Additive Manufacturing
13 inch wheel	18 inch wheel	18 inch wheel
Steel 15CDV6	Aluminium 7075	Titanium Ti-Al-6V
1.4 kg	3.2 kg	2.3 kg

Fig. 4 This comparison between the original, aluminium machined and optimised AM part shows the weight saving achieved through topological optimisation of the part

> *"Once this initial design was structurally validated, a thin wall scoop was integrated for the brake air cooling. Now comprising just one piece, the new design eliminated the need for fastenings and the locally increased wall thicknesses required to hold them..."*

automotive components by AM, Poly-Shape was approached for design and manufacturing input.

An upright (or knuckle) is a safety-critical component of a car's suspension, containing the wheel hub or spindle and attaching to the suspension parts. As such, it was of paramount importance that Poly-Shape design a full-scale testing programme involving mechanical tests, metallographic characterisation and other non-destructive control processes, as well as on-track testing in real conditions.

Titanium alloy Ti-Al-6V was selected as the production material for its high strength-to-weight ratio and, following the creation of a number of design iterations using topological optimisation in line with the principles of DfAM, the part was finalised for manufacture using Laser Powder Bed Fusion (LPBF) on an EOS M290 metal Additive Manufacturing system. Once this initial design was structurally validated, a thin wall scoop was integrated for the brake air cooling. Now comprising just one piece, the new design eliminated the need for fastenings and the locally increased wall thicknesses required to hold them, as well as removing the time and risk associated with assembly and eliminating potential failure sites.

At the same time as Poly-Shape was developing its solution, an alternative was created by Norma Auto Concept which could be machined traditionally from a block of aluminium alloy 7075, resulting in a mass of 3.2 kg. As shown in Fig. 4, the additively manufactured approach resulted in a part weighing just 2.3 kg, despite being produced from the denser but stronger titanium alloy. When applied to all four uprights on a vehicle, the total weight saving was almost 4 kg when including an air scoop; a reduction of more than 30% compared to the aluminium alternative. As a result, Norma Auto Concept opted to use the additively manufactured uprights and, after completion of testing, the parts were built, machined and finished by Poly-Shape.

Romain Dumas, who went on to win the 2017 edition of the race in the Norma MXX RD, stated, "With Poly-Shape, it was an amazing meeting. Poly-Shape designed the uprights, manufactured them and improved their stiffness. They represent, I think, more than just a breakthrough for these big 18-inch wheels. For us, they are the most beautiful pieces of the car."

Dale Coyne Racing: Verizon IndyCar Series 2018

Currently in its 23rd season, the Verizon IndyCar Series is arguably the premier open-wheel racing event in North America. The 2018 series is comprised of seventeen races, beginning in March with the Firestone Grand Prix of St. Petersburg, Florida, and culminating in September with the Grand Prix of Sonoma, California.

The IndyCar Series originally required all teams to purchase a stock chassis from Dallara.

However, from 2017, the series began to allow teams to manufacture certain Dallara designed components in-house to take advantage of any cost savings they could identify. Modifications to some stock Dallara parts were then also allowed, enabling teams to redesign parts to achieve better performance and weight savings. One team to take advantage of these changes to the regulations was Dale Coyne Racing (DCR), which, in 2017, approached Poly-Shape for design guidance on the production of its front and rear anti-roll bar components (Fig. 6) using metal Additive Manufacturing.

An anti-roll bar is a system within a car's suspension which helps to reduce body roll during fast cornering or when travelling over road irregularities. It connects the opposite (left and right) wheels using short lever arms, which are linked by a torsion spring. The anti-roll bars produced from the existing stock design were stiffer than needed for some tracks. They were also fabricated assemblies, which were welded together by hand, and as such were heavier than necessary. DCR's goal was to produce parts which were as light as possible and softer in spring rate, while maintaining the strength required to resist the loads and resulting deflections of the car in race conditions.

Poly-Shape worked through numerous iterations with DCR's engineers, eventually presenting an optimised inconel design to the IndyCar Series for approval. However, the series regulators rejected the redesigned parts due to their lack of visual similarity to the Dallara design. As a result, revised designs were created and manufactured by Poly-Shape on a LPBF Additive Manufacturing system, with production, heat treatment, hand finishing, NDT and dimensional inspection taking around three weeks overall (Fig. 7).

The stipulation that the redesigned parts should look similar to the stock part prevented the company from incorporating the holes, pockets and thickness

Fig. 5 Dale Coyne Racing's 2018 car. The Verizon IndyCar Series is North America's premier open-wheel racing event (Courtesy Poly-Shape)

Fig. 6 The original Dallara anti-roll bar component (Courtesy Poly-Shape)

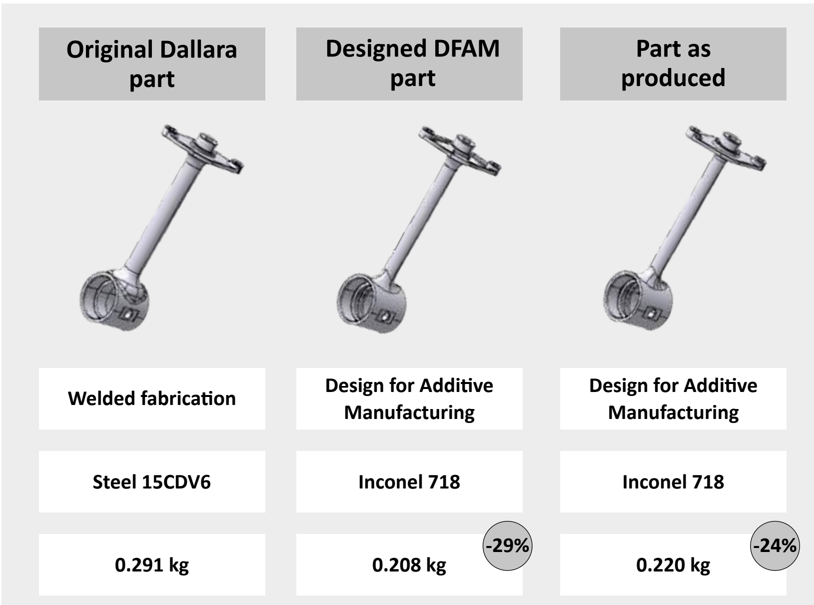

Fig. 7 Comparison between the original Dallara anti-roll bar, the optimal DfAM component and the final part as produced to race regulations

Fig. 8 The original Dallara anti-roll bar stem (top) and Poly-Shape's additively manufactured stem (bottom) (Courtesy Poly-Shape)

variations, which enable a part to take full advantage of the possibilities offered by AM, thus limiting the weight savings it could achieve. However, the final design remained considerably lighter than the original, eliminated the assembly and weld steps by consolidating the parts, and offered better dynamic properties (Fig. 8).

Craig Hampson, DCR Race Engineer, stated, "By using Additive Manufacturing, we were able to create parts that were manufactured as a single piece, rather than welded-up fabrications. The parts are both lighter and stronger, and we were able to optimise the material thicknesses to maintain a consistent level of stress. Our original design brief was to create anti-roll bars which were softer in spring rate but would still fit within the confines of the Dallara chassis and IndyCar rules. Poly-Shape was able to help us accomplish that, particularly because of their high-level finite element stress analysis and topology optimisation capability." The new anti-roll bars will be used depending on the track's configuration, being either street circuit or oval. Poly-Shape is now working on a magnetic alloy to meet IndyCar's recent revision of the regulations.

"By using AM, we were able to create parts that were manufactured as a single piece, rather than welded-up fabrications. The parts are both lighter and stronger, and we were able to optimise the material thicknesses to maintain a consistent level of stress."

PIPO Moteurs: World Rallycross and World Rally Championship

PIPO Moteurs, Guilherand-Granges, France, specialises in the design, development, manufacture, and maintenance of race engines. Over its forty-five year history, the company has been responsible for the Peugeot 306 Kit Car, 206 & 307 WRC, Ford Focus WRC, Ford Fiesta S2000 WRC, Hyundai i20 WRC, i20 R5 & i30 TCE, Bentley Continental GT3, Ford Fiesta WRX Hoonigan and DS3RX Solberg. Vehicles with engines by PIPO Moteurs have

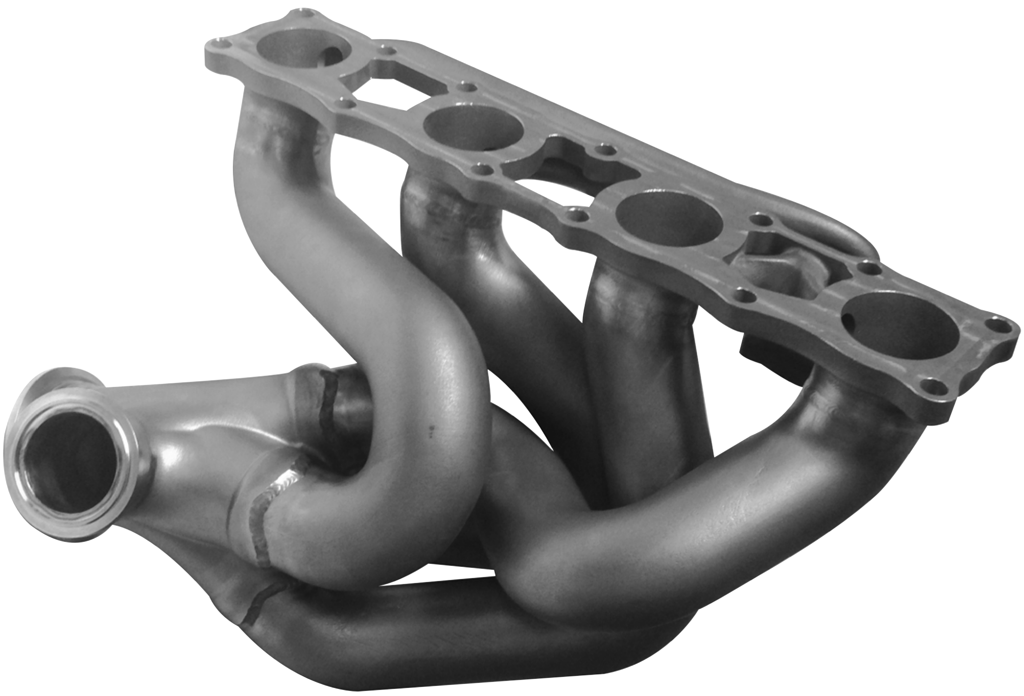

Fig. 9 The exhaust assembly for a PIPO Moteurs RALLYX rallycross engine, redesigned and produced by Poly-Shape (Courtesy Poly-Shape)

won five World Rally Championships (WRCs) and two World Rallycross (WRX) FIA Championships.

The company recently worked with Poly-Shape to design and additively manufacture the exhaust assembly for its turbocharged 1997cc inline four engine, designed for non-factory private teams competing in World Rallycross and Word Rally championships. The final exhaust assembly consisted of six additively manufactured components:

- A flange, with integrated tubing and fresh air collector
- A 4:1 collector with bypass wastegate
- Four individual primaries

These parts were produced individually from Inconel on a Laser Powder Bed Additive Manufacturing system, before being welded into a complete assembly with the addition of one machined V clamp flange (Fig. 9). With the new design of the fresh air flange and the exhaust plate, the complete exhaust assembly comprises eight parts instead of eighteen, yielding an 18.9% mass saving while reducing assembly and welding failure risks.

Porsche: Aftermarket application

One application area for which the potential of metal Additive Manufacturing is increasingly recognised is in the automotive aftermarket, for the provision of spare and replacement parts for older or collectible vehicles. Some major automotive companies to have recognised this potential are Mercedes-Benz, Audi and Porsche Classic, all of which have recently adopted metal AM for the production of parts for vehicles which are no longer produced, or which were produced in very limited runs.

The production of metal replacement parts has traditionally been dependent on the availability of the blueprint for the original part, the type of tool used in their original manufacture and the original materials, meaning that the cost of obtaining replacement parts for older models can be prohibitively high, especially when the part is required in small batches or as a one-off order.

The use of Additive Manufacturing can allow the original part design to be inputted and reproduced using a single system, thus making production more cost-efficient even at low quantities compared to where the retooling of conventional machinery is required. However, where the original part design is not available, it may be necessary to retro-engineer the design for AM.

In this example, Poly-Shape was approached to produce a replacement for a SCART aftermarket 'three into one' exhaust collector for a Porsche 911 Turbo 997. The company used data collected from a point cloud using a 3D scanner to generate an electronic model of the part, from

Fig. 10 The original exhaust collector, 3.13 kg (left), the SCART aftermarket collector, 2.45 kg (middle) and the final part produced by Poly-Shape, 2.3 kg (right)

which it was able to reverse engineer it into a single component for production on a LPBF system.

The original exhaust collector produced by Porsche would have been in stainless steel and weighed 3.13 kg, while the SCART aftermarket iteration, also in stainless steel, weighed 2.45 kg. By changing the material to Inconel and consolidating the collector into a single component, Poly-Shape was able to reduce the weight to 2.3 kg (Fig. 10). In addition, by eliminating all weld areas, the life span of the part was extended.

Poly-Shape looks to the future

In order to work more closely with its customers and to better accelerate the adoption of Additive Manufacturing for industrial applications, Poly-Shape told *Metal AM* magazine that it is now developing two additional services which will, firstly, enable clients to better understand and apply Design for AM and, secondly, enhance and ensure the quality of raw materials used in AM and the material properties of the finished part.

With the launch of CREADDITIVE, its new design service, the company is looking to shift the mind-set of its customers from traditional to additive design by offering tools, training sessions, collaborative workshops and further courses. This, it is anticipated, will enable customers not only to accelerate their adoption of AM but to ensure that they take full advantage of the freedom of design which the technology offers.

Beginning with an assessment of the client's level of DFAM expertise, Poly-Shape adapts each course and its duration specifically to the needs of each customer, with varying goals: from improving an individual's capacity for creative design and identifying potential AM applications through an investigation of existing parts, to educating multiple departments at a company in AM and identifying the patentability potential of an AM concept.

Beyond a need to grow an understanding of DfAM, Impellizzeri believes that the main factor limiting the adoption of metal Additive Manufacturing is the lack of materials available to manufacturers. "The material choice is currently not at the same level that you can get with traditional processes," he explained, "but this will be less and less true as more and more materials arrive on the market. Some of them will even be especially developed for AM, bringing new properties

> *"Beyond a need to grow an understanding of DfAM, Impellizzeri believes that the main factor limiting the adoption of metal AM is the lack of materials available to manufacturers..."*

you wouldn't be able to reach with traditional processes."

Poly-Shape is now placing materials at the forefront of its research and development efforts, having added to its services a new materials analysis laboratory at which it is investigating new materials and processes, as well as ensuring the quality of the raw materials currently used in its Additive Manufacturing processes and the final properties of the parts produced. The new laboratory is fully equipped for inspection of the chemical and mechanical properties of metal powders and the metallurgical compliance of the finished part.

"For each part which is produced, we generate a new metallurgical structure and this is one of the main differences when comparing AM to machining," states Impellizzeri. "That means we need to validate all of the process parameters, the raw material - which is the powder with its own characteristics - and design, and once the desired outcome is reached in terms of mechanical properties, geometry and surface roughness, we have to freeze them for production. Then, conventional inspection methods can be used on the finished part, especially tomography, which allows both geometrical and metallurgical inspection, whatever the complexity of the part."

Poly-Shape describes itself as having a 'mission' to continue to implement Additive Manufacturing throughout motorsports as well as in other industries, and to increase its awareness as a viable technology for international equipment manufacturers, their sub-tiers and, eventually, across the entire value chain. To that end, the company continues to develop an expertise which covers the entire Additive Manufacturing workflow, supporting its customers through the initial concept and design through CREADDITIVE, up to the manufacture, testing and integration of the part into the final product.

Looking to the next ten years, Impellizzeri highlights one issue he believes will be key to the industry's success. "We are still in the initial growth phase of this industry and machine manufacturers are still exploring a lot of potential solutions, and do not spend time making sure their machines are totally reliable before they put them on the market," he states. "At Poly-Shape, some machines have had to be improved or tuned by ourselves in order to make them production ready!"

Over the next decade, he forecasts, "Machines will definitely be more affordable, more productive and more consistent. Young engineers and designers will be better trained to really design for AM, and our customers will consider this technology as a real candidate from the earliest stage of their development projects."

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LPW Technology: AM materials specialist expands into metal powder production

LPW Technology, a provider of ultra-clean metal powders for Additive Manufacturing, recently celebrated the official opening of its new purpose-built metal powder manufacturing facility in Widnes, Cheshire, UK. The result of a £20 million investment, the company expects that this new plant will be capable of producing around 1,000 tonnes of gas atomised alloy powders per annum, with complete digital integration of manufacturing control processes. Bernard Williams, Consulting Editor at *Metal AM* magazine, reports on his visit to the official opening of the 9,700 m^2 plant and tour of the new facility.

LPW Technology Ltd was established in Lymm, Cheshire, UK, by Dr Phil Carroll in 2007, initially as a consultancy for developing machines and expert application support for metal AM processes. Over the first few years, Dr Carroll, who obtained his PhD in alloy development at the University of Sheffield, realised that no matter how good the Additive Manufacturing hardware or process, if the metal powders were not consistent it would be impossible to produce consistent additively manufactured parts from them. Therefore, over a period of less than ten years, the company focused on developing a full range of optimised alloy powders specifically for Laser Powder Bed Fusion (LPBF), Laser Metal Deposition (LMD) and Electron Beam Melting (EBM).

Over the course of its development, LPW established that there is no single powder production process which is suited for all metal AM applications, and that one must develop and optimise powders for each process in order to achieve consistency.

As a result of its efforts, LPW's sales turnover has risen from around £100,000 in its first year, when it employed only two people, to an anticipated turnover of more than £15 million in 2018, with a staff of eighty-five. With this rapid growth, the company relocated to larger facilities first in Daresbury, then in Runcorn, before finally making a significant investment in a new purpose-built AM metal powder manufacturing facility in Widnes, near Liverpool, capable of meeting the company's growing need to produce small-to-medium volume batches of very clean gas atomised powders in-house; primarily custom titanium, nickel, cobalt, aluminium and steel alloys.

Fig. 1 LPW's new purpose-built facility in Widnes, near Liverpool

Fig. 2 HRH Duke of Gloucester (left) formally opening the facility with Dr Phil Carroll (right)

Fig. 3 Guests at the opening of the new LPW metal powder facility

The £20 million powder production facility, officially opened in June 2018, received significant financial support from the UK government's Advanced Manufacturing Supply Chain Initiative (AMSCI) and a strategic investment from Stratasys, Israel. LPW has been working with Stratasys for over four years to gain a deeper understanding of AM manufacturing across vertical markets including medical, aerospace, defence and automotive. Alon Elie, Vice President of Corporate Development at Stratasys, told *Metal AM* magazine that the company, which is already a significant player in metal AM, sees its investment in LPW as further strengthening its capabilities in this rapidly growing sector.

Dr Carroll stated that, in building the new powder plant, the company wanted full control over all aspects of production. "We're not inheriting an established powder atomisation facility that has been there for ten or twenty years," he commented, "we've built an AM powder plant specifically to be digital. Purity, particle size, consistency and cleanliness are our watchwords."

A powder production plant tailored to AM applications

LPW states that the Widnes powder production plant is the first dedicated exclusively to the manufacture of a new generation of ultra-clean metal and alloy powders suitable for use in safety critical industries, such as aerospace. The new powder plant has adopted pharmaceutical levels of cleanliness, with pressure, temperature and humidity control in manufacturing cells that are dedicated to specific materials, and areas of the plant divided by air showers and interlocking doors. These cleanroom conditions aim to remove any risk of cross-contamination of powders and the complete digital control of all manufacturing stages gives the company the capability to make what it claims will be the cleanest metal alloy powders in the world.

At the heart of the plant is a custom designed vacuum inert gas atomisation system, presently capable of producing around 1,000 tonnes/year of ultra-clean alloy powders, with ample room remaining for additional powder production units on the seven acre site. Feedstock is sourced in the form of qualified bought-in bar stock, which is melted at temperatures of up to 1700°C in a 400 kW electric furnace having a melting capacity of around 450 kg, depending on the alloy powder being produced. Ceramic crucibles are used for melting, each dedicated to a specific metal or alloy to avoid cross-contamination of elements. The melt is then poured into 30 kg tundishes heated with an induction coil before being fed into the atomising chamber. Argon gas at pressures of around 80 bar is primarily used as the atomising medium and the company has designed its own atomising nozzle and melt flow-gas pressure combination in order to achieve a high level of the desired median powder particle size. The target powder particle size for AM is in the

15–70 µm range and the company aims to achieve a yield of around 70% in this range from the melt when the atomisation plant is fully operational and the process has been optimised. Total cycle time for each melt batch using the new atomiser is said to be around two and a half hours. Fig. 4 shows the new atomiser at the LPW plant.

The gas atomised powders, having a spherical and smooth particle shape, are collected at the bottom of the fifteen metre high atomisation chamber and samples are transferred to a new state-of-the-art LPW PowderLab for chemical analysis, morphology, flow and contamination analysis before being released for further processing. Using SEM equipment, the PowderLab can also identify whether the powder particles have internal porosity caused by gas entrapment during the atomisation process.

Sieving and blending of the atomised powders is carried out in a separate area, where the environment is again strictly controlled. This section of the plant is equipped with two large scale sieving machines capable of sieving down to 15 µm particle size in precise cuts. Each material has allocated sieve decks in the full range of sizes and each sieve is clearly labelled with an identification number marked with the alloy powder it must be used on. Air classification equipment is used to classify powders below 15 µm. Blending is carried out in a V-cone blender.

In addition to the atomised powders produced in-house, LPW will continue to process powders made by other processes such as Electrode Induction Melting Gas Atomisation (EIGA), Plasma Atomisation (PA) and the Plasma Rotating Electrode Process (PREP). Particle size is critical for different AM machines and all alloy powders produced can be optimised to their specific application or AM machine type through sieving, blending and sizing.

Fig. 4 The new atomiser at LPW's metal powder plant in Widnes

The PowderLife system

Key to the successful functioning of LPW's new digital factory is its proprietary PowderLife system, which has been fully integrated into the operation in Widnes. The result of an ongoing R&D effort by the company, PowderLife has a number of separate elements which, when combined, have helped to produce an innovative range of tailored alloy powders for AM. Transportation and storage solutions, as well as powerful software and sensors, enable the monitoring of powders produced at LPW, with a focus on powder properties and material traceability from initial supply through to use and reuse.

"As the first step in a supply chain for powder which is going to companies that will eventually be building parts for aircraft, F1 cars and rockets, for example, we are designing products and services to supply materials which can be relied on to perform in critical applications," stated Joseph Roddis, Mechanical Design Engineer at LPW. Using 2D printing as an analogy, Roddis explained that in a colour inkjet printer, "you don't pour ink into the printer yourself, you

Fig. 5 HRH Duke of Gloucester in the powder sizing area of the LPW facility, equipped with blending, sizing and classification equipment in a cleanroom environment

install the cartridge and go. We want to be able to deliver what is basically an ink cartridge," he added. "As a result, we developed PowderLife, which mitigates contamination, provides traceability all the way through the supply chain and delivers metal powder ready for direct use when it arrives with the customer."

"PowderTrace hoppers are fitted with LPW's PowderEye sensor technology for real-time wireless monitoring of the temperature, humidity, pressure and oxygen content of the powder in the hopper during transportation and storage..."

PowderTrace and PowderEye

PowderTrace, part of the PowderLife offering, includes specially designed smart hoppers made from medical grade stainless steel to store and transport powders for AM in quantities up to 1 tonne. The hoppers, which are primed with argon to create an inert environment and have a positive pressure to prevent powder degradation in storage, can be connected to blenders and adapted for use with all standard AM machines. They are fitted with load cells to monitor the powder mass so that operators know when the powder level is low, and are designed to be returned to LPW after use for refilling.

PowderTrace hoppers are fitted with LPW's PowderEye sensor technology for real-time wireless monitoring of the temperature, humidity, pressure and oxygen content of the powder in the hopper during transportation and storage, as well as the environment in the user's plant. PowderEye sensors, developed specifically for metal AM powders, are also used to measure the environment in sieving and blending equipment, and collect and collate data for LPW's cloud-based powder lifecycle management software – PowderSolve.

Data covering temperature, humidity, oxygen content, pressure and mass are sent to the database via an encrypted wireless connection if within range (100 m), or stored internally until a connection is available. This ensures complete data retention wherever the powder hopper is located.

PowderSolve

LPW's PowderSolve is a unique suite of software from LPW that provides complete traceability of AM powders and parts throughout the AM process, including mechanical test data. It also manages powder build data, with the ability to trace material to a particular build, and gives accurate information on powder stock quantities. A number of LPW customers in the nuclear, defence and automotive sectors are already using PowderSolve software to manage data from powders across multiple locations, giving a clear overview of production status and traceability. It was also reported that a US medical implant manufacturer has now implemented the software for its metal AM operation.

"What we're looking for is end-to-end traceability within a closed loop system," explained Callum Healey, Design Manager. "Data are collected directly from our manufacturing and testing processes and recorded directly into PowderSolve, to ensure full traceability of our powders in manufacture. Once the powder ships, our customers that are using PowderSolve are able to track that powder through its use in their machine, therefore having traceability all the way through from the melt of the powder to its use in parts. This helps us to have confidence in the powder all the way through the process."

Fig. 6 A PowderTrace hopper and PowderEye (inset)

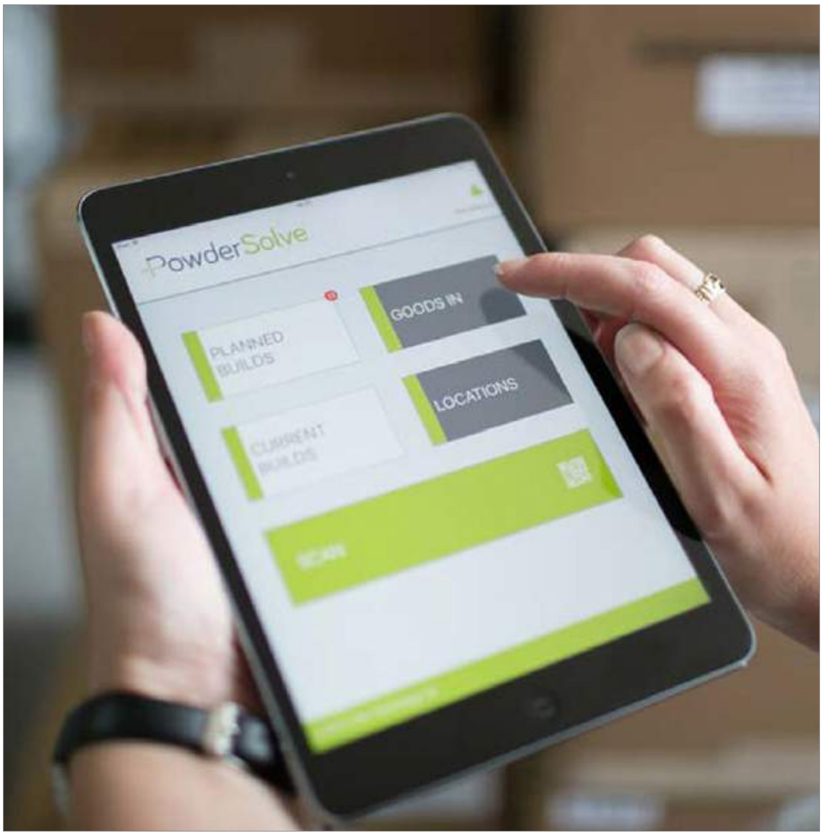

Fig. 7 LPW's PowderSolve is a unique suite of software that provides complete traceability of AM powders and parts

LPW's in-house PowderLab

In addition to manufacturing AM-specific metal and alloy powders, the new LPW facility houses a well-equipped PowderLab capable of fully characterising metal powders; analysing powder flow, apparent density, morphology, etc. A Trumpf TruPrint 1000 AM machine is available in the lab for process parameter development, powder degradation studies and to analyse the root causes of failed builds. Results from these tests are uploaded into PowderSolve.

A current goal under development in the lab is to make it possible for users to decant powders directly from LPW's PowderTrace hoppers into

Fig. 8 Guests observe the PowderLab at LPW

Fig. 9 Inside LPW's PowderLab

their own Additive Manufacturing systems and process them, all while maintaining a constant link between the hopper and PowderSolve. Graham Robertson, Project Manager, explained: "I've visited many metal AM facilities over the past five years and I've seen many ten kilo powder containers with hand written notes all over them, messages scribbled out and then written on again, to say for example, 'this is now at recycle five.' That is not a sustainable approach to maintain production in critical applications such as aerospace. Our hoppers are labelled with QR codes; you scan that and all of the information on the powder's current state will be available in PowderSolve or on the app."

Drawing on the work carried out within its PowderLab, LPW has published a number of case studies and datasheets for public use, with the aim of furthering the understanding of powders for metal AM among the wider manufacturing community.

The latest service datasheet to be released by the PowderLab covers apparent density testing. "The apparent density measurement is a quick, cost-effective, standardised method of characterising the volume occupied by a given mass of metal powder," said Lisa Holman, LPW's Laboratory Manager. "It provides a useful measure of powder consistency for comparison and assurance. Not only do we conduct this test in our state-of-the-art laboratory, we also include the equipment in the LPW PowderFlow kit allowing Hall and Carney flow testing, apparent density test and angle of repose to be performed in the end-user's own facility."

The PowderLab previously issued a data sheet on tap density testing for metal powders. "Tap density is influenced by the metal powder's particle shape and particle size distribution, among other properties," says Holman. "The results can give an indication of the powder's cohesivity, which can influence flow and affect its behaviour in the AM process. It's a useful measure of powder consistency for comparison and assurance, and also indicates how a powder might consolidate in transit."

The PowderLab is working to the ISO 17025 standard, whilst the company's metal powders are produced to the AS9100, ISO13485 and ISO9001 standards. Key to its certification as a supplier to the safety-critical aerospace and medical industries are the steps LPW has taken to prevent contamination, nowhere more evident than in the PowderLab. Aside from an emergency exit, the only entrance into the Physical and Chemical Testing Laboratory is via an air shower. All powders arriving in the lab, whether from production or a customer, enter through a wall hatch and are immediately assigned a sample code and a QR code linked to a datasheet in PowderSolve, through which testing is scheduled. In addition, contamination stations throughout the Widnes facility are constantly monitored by the laboratory staff to ensure contamination has not been introduced at any point.

Fig. 10 One of the storage areas at LPW from which metal powders are available to ship within 24 hours

LPW's current metal powder range

LPW has to-date created a unique and comprehensive range of off-the-shelf and custom metal AM powders, manufactured by external suppliers but optimised by LPW for specific machine type including those from EOS, SLM Solutions, Concept Laser, Renishaw, 3D Systems, Trumpf and Arcam. The company states that, for many alloys, it can offer different products of the same composition, which have been optimised for a particular application. For example, custom powders can be provided with improved flowability for 'flow-critical' AM machine platforms, or powders can be produced with lower residual elements and controlled interstitials for applications demanding enhanced mechanical properties. LPW also undertakes reconditioning of alloy powders that have been used several times within an AM machine. Powder purity, morphology and surface contamination change during use, especially interstitials (O_2, N_2 and H_2), and need to be brought into specification before reuse.

Powder alloys already optimised for AM by LPW include AlSi17Mg and AlSi10Mg aluminium alloys, Co6 and CoCr cobalt alloys, a range of stainless steels and high alloy steel powders, nickel base superalloys and titanium and Ti6Al4V alloy. Other alloys in the company's AM range include tungsten carbide, copper, tantalum and tungsten. All powders are shipped with a test certificate to assure the customer of their consistency and specification and that they have been checked and confirmed by the LPW PowderLab.

One recent addition to the company's portfolio of customised AM powders is Scalmalloy®, an aluminium-magnesium-scandium alloy developed by Airbus APWorks GmbH. Scalmalloy is said to be the world's first material specifically developed for AM and, due to its high cooling rates and rapid solidification during atomisation, it possesses a

"...custom powders can be provided with improved flowability for 'flow-critical' AM machine platforms, or powders can be produced with lower residual elements and controlled interstitials..."

unique microstructure which remains stable at high temperatures. It offers exceptionally high fatigue properties, weldability, strength and ductility compared to other aluminium alloy powders, which makes it particularly well-suited to aerospace, transportation and defence applications, among many others.

LPW states that, compared to all other aerospace aluminium alloys, Scalmalloy additionally offers a unique level of corrosion resistance and its high strength-to-weight ratio makes it perfect for light-weighting applications, crucial to optimising the build to use ratio in component design. As a result it gives the lowest buy-to-fly ratio compared to conventionally designed and manufactured aerospace parts

Commenting on what sets LPW's powder range apart from that of other suppliers, Steve Graham, Quality Assurance Manager, stated, "In terms of the workflow, if you look at the way traditional powder mills are run, there is a high risk of cross-contamination – not just across alloys but in terms of the environment in which the powder is produced, for exposure to oxygen, etc. All of our powders are in enclosed systems, right to the point when they are transferred into the customer's AM machine. The goal is that none of our powder should ever see oxygen."

While he could not comment on activities currently underway at other LPW sites globally, he stated that the end-goal is, "to increase manufacturing capacity across LPW's facilities. In terms of secondary processing facilities, we've increased capacity at our Pittsburgh, USA, site, adding blending and sieving capabilities." LPW's US operation recently moved to a new 1,115 m^2 factory, with facilities for sieving, blending and packaging, and it is expected that that a new, larger laboratory will increase the company's analytical and reconditioning capabilities to improve the reusability of its powders.

Conclusion

There is no doubt that the market for metal powders for AM will continue to see tremendous growth in the coming years. Whilst this growth is attracting many new entrants to the field, it should be remembered that technology for the production of advanced AM grade metal powders, originally developed for powder metallurgical processes such as Metal Injection Moulding (MIM) and Hot Isostatic Pressing (HIP), has been evolved by specialist companies over decades. New entrants to this market face significant challenges, from control of the powder production process and the need to ensure a sufficient yield of the required size fractions, to developing the required in-depth understanding of the specific requirements of final applications. With more than ten years of expertise in the evaluation and optimisation of metal powders for AM and an established customer base, combined with a strong in-house R&D team, LPW is uniquely positioned to succeed in expanding its offering to the AM industry.

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From the way we reduce carbon emissions to the way we replicate nature's creative processes, additive manufacturing (AM) is fueling a revolution, layer by layer.

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The 2nd Munich Technology Conference on Additive Manufacturing (MTC²) will advance idea exchange among world-renowned decision makers and leaders from industry, academia and politics. The main focus of the conference is the industrialization of additive manufacturing. Participants will consider the challenges of different markets (aerospace, automotive, medical etc.), the entire process chain as well as its individual parts. Further questions the conference will look at include:

- How can we speed up the industrialization of AM?
- Which materials are being used today and in the future?
- What are the main cost drivers? What does a cost roadmap for AM look like?
- What is possible to print, what are limitations?

MTC², hosted by Oerlikon together with the Technical University of Munich and other partners, will be held **October 10–11, 2018 in Munich, Germany.**

For more information, visit
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An introduction to metal powders for AM: Manufacturing processes and properties

As the AM industry grows, so does the number of metal powder suppliers and the range of different powder types that are available. In the following article Toby Tingskog presents a beginners' guide to understanding metal powders for AM. Topics include powder manufacturing processes, spherocity, chemistry and measurement technologies, as well as considerations in relation to heats, lots and batches. As such, it is hoped that this review will allow for a clearer understanding of powder properties and reduce confusion among end users.

Metal powders have been used in a wide range of industrial applications for over a hundred years; Additive Manufacturing is just the latest sector to benefit from a technology that has evolved throughout this time. Metal powders are used from the most mundane applications such as oxygen getters in food packaging to the most advanced applications such as nickel-cobalt superalloy gas turbine discs.

The major manufacturing processes for AM powders are Gas Atomisation, Induction Melted Bar Atomisation (EIGA), Plasma Atomised Wire (PAW) (Fig. 1) and Plasma Rotating Electrode Atomisation (PREP). There are, of course, many other methods for the manufacture of metal powders. Additional powder production routes which can be used for selected AM processes include water atomisation, crushing and spheroidising, and precipitation from chemical solutions and gas phases. The advantages and disadvantages of the major processes are shown in Table 1.

Metal powder production processes for AM

Gas Atomisation

In Gas Atomisation, a molten metal stream is disintegrated into droplets by a high-pressure gas stream. The drops free fall inside a tower and solidify before collection. During free fall, the surface tension of the metal has time to pull the drop into a sphere. To protect the metal from oxidation, the atomising gas is usually nitrogen or argon.

Melting of the starting material, or charge, can be performed in an open atmosphere, under cover gas or in a vacuum (Fig. 2). The melting method and atomising gas have a significant influence on powder

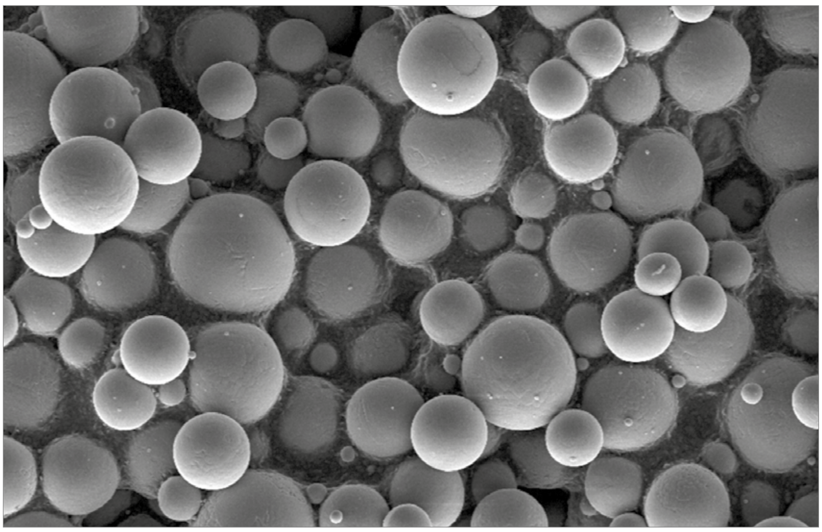

Fig. 1 Highly spherical titanium powder produced by Canada's AP&C using the plasma atomisation process (Courtesy AP&C)

Process	Advantages	Disadvantages
Gas Atomisation (GA)	• Excellent metallurgical quality • High powder flow rates • Wide selection of alloys • New and modified alloys can easily be made • Scalable technology: very high volumes available and can easily support AM growth • Large supply base • Relatively low cost, especially when AM increases quantities	• Variability in powder properties between suppliers • Large number of suppliers and atomising technologies can be confusing • Reactive and high melting point alloys not available • Few companies currently atomising titanium
Induction Melted Bar Atomisation (EIGA)	• Excellent metallurgical quality • High flow rates • Reactive and high melting point alloys can be made • Titanium alloys available • High production rates, but restricted by yield considerations	• Limited supply base - but growing • Only alloys available as bar can be made • High cost
Plasma Atomised Wire Process (PAW)	• Excellent metallurgical quality • Very high flow rates – near perfect spheres • Reactive and high melting point alloys can be made • Titanium alloys available	• Limited supply base: only a few suppliers, and new patents may lock out additional suppliers • Only alloys available as wire can be made • High cost
Plasma Rotating Electrode Process (PREP)	• Excellent metallurgical quality • Very high flow rates – perfect spheres • Reactive and high melting point alloys can be made • Titanium alloys available	• Limited supply base but growing • High quality bar needed as starting material • High cost
Water Atomisation (WA)	• Low cost • Scalable atomising technology	• Metallurgical quality lower than gas atomisation • Powder not natively spherical • Not yet established for powder bed applications

Table 1 Advantages and disadvantages of the leading metal powder manufacturing methods for metal AM

cost, with the costliest variant being vacuum melting with argon atomisation.

Gas Atomisation is, in many cases, the best technology for producing high quality powder at a reasonable cost. The alloy is made in the melting furnace from various raw materials, which gives a tremendous flexibility on composition. The powder has very high cleanliness and very good flow rate. Powder size can be controlled by adjusting metal flow rate, gas pressure and flow, and nozzle design. It is worth pointing out that gas atomised powders were used in the early development of many of the AM processes and as such provided a foundation for the technology.

Induction Melted Bar Atomisation

Induction Melted Bar Atomisation, called EIGA by ALD Vacuum Technologies GmbH, is a version of Gas Atomisation. The tip of a bar, typically 50 mm diameter, is heated by an induction coil until a melt stream forms which can be atomised with high pressure gas.

The powder is similar to that produced by standard Gas Atomisation; however, the advantage is that reactive materials such as Ti6Al4V can be melted, since the metal does not make contact with any ceramic crucible or nozzle. One disadvantage is that a high-quality bar stock is needed as the starting material, limiting alloy choice and increasing raw material cost.

Plasma Atomised Wire process

In the Plasma Atomised Wire (PAW) process, plasma torches are used to melt a wire and produce the powder. The droplets are cooled and collected in a manner similar to Gas

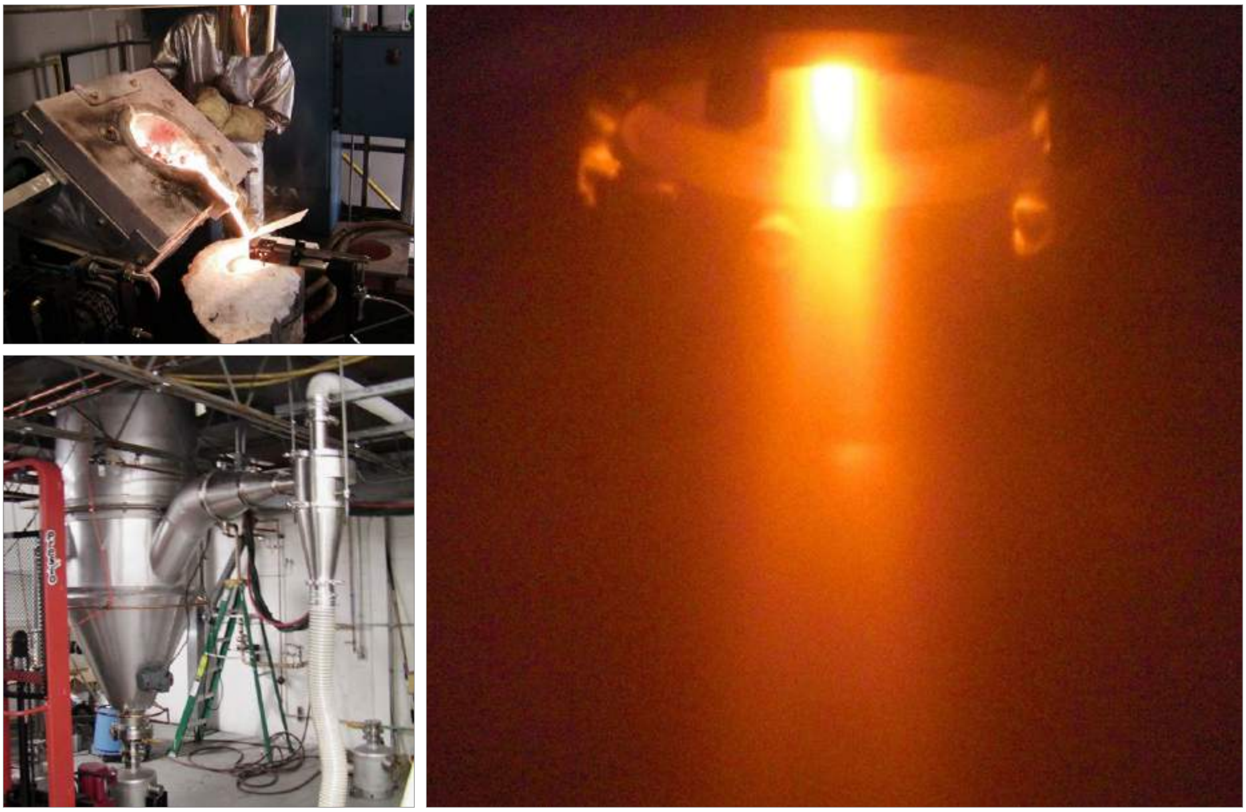

Fig. 2 In the Gas Atomisation process, molten metal is poured into a crucible above the atomisation chamber (top left). It then disintegrates under high pressure gas streams (right) before being extracted from the atomisation tower (lower left) (Courtesy Joe Strauss, HJE Company, Inc.)

Atomisation. The PAW process is primarily used for titanium alloys due to the challenges of handling molten titanium in Gas Atomisation.

PAW powders are very clean since the chemistry comes from a solid metal wire and the powder is spherical with excellent flow rate. The main challenges with the PAW process are the high manufacturing costs, due to low production rates, and limited alloy flexibility, as the starting material has to be available as wire.

Plasma Rotating Electrode process
The Plasma Rotating Electrode Process (PREP) process has long been considered the 'Rolls-Royce' of metal powder production processes. The powder is manufactured by spinning a bar at high RPMs and melting the end with a plasma torch. The centrifugal force then throws the liquid metal out radially and droplets are formed and solidified. The powder is perfectly spherical and very clean.

PREP is best for coarser powder; however, new plants use higher RPM systems that can decrease the particle size to better suit AM. This has also reduced costs to within a competitive price range for high quality AM applications.

Water and hybrid atomisation
Water atomisation is the highest volume metal powder production technology. It is used primarily to produce powder for press and sintered Powder Metallurgy automotive parts, as well as being popular in the Metal Injection Mouding (MIM) industry.

In this process, a metal stream is disintegrated with high pressure water. Since the metal is cooled very quickly, the droplets do not have time to spheroidise, resulting in an irregular powder. The smaller fractions of the water atomised powder (below 30 µm) are, however, more spherical and can potentially be used for powder bed processes which can spread finer powder.

There are also gas/water hybrid processes in which the metal stream is 'pre-atomised' with gas, then hit with water jets. This makes the powder more spherical while reducing the cost somewhat compared to Gas Atomisation.

How to describe and quantify powders

Powders are usually tested to find the following data; chemistry, Particle Size Distribution (PSD), Apparent Density (AD), Packing Density (PD) and Hall Flow rate. The manufacturer documents the powder with a Test Certificate, or cert, that has the above information listed and the powder specifications issued by users include these measurements.

The question of spherocity
Before considering the above data, the question of powder spherocity is often raised. As an oversimplification, it is said that Additive Manufacturing

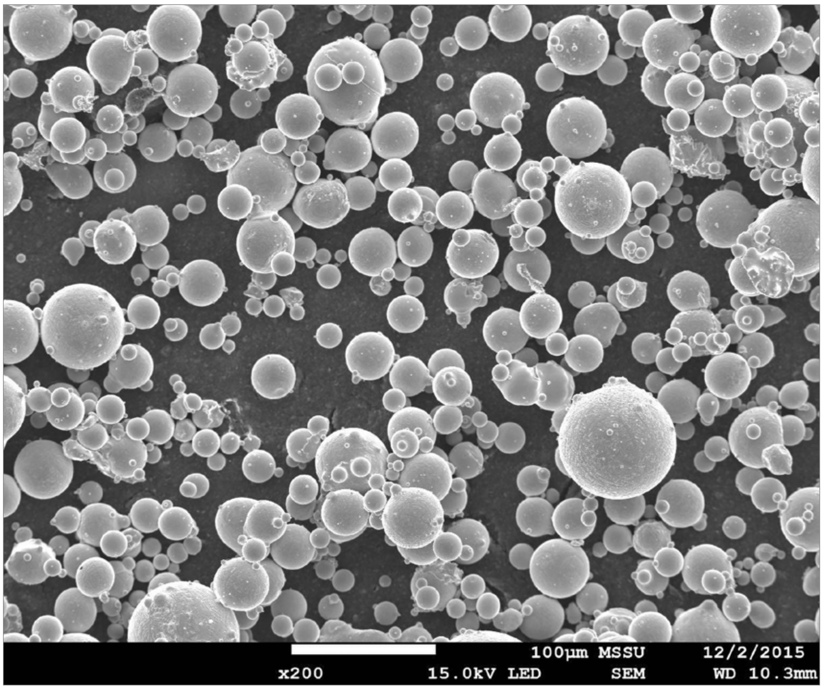

Fig. 3 An SEM of IN718 gas atomised powder (Courtesy Metal Powder and Process Ltd.)

Nickel	50.0-55.0
Chromium	17.0-21.0
Niobium	4.75-5.50
Molybdenum	2.80-3.30
Iron	Balance
Titanium	0.65-1.15
Aluminium	0.20-0.80
Carbon	0.03 max
Silicon	0.35 max
Manganese	0.35 max
Sulphur	0.015 max
Phosphorus	0.015 max
Boron	0.006 max
Cobalt	1.00 max
Copper	0.30 max

Table 3 Superalloy IN718, UNS N07718 chemistry, percent by weight

requires spherical powders. This has led to a series of claims that manufacturer X has the 'most spherical' powder, which is therefore best for AM. So what is the reality on spherocity? It is perhaps better to say that non-spherical powders are unsuitable for AM. A spherical shape improves both flow rate and relative density, both of which are desirable for most AM process.

There are no generally accepted methods for measuring powder shape or morphology, even if new technologies make this possible. SEM pictures can be analysed or other photographic techniques can be used.

The spherocity of a powder may be interesting but, in the end, it is rather academic. It is better to directly measure powder properties, such as flow and packing behaviour. It is also preferable to evaluate the dynamic properties of a powder rather than taking static measurements. Instruments from Granutools, Belgium, for example, can give good indications on powder behaviour in various AM systems by measuring powder in motion.

Chromium	16.00-18.00
Nickel	10.00-14.00
Molybdenum	2.00-3.00
Silicon	1.00 max
Manganese	2.00 max
Sulphur	0.03 max
Phosphorus	0.045 max
Carbon	0.03 max
Iron	Balance

Table 2 316L Stainless steel, UNS S31603 chemistry, percent by weight

Chemistry

The chemistry of a powder is paramount since it defines the alloy. The analysis is specified with a range for each element. There are major, minor and trace elements for most alloys. For example, 316L stainless steel has Cr, Ni, Mo as major elements, Si and Mn as minor elements, and C, P, S, N and O as trace elements. The balance is Fe.

Major elements determine the alloy properties. It should be noted that elements interact and must be kept in proportion for some alloys. For example, if Cr and Mo are at the upper limits and Ni on the low side in 316L, the alloy will start to have a ferritic phase and become magnetic. Minor elements also impact an alloy's phases and can have negative effects on weldability and sinterability in AM.

Trace elements usually only have maximum limits. They can also have a dramatic effect on properties such as crack sensitivity and impact toughness. 'Balance' is the term given on some alloys to account for what is left in the analysis. Since 316L is a steel, the balance is Fe. This is a convenient way to allow for variations in chemistry. The balance is used instead of a number, since summing up elements would not yield exactly 100% due to variations in analytical methods (Table 2).

Some alloys are quite complex, such as IN718, a popular high-temperature superalloy in AM. Table 3 lists the chemistry of UNS N07718. In 718's case the balance is not nickel, as would be expected with a nickel-base superalloy, but iron.

Aluminium and titanium are important elements in 718 as they allow for hardening and phase development in the alloy. They can be affected by the AM process by volatilising or forming oxides or nitrides if the atmosphere is not properly controlled.

Most of the standard alloys used in AM have ranges established for cast and wrought alloys. These are spelled out in ISO, ASTM and UNS standards. It is worth noting that there are virtually no special powder chemistry specifications for AM powders – or for other applications that make parts from metal powders. The chemistry refers to the finished part. So, referring to ASTM B348 for a Ti6Al4V Grade 5 powder is incorrect. It is better to use UNS R56400, which gives the chemical analysis for the alloy.

The end-user expects the built part chemistry to conform to an analysis, since this determines alloy properties. Many values can change during processing in AM systems. It is easy to increase oxygen and nitrogen during processing and some elements, such as Cr and Al, are sensitive to burn-off.

The problem with powder versus part chemistry is well known in MIM, a process which is technically close to binder jetting. Part manufacturers generally report the powder chemistry since it is impossible to do a chemistry test on individual parts and difficult to even test batches. The analysis may even differ on a single part, depending on wall thickness and furnace orientation.

For AM parts, it is possible to include a few test pieces in a build for chemical and mechanical testing. With long build cycles for laser and electron beam-based powder bed processes, this is a good option for chemistry and will not add much to part cost.

Internal powder specifications from part producers often have tighter ranges and maximum limits than UNS/ISO to compensate for what happens in AM machines during build-up or sintering. Obviously, weldability is a concern for laser and electron beam processes, while sinterability is key for binder jetting and other MIM-like processes.

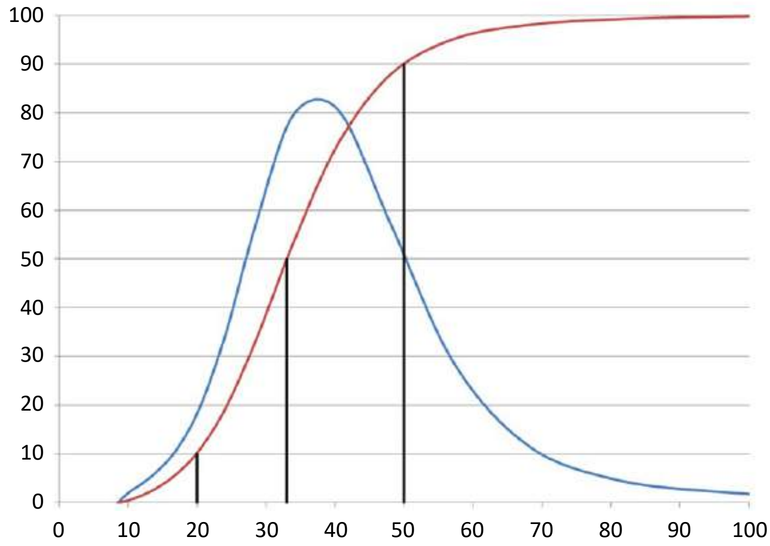

Fig. 4 PSD chart with cumulative volume in red and interval percentage in blue. Black lines indicate D10, D50 and D90

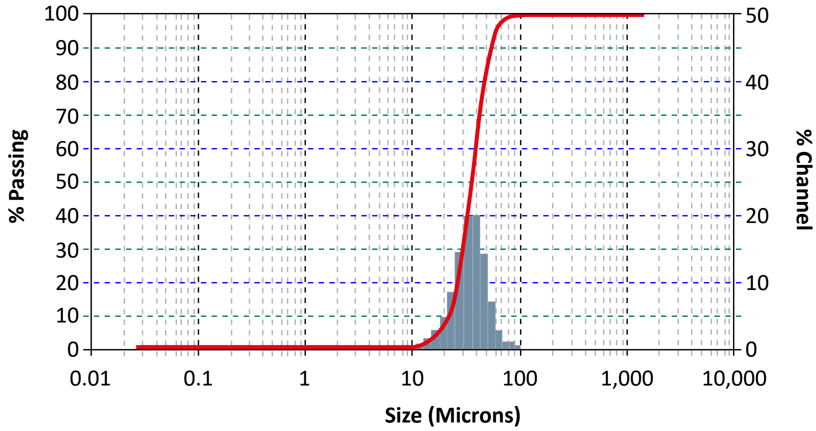

Fig. 5 Log scale plot of PSD volume data

Particle Size Distribution

All AM metal powders are specified with a Particle Size Distribution (PSD). The PSD is usually described in percentiles: D10, D50 and D90. D10 indicates that 10% of powder by weight is finer than this micron size. The D90 size indicates that 10% of the powder by weight is coarser than the micron size. The D50 shows the middle of the distribution. Fig. 4 shows a 15-45 µm PSD based on volume of powder particles– which translates directly to weight. The data are from laser diffraction analysis.

In most cases, the powder manufacturer or equipment OEM only gives the D10, D50 and D90 on the test certificate. On request, it is possible to get the complete PSD from the manufacturer, or you can send a powder sample directly to an independent laboratory for analysis. Fig. 5 shows the chart that usually accompanies a full PSD report.

Figs. 5 and 6 show the same powder as Fig. 4. Fig. 5 is from the instrument manufacturer's software and uses a log scale, which is common for scientific data. However, it effectively hides any

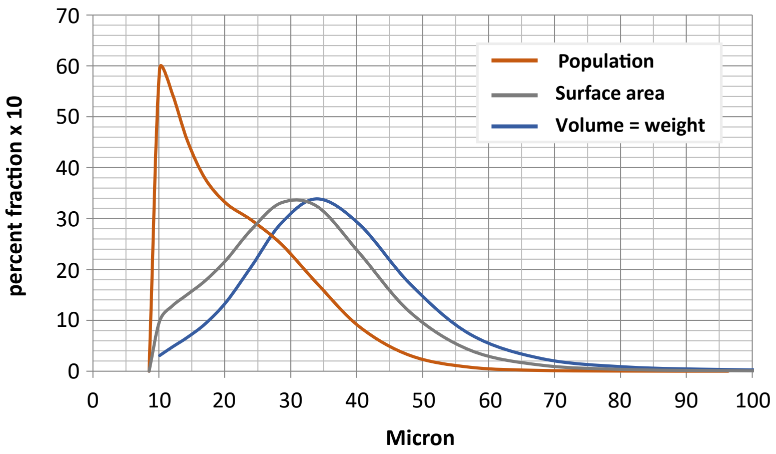

Fig. 6 Particle Size Distribution 15-45 micron CoCr by Microtrac

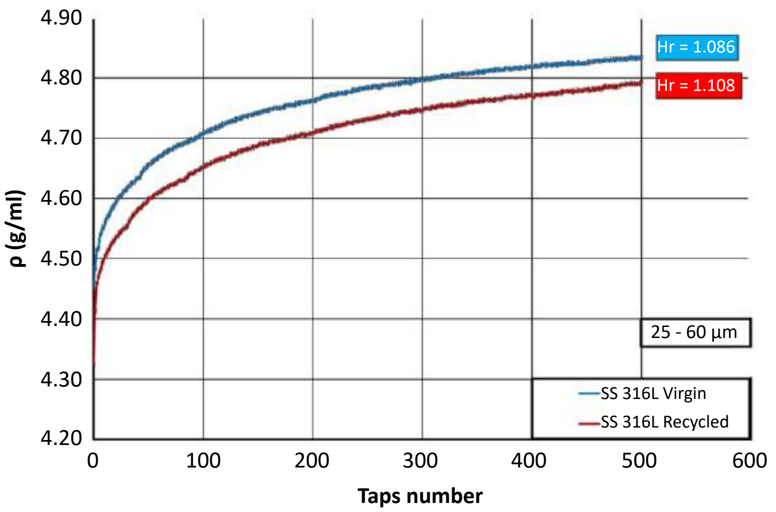

Fig. 7 Dynamic tap density curves from the Granupack system. The chart shows the change in densification behaviour between virgin 316L powder and powder after one build cycle in a laser PDF machine (Courtesy Granutools)

useful information when it comes to AM powders. This makes it necessary to re-plot the data to reveal important information. In Fig. 4, the cumulative curve is accurate. The interval data are the same as in Fig. 6, but are misleading in that no correction has been made for interval width. Fig. 6 has been drawn to show the area under the curve to be 100%.

PSD analysis for AM

There are several ways to look at Particle Size Distribution, as shown in Fig. 6. The most common is volume, which is the same as weight distribution. Microtrac and other laser diffraction instruments measure the diameter of the particles, as well as counting the number of them, in order to get the distribution. After some mathematics this gives a volume distribution, or surface area.

Population

The basis for understanding a powder is to study the particle count, also called population. Whilst it is obvious that a powder consists of a large number of individual particles, it is not necessarily obvious that 1 kg of the 15-45 µm powder in Fig. 4 has over 50 million particles! This is worth keeping in mind when looking at SEM pictures of powder. Only a tiny fraction of the powder is examined and any conclusions drawn can easily be incorrect for the bulk volume.

The population curve is dramatically different to the volume curve, since the latter is based on the r^3. The vast number of particles is on the finer end of the distribution. The volume curve effectively hides the fines and makes it difficult to see any variations.

The fine particles can have a significant effect on the AM process. They melt quickly in Laser Powder Bed Fusion, which is helpful, but can evaporate, creating smoke or porosity. The flow characteristics are also affected, as a small amount of fines can act as ball bearings, improving flow, while large amounts of fines tend to increase particle cohesion, resulting in a lower flow rate.

From a particle population standpoint, there is a big difference between 15-45 µm and 22-53 µm. Binder based MIM-like processes rely on sintering for densification. The higher the surface area, the better the material will sinter (higher density, less slumping, lower sintering temperature required, etc). In this case, the surface area curve can give information helpful for processing.

PSD specifications

The PSD specification is important for both the powder producer and the end user, providing a direct control of the delivered material. A 15-45 µm powder specification could be:

- D10: >15 µm
- D50: 30–35 µm
- D90: <45 µm

There are problems with a specification like this, as it leaves the top and bottom tails open. Better would be:

- D10: 15-18 µm
- D50: 30-35 µm
- D90: 38-45 µm
- -10 µm: 1% max
- +53 µm: 1% max

Powder size is either measured physically with screens (RoTap) or with laser diffraction instruments (Microtrac, Malvern or others). Screens are very good for sizes 45 µm and over. 45 µm corresponds to 325 mesh, so -45 µm is -325 mesh.

Laser instruments are most effective on sizes below 45 µm down to a few microns. PSDs larger than 45 µm should not be analysed with laser instruments. The problem is that the RoTap measurements do not perfectly match the laser value for the same µm size. The laser usually shows a larger + percentage. Since the screens physically measure the powder they are always 'right' and should be used whenever possible. The RoTap is more reliable for the coarser end of the distribution, so many specifications use mesh screening for 45 µm, 53 µm and coarser sizes.

Since Electron Beam Melting (EBM) uses 45-105 µm and Direct Energy Deposition (DED) uses 45-180 µm powder (-140/+325 mesh) the distribution can be completely specified with screens.

Powder size ranges for AM processes

There are four main technology groups for metal powder-based AM and each has different size and powder property requirements.

Laser Powder Bed Fusion

Laser Powder Bed Fusion (LPBF) is also known as Selective Laser Melting (SLM), which is technically a more accurate term for what happens on the powder bed. Many different LBPF system suppliers exist, including EOS, SLM Solutions, Renishaw, Concept Laser, Trumpf and Additive Industries. Typical powder size ranges for this process are 15-45 µm and 22-53 µm, depending on the machine and powder alloy.

Electron Beam Melting

Currently, Arcam is the only supplier of Electron Beam Melting (EBM) technology, but other companies may enter select markets. Powder size ranges for this process are typically 44-105 µm.

Binder Jetting and MIM-like processes

Binder Jetting is a powder bed process like SLM and EBM, but here powder is sintered in a separate step to the shape creation. ExOne is one of the oldest suppliers of technology for this process, but other companies are entering the market, including Desktop Metal with its Production System and Digital Metal.

In addition, a range of processes based on MIM feedstocks are being developed, either using a Fused Filament Fabrication (FFF) process or the extrusion of a pellet/rod-based material. As with Binder Jetting, parts need to undergo a secondary debinding and sintering process. Typical powder sizes for these processes are -45 (0-45) µm, -31 µm, -22 µm and 15-45 µm.

Direct Energy Deposition

Direct Energy Deposition (DED) is a powder fed process as opposed to the powder bed processes detailed above. This is essentially three-dimensional laser welding, where the powder is fed through nozzles in a torch. Typical powder size ranges are 44-180 µm, 44-150 µm, 44-105 µm and 53-180 µm.

Apparent and Packing Density

Apparent Density is usually measured by collecting powder under a Hall Flow meter in a 25 ml cup, weighing and the calculating g/cm^3. In other words, this is a very loosely packed powder. AD is a critical measurement for press and sinter Powder Metallurgy, where powder is filled in a cavity under gravity and then compacted mechanically.

Packing Density is measured with a machine that 'taps' a graduated cylinder for a fixed number of times to rearrange the powder and decrease the volume to a minimum value. This is then referred to as the 'Tap Density' or 'Packing Density'. The Tap Density is a critical value in Metal Injection Moulding, where it determines the maximum loading of metal powder in the organic binder.

The density of the powder in a powder bed AM machine falls somewhere between the Apparent Density and the Packing Density. This will depend on the design of the feeder and spreader in the machine. Most machines use a doctor blade for spreading and levelling the powder, but some use a roller to pack the powder down tighter.

Fig. 7 shows how density increases during 'tapping' measured with a Granupack instrument from Granutools. The curve makes it possible to estimate the powder bed density. It is also possible to see lot-to-lot differences, packing behaviour variation between powder suppliers and changes in recycled powders compared to virgin materials.

The relationship between Tap Density and AD is called the Hausner Ratio (H). A lower value of H (closer to 1.0) is desirable for AM powder bed equipment. If AD and Tap Density are close there is less room for variability in the powder in the build volume.

Hall Flow Rate

The Hall Flow meter is an extremely simple instrument with a long history dating back to mechanical stopwatch days. The time to flow 50 g of powder through a 2.5 mm orifice is measured manually in a funnel shaped device. Some AM machine manufacturers use a 4 mm orifice instead of 2.5 mm.

Perhaps the best attribute of the Hall Flow measurement is its extensive use and historical database. On the other hand, it is

Fig. 8 The Granudrum works on the rotating drum measurement principle, associated with a customised image treatment algorithm (Courtesy Granutools)

subject to operator variability and has limited 'resolution'. The latter is needed to check if a powder lot has deteriorated after use and needs to be adjusted before charging back in the AM machine.

Fortunately, there are instruments that are based on 21st century technology. Fig. 8 shows the Granudrum instrument, which measures how powder flow properties change with velocity. It has an open/unrestricted flow that correlates well with AM powder bed processes, and the information generated is vastly superior to Hall Flow when evaluating and engineering AM powders.

Heats, lots, batches and blending

There is sometimes confusion around how a powder is specified on the test certificate and the origin of each batch of material. Bulk metals such as bar and plate have a 'heat number' which refers to the chemistry of the material. Wrought material originates in large melts, up to 100 tons for carbon steel, while stainless steel and nickel alloys are made in 25-50 ton melts. This is a substantial quantity of material and it is easy to assign a heat number that identifies the material through downstream processing and to the final customer.

Melts made in powder facilities are also assigned heat numbers. The largest metal powder plants can make melts of 5–6 tons in one cycle. Most high-volume production plants have 500–1000 kg furnaces.

Powder yields

The yield of finished material has an effect on how a batch is handled. For the Hot Isostatic Pressing (HIP) of billets, virtually 100% of the powder produced is used and several bars can be made with the same heat number from a 5 ton melt. The same goes for Plasma Transferred Arc and Laser Weld Overlay, where yields are high and it is easy to keep track of a heat.

Most AM powder is made on smaller plants with 250 kg or smaller melting furnaces. The yield here can be low; 30–40% is common but it is sometimes even lower depending on the desired powder fraction.

There is, however, growing demand from AM machine users to receive large heats. This is driven by powder lot qualification. During the development of critical applications in particular, a powder is used to make test bars and to verify machine parameters. When this is done, all

"Most AM powder is made on smaller plants with 250 kg or smaller melting furnaces. The yield here can be low; 30–40% is common but it is sometimes even lower depending on the desired powder fraction."

powder from the lot is considered qualified. Large lots, therefore, mean less testing and a more efficient operation. On the negative side, a larger inventory is required.

Blending

Nearly all AM powder sold today is produced by blending material from several heats. It may still have a 'heat number', but it is really a lot number. Blending is done in small or large blenders, from 250 kg up to several tons. Blending is an old and well-developed technology and, if done correctly, the powder chemistry and size is homogeneous through the batch. Since there are millions of particles per kg, the powder will be consistent even for very small volumes in a thin powder bed layer.

The powder manufacturer will certify the blended chemistry and will not give any information on the lots used, like number of lots or their individual analysis or PSD.

Traceability

The powder manufacturer keeps track of heats made, how they were screened and how much were used in the blends.

The AM parts producer should find out how the powder manufacturer composes the blend; in some cases, many heats and sub lots are used to make the blends. Put another way, all sorts of 'leftovers' may be combined for a batch.

If there is a production issue with a batch, it would be very difficult to identify the problem heat or heats. It is better to ask the powder producer to minimise the number of components of a blend if making critical parts. It may be possible to negotiate a discount if lots of 'leftovers' are used to make a batch.

Blended lot properties

The advantage with blended lots is that it is possible to produce a more consistent chemistry and PSD. Combining heats with higher and lower values will even out the analysis. It is even possible to bring out-of-spec heat chemistry into spec by blending with another heat to average out the analysis. Many aerospace and medical specifications require that all individual batches in a blend are within required ranges on powder analysis and size, which may prevent surprises in the built AM part.

Fig. 9 The laser diffraction particle size analyser, such as the Mastersizer 3000 from Malvern Instruments, is an important tool in the metal powder laboratory

Blending recycled powders in production

The fact that all AM powders are already blends makes it easier to recycle material. As the original powder producer keeps track of heats and lots and how a blend was combined, the AM part producer can do the same and rehomogenise powder lots to avoid disposing of good powder. This will involve careful documentation of chemical analysis and PSD, as well as the weight used. Naturally, a good blender and knowledge of blending techniques are also required.

Conclusion

As has been shown, Additive Manufacturing using metal powders has some unique requirements. The metal powder data that has been collected and reported on over many decades is very useful, but additional attention is required as AM technology is very different to other metal powder-based part production processes such as Powder Metallurgy, MIM, HIP and thermal spray. However, through additional analysis of PSD and chemistry, as well as the use of new open flow instruments, it is possible to control and improve the powders used in AM.

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Design for Additive Manufacturing presents opportunities for software developments

Designing a component for AM whilst taking advantage of all the opportunities that the technology presents can result in many variables. Even a group of experienced Design for Additive Manufacturing (DfAM) experts will end up with significantly different build strategies for an identical part. In the following article, Olaf Diegel and Terry Wohlers consider how software innovations could further streamline the AM process, from part positioning and stress management to surface finish considerations and quality control.

After a part has been designed for Additive Manufacturing, it must be prepared for production on an AM system. This is usually done using software provided by the system manufacturer or with generic AM file preparation software. The steps include setting up the part orientation on the build platform and generating the support structures, also referred to as anchors, for the part, as well as selecting build parameters and nesting multiple parts on the platform to make the build as efficient as possible. If you do not, the cost per part can become unaffordably high.

With any AM process, the decisions made during the file preparation process can have a vast impact on the surface quality, part cost and mechanical properties of the part. Also, they can affect the amount of manual post-processing that needs to be undertaken after the part has been manufactured. Due to the very high thermal stresses acting on a metal part during the build process, choosing the best build orientation, support material strategy or process parameters can prevent machine crashes and disastrous results.

Today, the software used to prepare a metal AM component for production relies on the knowledge and experience of the operator to set up a part in the best possible way. This means achieving the best surface finish, best mechanical properties, shortest print time and easiest support removal method. The removal of support material involves cutting and grinding away metal that is welded to the part. If three different machine operators set up the same part for a build, the results are three different part qualities because they will each likely use a different approach.

Fig. 1 The design and manufacture of complex AM parts such as this hydraulic manifold from Atlas Copco relies heavily on specialist AM file preparation software

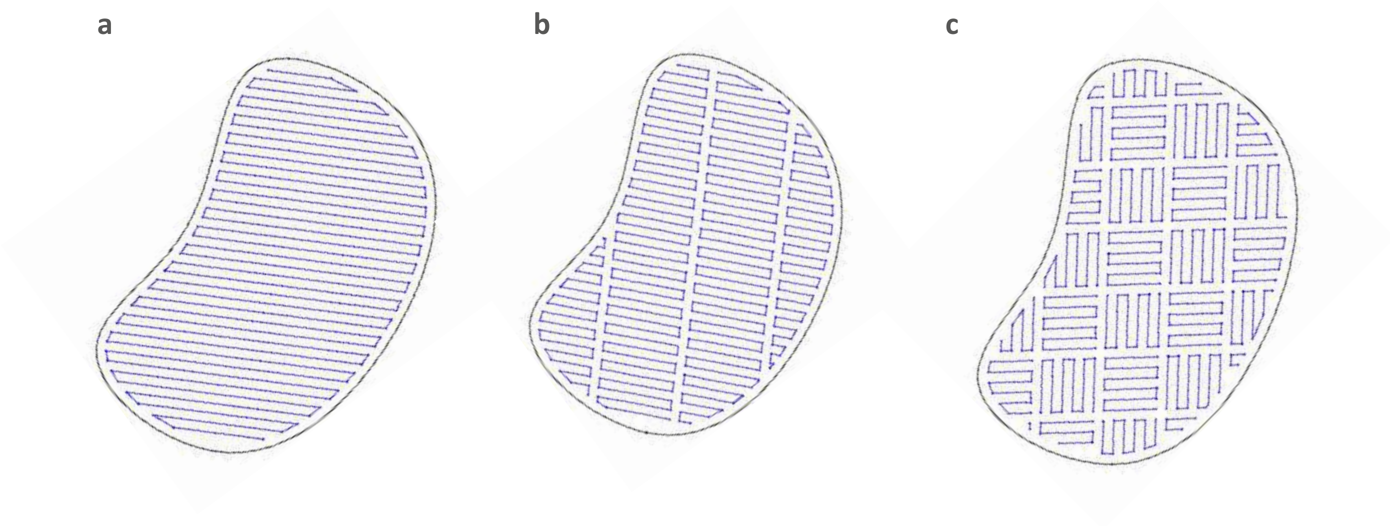

Fig. 2 Laser hatching can have a profound effect on residual stress; (a) shows a meander hatch pattern, which offers a high build rate but high residual stress, (b) shows a stripe hatch pattern that offers a medium build rate and medium residual stress and is suitable for medium-sized parts, (c) shows a chessboard hatch pattern, which builds more slowly but offers the lowest residual stress of the three and is most suitable for large parts

This state of affairs is one of the factors which adds a level of difficulty to metal AM and impacts its adoption by industry. Even so, it represents a great area of opportunity for software developers to create more intelligent software which streamlines and automates as much of the AM file preparation process as possible. Although the examples presented here refer to metal Powder Bed Fusion (PBF), many of the principles apply equally to other AM processes.

Automatic part positioning

It should be possible to analyse a part and, based on a number of factors, automatically orient it in a way that makes production as reliable and low-cost as possible. The decision on how to best position a part on a build plate is critical and is driven by the following factors:

Anisotropic direction
An anisotropic part is one with mechanical properties of varying values in different directions. This must be taken into account when positioning a part in an orientation that results in the highest possible strength for the features that require it most. This is usually the horizontal position, or as close to horizontal as possible. The orientation is often a compromise, because a part may have features in multiple directions.

Feature quality
Holes that are printed horizontally are usually not round, but slightly elliptical, and suffer from a 'stair step' effect caused by the layer-upon-layer build process. Also, because of the stair step effect, gently curving surfaces can vary in quality, especially when a surface is nearly horizontal. The quality of other features, such as text, can differ substantially depending on the build orientation. Such decisions could serve as good input for software that automatically suggests the best orientation of a part.

Surface quality
With AM, down-facing surfaces usually suffer from poor quality, compared to up-facing surfaces. Surfaces that are the most critical can play a role in making decisions about part orientation. This decision, however, is not always obvious. In some cases, the down-facing surfaces will need to be machined, so it would make sense to position the most critical surfaces downward, thus guaranteeing the best surface finish with machining.

Residual stress

Residual stress can occur whenever metal is cooling. Large masses of metal in a part, or sudden changes in the cross-sectional area of a part, can especially affect part quality. This is because the thicker parts cool down slower than thinner parts, and can distort the part or create a weakness within it. Residual stress is also one of the main reasons why parts are usually heat-treated after printing. Proper heat treatment will relieve the built-up stresses.

Suppose all design precautions have been taken into account to minimise residual stress, such as minimising large masses of materials. In the case of laser-based PBF, the main parameter that a user can control to reduce residual stress is the laser scan strategy. In a part with large surface areas, the laser hatching can have a profound effect on residual stress. A 'chessboard' pattern, for example, creates less residual stress than a large 'meander' pattern, although the chessboard pattern builds more slowly. Rotating the scan directions for alternating layers, usually by 67°, can also help to prevent residual stress in a single direction.

Fig. 2a shows a meander hatch pattern, which offers a high build rate but high residual stress. This is suitable for small and thin parts. Fig. 2b is an example of a stripe hatch pattern. This offers a medium build rate and medium residual stress and is suitable for medium-sized parts. Fig. 2c shows a chessboard hatch pattern, which builds more slowly but offers the lowest residual stress of the three. It is most suitable for large parts.

Maximum build speed is always desirable, and improved software could help. Based on analysis and predictive results of the residual stress, the print preparation software would dynamically change the laser scan hatch pattern to best minimise the residual stress for each feature of a part.

Large horizontal areas

When building large horizontal surfaces on most AM systems, the build material tends to curl upward and detach from the support material. This can result in the formation of cracks. Rotating a part by 10–45° will reduce the size of large cross sections, although it can greatly increase print times. Changing the laser scan strategy for the hatch pattern can minimise the problem, presenting the opportunity for part preparation software to automate the process.

Fig. 3 shows an electronics enclosure measuring 99 x 80 x 33 mm. The surface is good when printed at a 45° angle. The time to build three parts at this orientation is 54 hours. Fig. 3c shows the enclosure printed horizontally. Three copies of the part took only 22 hours to produce, but cracks developed on the bottom surface.

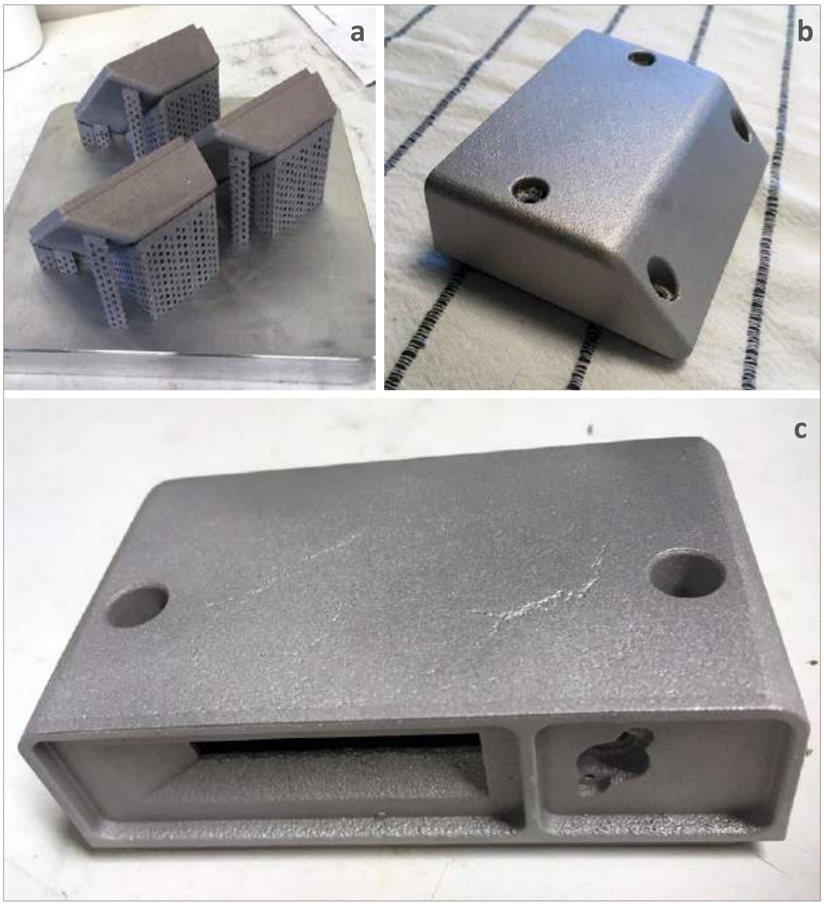

Fig. 3 Image (a) shows the print orientation for the part in (b). The bottom surface did not crack, but it required a print time of 54 hours for the three parts. (c) shows the same part printed horizontally, which resulted in cracks in the bottom surface, however the print time was 22 hours for the three parts

Support material requirements

Any surfaces below a certain angle, often 45°, require support material that needs to be removed. This support material also serves as a heat sink to help prevent distortion of the part and its features. The supports also serve to resist the mechanical force of the powder spreading mechanism, which might otherwise push and move the part. For this reason, it is critical that the part be well-anchored to the build platform, with the support material helping to prevent thin vertical sections of the part from being bent or knocked over.

"Any surfaces below a certain angle, often 45°, require support material that needs to be removed. This support material also serves as a heat sink to help prevent distortion of the part and its features."

Additional software improvements related to the generation of support material are possible. One interesting

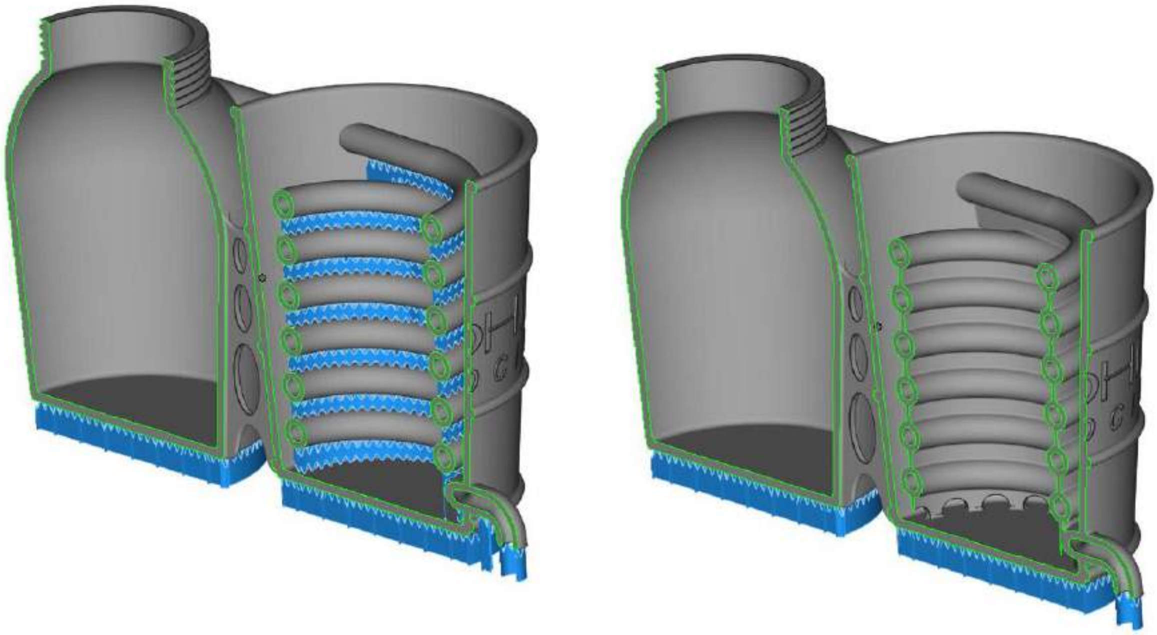

Fig. 4 In this distillery design, the support structures (blue) in the design on the left were replaced with solid walls in the design on the right. This small change substantially reduces the cost of post-processing operations

DfAM technique is to replace support material with a wall that becomes a permanent feature of the part. Consider the distillery design in Fig. 4. The blue sections represent support material which allows the transfer of heat down to the build plate. One option is to replace the support material between the coils with permanent walls, which serve the same function but do not need to be removed after production. This could be automated through software by giving the user the option to choose between supports or permanent walls.

Quality assurance

Many system manufacturers now offer in-situ process monitoring options that produce a digital image of each layer of the build. Currently, they offer little intelligence, leaving it to the user to review the images manually to identify why a defect has occurred. This is another opportunity for software automation. Image processing systems have been available for many years and are currently being used in a number of industries to automatically identify flaws in products. One can imagine future AM systems analysing and drawing a conclusion from each image as it is taken. If an error occurs, such as unintended porosity, the software would make the decision to reprocess that area and/or pinpoint the problem and alert the person responsible for the machine.

> *"Part consolidation requires experience and skill. New software tools could help the designer by suggesting which parts could be combined into one, making the process easier and more streamlined."*

Future software developments

Improved software could also help in other areas of metal AM. For example, it is possible to consolidate two or several parts into one, digitally, and then build a much more complex part. Airbus, GE and many other companies have done this successfully and serve as inspiration for a growing number of organisations that are adopting metal AM. However, part consolidation requires experience and skill. New software tools could help the designer by suggesting which parts could be combined into one, making the process easier and more streamlined.

Another area is the use of topology optimisation and lattice, mesh and cellular structures to reduce material and weight while producing strong parts. Many software tools that offer these capabilities have been commercialised, but most are stand-alone and not seamlessly integrated into the design and AM work flow. The AM industry has the opportunity to use generative design and cloud computing to further streamline the product development and manufacturing process and intelligently suggest new designs based on a number of inputs and parameters. The integration of AM design rules and guidelines would also help designers reduce the costly and time-consuming process of trial and error to a minimum.

These examples of the automation of important process steps through software only scratch the surface of the challenges and opportunities of manufacturing good metal AM parts. However, they identify some of the areas in which intelligent software could make metal AM easier to use as a technology, and thus help to increase its industrial adoption. Software tools for part consolidation and other methods of design could be fully integrated into the AM work flow and greatly assist designers. These needs are significant and greatly impact the economics of metal AM, so request and watch for these capabilities in the future.

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How process parameters drive successful metal AM part production

A number of factors drive the selection of process parameters in Laser Powder Bed Fusion (LPBF). In this invaluable resource Marc Saunders, Renishaw plc's Director of Global Solutions Centres, details how these parameters define the 'operating window' in which AM users must work, and offers advice on identifying the ideal process parameters for metal AM parts. The sensitivity of the process to changes in part geometry is also considered, along with how this may drive part developers towards application-specific parameter choices.

To ensure the successful production of metal components by Laser Powder Bed Fusion, it is important to carefully consider the processing parameters used to melt and solidify the metal powder on the powder bed to the desired shape. Because the thermal response of an alloy affects both its integrity and strength, the correct parameters must be selected to suit the material in question and the requirements of the as-built component. This becomes especially important in the context of series production, where the repeatability of the AM build process is key to avoiding quality issues further down the line.

In the LPBF process, a powerful ytterbium fibre laser beam is focused onto a small spot that contains sufficient energy intensity to fully melt a thin layer of metal powder. To direct the laser energy, a pair of articulating galvanometer mirrors are combined to move the spot across the powder bed. The result is a track of solid metal securely welded to its neighbour and the layer below. A shielding gas flow then passes across the build plate to safely remove process emissions while protecting the heated metal from oxidation.

Each weld track is somewhat wider than the laser spot (by as much as 2–3 times the spot diameter), as the heat from the laser is conducted into the surrounding powder particles, incorporating them into the moving melt pool. Multiple melt tracks are joined together and overlapped to create a solid layer corresponding to a slice through the component. The melt track must also be sufficiently deep to partially re-melt the layer below to form a fully-dense solid structure. In this way, the component is built up slice by slice.

Fig. 1 The laser melting process in a Renishaw AM400 build chamber

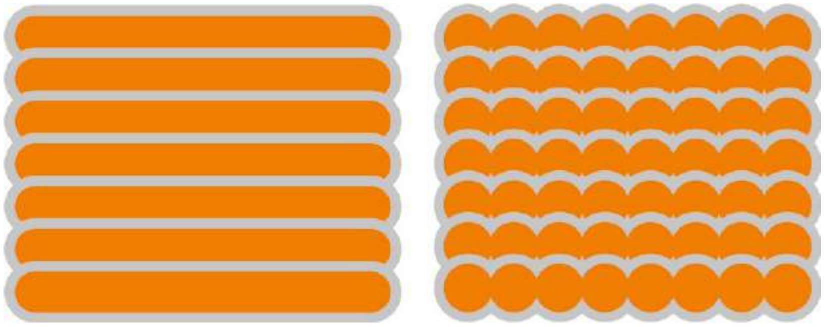

Fig. 2 Continuous wave laser scanning (left) involves a series of overlapping scan lines, each formed with the laser operating continuously. Modulated lasers achieve the same effect using a series of sequential exposures (right)

Two main techniques are used to melt powder – continuous and modulated scanning (Fig. 2). In continuous mode, as the name suggests, laser energy is delivered continuously to melt the powder by guiding the laser beam to and fro across the surface of the powder bed to solidify the metal. The scan lines overlap, so that each successive pass of the laser partially re-melts the previous scan line, creating a solid mass of welded material.

In modulated mode, the lasers operate in a slightly different way. Here the laser is turned on and off, creating a series of exposures, with a short (10–20 microsecond) pause between them. Each exposure partially overlaps with the previous one. These can be formed into similar scan lines that move efficiently across the powder bed to solidify the bulk of the component.

Process parameter basics

The way in which laser energy is transferred into the powder bed is governed by process parameters. These define how much energy is applied and how fast. The critical parameters are:

- Laser power: the total energy emitted by the laser per unit time
- Spot size: the diameter of the focused laser beam - this may be fixed or programmable depending on the focusing system on the machine
- Scanning velocity: the speed at which the spot is moved across the powder bed along a scan vector - this is defined by point distance and exposure time on a modulated laser system
- Hatch distance: the spacing between neighbouring scan vectors, which is designed to allow a certain degree of re-melting of the previous weld track to ensure full coverage of the region to be melted
- Layer thickness: the depth of each new powder layer to be melted.

Each of these parameters can be adjusted independently, making parameter selection a multi-variable problem.

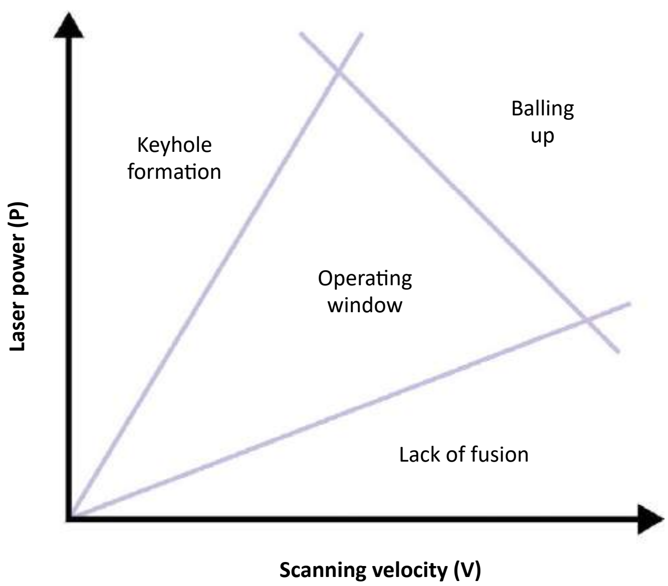

Fig. 3 Laser power vs scanning velocity graph – how process outcomes vary with parameter choices

Finding the operating window

The first consideration when choosing the parameter is to achieve a consistent, fully-dense component. Part density is a key indicator of melting quality - if the part is porous, it is unlikely to exhibit the strength, ductility and fatigue / creep performance that we need. But with so many parameters to play with, how do we choose the right combination?

Simplifying things helps. For any given build, the powder chemistry and particle size distribution are fixed. We are also likely to fix the layer thickness based on the resolution and surface finish that we need for our component. If we also fix the laser spot size (which cannot be varied mid-build on many machines) then we are left with power, speed and hatch distance.

The explanation below is adapted from work by Robert M Suter and colleagues at the Stewardship Science Academic Programs (SSAP)

Symposium in Chicago, April 2007 [1]. A helpful way to think about this is to plot our parameter choices in P-V space, plotting laser power (P) against scanning velocity (V). Our choice of parameters will affect the process outcome, as shown in Fig. 3. If we scan too fast with too little power, then we will see regions of the part which do not fully melt, leading to 'lack of fusion' porosity. By contrast, if we apply too much power for the chosen speed, then we may overheat the melt pool, causing deeper energy penetration and leading to an effect known as 'keyhole formation.'

Between these two extremes lies an operating window where we will achieve good part density. Here, the energy from our laser is sufficient to fully melt the powder and underlying metal without penetrating too deeply. Fig. 3 suggests that we can increase both power and speed together to build faster, and to an extent this is true. However, there is a limit to how hard and fast we can go, beyond which the weld pool behaviour becomes unstable and we get a beading effect known as 'balling up.' We also tend to see an increase in spatter formation at higher laser power.

Processing in the operating window

The central operating window on the P-V diagram in Fig. 3 is where the right combination of speed and power generates a stable melt pool of the optimum size. It is where the laser energy is being efficiently absorbed by the powder, creating a melt pool of sufficient depth to fuse strongly with the layer below whilst avoiding excessive re-melting.

In this processing zone, the laser recoil pressure creates a shallow cavity. The laser heats the front face of this cavity as it moves, creating a metal vapour plume that is ejected normal to the surface – i.e. upwards and backwards. The shallow cavity does not allow for internal reflections, so no additional melting occurs. Heat energy is conducted into the melt pool, which experiences a degree of turbulent flow due to the high temperature gradients within it and the surface tension. This flow will result in some matter being ejected in the form of weld spatter.

The moving vapour plume creates an environment around the melt pool that is analogous to a weather system. It can entrain powder from next to the weld track, drawing it towards the laser beam through the Bernoulli effect and then ejecting it outwards. Some of this material will be heated as it passes through the laser, while other material is blown around by the induced gas flow in the form of 'winds' adjacent to the laser beam.

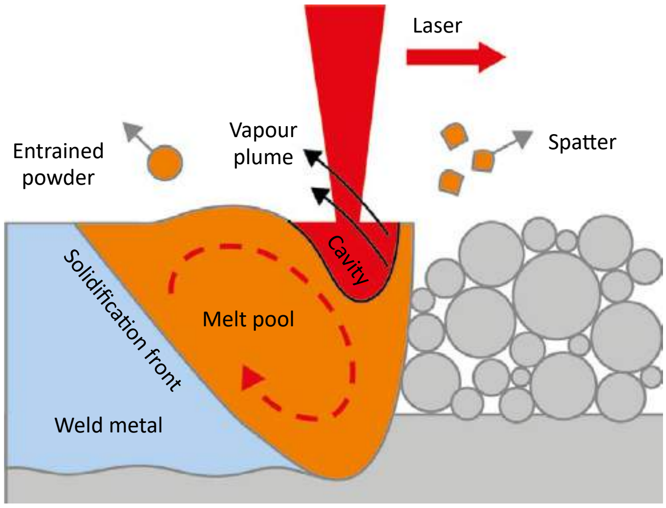

Fig. 4 Efficient processing where we have an optimal combination of speed and power, creating a stable melt pool that penetrates to the correct depth

Lack of fusion

If we use less power for a given speed, then the melt pool will be smaller. This means that it is likely to experience less turbulence and generate less spatter as it solidifies more rapidly. The vapour plume will also be less vigorous and so entrainment of neighbouring powder will also be reduced.

The bad news is that now the lower laser energy may not penetrate deeply enough to fully melt the powder layer and the top surface of the solid metal below. This leaves unmelted powder beneath the melt pool, resulting in excessive porosity and risk of delamination as illustrated in Fig. 5.

> *"If we scan too fast with too little power, then we will see regions of the part which do not fully melt, leading to 'lack of fusion' porosity..."*

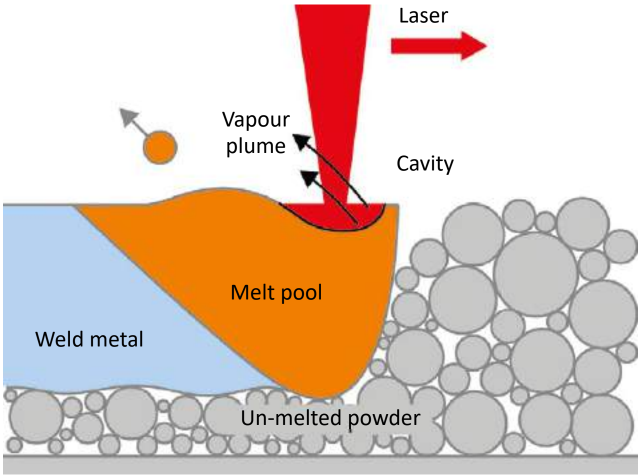

Fig. 5 Insufficient penetration of the laser energy leaves unmelted material and weakness in the component

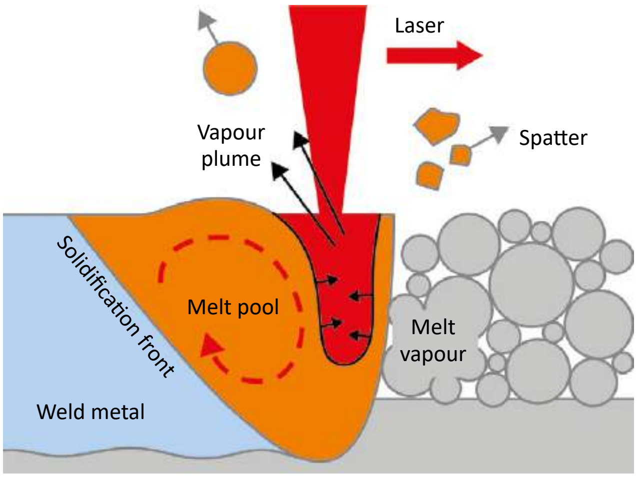

Fig. 6 Moderate keyhole effect - a deep cavity is formed by an intense laser spot

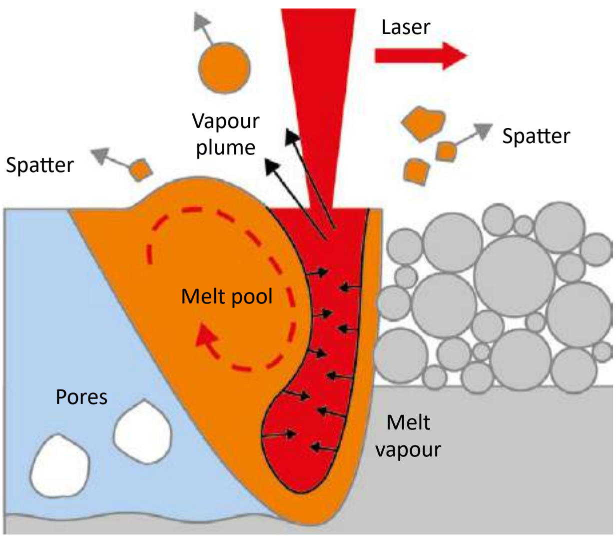

Fig. 7 Excessive keyhole effect – a very deep cavity can trap gas in a pore below the component surface

Keyhole formation

When too much power is used for a given speed, we see excess penetration of the laser into the metal under the layer of powder, forming a keyhole (Fig. 6). This deep melt cavity in the surface sees metal vapour being ejected more vertically than before. Internal reflections of the laser energy within the cavity trap more heat deeper in the material, leading to a deeper, longer-lasting melt pool. This increase in energy input will increase melt pool turbulence and spatter formation, whilst a stronger 'weather system' will lead to more powder entrainment.

Where the keyhole becomes unstable (affected by power, scan velocity and melt pool dynamics), the melt pool can collapse in on the cavity to form a pore of inert gas at the base. Such pores may not close up as the melt pool solidifies, generating sub-surface porosity in the welded metal. A greater degree of re-melting of the layers below will also occur, affecting the microstructure of the solidified material (Fig. 7).

Experimental evidence from the National Institute of Standards and Technology (NIST) illustrates the impact of parameter choices on melt pool size (Fig. 8) [2]. Measuring an Inconel melt pool from above using an infrared camera, NIST observed that the melt pool length is roughly constant for different scanning speeds at the same laser power. However, the melt pool width, and hence area, increases as the speed reduces. In this case, at 200 W laser power, the length of the melt pool is approx. 0.6 mm at speeds varying from 200 mm/sec to 800 mm/sec. The wider (and thus deeper) melt pool created at slower scan speeds contains more thermal energy and so takes longer to solidify - up to 3 ms in the most extreme case.

At higher speeds, the melt pool can become unstable. High surface tension gradients can lead to the formation of voids behind the laser beam that expand as the laser moves on, causing the melt pool to break apart into separate islands that solidify as beads (Fig. 9).

Solidification and microstructure

So far, we have considered the melting aspects of the LPBF process and their effect on part density. It is, however, the solidification process that is most critical to establishing the performance characteristics of the metal component. Solidification defines microstructure, which in turn drives material properties.

Many alloys are complex and can exist in multiple phases at different temperatures and compositions, and so solidification does not happen all at once. Nor does it happen uniformly within a typical weld track. Cooling is most rapid where the heat can escape and most of the heat is conducted out of the melt pool and into the surrounding solid metal. Relatively little heat is lost into the neighbouring unmelted powder, or via radiation up into the chamber.

As the molten metal cools, the outer regions of the melt pool fall below the liquidus temperature and one or more phases of the alloy will start to solidify. Cellular-dendritic crystals form at the outer edge of the melt pool, growing in towards the centre. The remaining liquid phases are trapped between these primary dendrites, only solidifying once their lower melting points are reached. Opposing cellular-dendritic growth fronts form the individual grain boundaries where the remaining liquid phase can also accumulate.

The cooling process places strains on these cellular and grain boundary regions, which can result in unwelcome porosity through a process known as 'hot tearing' or solidification cracking in some materials (Fig. 10). This is worst where there is a large difference between the temperatures at which the different phases solidify.

As we can see, the size, duration and cooling rate of the melt pool is important, as it governs the thermal response of the material. A longer-lasting melt pool that cools more slowly will produce a coarser microstructure, with larger grains and thicker dendrites. By contrast,

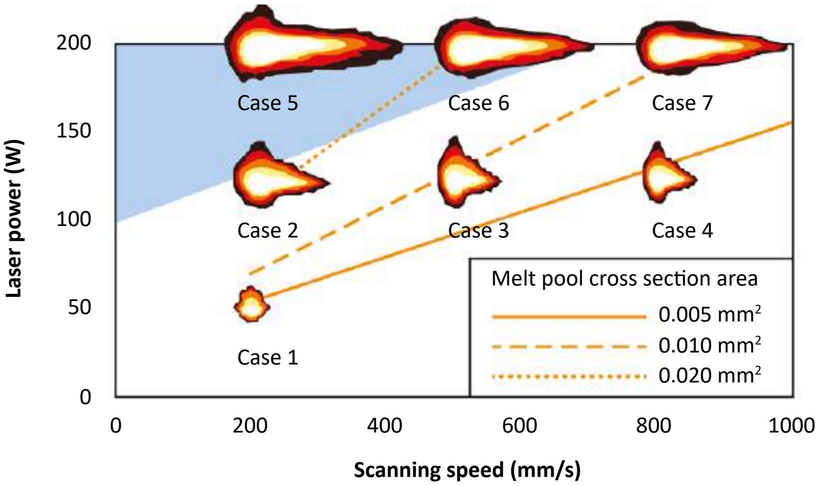

Fig. 8 Experimental measurement of melt pool dimensions in Inconel 625 at various locations in P-V space. The power and speed combinations at the top left of the diagram (most notably case 5) fall into the shaded keyhole formation zone [2]

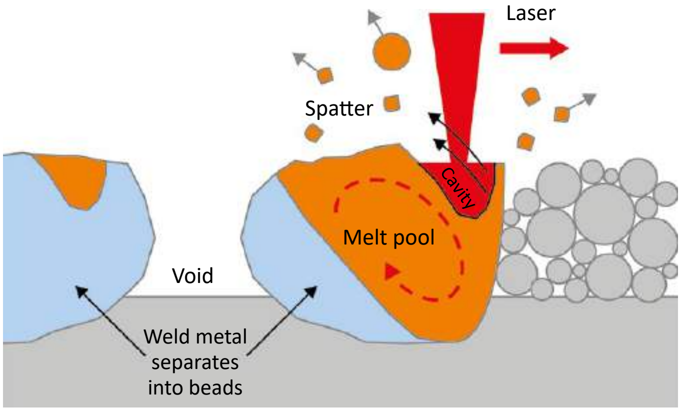

Fig. 9 Unstable melt pool caused by excessive scanning speed

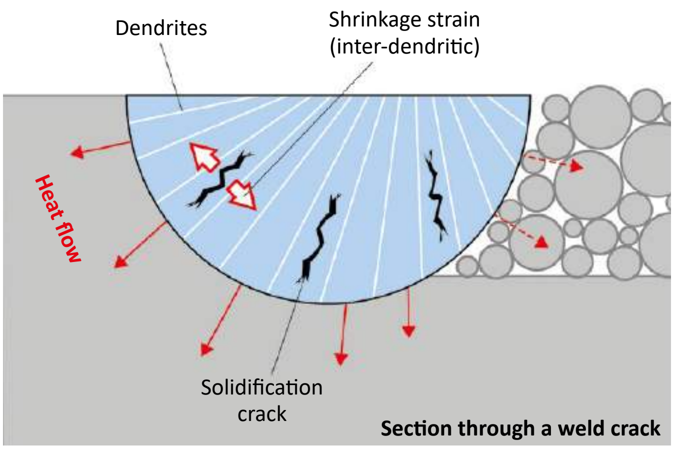

Fig. 10 Cooling dendrites place strain on the 'mushy' regions, leading to solidification cracking

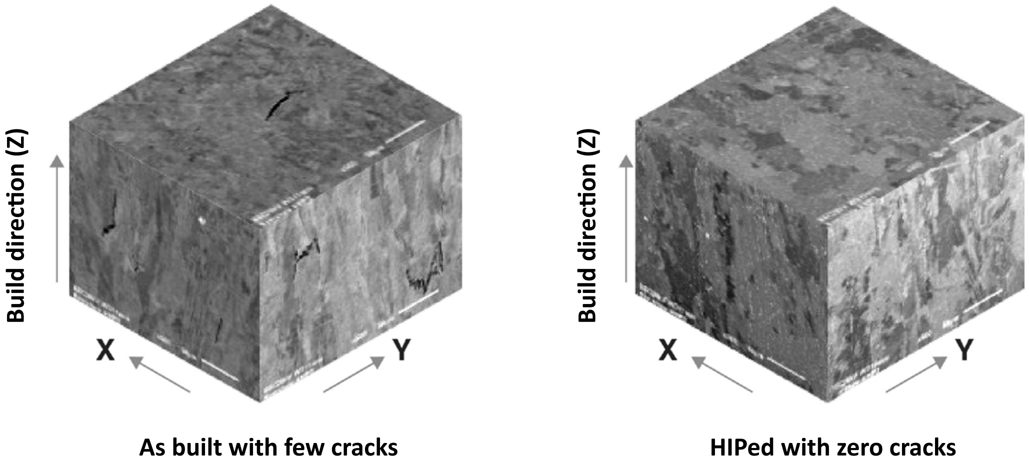

Fig. 11 Columnar grain formation in 'as-built' nickel superalloy processed using LPBF (left), showing elongated grains spanning multiple layers, aligned in the build direction. This material also suffers from some solidification and grain boundary cracking. Post-process heat treatment can close up such porosity and can also modify the microstructure to produce more equiaxed grains and normalised material properties

smaller melt pools will cool more rapidly, creating a finer microstructure.

A deeper melt pool will also cause more re-melting of the previously-solidified metal, as well as affecting its microstructure. Higher laser power correlates with the formation of longer columnar vertical grains, each spanning multiple layers. Since a deeper melt pool has a larger contact area with the solid metal below, more heat is conducted downwards, increasing the vertical alignment of grains. This can result in a greater difference between mechanical properties in directions perpendicular to and parallel with the build direction (Fig. 11).

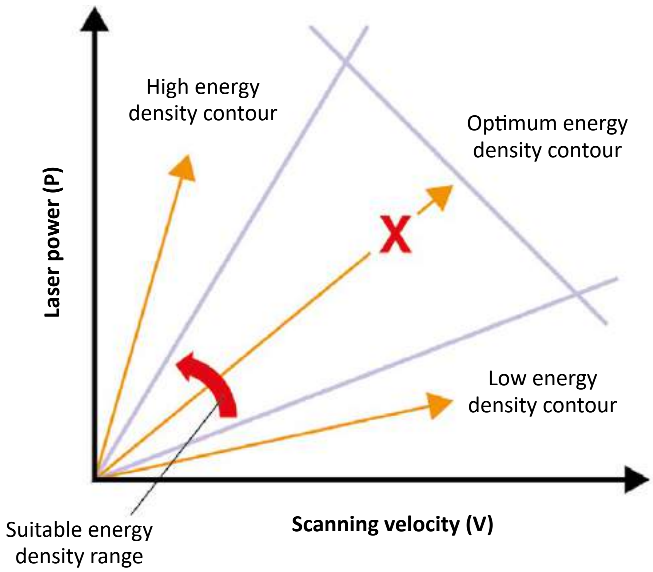

Fig. 12 The ideal operating window, identified as X

The ideal operating window

So, we are looking for a combination of speed and power that creates a melt pool of the optimum depth, width and duration. This means putting the optimal amount of energy into our part. When we get this right, we achieve a combination of low porosity with a microstructure that yields our desired material properties and achieves an acceptable level of productivity.

One way to think about this is in terms of energy density; the amount of energy that we apply to the material per unit volume. For a constant energy density, laser power and scanning velocity are inversely related to one another, so, in P-V space, energy density contours radiate from the origin, with the density being related to the gradient of the contour.

For our chosen material and layer thickness, there will be an optimum energy density at which it will process most efficiently and deliver the microstructure that we are looking for. When choosing our process parameters, we want to be as far along this contour as we can reach with the laser and focusing optics available on our AM machine, without venturing too far towards the 'balling up' region. This will give us the best material properties, combined with the best productivity.

Hatch distance

The analysis shown above is missing one crucial factor: hatch distance. Our graph assumes that the hatch distance is fixed, so that energy density is governed only by laser power and scan velocity. Of course, hatch distance can be varied independently of power and speed and it also affects the energy density. It is therefore possible to maintain the same energy density along a range of P-V contours by varying the hatch distance. We can put the same total amount of energy into the layer in many different ways (Fig. 13).

All three contours shown by the orange arrows in Fig. 14 have the same energy density. For instance, if we adopt a higher power-to-velocity ratio (i.e. we choose a steeper contour that is closer to the keyhole formation zone) we can keep the energy density constant by increasing the hatch spacing. This makes sense - if we create a wider, deeper melt pool with a more penetrative laser beam, then we can afford to space them further apart whilst still fusing them to one another.

However, by doing this we will see a drop-off in material properties for the reasons outlined above. By venturing close to the keyhole formation zone, we are also reducing the safety factor in our process, which may limit the applicability of these parameters to certain geometries. It is important to pick a hatch distance that keeps us on a central P-V contour that is well away from both the lack of fusion and keyhole formation zones.

Whilst parameters in the blue zone in Fig. 14 should provide acceptable results, the ideal operating point is still that defined by 'X'. Since most of the energy from the laser beam is absorbed within the laser spot in the centre of the melt track, a hatch distance that is similar to the spot size (or approximately half the width of the melt track) is generally most effective.

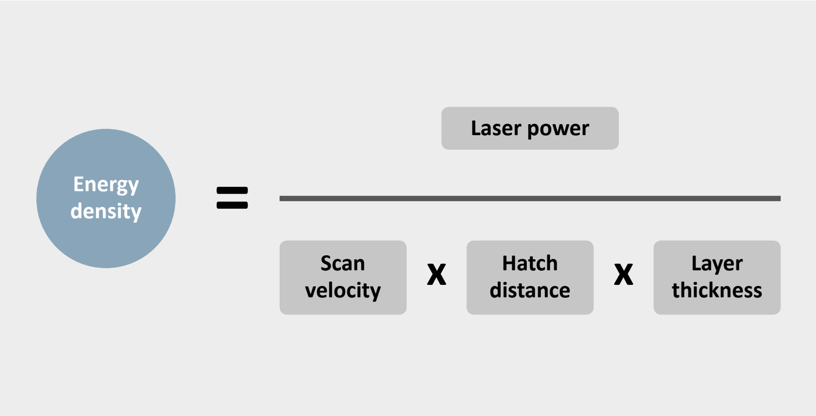

Fig. 13 Energy density formula

Layer thickness

In the above discussion, layer thickness was fixed. What if we vary this too? If we are not too concerned with surface finish, can we increase the layer thickness to increase build rates? The answer is yes - up to a point. Clearly, thicker layers require deeper penetration of the laser energy to ensure complete fusion to the metal below. To achieve the optimum volumetric energy input to fully melt the material, as we increase the layer thickness, we must also increase the energy input per layer. Our energy density contour therefore becomes steeper.

Increasing layer thickness pushes the 'lack of fusion' region on Fig. 15, narrowing the gap between it and the keyhole formation zone. The keyhole formation zone itself may not vary much with layer thickness, since this behaviour is governed by the intensity and speed of the laser spot and how this interacts with the material.

The operating window is therefore closing and eventually we reach a layer thickness where we cannot penetrate deep enough whilst maintaining a stable melt pool and sufficient fusion to the metal below.

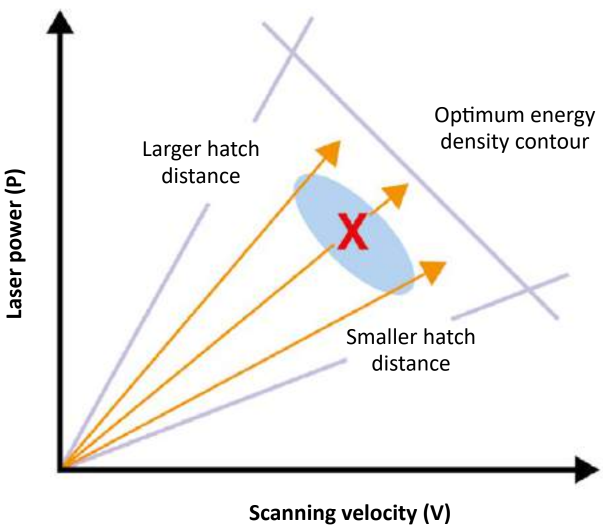

Fig. 14 Impact of the hatch distance on melting process outcomes

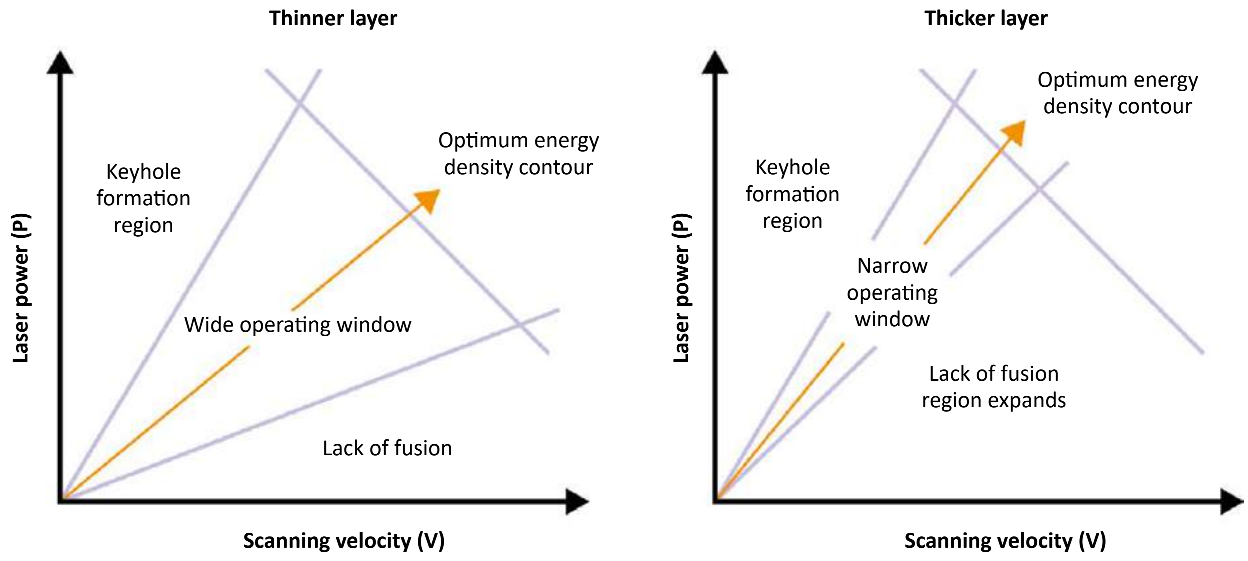

Fig. 15 Thicker layers reduce the operating window

The practical layer thickness that gives us a reasonable operating window varies with material, but generally falls in the range of 30 to 90 microns for laser spots of 70 to 100 microns in diameter for laser powers up to 500 W. Thicker layers can be accommodated by increasing the spot size to reduce the spot intensity at higher laser powers. However, this change is accompanied by a loss of fidelity, an increase in melt pool size and spatter formation, and may also affect the microstructure and material properties.

Why do we need a safety factor?

The reason that we want to process in the middle of a wide operating window is that we will not always face constant thermal conditions in all regions of the build. As each new layer is added, heat is conducted down into the previously built layers below. How well this heat is dispersed will depend on the local geometry of the component and the material properties.

Where there is a good thermal connection to the substrate below, heat will dissipate effectively (Figs. 16a, 16b). By contrast, if the part geometry involves thinner walls, or if there is a bulky region immediately above a much thinner section, then heat will not be able to flow down so easily, resulting in more heat being retained near the top of the part. This effect is most marked in materials with a relatively low thermal conductivity, such as Ti6Al4V.

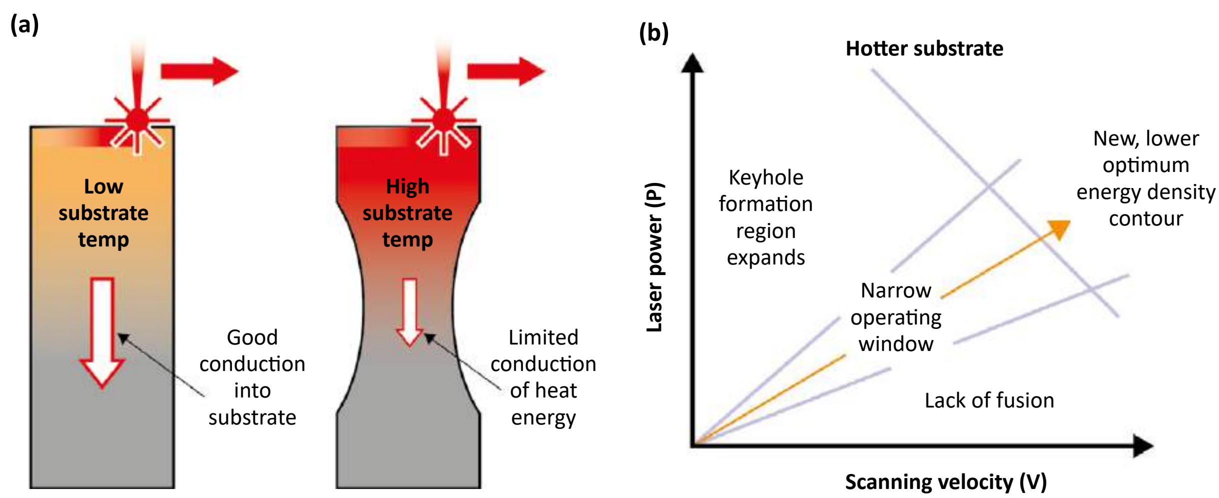

Fig. 16 Impact of geometry on heat retention (a) and retained heat narrows the operating window (b)

In these conditions, the substrate and the powder are preheated and thus require less energy input to create the same melting effect. The impact of this preheating on the melting process is to expand the keyhole formation region, reducing the power at which keyhole porosity will occur. The new optimum energy density contour is lower than before, and the operating window is narrower.

One possible remedy is to use simulation to identify the regions of the part that are most likely to overheat, and to reduce the laser energy input in these regions to offset this pre-heating effect.

Combining this point with the previous one on layer thickness leads to the conclusion that building thin-walled parts in thicker layers will be particularly challenging.

Nominal and specific parameter sets

So far, we have concentrated on finding the ideal bulk processing parameters for a material, enabling us to produce good metal as quickly as we can. But a working parameter set requires more than just one setting, as we encounter different melting and cooling conditions in different regions of our component. To deliver functional parts, we need to complement our bulk parameters with specialised settings for the various geometries that we are producing.

Every component will comprise both bulk regions and surfaces orientated in various directions. In the bulk regions we want high density, rapid build and good material properties. Our priorities for borders will be different - surface finish may be our biggest concern, or it may be suppression of surface defects that could lead to damage during post-processing. Down-skin surfaces typically cool more slowly, as they lack a solid substrate below, and here we are trying to avoid distortion and dross (Fig. 17).

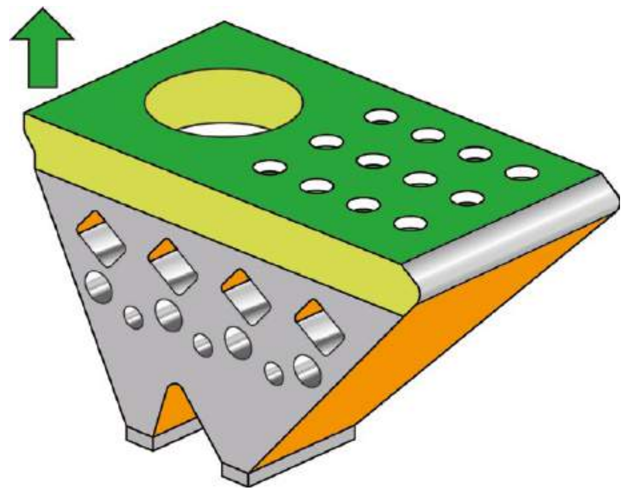

Fig. 17 Bulk borders, up-skins and down-skins typically require different parameters to the bulk of the component

We typically deploy quite different parameters in these regions and so even nominal parameter sets include a range of settings and scan strategies for different regions of the part. To achieve the optimum quality in all regions of the part, it may be necessary to develop more application-specific parameters.

Summary

Process parameter selection is critical to the success of our AM build, as it governs how the material will melt and solidify to form our component. Since each alloy powder absorbs laser energy, transmits heat, flows and solidifies in different ways, our choices must be tailored to the characteristics of the alloy that we are melting.

We must work within the capabilities of our AM machine to find an operating point in the middle of a wide operating window. This provides a safety margin to accommodate a range of local melting conditions. Even so, some part geometries may demand modified parameters to accommodate variations in retained heat. Borders and down-skin regions will also require different processing parameters and scanning strategies to deliver the required surface quality.

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[2] J.C. Heigel, B.M. Lane, Measurement of the melt pool length during single scan tracks in a commercial laser powder bed fusion process, ASME 2017 12th International Manufacturing Science and Engineering Conference, June 4-8, 2017, Los Angeles, USA (MSEC2017-2942)

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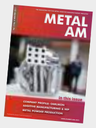

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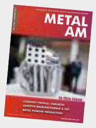

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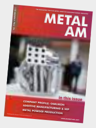

World PM2018 - World Conference on PM
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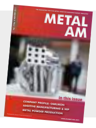

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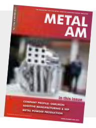

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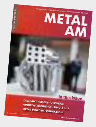

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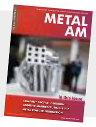

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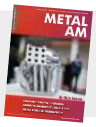

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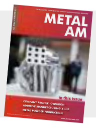

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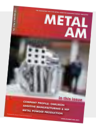

2019

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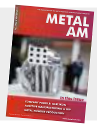

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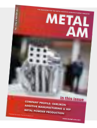

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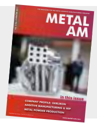

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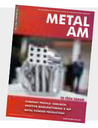

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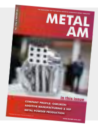

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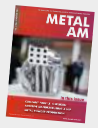

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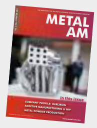

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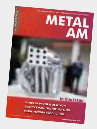

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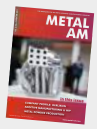

SME's Metal Additive Manufacturing Developments Seminar
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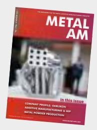

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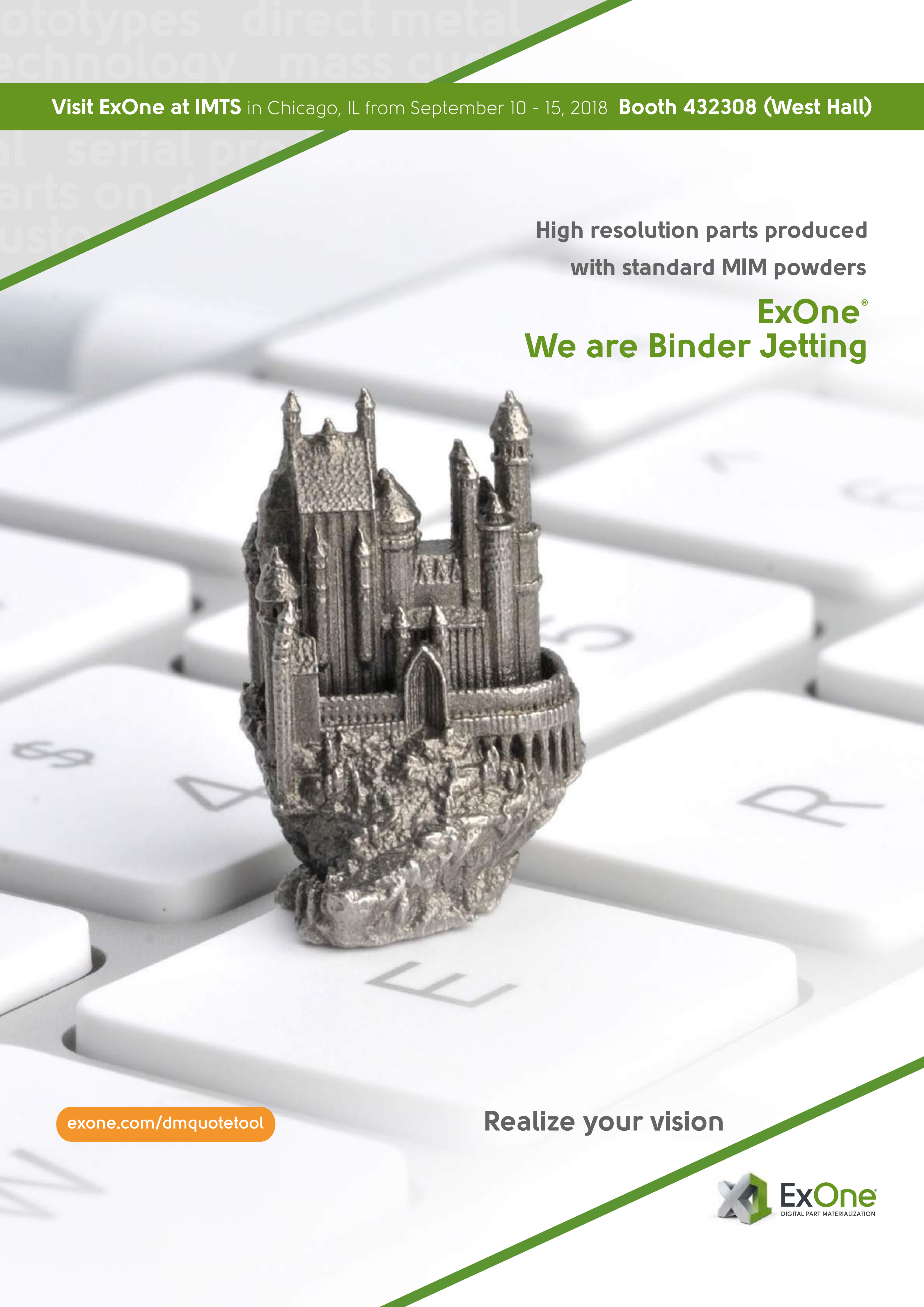
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