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THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

METAL AM IN JAPAN
TITANIUM FOCUS
INVESTING IN AM

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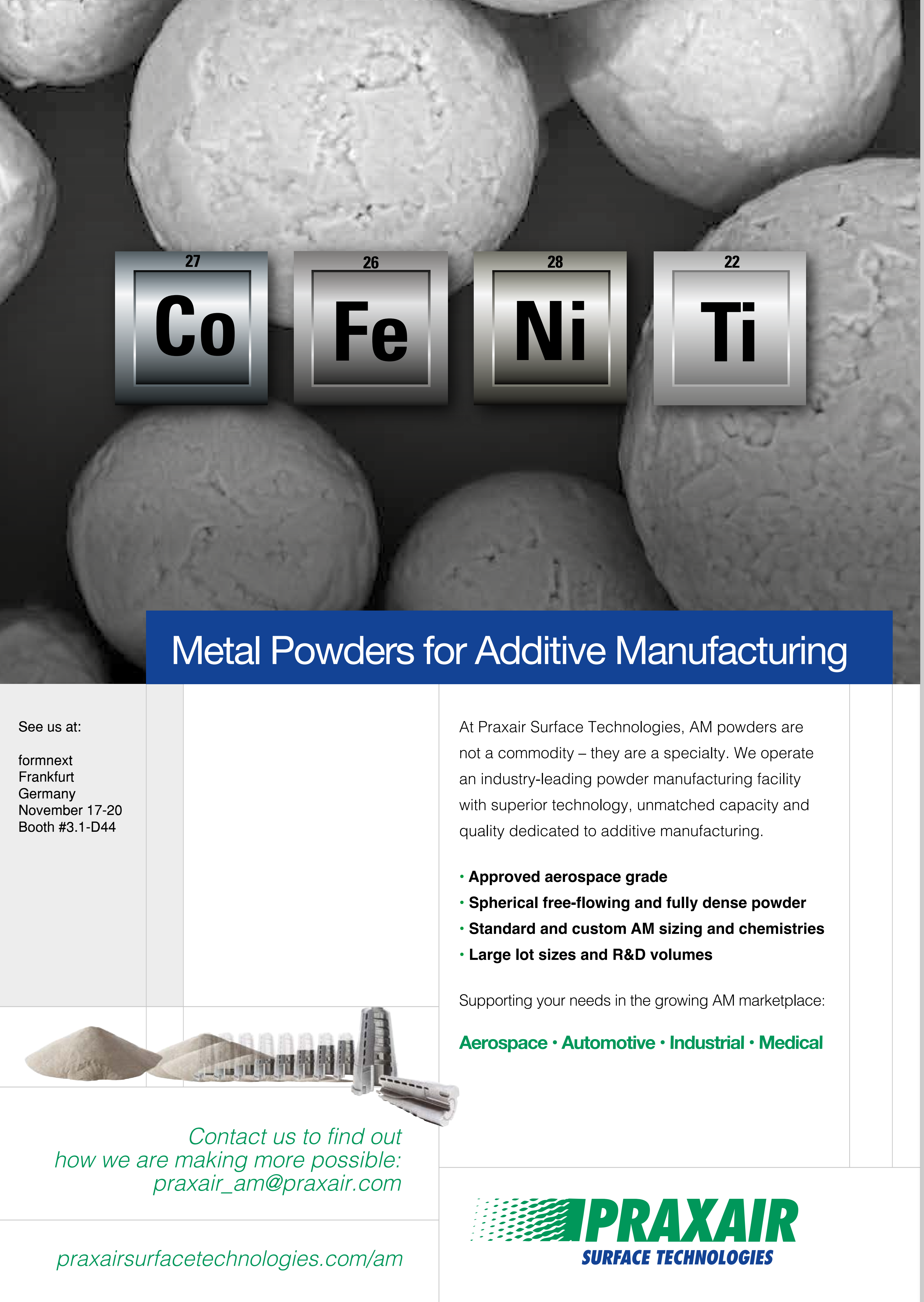
www.metal-am.com



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A new global platform to showcase Additive Manufacturing

There is growing excitement amongst the metal AM community as a major new European event for the industry gets ready to open its doors. The event, formnext, takes place at the Frankfurt Exhibition Centre, Germany, from the 17th to the 20th of November.

The very strong level of support that this event has generated can in many ways be seen as a milestone in the evolution of the international Additive Manufacturing industry. For the first time, competing metal AM technology suppliers appear to have come together to speak with one voice in committing to formnext, an event that promises to be one of the most important global platforms for the industry.

In addition to more than 200 international exhibitors, there will be an exciting conference programme provided by the organisers of the UK's long established TCT exhibition. We at *Metal Additive Manufacturing* magazine are of course also excited to be part of this adventure and we extend an invitation to our readers to visit us on booth 3.1/B66 and pick up the print edition of our latest issue.

As readers of previous issues of *Metal AM* will recognise, our publication continues to grow in both size and the level of support from the international community. In this 80 page issue we continue to offer a balance of international industry news, unique market insights through contributions by international experts, and reviews of the latest cutting edge research from the international conference scene.

Nick Williams
Managing Director

Cover image
China has approved the use of additively manufactured replacement hip joints made by AK Medical, China's largest manufacturer of artificial joints (Image courtesy of Beijing AK Medical Co Ltd, China)

Autumn/Fall 2015

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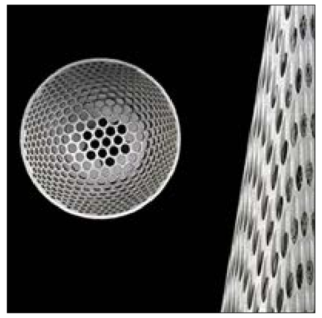

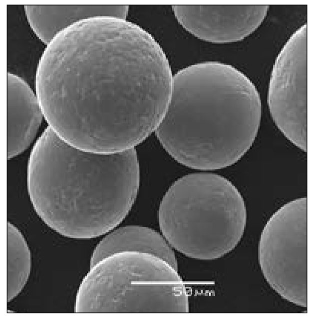

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31 The current status and outlook for metal Additive Manufacturing in Japan

Despite playing a significant role in the early development of AM technologies, there is a belief in Japan that the country's industry has fallen behind in the wider adoption of metal AM. In this report Prof. Hideki Kyogoku reviews the history of the technology in Japan as well as its current status. He also presents the work being undertaken by TRAFAM on the development of the next generation of metal AM systems and materials.

41 A story of failure and success in metal AM: The reality of developing a titanium bike part

Metal AM promises to enable smaller organisations to compete with global corporations in the development of new products. As US-based designer and engineer Spencer Wright reveals in this insightful report, the reality of developing a low volume titanium part exposes a number of challenges that the industry needs to overcome.

53 AM developments at PM Titanium 2015

The PM Titanium 2015 conference, Lüneburg, Germany, was the latest in the series of international conferences specifically focused on the processing, consolidation and metallurgy of titanium. Dr David Whittaker reports for *Metal Additive Manufacturing* magazine.

63 To invest or not to invest: The business cases for entering the AM arena

With such intense levels of interest in AM, the pressure for businesses to adopt AM technology can be high. However as Onno Ponfoort and Chris Krampitz explain, expectations need to be managed and the business opportunities and challenges need to be understood.

71 Hoeganaes Corporation: A global leader in metal powder production targets AM

Few companies have the track record of Hoeganaes Corporation when it comes to the production of metal powders for industrial parts production. Here the company reports on its development of gas atomised titanium powders for metal AM, along with its ambition to introduce more cost effective water atomised powders.

75 Size and shape optimisation of metal powders for Additive Manufacturing

The correct characterisation of powders enables the necessary quality control to ensure powder behaviour is predictable and repeatable from batch to batch. Dr Paul Kippax and Dr Robert Deffley report on the process undertaken at LPW to ensure its powders meet customer expectations.

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industry news

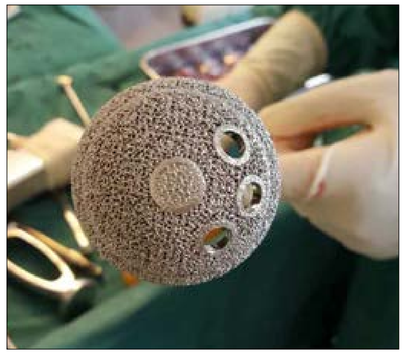
China's Food and Drug Administration approves use of Additively Manufactured hip joints

China's state Food and Drug Administration is reported to have approved the use of replacement hip joints made in China by Additive Manufacturing. The hip joint prosthesis was developed by Professor Zhang Ke, Liu Zhong Jun and Cai Hong at Peking University Third Hospital, in cooperation with AK Medical, China's largest manufacturer of artificial joints.

AK Medical manufactured this hip joint using an EBM system from Arcam AB

Made using an Electron Beam Melting (EBM) system supplied by Sweden's Arcam AB, the product is the first additively manufactured artificial hip joint to be registered in the country after passing a number of clinical trials.

The Additive Manufacturing of medical devices has been the focus of research for a number of years in China. Professor Zhang Ke has been developing and experimenting with AM hip implants since 2009. From 2012 onwards, patients began to receive AM hip implants with the results being documented via clinical observation.



The additively manufactured hip joint has undergone clinical trials

The demand for hip replacements is growing in China. "Artificial joint replacement has reached 400,000 units per year, growing at a rate of more than 30%," stated Professor Zhang Ke. Currently, the cost of imported implants is around 70% of the total cost of the procedure. "Using 3D printing will greatly reduce the patient's medical costs," added Professor Zhang Ke.

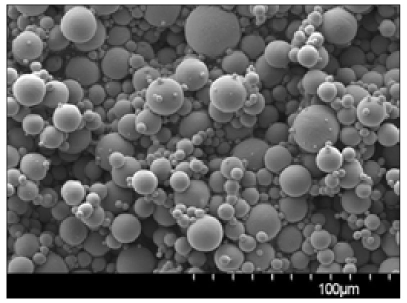
www.ak-medical.net ■■■

AP&C installs two new atomisation reactors

Arcam AB has announced that its metal powder subsidiary AP&C, based in Montreal, Canada, is building its fourth and fifth reactors, adding significant capacity to its titanium and nickel superalloy powder manufacturing operation.

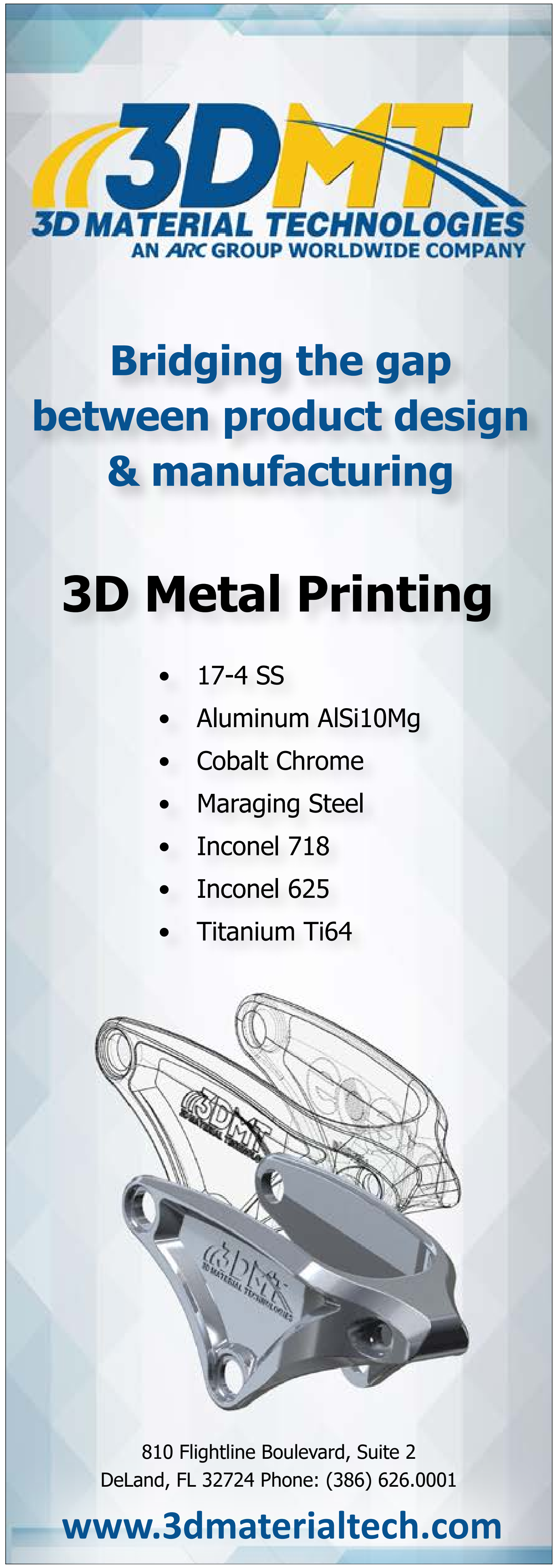
AP&C uses proprietary plasma atomisation technology to produce highly spherical powders of reactive and high melting point materials such as titanium, nickel, zirconium, molybdenum, niobium, tantalum, tungsten and their alloys. Its powders are suited to a range of processes such as Additive Manufacturing, Metal Injection Moulding, Hot Isostatic Pressing and coating applications.

"With this new generation of atomising technology, AP&C is now in a position to supply aerospace and medical part manufacturers' titanium powders in volumes needed today and in the future. With a multiple reactor operation, AP&C can produce its standard products on dedicated reactors and equipment, therefore eliminating cross-contamination risks," stated Jacques Mallette, President of AP&C.



SEM of Ti-6AL-4V powder from AP&C

www.advancedpowders.com ■■■



Materialise opens titanium AM facility in Germany

Materialise NV, a leading provider of Additive Manufacturing software and production services, has announced the start of metal AM activities at its site in Bremen, Germany. The new production line, located in Materialise's Metal Competence Centre, will serve industrial customers looking to manufacture parts in titanium.

Materialise has built extensive expertise in metal printing, most notably by developing metal AM software and releasing build processors with leading metal OEMs. In regards to hardware, Materialise recently announced the completion of an in-house metal printing project that saw a medical production line being installed at their headquarters. Now, with the technology maturing and the demand for printed metal parts increasing, the company has begun expanding its metal offering on the industrial services side, with the availability of aluminium already being announced earlier this year.

With a global capacity of more than 120 3D printers and wide variety of available technologies, Materialise has grown into one of the world's largest providers of Additive Manufacturing services. The company states that every day over 2,000 parts are produced and shipped to customers all over the globe. The metal production facility in Germany is Materialise's fourth industrial production unit in Europe, following the main factory in Belgium and those in Poland and Czech Republic.

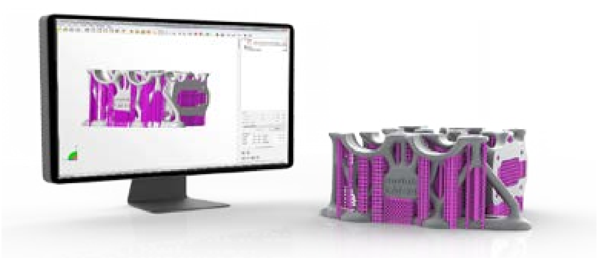
"In terms of commitment to the German market, this is an important step," stated CEO Fried Vancraen. "It allows us to manufacture parts close to our customers in aeronautics and the industrial goods industry. With this scalable site in Bremen, we clearly put metal printing on the agenda as a strategic part of our industrial offering."

The entire activity will be incorporated into Materialise's Bremen office, where the company's know-how in software for metal printing has been centralised since the acquisition of Marcam Engineering in 2011. "This operation solidifies the Bremen office's role as Materialise's Metal Competence Centre. Our team of specialists already has a strong understanding of the needs and challenges of metal AM and, by starting this new production line, we will be able to expand our knowledge and apply it to the next generation of software while also offering high-quality manufacturing in titanium to our industrial customers," stated Marcus Joppe, Managing Director of Materialise GmbH.

Materialise will be using TiAl6V4, one of the widest-known alloys, combining excellent mechanical properties with a very low specific weight. The material is corrosion resistant and is used in a variety of demanding engineering environments such as aeronautics. Applications include functional prototypes, solid end-use parts and spare parts.

www.manufacturing.materialise.com

Autodesk to acquire netfabb and enter strategic partnership with FIT AG



Autodesk, Inc., headquartered in California, USA, has signed a definitive agreement to acquire netfabb GmbH, a developer of software solutions for industrial additive design and manufacturing based in Lupburg, Germany. Autodesk announced it will also make a strategic investment in FIT Technology Group, the parent company of netfabb and provider of various Additive Manufacturing services. The two companies will collaborate to increase adoption of the technology for industrial Additive Manufacturing.

"Autodesk has always been impressed by FIT's track record in creating powerful solutions to meet the challenges of industrial Additive Manufacturing and together we will accelerate a new future of making things," stated Samir Hanna, Autodesk Vice President and General Manager, Consumer & 3D Printing. "We look forward to welcoming the netfabb team to Autodesk and helping designers and manufacturers worldwide take 3D printing beyond prototyping and plastics to reliably creating production-grade parts at scale."

More than 80,000 designers, manufacturers, artists, researchers and developers worldwide currently use netfabb solutions as part of their 3D printing process. Autodesk plans to support and expand this community by continuing to develop, sell and support netfabb software as well as integrate netfabb technology into Autodesk's solutions for product design and additive manufacturing, including Autodesk Fusion 360 the Spark 3D printing platform.

"Autodesk shares FIT's goal of delivering high quality industrial additive manufacturing. We're looking forward to cooperating with Autodesk, our newest investor, and we are confident that netfabb will continue to thrive and grow as part of Autodesk," stated Carl Fruth, CEO, FIT AG, parent company of the FIT Technology Group.

www.autodesk.com | www.pro-fit.de
www.netfabb.com ■■■

MetalFAB1 to premiere at formnext

Additive Industries b.v., based in Eindhoven, The Netherlands, has announced that its new industrial metal Additive Manufacturing system, MetalFAB1, will be launched at the formnext exhibition taking place in Frankfurt, Germany, November 17-20, 2015. The company states that its MetalFAB1 is the first integrated metal AM system designed for high-end industrial applications in demanding markets such as aerospace, defence, medical, high-tech equipment, tooling and automotive.

The Additive Industries team began working on the development and realisation of an integrated metal Additive Manufacturing solution aimed at industrial series production in 2012. The modular MetalFAB1 system has a broad range of new features including fully automated build plate and product handling, multiple full field lasers, continuous in-process calibration and integrated heat treatment.

"Last year we exhibited in Frankfurt with a large wooden machine crate and promised to launch our industrial 3D metal printing system in Frankfurt this year. Now we are fulfilling our promise and we are planning to show how the future Additive Manufacturing will look like and rock the show," stated Daan Kersten, CEO of Additive Industries.

www.additiveindustries.com ■■■

NanoSteel introduces powders for binder jet 3D printing systems

NanoSteel, headquartered in Providence, Rhode Island, USA, has announced a range of powders designed specifically for the binder jet 3D printing process. The materials, BLDRmetal™ J-10 and BLDRmetal™ J-11, enable the 3D printing of components for highly abrasive environments that can benefit from Additive Manufacturing's ability to eliminate tooling, create advanced geometries and build custom parts on demand.

The company states that industrial components made using J-10 feature twicw the elongation and three times the wear and impact resistance of an equivalently infiltrated 420 stainless steel. NanoSteel demonstrated this capability working with 3DX Industries, an Additive Manufacturing service provider, to print a security tool used by a global avionics company for removing and replacing aircraft panels.

In this commercial application, the tools made with J-10 lasted five times longer than the previous solution, significantly decreasing the risk of delays in servicing the aircraft. "The NanoSteel solution enabled us to create a tool that delivered the durability and reliability the customer required in a fast turnaround environment," stated Roger Janssen, President and CEO of 3DX. The avionics service team is planning further adoption of this new technology across their global operation.

The BLDRmetal product line of binder jet powders also includes J-11, which is designed for extreme wear low-impact applications. Components made with J-11 provide ten times the wear resistance of an equivalently infiltrated 420 stainless steel. The performance of both NanoSteel products is based on the combination of complex metallic phases that provide wear resistance and a steel matrix that delivers ductility and toughness.

"These first BLDRmetal powders offer compelling alternatives to existing materials for the binder jet printing process," stated Harald Lemke, General Manager and Vice President of Engineered Powders at NanoSteel. "The company's entry into the market enhances the applicability of binder jet printing by enabling the Additive Manufacturing of high-complexity, lower-cost components with exceptional wear performance."

NanoSteel stated that the binder jet process is well suited for cost effectively producing industrial metal parts due to the faster building speed. These are the first in the company's portfolio of BLDRmetal powders for hard metal applications that will include new products for each of the current metal 3D-printing processes. BLDRmetal J-10 and BLDRmetal J-11 are intended for industries such as oil and gas, tool and die and energy in applications such as drilling and pump components, moulds and dies.

www.nanosteelco.com ■■■

Renishaw looks to establish network of Solution Centres

Additive Manufacturing systems maker Renishaw, headquartered in the UK, has announced plans to open a global network of Renishaw Solutions Centres to provide cost-effective access to machinery, facilities and expertise for metal 3D printing.

"Additive manufacturing is still mostly used in rapid prototyping applications, where the ability to build metal components direct from CAD, with no special tooling, is especially valuable," stated Clive Martell, Head of Global Additive Manufacturing. "However Additive Manufacturing has so much more potential than this - it enables us to design and make innovative products with spectacular gains in performance and efficiency."

"Renishaw's vision is to make Additive Manufacturing a mainstream manufacturing technology, used in series production of high performance parts for aerospace, medical, automotive, oil & gas, mould & die and consumer products," added Martell.

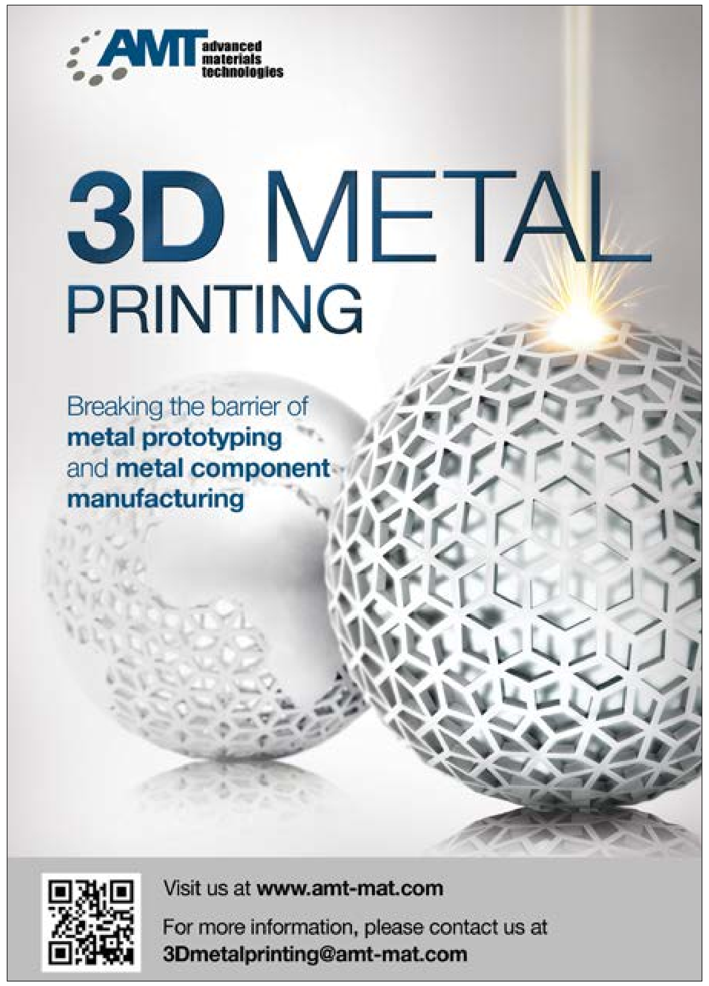
Equipped with the latest AM machines and staffed with knowledgeable engineers, the Solutions Centres will provide a confidential development environment in which firms can explore the benefits that AM can bring to their products and quickly build their knowledge and confidence in AM as a production technology.

Each Solutions Centre will feature Incubator Cells - private development facilities containing an AM machine, design workstation and all the ancillary equipment needed to design, build and refine a new product design. As the product and process design matures, Renishaw will also provide pre-production capacity where the productivity and capability of the AM process can be established. Renishaw will provide support in the form of operators and applications engineers, as well as access to a range of machining, finishing, treatment and metrology processes.

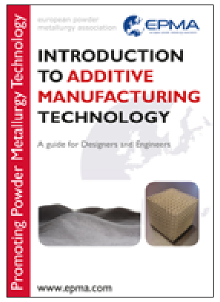
"Whilst Additive Manufacturing can create complex geometries in a single process step, some level of finishing is generally required to produce functional products," added Marc Saunders, Director - Global Solutions Centres. "Renishaw's knowledge of metrology, machining and finishing processes can help customers to develop an integrated manufacturing solution for their innovative new product."

The network of Renishaw Solutions Centres will open during the final quarter of 2015 and the first half of 2016, and will include facilities in the UK, Europe, USA, Canada, India and China.

www.renishaw.com ■■■



Introduction to AM brochure published by EPMA



The European Additive Manufacturing Group (EAMG), a sectoral group of the European Powder Metallurgy Association (EPMA), has announced the publication of its new guide to Additive Manufacturing. The 44 page booklet, Introduction to Additive Manufacturing Technology, is available in both PDF and print format from the EPMA.

The guide brings together information on all the various metal Additive Manufacturing processes and has been created specifically for designers and engineers who are new to Additive Manufacturing. The booklet looks in detail at the different metal AM technologies and processes available on the market today as well as the range of metal powders used in the process.

A comprehensive explanation of designing components for AM is included, along with a good number of case studies from end user sectors such as aerospace and consumer goods.

The 'Introduction to Additive Manufacturing Technology' brochure is available as a PDF download from the EPMA website. Print versions can be ordered by contacting Scarlett Williams: sw@epma.com

www.epma.com ■■■

Arcam receives further orders from its customers in medical and aerospace sectors

Sweden's Arcam AB, has announced that it has received an order for five Arcam Q10 systems from Beijing AK Medical based in China. The systems will be used for volume production of orthopaedic implants. Beijing AK Medical, established in 2003, specialises in the research, development, manufacture and sale of artificial joint prostheses and surgical instruments. The company has been a customer of Arcam since 2010 and recently announced the formal approval from the Chinese State Food and Drug Administration (CFDA) for EBM manufactured implants.

"We are excited to move into volume production with the EBM technology. Having worked with Arcam since 2010 we are now ramping up our activities, following the recent approval by the CFDA", stated Mr Li Zhi Jiang, CEO of Beijing AK Medical.

Arcam also confirmed it had received an order for two EBM systems from CalRAM, a US based supplier to the aerospace and defence sectors. The EBM systems will be used for production of aerospace components.

CalRAM was acquired by Midstate Berkshire in October 2014 and has been a customer of Arcam since 2005. The company currently operates five EBM systems. "With demand for Additive Manufacturing production increasing rapidly, we continue to invest in EBM technology to secure capacity and give CalRAM an edge in the aerospace industry," stated Duane Pekar, CEO of Midstate Berkshire.

The Arcam Q10 EBM machine is designed for industrial production of orthopaedic implants

"Arcam is the leading supplier of titanium Additive Manufacturing systems and we turned to them with confidence, having used their EBM products for years," added Pekar.

"Arcam's strategy is to offer Additive Manufacturing solutions specifically targeting production volumes in the aerospace and orthopaedic industries. This deal confirms the potential for our EBM technology within the aerospace industry," stated Magnus René, CEO of Arcam.

www.arcam.com ■■■

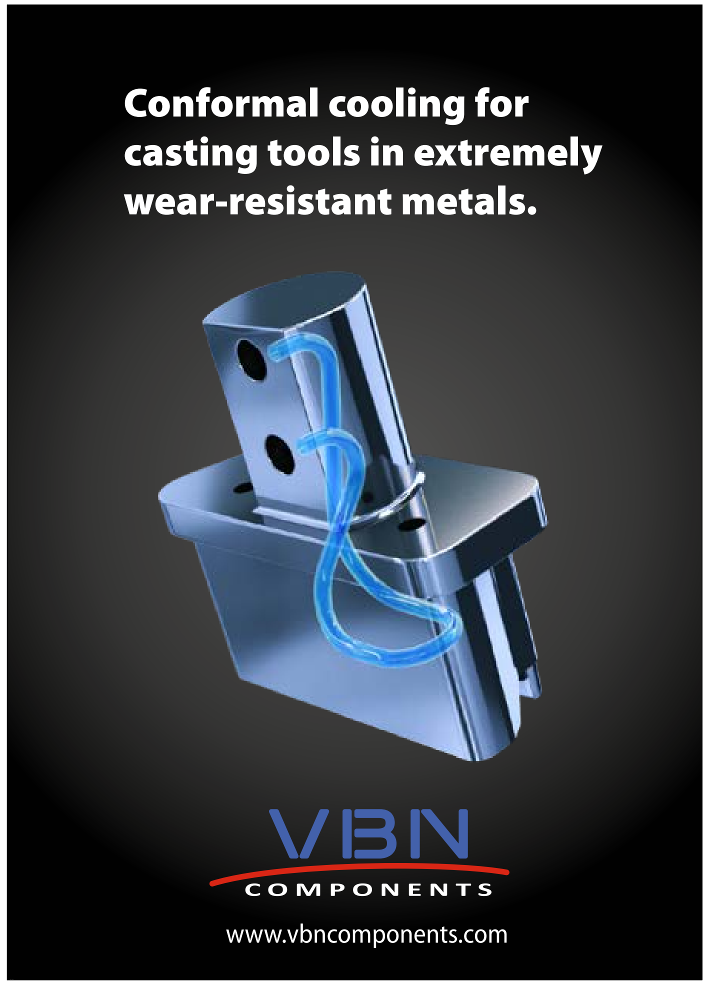
Xilloc expands and installs four new EOS Additive Manufacturing systems

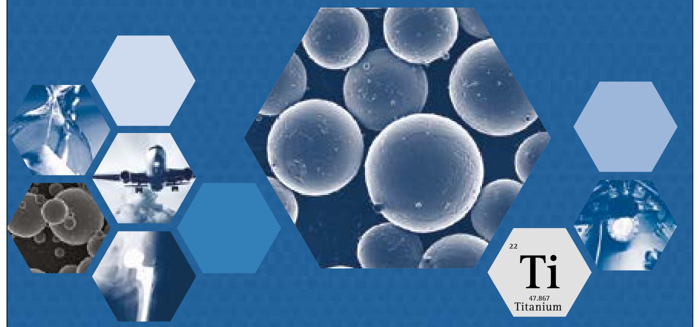
Dutch company Xilloc Industrial B.V. has announced further investment at its facility in Brightlands Chemelot Campus, Sittard-Geleen, The Netherlands. Together with the Brightlands Chemelot Campus and with financial support from the Province of Limburg, four new EOS 3D printers are being installed to establish an advanced manufacturing facility, which also includes state of the art automated milling machines.

Xilloc has gained its reputation in the medical sector with the world's first 3D printed titanium skull implant in 2006 and the first 3D printed full mandible replacement in 2011. The company offers Additive Manufacturing services in metals, polymers and ceramics and earlier this year introduced a new bone-like implant material.

The company's industrial business unit aims to provide the same high quality 3D printing services necessary for their medical activities to companies in other sectors such as aerospace, automotive and tooling. Amongst the four new AM machines is the EOS M 400, one of the largest metal machines currently available on the market. "Xilloc takes pride in delivering the highest quality to its customers. Therefore we choose to work with the systems from EOS," stated Maikel Beerens, CEO of Xilloc.

industrial.xilloc.com ■■■





Materials Solutions announces strategic investment from Siemens Venture Capital

Materials Solutions Limited, Worcester, UK, one of the largest commercially available metals Additive Manufacturing centres worldwide, has announced a strategic investment from the Venture Capital Unit of Siemens (SVC). Materials Solutions is a specialist in AM of high performance nickel superalloy components for gas turbines (land based and aero engines), specialist steels and titanium components for aero systems and auto sports.

Announcing the investment, Materials Solutions founder and CEO Carl Brancher stated, "I am extremely pleased that SVC has chosen to invest in Materials Solutions. I believe this investment validates Materials Solutions as the global technology leader in Additive Manufacturing of nickel superalloys. Since starting up in 2006, Materials Solutions has developed high performance materials and manufacturing processes for laser powder bed Additive Manufacturing particularly targeting gas turbine applications."

"There are now strong signs that Additive Manufacturing will move into mainstream production for land and aero gas turbine components," stated Ralf Schnell, CEO of the Venture Capital Unit of Siemens. "Materials Solutions are outstanding in capability and experience and we will support their expansion."

www.materialssolutions.co.uk ■■■

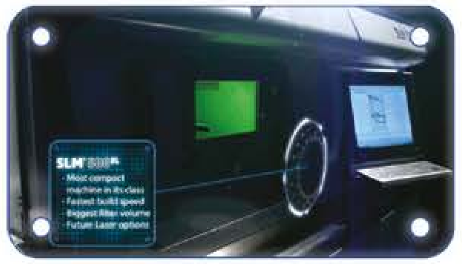
YaHao Materials & Technology aims to be China's leading alloy powder supplier

YaHao Materials & Technology Co,.Ltd. based in Hebei Province, China, is one of the largest manufacturers of soft magnetic powders in China. The company is now offering a wide range of other alloy powders for various applications and is aiming to be the leading alloy powder supplier in China.

Sales in 2014 were reported to be around 10.1 million RMB with exports accounting for around 50% of the company's total consolidated sales. The company has more than 120 employees and alloy powder production for the year totalled 2,365 tons.

YaHao states that it has multiple water and gas atomisation systems with alloy powder capacity currently being around 5,000 tons per year. Its range includes powders for Metal Injection Moulding, pre-alloyed powder for diamond tools, amorphous powder and single element powders.

www.yahaochina.com ■■■



Praxair to begin full scale production of fine titanium powders

Praxair Surface Technologies, headquartered in Indianapolis, USA, has announced it will begin full-scale production of its fine, spherical titanium powder specifically for use in Additive Manufacturing systems in the third quarter of 2015.

"Until now, there's been limited availability of fine titanium powder in the marketplace to create parts," stated Dean Hackett, Vice President of Advanced Materials and Equipment for Praxair Surface Technologies. "That won't be the case for long as we move into full-scale production of aerospace-grade, fine, spherical titanium powder starting in the third quarter of 2015. In addition to supplying the powder, Praxair also offers the associated industrial gases to the Additive Manufacturing industry."

Praxair's ability to produce large-scale volumes of titanium powders designed for AM is rooted in its more than 50 years of experience producing gas atomised powders for the thermal spray coating industry. In recent years, research and development efforts have focused on the production of metal powders, including cobalt, iron and nickel, for 3D printing purposes. Further development of a proprietary atomisation process designed specifically for titanium allows Praxair to make some of the largest batches of fine titanium powder in the world, stated the company.

"What makes our production of titanium powders different from those currently on the market is that we use close-coupled, high-pressure gas atomisation to produce fine, spherical titanium powder in large quantities," stated Andy Shives, Additive Manufacturing Marketing Manager for Praxair Surface Technologies.

www.praxair.com ■■■

CETIM installs ECM furnace for heat treatment of metal AM parts

ECM Technologies, a French manufacturer of heat-treatment vacuum furnaces, is to equip the Technical Centre for Mechanical Industry (CETIM), France, with a horizontal furnace dedicated to high temperature treatment of metal parts produced by Additive Manufacturing.

Heat treatment is often a necessary step to ensure the physical integrity of AM parts. After the fusion of metal particles into the required shape, the part is heat-treated to reorganise its structure and improve its mechanical properties.

The furnace from ECM Technologies allows low-pressure treatment at 600°C for stress-relieving, a necessary phase to relieve constraints and stress due to the AM process.

www.ecm-furnaces.com ■■■

Cancer patient receives AM ribs in world first surgery

A Spanish cancer patient has received an Additive Manufactured titanium sternum and rib cage in what is stated to be a world-first operation. The design and manufacture of the implant was the result of international collaboration between the patient's surgical team based at Salamanca University Hospital, Spain, and Anatomics, a medical device company based in Melbourne, Australia, along with CSIRO's 3D printing facility, Lab 22, in Clayton, Australia.

The 54 year old patient, suffering from a chest wall sarcoma, required his sternum and a portion of his rib cage to be replaced. This part of the chest is stated to be difficult to recreate with prosthetics due to the complex geometry and individual design required for each patient. The surgical team identified Additive Manufacturing as the best option for a fully customisable sternum and rib cage.

The surgical team, Dr José Aranda, Dr Marcelo Jimene and Dr Gonzalo Varela from Salamanca University Hospital, knew the surgery would be difficult due to the complicated geometries involved in the chest cavity. "We thought, maybe we could create a new type of implant that we could fully customise to replicate the intricate structures of the sternum and ribs," stated Dr Aranda. The implant was designed and manufactured by medical device company Anatomics, who utilised CSIRO's 3D printing facility, Lab 22.

"We wanted to 3D print the implant from titanium because of its complex geometry and design," stated Andrew Batty, CEO of Anatomics. "While titanium implants have previously been used in chest surgery, designs have not considered the issues surrounding long term fixation. Flat and plate implants rely on screws for rigid fixation that may come loose over time. This can increase the risk of complications."

Working with experts at CSIRO's 3D printing facility Lab 22, the team manufactured the implant out of surgical grade titanium alloy using an Arcam EBM system. Once the prosthesis was complete it was couriered to Spain and implanted into the patient.

"The operation was very successful," Dr Aranda stated. "Thanks to 3D printing technology and a unique resection template, we were able to create a body part that was fully customised and fitted like a glove."

www.anatomics.com

www.csiro.au ■■■

Precision gear manufacturer sees future of business in Additive Manufacturing

Indiana Technology and Manufacturing Companies (ITAMCO), based in Plymouth, Indiana, USA, specialises in precision gear manufacturing, with capabilities ranging from mining gearing to production runs of CBN-ground transmission gears. The company, which this year celebrated its 60th anniversary, is a member of a team researching optimised support structures for metal Additive Manufacturing and recently received a funding award from America Makes.

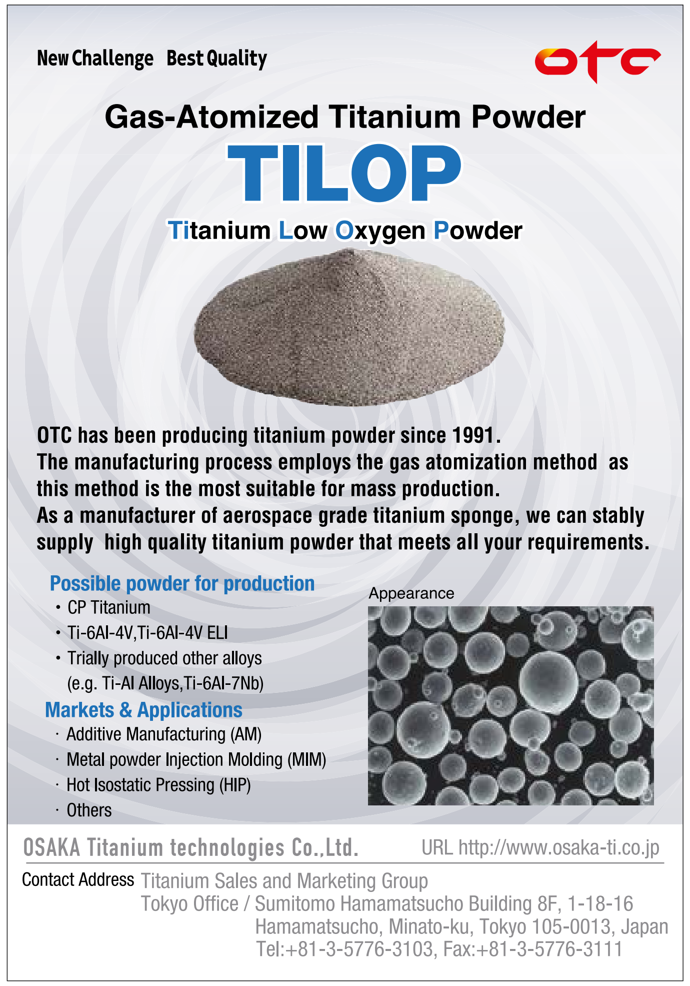
The newly funded research project "Parametric Design of Functional Support Structures for Metal Alloy Feedstocks" is led by the University of Pittsburgh in conjunction with Johnson & Johnson, ITAMCO and the University of Notre Dame. The aim is to develop parametric designs of functional support structures for metal alloy feedstocks. Specifically, the project team aims to codify the design rules for support structures used in Direct Metal Laser Sintering (DMLS) to inform and then automatically recommend the optimal part orientation and the designs for optimised supports.

While acknowledging the company will always offer subtractive manufacturing like gear grinding, ITAMCO believes that Additive Manufacturing is the future of their business. Prior to receiving the America Works funding award, the company was pursuing the development of Additive Manufacturing through its "Strategic Technology Initiative for Additive Manufacturing."

ITAMCO delivers precision-machined components to OEMs worldwide in mining, off-highway vehicles, marine and aviation. "I believe the success of ITAMCO is due to uncommon perseverance and a true spirit of innovation. Embracing technology while holding to solid and proven principles has given us an atmosphere that is creative, yet built upon a foundation that can be relied upon," stated Gary Neidig, ITAMCO's President.

"The R&D award and subsequent results will go a long way to bringing Additive Manufacturing into our offerings," stated Joel Neidig, Engineer and lead IT developer at ITAMCO. "As a gear manufacturer, we will always do subtractive manufacturing, but we recognise that Additive Manufacturing is the future of our business."

www.itamco.com ■■■



Award for innovation in laser technology announced


Finalists in the 2014 awards

The Innovation Award Laser Technology offers a winning prize fund of €10,000 and is presented to European researchers in recognition of outstandingly innovative work in the field of laser technology. Organisers of the award, the Arbeitskreis Lasertechnik e.V. and the European Laser Institute ELI, have issued a call for proposals with a closing date of January 15, 2016.

The award addresses laser manufacturers, laser users and researchers who have successfully conceived and implemented an innovative idea relating to laser technology, following the project through from application oriented research to ultimate industrial application. The closed scientific and technological projects in question must centre on the use of laser light in materials processing and the methods of producing such light, and must furthermore be in their practical implementation of demonstrable commercial value to industry.

A shortlist of the best candidates will be compiled by an international jury consisting of members recruited from industry and the research community. The official presentation of the award will take place at the International Laser Technology Congress AKL´16 on April 27, 2016 in Aachen, Germany.

www.lasercongress.org
www.innovation-award-laser.org ■■■

3D Systems and Penn State launch partnership to support US aerospace and defence industry

3D Systems, headquartered in Rock Hill, South Carolina, USA, has announced a partnership with Pennsylvania State University to support operations in the Center for Innovative Materials Processing through Direct Digital Deposition (CIMP-3D). The centre serves as the official Additive Manufacturing Demonstration Facility for the US Defence Advanced Research Projects Agency (DARPA) and is a major component of a Department of Defence University Affiliated Research Center and strategic facility for the aerospace and defence sector.

The lab includes direct metal printing experts from Penn State and 3DS conducting research together on 3DS' ProXTM Direct Metal Printing (DMP) technology. The collaboration has three basic goals: to develop cutting-edge, high-resolution DMP technology; to enable government agencies (including DARPA and the Navy) to sponsor projects that qualify DMP for defence companies' adoption; and to provide training in 3DS' DMP technology within the US defence/aerospace workforce.

"The CIMP-3D is a great national institution and we are honoured to be working with Penn State to advance American innovation and national security through direct metal printing technology," stated Neal Orringer, 3D Systems' Vice President of Alliances and Partnerships. "We are eager to welcome aerospace and defence companies at every tier of the supply chain, as well as key defence labs, to join us as we revolutionise manufacturing."

"We are extremely excited by the prospect of establishing true collaboration with a leading US 3D printing technology provider," stated Dr Richard Martukanitz, Director of CIMP-3D. "Fostered by the joint technical resources of 3D Systems and CIMP-3D, our goal is to develop and provide enablers for the adoption of additive manufacturing for critical applications to the DoD and US industry." 3DS and Penn State researchers are working on-site on several Government-funded projects, including:

- Air Force research to accelerate wider adoption of DMP, beginning with Honeywell Aerospace's supply chain, focused on producing and rapidly qualifying 3D printed metal aerospace parts;
- An Air Force effort to establish an architecture for manufacturers such as Northrop Grumman and Honeywell to integrate DMP into manufacturing networks on their 21st century factory floors and embed quality control monitoring equipment; and
- Navy projects to develop performance and safety processes for qualifying DMP in key production processes.

www.cimp3d.org
www.3dsystems.com ■■■

ExOne opens new design and re-engineering centre for Additive Manufacturing

The ExOne Company has announced the opening of its new state-of-the-art Design and Re-Engineering for Additive Manufacturing (DREAM) centre located within its North Huntingdon, Pennsylvania, USA, facility. The DREAM centre has been strategically developed as a physical and virtual site for collaboration with customers to explore and incorporate the benefits of ExOne's binder jetting technology. By providing global access to the company's creative technical expertise and offering the most advanced software currently available, the centre will enable customers to create designs of metal components which maximise the benefits of AM.

S Kent Rockwell, Chairman and CEO of The ExOne Company, stated, "As we focus on accelerating the adoption rate of our binder jetting technology for industrial manufacturing of metal components, we're excited to launch our world-class DREAM centre. It is an integrated engineering environment supporting our customers, our production service centres, our research and development activities and our global sales team. We believe the DREAM centre will further facilitate customer training and design support, helping users optimise 3D printing and the benefits it can bring to their manufacturing processes."

www.exone.com

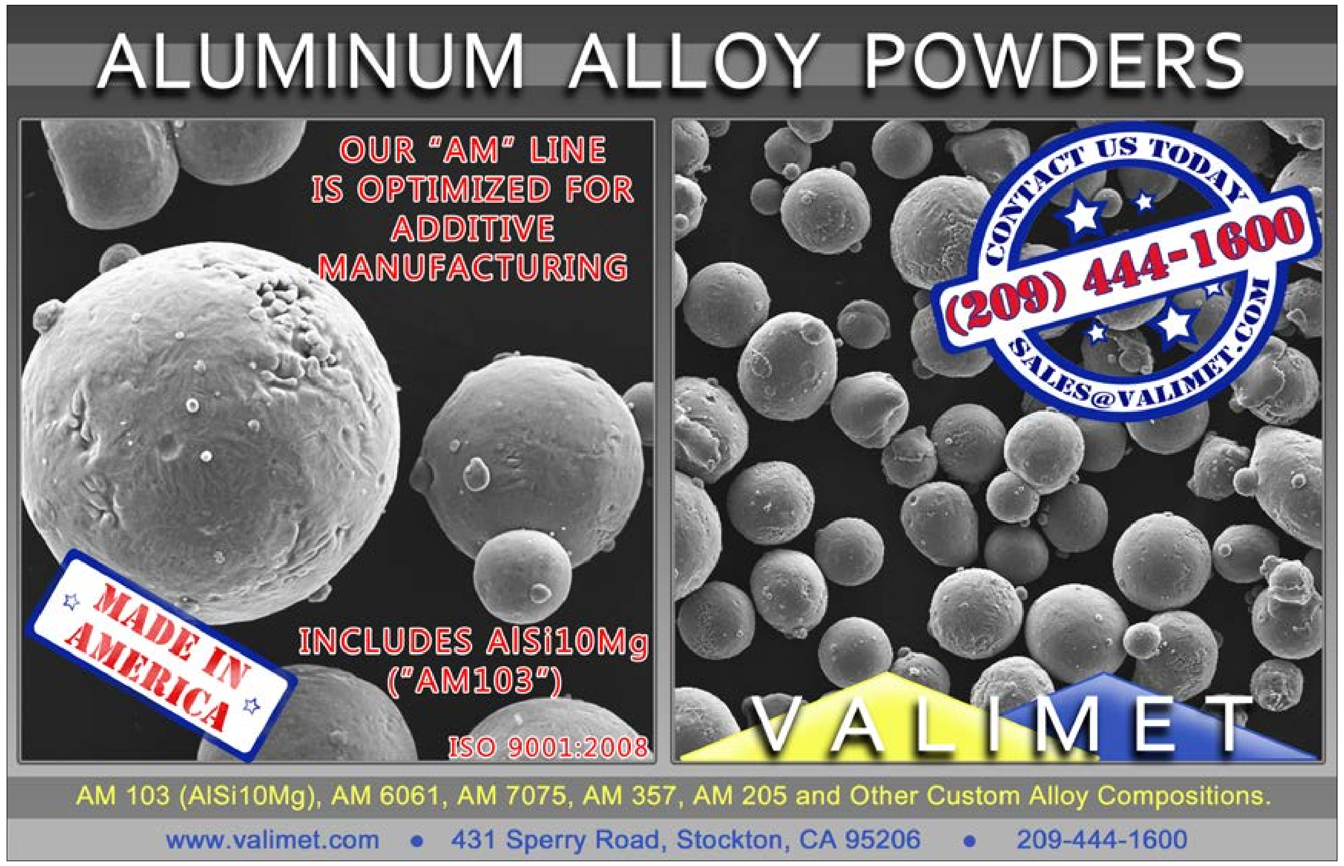
Concept Laser reports further revenue growth in first half of 2015

Concept Laser, headquartered in Lichtenfels, Germany, has reported continued growth in the first half of 2015. Following revenue growth of 75% in 2014, Concept Laser consolidated its growth at a high level with a further 35% revenue increase in the first six months of 2015. While 45 systems were sold in the same period of the previous year, the company has already received 68 orders this year, a significant increase of roughly 50%.

"We are very proud that we not only succeeded in maintaining the great growth from last year, but have even managed to build on it. That shows that we are still moving in the right direction," stated Frank Herzog, CEO and President of Concept Laser.

The company stated that its revenue growth was solely due to sales of its large-scale systems in the 1000 W laser class and demand from the aerospace industry in the USA. Staff numbers also increased by a further 30% compared with 2014 in the first half of 2015. In January 2015 the company introduced its X line 2000R® range in the large-scale system segment, which combines a build envelope of 800 x 400 x 500 mm and two 1000 watt lasers resulting in increased build rates. Key buyers are said to be from the automotive and aerospace sectors.

www.concept-laser.de



Norsk titanium receives investment from RTI International Metals to expand its 3D-printing technology

Norsk Titanium AS (NTi), a Norway-based leader in manufacturing titanium components for industrial applications, has announced that RTI International Metals, Inc. (NYSE: RTI), a global supplier of titanium and specialty metal products and services, has become a strategic investor and minority partner with the company. RTI made an investment of an undisclosed amount for strategic cooperation projects surrounding NTi's Direct Metal Deposition (DMD) technology, used in NTi's patented process for the manufacture of premium quality titanium components.

"This investment is an important endorsement of the hard work and achievements of the NTi team, who are poised to accelerate the market reach of our company's game-changing technology for the production of titanium components, delivering to our customers the benefits of reduced price, shorter lead times and increased design flexibility," stated Executive Chairman of NTi's Board of Directors John Andersen, Jr.

"RTI is pleased to be a strategic industrial investor in NTi. Its DMD technology, a form of Additive Manufacturing or 3D printing, is a game-changer," said Dawne Hickton, Vice Chair, President and CEO of RTI. "Combining NTi's innovative technology with RTI's upstream raw materials and downstream fabrication capabilities has significant applications in the titanium closed-die forging market, with commercialisation opportunities within the next twelve months."

Vice Chairman of NTi's Board of Directors Christopher E. Kubasik, who also is President and CEO of New York-based Seabury Advisory Group and a former Lockheed Martin Corporation executive, added, "NTi has entered into an incredibly exciting time as we gain this strategically important investment. We anticipate further initiatives in the near-term which will position NTi as the unquestionable global leader in advanced industrial applications for titanium components serving the fast-growing needs of such industries as aerospace & defence (A&D), oil & gas and marine."

NTi has achieved technology readiness level six (TRL6), which demonstrates its ability to meet stringent A&D material requirements. NTi expects to achieve technology readiness level eight (TRL8) by the fourth quarter of this year. The A&D industry is the largest and most demanding segment for titanium components. In addition, oil & gas, automotive and other industries require high quality, complex titanium components.

www.norsktitanium.no
www.rtiintl.com

Aachen Centre for Additive Manufacturing opens

The Aachen Centre for Additive Manufacturing (ACAM), located in Aachen, Germany, celebrated its official opening with a ceremony and networking event on September 23, 2015. Founded by the Fraunhofer Institutes for Production Technology IPT and for Laser Technology ILT, the new centre aims to help companies employ the AM method usefully and profitably for their production processes.

"We approach a topic here in an integrated way from project, advanced training, feasibility studies, consulting all the way to compiling knowledge in an AM community," stated Dr Kristian Arntz of Fraunhofer IPT and joint Managing Director of ACAM.

Companies are able to participate at various levels as a partner in the ACAM community. "Starting in 2016, we will establish, along with RWTH Aachen University, a wide range of seminars tuned to the needs of the industry. In the long term, ACAM is striving for a qualified, certified degree for this area – thus, a Master or Bachelor of Additive Manufacturing," stated Dr Johannes Witzel of Fraunhofer ILT and joint Managing Director of ACAM.

www.acam-aachen.de

Sigma Labs announces OEM partner programme for its quality assurance systems

Sigma Labs, Inc., a developer of advanced, in-process, non-destructive quality inspection systems for metal-based Additive Manufacturing and other advanced manufacturing technologies, has announced that it has launched an OEM Partner Program to expedite the trial and incorporation of the Company's PrintRite3D® quality assurance software into AM machines worldwide.

The company stated that working closely with OEMs remains an important element of Sigma Labs' growth strategy, with the goal of having its software embedded in machines before they are sold to end users.

"This OEM Partner Program, like our Early Adopter Program, is designed specifically to expedite trial and usage of our PrintRite3D® software for in-process quality assurance during 3D printing," stated Mark Cola, President and CEO of Sigma Labs."Working directly with OEMs will increase the adoption of our systems and provide important feedback for application development in real-world scenarios. We look forward to partnering with some of the globe's AM machine and software technology leaders to advance an understanding of our software and broaden awareness of the Company in general. We expect to have a number of manufacturers licensing our systems for deployment in the very near future," added Cola.

www.sigmalabsinc.com ■■■

Sciaky anouces reseller agreement with EFESTO

Sciaky, Inc., a subsidiary of Phillips Service Industries, Inc. (PSI) based in Chicago, Illinois, and a leading provider of metal 3D printing solutions, has announced that it has entered into a structured reseller agreement with EFESTO, LLC that includes the sale of Sciaky's Electron Beam Additive Manufacturing (EBAM) systems and services to targeted countries and named accounts. Under terms of the agreement, EFESTO will provide exclusive sales representation and resale of Sciaky's EBAM solutions to Australia, Brazil, China, India, Japan, Nigeria, Poland, Russia and South Korea, along with named accounts in the Middle East and the US oil & gas sector.

EFESTO is a rapidly growing advanced technology enterprise, committed to engineering an industrial revolution in the field of 3D printing of metals and metal composites. It has deep knowledge and experience in Directed Energy Deposition (DED) technologies and their industrial applications. EFESTO is also establishing premium service bureaus that will utilise the largest and fastest metal 3D printers available.

www.sciaky.com | www.efesto.us ■■■

Alcoa expands R&D centre to accelerate Additive Manufacturing capabilities

Alcoa has announced $60 million expansion plans to include a state-of-the-art Additive Manufacturing facility at its Alcoa Technical Center, the world's largest light metals research centre near Pittsburgh, Pennsylvania, USA. Focused on feedstock materials, processes, product design and qualification, Alcoa states that it will be producing materials designed specifically for a range of additive technologies to meet increasing demand for complex, high-performance 3D-printed parts for aerospace and other high-growth markets such as automotive, medical and construction.

"Alcoa is investing in the next generation of 3D printing for aerospace and beyond," stated Alcoa Chairman and Chief Executive Officer Klaus Kleinfeld. "Combining our expertise in metal alloys, manufacturing, design and product qualification, we will push beyond the limits of today's Additive Manufacturing. This investment strengthens our leadership position in meeting fast-growing demand for aerospace components made using additive technologies."

www.alcoa.com ■■■

Betatype releases new CAD/CAM software for high complexity geometry in AM


The software will make designing complex geometry easier

Betatype Ltd, London, UK, is to release its latest software tool for the design and manufacture of complex geometries in Additive Manufacturing. The Alpha version of Engine for AM will be released in November 2015 and is aimed at implementing architectured materials onto volumetric designs.

Engine has been developed to make the task of designing complex geometry easier for the designer by removing the need to create a solid mesh. By using an abstracted representation, the complexity and file size of CAD data is reduced and more manageable. Betatype has developed a new open format, ARCH, that contains both geometry and process specific parameters that can be exported from CAD packages through plugins, or written directly. The software converts ARCH data into a range of general and specialised toolpaths that have been developed by Betatype for industrial AM processes.

Engine generates both generic (.cli) and specific machine formats. Combined with material calibration, Engine can provide higher detail and faster build times than with current standard approaches. The software is also a platform for Betatype's architectured materials library, enabling users to simply drag and drop a range of materials onto CAD designs.

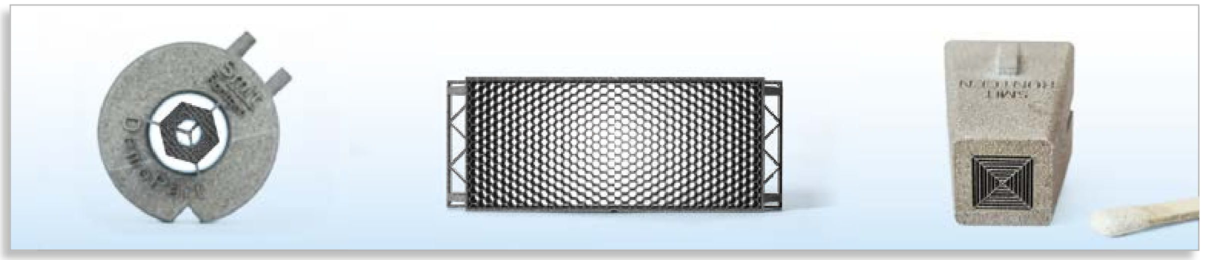
www.betaty.pe ■■■

PM2016, Powder Metallurgy World Congress and Exhibition: Call for Papers issued

The World PM2016 Congress & Exhibition, organised by the European Powder Metallurgy Association (EPMA), will take place in Hamburg, Germany, October 9-13, 2016. The PM World Congress is held in Europe once every six years and is an essential destination for those in the international PM community to meet suppliers, producers and end-users.

A Call for Papers has been issued and abstracts can be submitted online until November 12, 2015. The all topic event includes sessions on Additive Manufacturing, hard materials, Hot Isostatic Pressing, new materials and applications, Powder Injection Moulding and PM structural parts

www.worldpm2016.com ■■■



Marine applications for Additive Manufacturing to be focus of new consortium


SLS 3D printed propellor (Photo © Van Dalen Products)

The question of whether it is possible to print spare parts for ships that can actually withstand the demanding real world requirements of maritime activity is set to be answered by a new project that will look at the 3D printing of maritime spare parts. Twenty-seven marine related companies have formed a consortium initiated by InnovationQuarters, in close cooperation with Havenbedrijf Rotterdam and RDM Makerspace. AEGIR-Marine is one of the participants.

The 27 participating companies contribute financially and by sharing their expertise. In anticipation of the pilot project's official start, they selected 30 possible spares. From these parts, parts were chosen for actual 3D print production.

The consortium were scheduled to test the newly produced spare parts in September 2015 to determine whether these new spares live up to the requirements that everyday practice demands. In addition, the partners will build a database of products suitable for 3D printing. This database will provide a guide for marine companies when selecting materials and manufacturing and machining methods.

This project will yield a list of possibilities and advantages of 3D printing and offers the participants not only knowledge but also the possibility to actually deploy this new technology for their company. The first results and the 3D printed spare parts will be presented at the Rotterdam Port Days event in early September and the final results will be presented during a conference in Rotterdam, scheduled for autumn 2015.

www.innovationquarter.nl ■■■

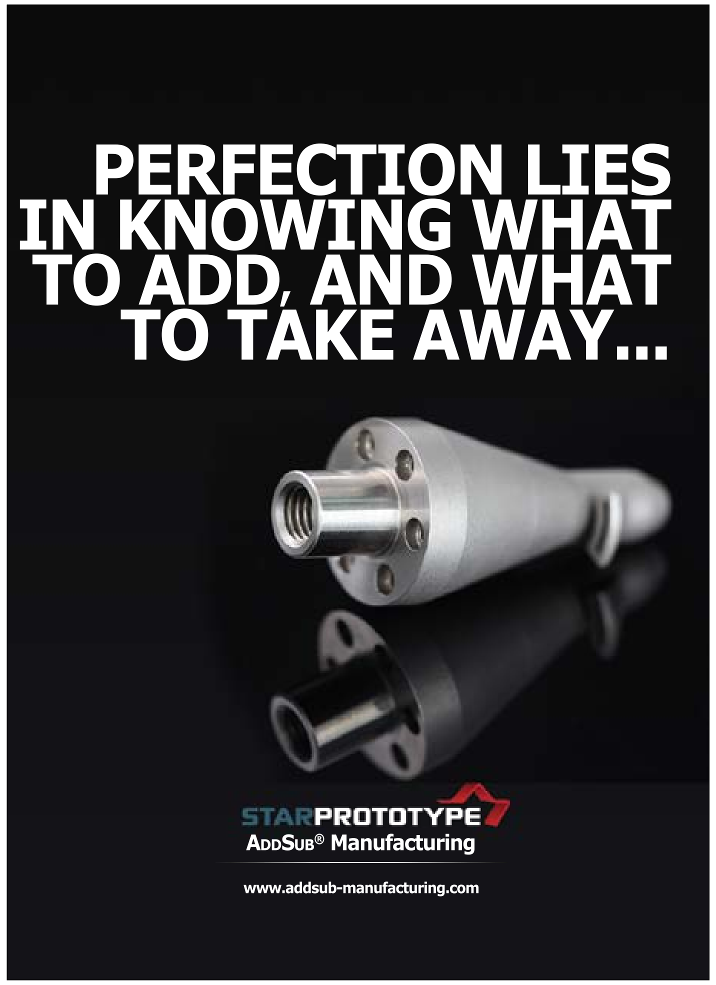
Applications sought for International Additive Manufacturing Award

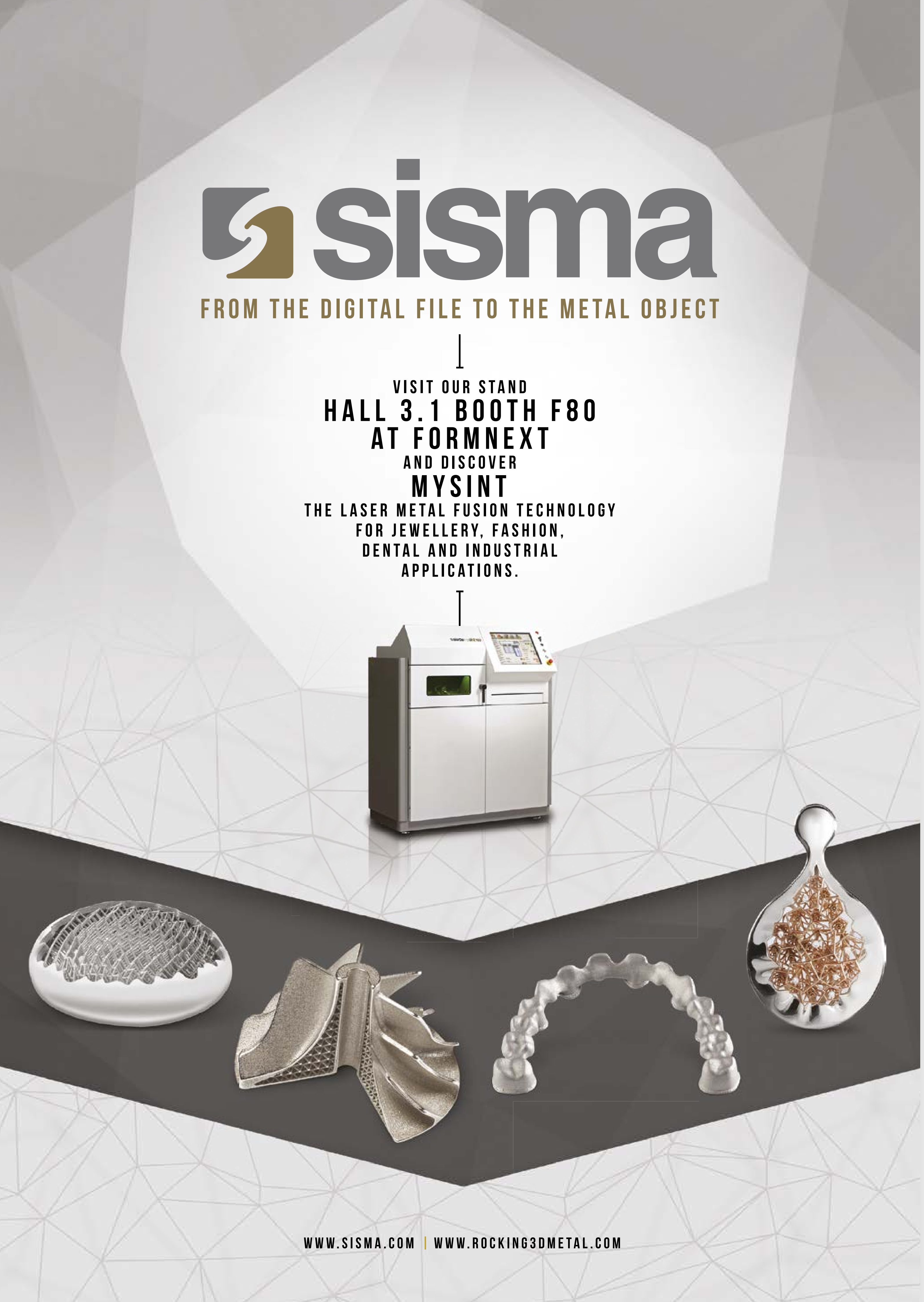
The application procedure for the International Additive Manufacturing Award (IAMA) – the international award in the field of 3D printing – has begun. Organised by AMT and VDW, the International Additive Manufacturing Award (IAMA) recognises the world's best innovations in the growing expanse of additive processes in all areas of modern manufacturing. The winner will receive US $20,000, plus a media package worth US $80,000 for publicising the innovation concerned. The closing date for applications is December 7, 2015.

System manufacturers, users, component suppliers, data modellers and international academics are invited to apply. The applications will be scrutinised by an international jury consisting of high-ranking representatives from the industrial sector and the academic community, along with the important customer grouping of medical technology users, media and trade associations.

The award will be presented during METAV 2016, the 19th International Exhibition for Metalworking Technologies, taking place in Düsseldorf, Germany, February 23-27, 2016.

www.additive-award.com ■■■



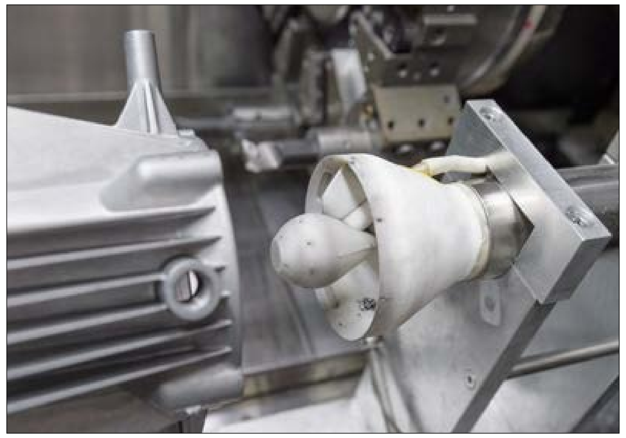


Additive Manufactured suction nozzles for industrial vacuums

Industrial vacuum specialist Ringler GmbH, located in Waldstetten, Germany, and part of the Kärcher Group, has announced that it has begun making a range of suction nozzles by Selective Laser Sintering. The Additive Manufacturing process results in considerably faster production and enables better airflow properties inside the nozzle, the company stated.

Standard nozzles are often unable to completely remove shavings and dust from increasingly complex workpieces in processing machines. Part cleaning plays an important role in the industrial production process as only clean workpieces can be further processed without faults. Until now, custom-built nozzles entailed high design engineering and manufacturing costs due to the large number of individual components.

Typical construction practices involve many individual metal parts being welded into a single component. In the selective sintering laser process, nozzles are built in one piece and require no elaborate assembly design. As a result, suction nozzles can now be produced in around a quarter of the original time.



The selective sintering laser process enables the nozzles to be built in one piece instead of many individual metal parts being welded into a single component.

In addition to improvements in speed and product design, airflow properties inside the nozzle have been refined to reduce loss of suction power. The new design allows for a blowout function to be integrated with a blast of air through an additional airway connected to a pressurised airline removing any adhering swarf and dust or ejecting it from recesses, after which it can easily be vacuumed up.

www.ringler-gmbh.de ■■■

Additive Manufacturing Users Group opens online registration for its 2016 conference

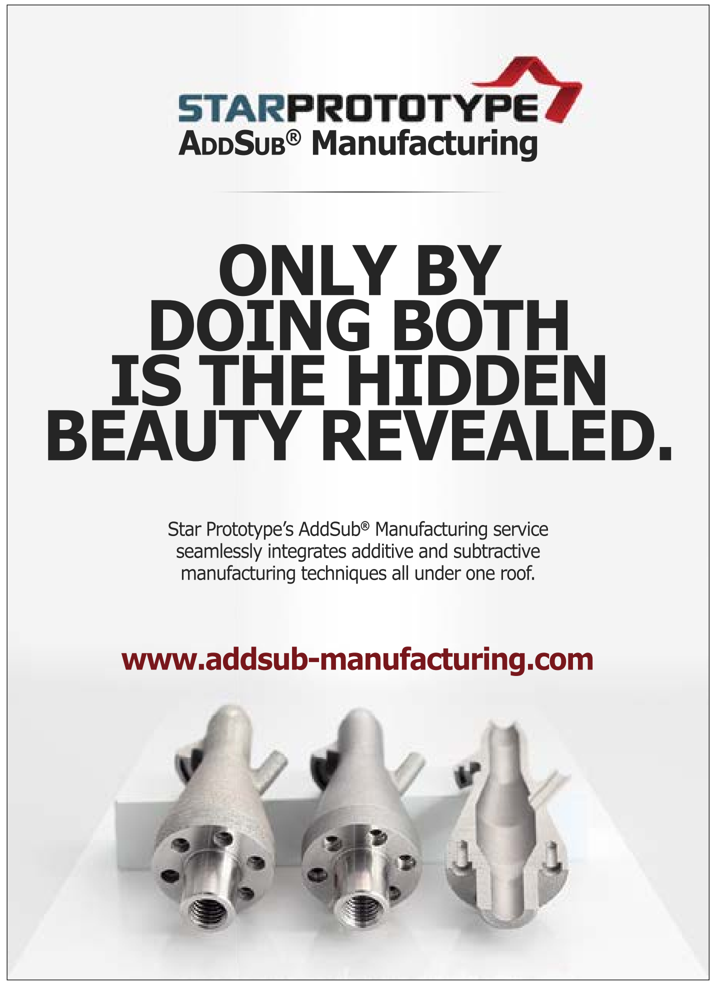
The Additive Manufacturing Users Group (AMUG) has announced that online registration is now available for its 2016 Education & Training Conference, which will be held in St. Louis, Missouri, April 3 - 7, 2016. The users group conference, now in its 28th year, is open to owners and operators of Additive Manufacturing (3D printing) technologies.

AMUG brings together engineers, designers, supervisors, plant managers and educators from around the world to share expertise, best practices, challenges, and application developments in additive manufacturing. The AMUG Conference will include technical sessions and hands-on workshops designed to help users get more from, and do more with, their systems.

Through its Technical Competition and Awards Banquet, excellence in applying Additive Manufacturing and contributions to the industry will be recognised. The five-day event also includes the two-night AMUGexpo, networking receptions, student poster session and catered meals.

The conference agenda is expected to contain over 200 presentations and hands-on workshops.

www.am-ug.com ■■■



The current status and outlook for metal Additive Manufacturing in Japan

Despite playing a significant role in the early development of Additive Manufacturing technologies, there is a belief in Japan that the country's industry has fallen behind in the wider adoption of metal Additive Manufacturing. In this report for *Metal AM* magazine Professor Hideki Kyogoku, of Kinki University, and a project leader of the country's Technology Research Association for Future Additive Manufacturing (TRAFAM), reviews the history of the technology in Japan and its current status. He also presents the work being undertaken by TRAFAM on the development of the next generation of metal AM systems and materials.

According to the Wohlers Report 2015, 27% of all industrial AM systems are installed in the Asia/Pacific region, with the majority being in Japan and China [1]. Within the Asia/Pacific region, it is estimated that Japan accounts for 34.5% of systems and China 33.9%. After President Barak Obama's State of the Union address in February 2013 many people, both in Japan and internationally, started paying much more attention to Additive Manufacturing technology. Since then sales of AM systems in Japan have increased dramatically. Industrial companies and academia are not only interested in plastics processing, but also in metal. A large number of the plastic AM systems in Japan are supplied by 3D Systems, Stratasys, and so on.

With regards to metal AM systems, it is estimated that these were sold in Japan at a rate of around five per year up to 2012, but this quickly increased and fourteen systems were installed in 2013, twelve of which were Selective Laser Melting (SLM) systems and two Electron Beam Melting (EBM) systems. Of these, the major suppliers were EOS, ARCAM, Concept Laser and Matsuura Machinery Co. Metal AM systems manufactured by SLM Solutions and 3D Systems were newly installed in 2014.

The Japanese market is therefore seeing a definite upward trend. The systems currently installed are primarily being used for prototype manufacturing during the commissioning of trial products for the aerospace, automotive and medical fields.

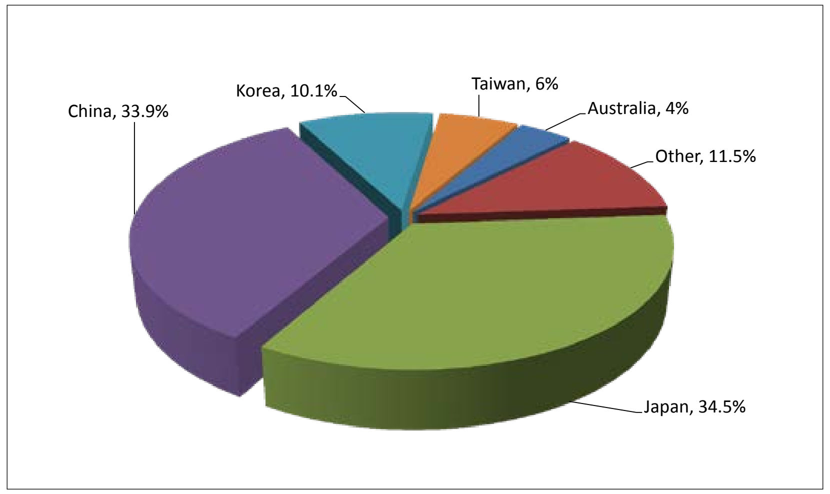


Fig. 1 Cumulative distribution of industrial AM systems in the Asia/Pacific region (~2014) Source: Wohlers Report 2015 [1]

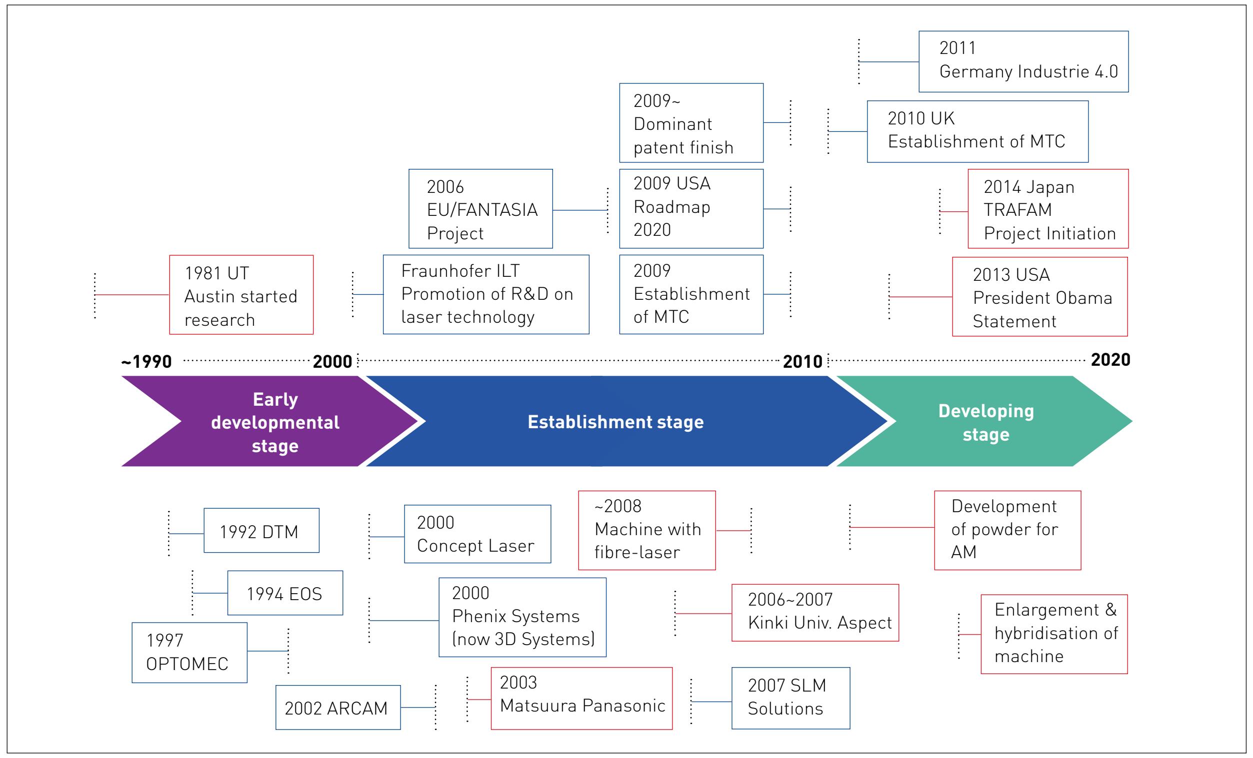


Fig. 2 A history of metal Additive Manufacturing technology

The history of Additive Manufacturing in Japan

In the early stages of the development of Rapid Prototyping, a significant number of Japanese companies pursued the technologies that are today central to the current growth in Additive Manufacturing. As far back as 1981 Kodama, the Nagoya Municipal Industrial Research Institute, published an account of a functional photopolymer rapid prototyping system [2]. The companies CMET and D-MEC were founded in 1988, with CMET offering vat photopolymerisation systems since 1992. By 2013 the company had sold a total of 340 systems [1]. Another company, Aspect, founded in 1996, developed a powder bed fusion system for plastics. More recently, Keyence has commenced the sale of a system using a material jetting process and Roland has started selling a system using a vat photopolymerisation process.

There is also a strong history of innovation in Japan in relation to metal Additive Manufacturing technology. Matsuura, a machine tool company, developed a hybrid metal AM system combining laser sintering and milling functions together with Matsushita Electric Works (now Panasonic Co.) in 2003. A similar type of hybrid metal Additive Manufacturing system was released by Sodick Co. Ltd. in 2014. These machines are Powder Bed Fusion (PBF) systems with fibre lasers.

Kinki University, Hiroshima, developed a PBF type test bench in collaboration with ASPECT Inc. under the Ministry of Economy, Trade and Industry (METI) project in 2006-2007. Aspect Inc. went on to develop a PBF type test bench with vacuum chamber together with the National Institute of Advanced Science and Technology (AIST) under the NEDO (New Energy and Industrial Technology Development Organization) project in 2010.

Machinery companies have also developed hybrid AM machines. DMG MORI Co. Ltd. developed a hybrid AM machine combining additive and subtractive manufacturing in 2013, and Yamazaki Mazak Co. developed a hybrid multi-tasking machine with laser cladding and machining in 2014. Mutoh developed a metal AM system using the arc-welding process in 2014.

It is the case, however, that Japan currently lags behind Europe and the US in the wider adoption of this technology. To address this, Japan's Ministry of Economy, Trade and Industry established a Study Group on New "Monodzukuri" (manufacturing) in October 2013, chaired by Prof. Shintaku of the University of Tokyo. The study group has since held several meetings to study the added-value that can be derived from Additive Manufacturing technology and the future directions of Monodzukuri, with the conclusions published as a report [3]. The Study Group identified the following issues as a priority;

- Developing equipment, materials and software
- Developing the necessary environment
- Fostering human knowledge and skills
- Seeking optimum approaches to creating enterprises.

In light of the above, METI invested around $36.5 million in 2014 to establish a new research association, the Technology Research Association for Future Additive Manufacturing (TRAFAM). The association's mission is twofold; to develop metal AM system technology and to develop binder jetting equipment for the rapid production of sand moulds [4]. The President of TRAFAM is Mr. Atsushi Maekawa, Vice-President of Mitsubishi Heavy Industries. The project leader for the metal AM systems aspect of TRAFAM is Prof. Kyogoku, Kinki Univesity, and the project leader of binder jetting of sand moulds is Dr. Okane, National Institute of Advanced Industrial Science and Technology (AIST).

Fig. 3 A hybrid AM machine combining laser sintering and milling (Courtesy of Matsuura Machinery Co.)

In addition, NEDO launched the "Innovative Design and Production Technology Project" under the Cross-Ministerial Strategic Innovation Promotion (SIP) program [5]. This project has 24 topics on innovative design and production technologies, including AM technology.

Developments in metal AM production equipment

Japanese AM system manufacturers and their main systems are detailed in Table 1. With regard to commercial

Category	Company and AM system
Binder Jetting	-
Material Jetting	Keyence: Agilista series
Powder Bed Fusion	Matsuura: LUMEX Avance-25, Sodick: OPM250L, Aspect: RaFaEl
Direct Energy Deposition	DMG MORI: LASERTEC65 3D, YAMAZAKI MAZAK: INTEGREX i-400AM
Sheet Lamination	-
Vat Photopolymerization	CEMET: ATOMm series, D-MEC: SCS1000, Roland: ARM series
Material Extrusion	Many companies

Table 1 Companies and their AM systems in Japan

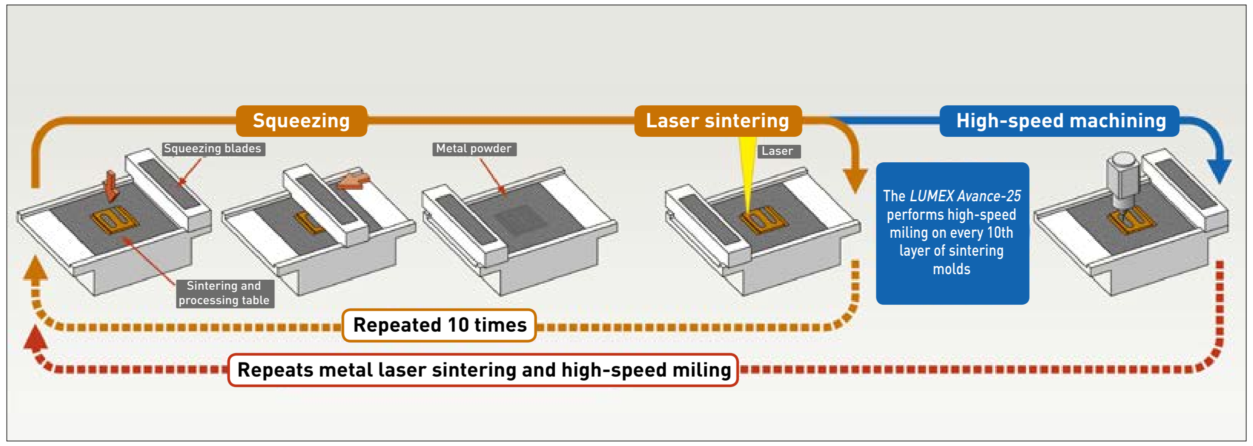


Fig. 4 The fabrication process for the hybrid AM system shown in Fig. 3 (Courtesy of Matsuura Machinery Co.)

Fig. 5 The Sodick OPM 250L hybrid metal AM system. The company states that it is able to manufacture at least 60 units of the OPM 250L annually (Courtesy Sodick Co., Ltd.)

Fig. 6 An example of a hybrid AM system combined with laser metal deposition and milling (Courtesy of Yamazaki Mazak Co.)

Powder Bed Fusion type systems with fibre lasers, Matsuura Machinery Co. has been a leading supplier in Japan since 2003. The similar type of hybrid metal AM system by Sodick Co. Ltd. was released in 2014.

Matsuura, primarily a machine tool maker, developed its hybrid metal AM system with laser sintering and milling with Matsushita Electric Works (now Panasonic Co.) in 2003, and it released a new type of hybrid AM system in 2011, as shown in Fig. 3 [6]. This machine is a hybrid Powder Bed Fusion type system that consists of Matsuura's time-proven machining centre combined with a metal laser sintering function. Tooling is manufactured very efficiently by using laser sintering and high-speed finish machining. The capabilities of this process bring not only a reduction in tool manufacturing time but also quality improvements in the moulds thanks to the flexible placement of cooling channels in the mould dies.

Sodick Co., Ltd., an EDM (Electrical Discharge Machining) machine maker, produces equipment that is mainly used for the production of dies and moulds, as well as other applications which cannot be produced by standard machining methods [7]. The company has developed a laser based metal AM system that integrates finishing by high speed milling using a rotating tool (Fig. 5).

Meanwhile, with regards to Laser Metal Deposition (LMD) equipment, DMG MORI Co., Ltd. launched a hybrid AM machine combined additive and subtractive manufacturing in 2013. This system combines Laser Metal Deposition with 5-axis milling [8].

Fig. 7 An example of mould fabricated by a hybrid AM machine (Courtesy of Matsuura Machinery Co.)

Mutoh developed a metal AM system using arc-welding process in 2014.

Yamazaki Mazak Co., a leading machine tool company, launched a hybrid type AM system combined with laser cladding and 5-axis milling in 2014 (Fig. 6) [9]. These machines are used for repairing and small lot production of very difficult-to-cut materials such as those used in the aerospace, energy and medical industries.

Industrial applications for metal AM technology in Japan

Mould and die making

As mentioned above, the sales of metal AM systems in Japan have increased rapidly since 2013. Mould and die makers have installed hybrid Powder Bed Fusion machines to improve the performance of moulds by the effective arrangement of water cooling pipes and formation of deep rib as show in Fig. 7. These high performance moulds bring a significant reduction in moulding time along with quality improvements in finished products. According to an article published in *Nikkei* in June 2013, Panasonic planed to facilitate the mass production of home appliances using metal AM technology. It was stated that the use of metal AM technology for tooling would reduce production costs by 30% and significantly shorten manufacturing lead-time.

OPM Laboratory Co., Ltd., a die design and milling-combined laser metal sintering process service bureau, was awarded a contract for research and application development using a hybrid laser PBF type machine [10].

Aerospace

The Japan Aerospace Exploration Agency (JAXA) plans to launch a new large-scale test rocket in 2020. Mitsubishi Heavy Industries (MHI) therefore announced that it is considering using metal 3D printing to manufacture rocket parts as JAXA's partner [11].

Fig. 8 A metal AM turbine blade (left) and impeller (right) manufactured by Metal Technology Co. Ltd (Courtesy of Metal Technology Co. Ltd)

Fig. 9 An example of medical implant (Courtesy of Teijin Nakashima Medical Co. Ltd)

Automotive

Koiwai Co., Ltd., a specialist producer of high precision castings for automotive and marine engine applications, is reported to be using not only sand Additive Manufacturing machines but also metal Additive Manufacturing machines [12]. One of the metal AM machines is an EBM machine for titanium alloys, whilst the others are SLM machines for aluminium alloys and others.

Metal Technology Co. Ltd. (Kinzokugiken) [13] is a company that provides advanced metal processing technology, such as heat treatment, HIP, sintering, etc. It has introduced EBM and SLM machines for aerospace and automotive trial parts, as shown Fig. 8

Medical

In the medical field, Teijin Nakashima Medical Co. Ltd. has developed and manufactured medical devices, such as artificial joints, and applied an EBM machine to produce free-form implants and porous components as shown in Fig. 9 [14].

Supply and development of metal powders

The metal powder supply chain for Additive Manufacturing in Japan primarily depends on the AM machine makers, however metal AM powder specialists such as LPW Technology are also active. The sole agent of LPW is Aichi Sangyo Co. Ltd. Other suppliers include Sandvik Materials Technology and a small selection of Japanese powder makers.

TRAFAM is developing powder production technologies and AM powders in cooperation with Daido Steel Co. Ltd., Sanyo Special Steel Co. Ltd., Fukuda Metal Foil & Powder Co. Ltd. and Toyo Aluminum K. K.. In the TRAFAM project, Daido Steel is developing new powder production technologies for heat-resistant alloys. Sanyo Steel is developing new powder sieving technology to control powder characteristics and Fukuda Metal & Foil is developing new powder surface coating technology to improve flowability, oxidation-resistance, etc. Toyo Aluminum is developing new aluminium alloy powder for AM technology.

The challenge of integrating Additive Manufacturing

According to the report of the Study Group on New Monodzukuri [3], Additive Manufacturing technology offers two challenges for Japan's manufacturing sector. The first is to understand the potential of Additive Manufacturing to integrate in the manufacturing of complex precision systems, such as vehicles, aircraft, and medical equipment, which require close collaboration between people in design departments and manufacturing sites, as an important element to succeed in creating new products.

The second is to broaden Japan's manufacturing industry base and enable small independent manufacturers, or new entities that do not have large-scale investment or facilities, to bring new products to market. This could be in the information technology area or the home appliance market, as well as other markets. Additive Manufacturing offers a route to bring these ideas into real objects, leading to the development of an appropriately sized market which places emphasis on advancing Monodzukuri via a network open to the public. Such a network can be developed by promoting business collaboration among individuals, entrepreneurs, professionals and other entities; the Study Group believes that it is important to tackle these issues, focusing on four steps. Firstly, developing technologies in which equipment, materials and software are all integrated; next, developing environments in order to expedite Monodzukuri using an open network; thirdly, fostering human resources who are familiar with processing three-dimensional data; and finally, seeking ideal approaches to creating enterprises that are able to flexibly address changes in sources of added value.

On the basis of this offering, METI established TRAFAM to develop metal AM system technology and a binder jetting system for the rapid production of sand moulds. As previously stated, NEDO also launched its "Innovative Design and Production Technology Project" under the Cross-Ministerial SIP Program. NEDO is pursuing the establishment of a new manufacturing style by developing innovative technologies in 24 technology areas related to design, production and manufacturing technologies to encourage regional innovation, create new markets that can achieve global prominence and reinforce the competitiveness of the Japanese manufacturing industry.

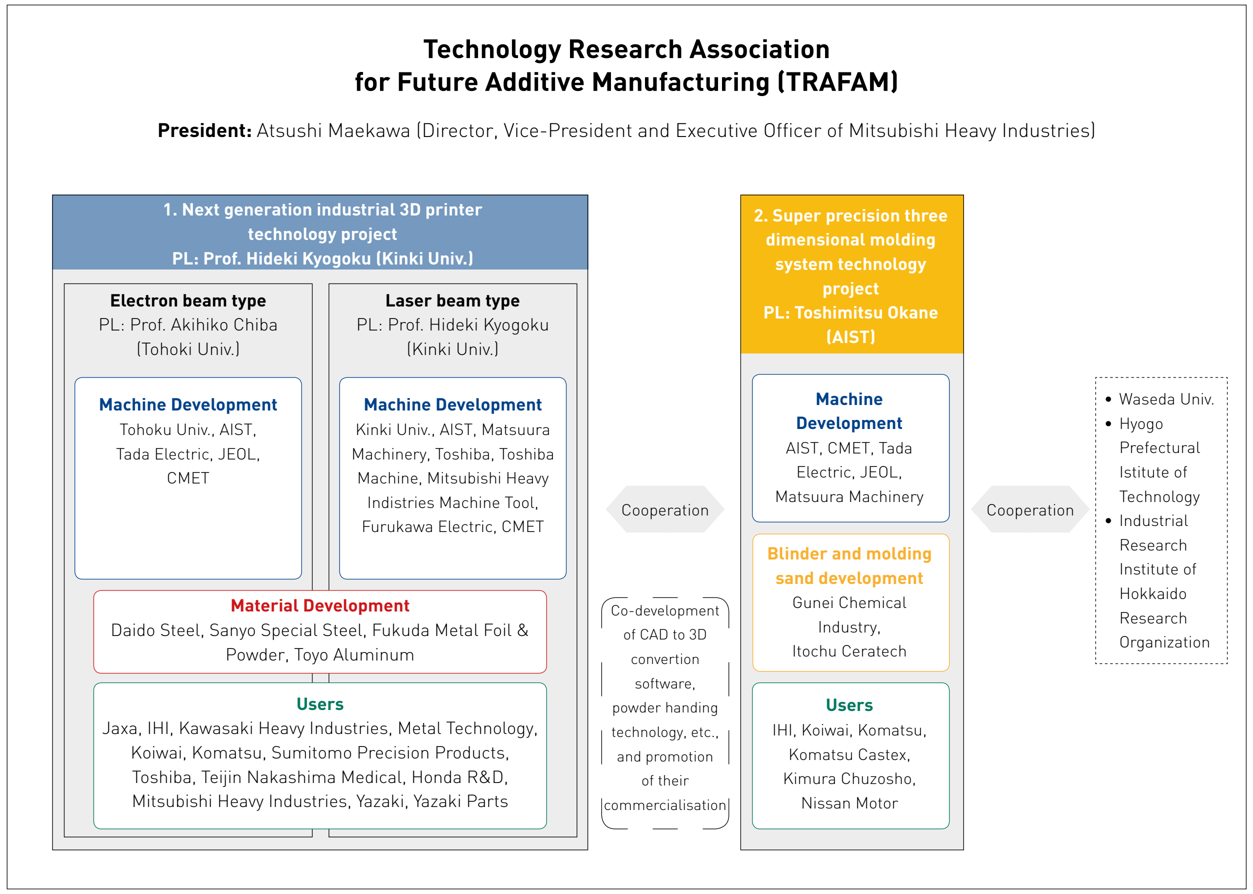
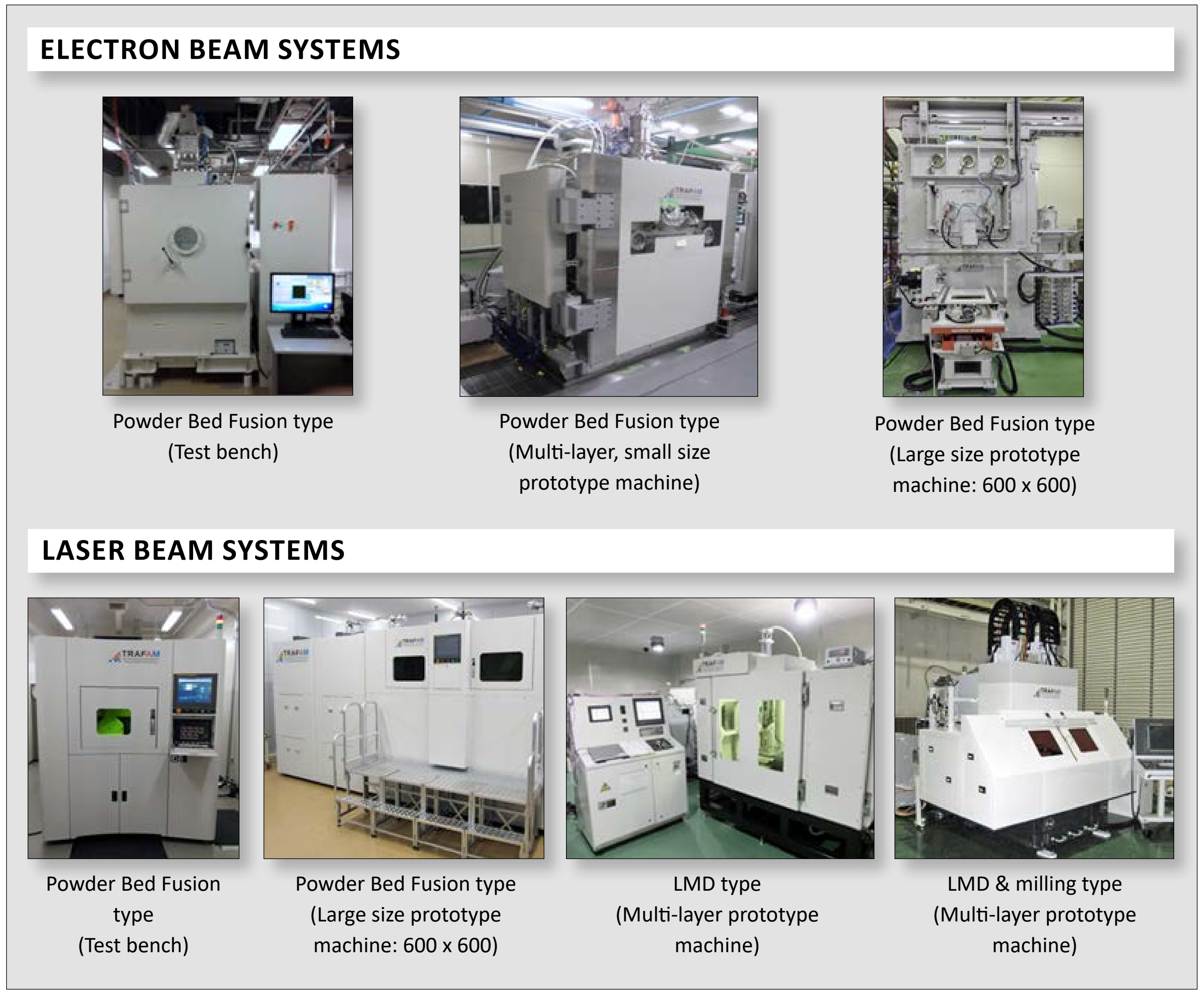


Fig. 10 The corporate structure of TRAFAM



ELECTRON BEAM SYSTEMS

Powder Bed Fusion type (Test bench)

Powder Bed Fusion type (Multi-layer, small size prototype machine)

Powder Bed Fusion type (Large size prototype machine: 600 x 600)

LASER BEAM SYSTEMS

Powder Bed Fusion type (Test bench)

Powder Bed Fusion type (Large size prototype machine: 600 x 600)

LMD type (Multi-layer prototype machine)

LMD & milling type (Multi-layer prototype machine)

Fig. 11 Electron beam and laser beam systems developed by TRAFAM in 2014, along with two test benches

Important Japanese materials societies have also moved to support the development of metal Additive Manufacturing in Japan. The Japan Society of Mechanical Engineers (JSME) launched its "Technical Section on Next Generation 3D Printing" in 2013, headed by Prof. Hideki Kyogoku, Kinki University, and the Japan Society of Powder and Powder Metallurgy launched its technical division on Additive Manufacturing technology in 2014.

The role of TRAFAM and new technology developments

METI invested about $36.5 million in 2014 to launch the new Technology Research Association for Future Additive Manufacturing (TRAFAM). The membership of TRAFAM includes three academic institutions and 29 companies, as shown in Fig. 10. The mission of TRAFAM project is to establish a new manufacturing industry in Japan centring on metal AM systems that will give rise to the next generation of innovative products.

The goal of the TRAFAM project is the development of innovative metal AM machines that will meet the world's highest standards as shown in Table 2. Key areas for improvement of metal AM technology include:

- Enhanced speed: approximately ten times the current speed
- Enhanced precision: approximately five times the current precision
- Upsizing: approximately three times the current build area range

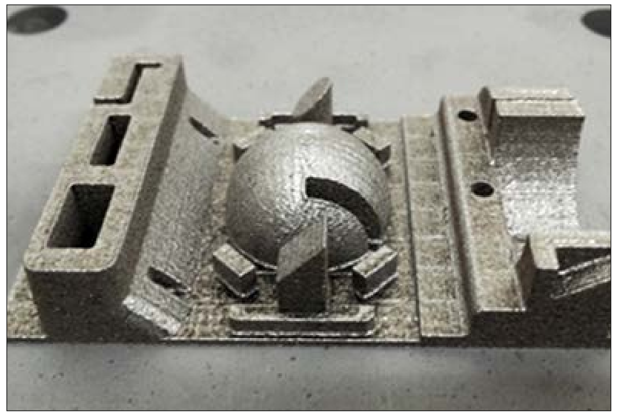


Fig. 12 A trial product manufactured using the TRAFAM Powder Bed Fusion machine

Fig. 14 An example of a casting and a sand mould produced using the TRAFAM prototype machine

Fig. 13 A trial product manufactured using the TRAFAM Laser Metal Deposition and milling machine

- Multi-material structures: different types of metal materials can be used
- Device cost: less than 50 million yen

TRAFAM is currently developing Powder Bed Fusion and Direct Energy Deposition types of AM machines with electron or laser beams. The software for controlling AM machines and the production technology of metal powder for AM technology is also being developed to improve the performance of AM machines. The development of the next-generation of 3D printing technology project is progressing well and, at the end of 2014, two test benches and five types of prototype AM machines have been developed (Fig. 11) and examples of trial products produced (Figs. 12 and 13).

These development machines are on track to achieve the project's goal in 2018. The optimal manufacturing conditions are currently being investigated by experiments using test benches as well as various simulations. The new powder production technology, new powder sieving technology and new powder surface coating technology have all been developed.

With regards to the development of an innovative 3D printer using a binder jetting process to produce sand moulds for casting, a prototype AM machine was developed in 2014 and examples of a trial sand mould fabricated by the machine have been produced (Fig. 14).

Outlook

Additive Manufacturing technology in Japan, in particular metal AM technology, lags behind Europe and the US. However, after 2013, the industry has developed rapidly in parallel with the usage of metal AM systems. TRAFAM's creation and the subsequent development work, in combination with the Strategic Innovation Promotion programme started by NEDO in 2014, is expected to improve the performance and growth of metal Additive Manufacturing in Japan and reinforce the competitiveness of Japan's manufacturing industry.

	Light source	Product Size (mm)	Manufacturing Speed (cc/h)	Dimensional Precision (μm)
Type I	EB	Large (1000 x 1000 x 600)	500	50
Type II	EB	Small (300 x 300 x 600)	500	20
Type III	LB	Large (1000 x 1000 x 600)	500	20
Type IV Deposition method	LB	Small (300 x 300 x 300)	500	20

Table 2 The ultimate goals of the TRAFAM project, to be reached in 2018

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Professor Kyogoku is a leading researcher in the development of both laser Additive Manufacturing technology and functional materials, such as shape-memory alloys made via Powder Metallurgy. He serves as a project leader in TRAFAM.

References

[1] Wohlers Report 2015, published by Wohlers Associates, USA, (2015). www.wohlersassociates.com

[2]J.J., Beaman, et al., "Solid Free-form Fabrication: A New Direction in Manufacturing", Kluwer Academic Publishers, (1997), p.13

[3] www.meti.go.jp/english/press/2014/0221_02.html

[4] www.trafam.or.jp/

[5] www.nedo.go.jp/english/index.html

[6] www.lumex-matsuura.com/english/

[7] www.sodick.jp/ir/pdf/tmp/20150625093836.pdf

[8] http://us.dmgmori.com/products/lasertec/lasertec-shape/lasertec-65-shape

[9] www.mazakusa.com/news-events/press-releases/mazak-introduces-new-hybrid-multi-tasking-technology/

[10] http://opmlabenglish.net/

[11] http://h2a.mhi.co.jp/library/gallery/h2a_f25/index_08.html

[12] www.tc-koiwai.co.jp

[13] www.kinzoku.co.jp

[14] www.teijin-nakashima.co.jp/en/cp/

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Conference Topics

Tue, Nov. 17, 2015, 1.30 p.m. – 4.00 p.m.
→ Opening and Introduction to Additive Technologies
KEYNOTE: Graham Tromans, owner of G.P. Tromans Associates

Wed, Nov. 18, 2015, 10.00 a.m. – 4.00 p.m.
→ Applications and Additive Technologies
Manufacturers and users will report on the latest and future applications.
The legal framework will also be discussed.
KEYNOTES: Dr. Hans Langer, Managing Director, EOS GmbH and Michael Breme, Head of Toolmaking at AUDI AG

Thu, Nov. 19, 2015, 10.00 a.m. – 4.00 p.m.
→ Additive Technology and New Technological Approaches
The use of additive manufacturing technologies in biomedicine and in production.
3D printing in fields of application, from development to production, as well as new technological approaches.
KEYNOTE: David Reis, Managing Director of Stratasys

Fri, Nov. 20, 2015, 10.00 a.m. – 4.00 p.m.
→ »Further Reading« Paves the Way for Users to Become Experts
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A story of failure and success in metal AM: The reality of developing a titanium bike part

Metal Additive Manufacturing promises to enable smaller organisations to compete with global corporations in the development of new products. Expensive tooling and traditional production lines, it is suggested, need no longer be a barrier to market. As US-based designer and engineer Spencer Wright reveals in this insightful report, the reality of developing a low volume AM titanium part for production exposes a number of challenges that the industry needs to overcome if it is truly able to serve a new generation of product developers.

Two years ago, I began the slow and surprisingly dramatic process of developing a product for metal Additive Manufacturing. I had moved to New York City not long before and MakerBot and Shapeways were dominating the hardware scene there. There was a lot of talk about distributed manufacturing, and more and more real world examples of design optimisation software being used. For the first time in my career, I felt a growing interest in industrial grade problems. I was excited.

I'm a self-taught engineer. My background spans project management, product development, and a ton of hands-on experience in conventional manufacturing. I've worked in a narrow range of industries, but in general my interest has been in engineered, mechanical consumer products. I like systems - assemblies that add up to more than the sum of their parts. So, while Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS) were appealing because of their ability to speed up model and tool making, it was only when I saw the aerospace and medical uses of metal powder bed fusion that I became really excited for 3D printing as a manufacturing method.

I'm also a cyclist. I grew up around bikes, and managed a small shop during college, and for a few years I owned a small business building custom bicycle frames. While I left the cycling industry years ago, cycling (and bicycle design) has

Fig. 1 The completed metal AM titanium seatmast topper with saddle attached (Courtesy Spencer Wright)

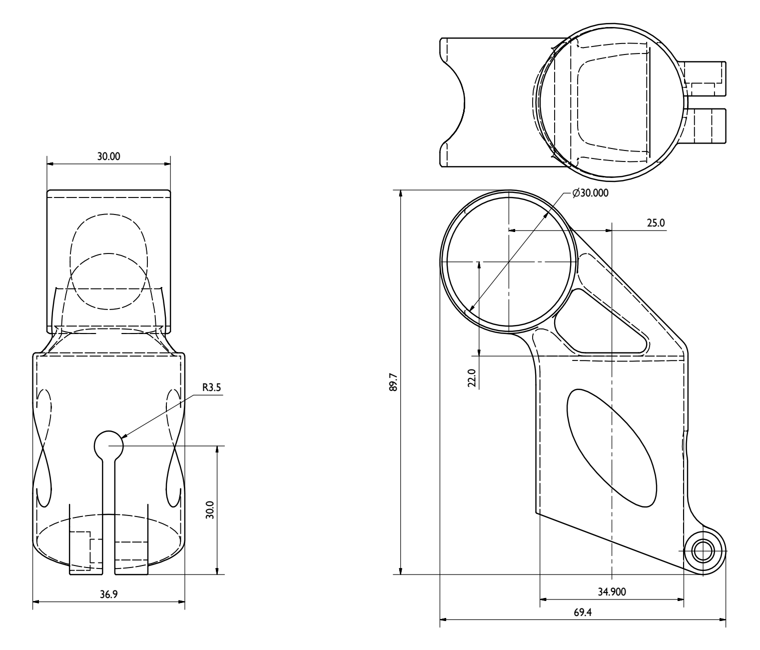


Fig. 2 An initial drawing of the seatmast topper (Courtesy Spencer Wright)

remained something of a fixture in my life. So when I started researching this new class of processes - ones which essentially amount to welding parts together from titanium powder - my mind went to the application that I knew well - bicycles.

As potential markets for metal AM go, high end road cycling is an excellent candidate. Reductions in weight and wind resistance are incredibly valuable. Custom, bespoke designs are prized. Sales cycles are relatively short, making just-in-time production attractive. Customers of high end bikes tend to have buying habits that are price inelastic; an expensive new product that offers genuine benefits can survive regardless of its price tag.

> *"As potential markets for metal AM go, high end road cycling is an excellent candidate. Reductions in weight and wind resistance are incredibly valuable"*

The seatmast topper

The part I'm building is a seatmast topper for high end road bicycles (Fig. 1). At about 60 g, it's fairly lightweight. It's also relatively small and fits easily within nearly every DMLS machine's build platform. Because of its function (seatmast toppers are used to hold a bicycle saddle onto the frame) its structural requirements are fairly predictable. These factors, plus the fact that seatmast toppers are easy for almost any cyclist to install on their own bike, make it a good candidate for AM.

But that doesn't mean it's easy to print. The part consists of two cylinders, oriented 90° apart and joined together by a funnelled neck. The part's wall thicknesses fall between 1 mm and 1.75 mm, roughly .039"-.068", and it's critical that these walls do not vary much in thickness; if they end up just .010" thinner, the part could be unusable (Fig. 2).

Harder yet, the inner diameters of both of the cylinders must be accurate and consistent. Again, variations of just .005" can have a big effect here - and if the cylinders end up with oval cross-sections, the part won't work at all. Also, the titanium 6/4 that my part will be made of is notoriously prone to built-in stresses, meaning that we'll have to be very careful setting up the build parameters and support structures to prevent the part from turning into a pretzel during the process.

First stage prototypes with the help of DRT Medical Morris

About a year before I began researching metal AM, GE acquired Morris Technologies, touching off a shift in the structure of the industry. I was aware of the acquisition because of GE's PR push around open innovation, so when word came to me that a small group had spun out and formed DRT Medical-Morris, I was excited to talk to them. After a half hour on the phone with Dustin Lindley, I knew I had found a team that would be capable - and willing - to go through the initial prototyping phase with me hand in hand.

I worked with Dustin (now at UCRI-University of Cincinnati Research Institute) and Dave Bartosik (his successor at DRT) through six build iterations of my part (Fig. 3). In all of them, the part was oriented on its side in an attempt to reduce total powder recoating time.

With each iteration, we (and by 'we' I mean Dave, whose creativity and enthusiasm for getting the build to work was inspiring) added solid supports in a number of places, chasing built-in stresses around the part with each iteration. The last of these prototypes, although non-functional, was nevertheless a big improvement on the earlier builds — and the process taught us a lot about the idiosyncrasies of my design.

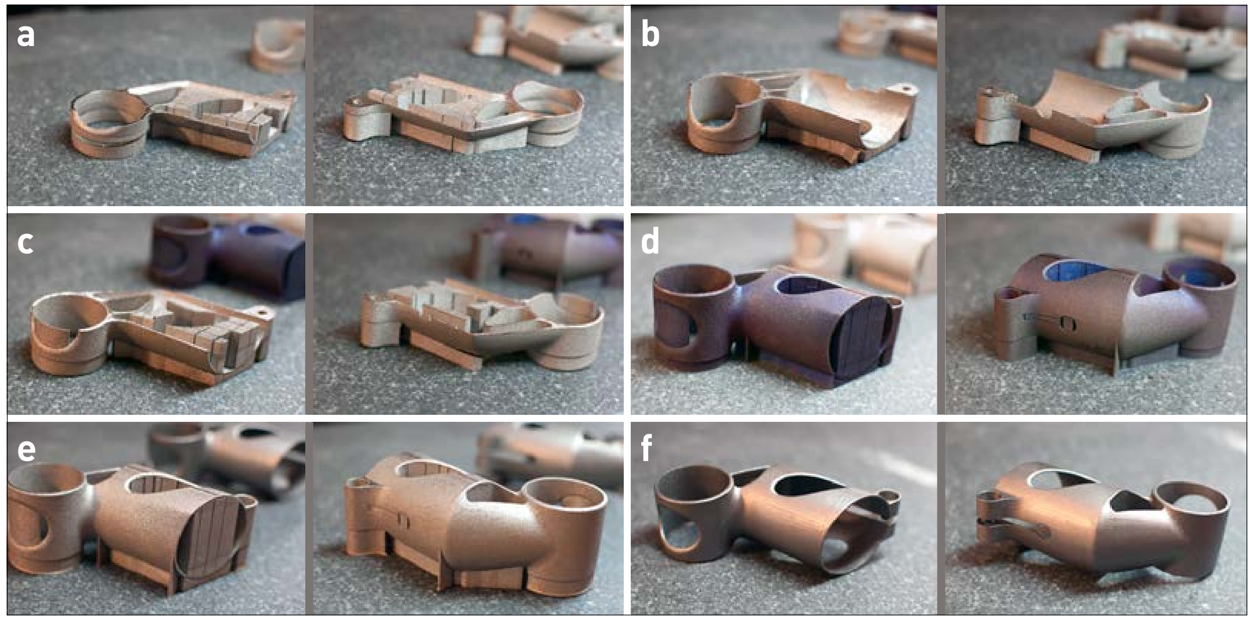


Fig. 3 The first six printed prototypes (Courtesy Spencer Wright)

Build 1
In this build, the part is laid on its side and supported only by mesh supports. The build failed at only 15.6 mm in the z-direction, when the recoater jammed on the saddle clamp end of the part, which had lifted from the build platform (Fig. 3a).

Build 2
Here, the seatpost clamp cylinder is firmly fastened to the build plate. But the stresses just concentrated on the other end of the part, pulling the bolt boss and some of the front edge off the platform at a height of 22.7 mm (Fig. 3b).

Build 3
Both ends of the part, the saddle clamp and the bolt boss, are firmly anchored to the build platform. But this created a complex bending moment, pulling the centre of the part upwards; the build failed at 22 mm (Fig. 3c).

Build 4
Here we've got solid supports on both the saddle clamp cylinder and the bolt boss, and added an additional solid rib to the middle of the part, tying it down there. This is the first build that completed; all of the others had failed midway through. We're clearly getting closer, but the bottom of the part has distorted, pulling in and looking like a big "D" (Fig. 3d).

Build 5
To prevent the bottom of the part from distorting like in Build 4, we added a second solid rib. It helped, but only below the centreline of the cylinder; above that, the wall still pulled in (Fig. 3e).

Build 6
Build 6 finally produced a part that's generally round and complete. This was achieved by extending the lower rib up the side of the part, giving external support to the entire bottom edge of the seatmast clamp cylinder. But although the top and bottom of the seatmast clamp are both basically round, the internal stresses still needed to go somewhere and ended up bulging out the middle of the tube instead (Fig. 3f).

Throughout each of these builds, three things have remained consistent. First, the surface finish on the exterior of the part leaves much to be desired; it will definitely need to be finished in a separate step. Second, the surfaces that needed to be EDM cut from their solid supports (the saddle clamp and the bolt boss) are irregular, and will need to be smoothed into the rest of the part. Third, the internal diameters will almost definitely need to be post-processed by machining or EDM - even the saddle clamp, which overall had passable surface finish, was undersized by .020" - about four times the desired variance.

The net effect is that after six build iterations, each of which took almost two full days to set up, build, stress-relieve and cut off of the build plate, we still didn't have a functional prototype to test.

Further developments working with Layerwise

As I've documented the process and frustrations of developing metal 3D printed parts, I've been pleased and surprised at the number of people who have reached out to me to commiserate (if you're reading this and want to do so yourself, please drop me a line). Without exception, they have expressed solidarity. "We share all of your frustrations," one person said. "I have been through the same pain as you," said another.

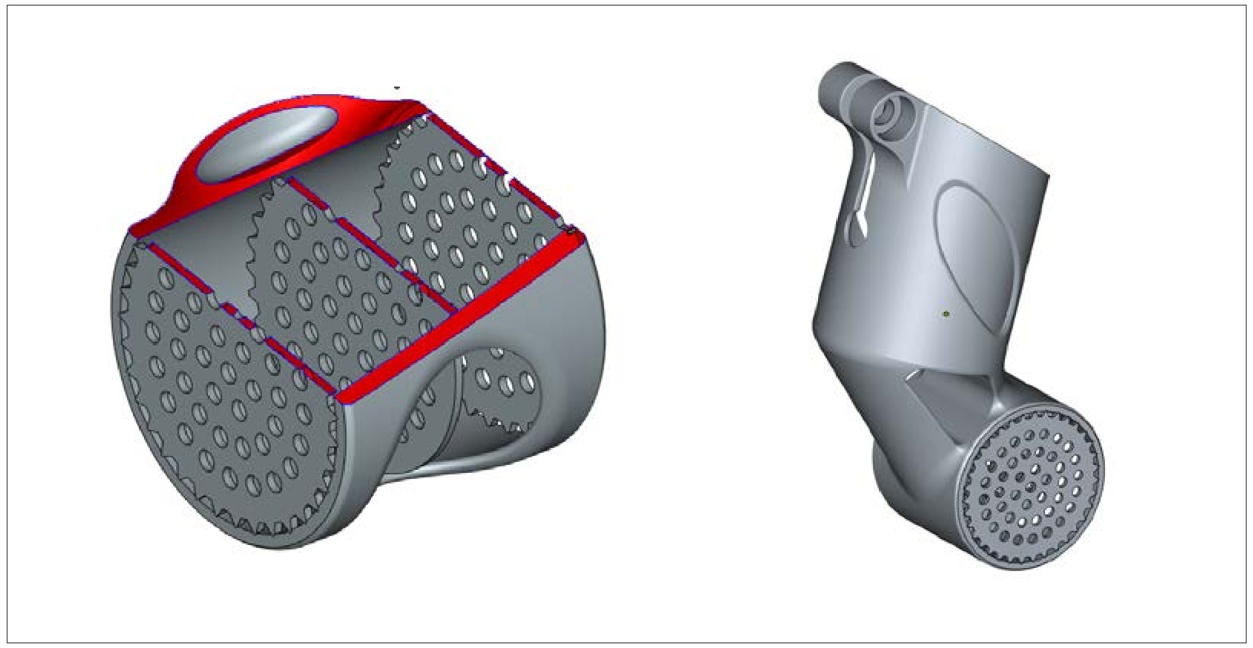


Fig. 4 Layerwise's first build configuration of my part (Courtesy Layerwise/3D Systems)

One of these people was Tom De Bruyne, General Manager at Layerwise. Layerwise is a Belgian company which was started out of the Catholic University of Leuven (one of the premier centres of Additive Manufacturing research); it was acquired by 3D Systems in late 2014. They're famous for being one of the few service providers who built their own laser metal powder bed fusion machines, and have a ton of experience making 3D printed parts at both prototype and production scale. We struck up a conversation, and soon agreed to work together.

While popular opinion would have you think that quantity is a non-factor with 3D printing, the realities of running a service bureau are much to the contrary. To job shops, quantity is a critical factor; if a part will be produced at large volumes, every detail of its design and manufacturing life cycle must be examined. If, on the other hand, you're printing a tool or a prototype of a part that will be manufactured conventionally, most shops will focus on getting the first print right without modifying its underlying geometry.

My project falls somewhere in the middle: while my design is certainly imperfect, there are many aspects of it which are very close. Moreover, it poses challenges (most notably its opposing cylinders, oriented 90° apart, and also its thin-wall construction and bolt boss) that will exist throughout any redesign, and solving them now will only improve my ability to deal with them in future iterations.

At the current juncture, the key questions to test were:

- Can we reliably build my current design with minimal post processing?
- Does my current design meet the necessary performance standards (strength, security, etc.) for bicycle seatmast toppers?

In practical terms, the first question boils down to whether we can build a part that can be installed on a bicycle. This means two things: maintaining inner diameters which are round and dimensionally accurate to within +/-.006", and having a bolt boss on the long cylinder which, when tightened, is capable of securing the part to a bicycle's seatmast.

I worked with Martijn Vanloffelt, a project engineer at Layerwise, on the next phase of prototypes. He used a few key tricks and built my parts on a machine that Layerwise designed themselves. In order to maintain roundness in the saddle clamp cylinder (the shorter of the two cylinders, which was was going to be oriented more or less parallel to the build plate), Layerwise reinforced the inner diameter with three serrated discs (Fig. 4). They also oriented the part slightly off-axis in both the X and Y axes. This brings me to a point that's worth highlighting: In metal powder bed fusion, a part's orientation has a number of effects. First of all, any surface with an angle of less than about 45° (depending on material) must be supported. As a result, it's generally better to orient a part so that all overhangs are as steep as possible.

But in addition, one must consider the angle between the part and the recoater blade. If the part lifts up at any point during the build, the recoater blade will strike it. The longer the area of contact is, the worse the result will be. Some machine manufacturers offer alternative recoaters to lower this risk (3D Systems ProX uses a roller; EOS offers a carbon fibre brush; Arcam uses a metal comb; and both Concept Laser and SLM offer soft polymer blades), but most use a piece of high speed steel (or, in the case of older EOS machines, a ceramic blade) to spread powder across the build platform. Regardless, it is usually better to orient parts slightly off axis in the XY plane, so that the blade doesn't contact the part's walls all at once.

Fig. 5 The first copy of the part that Layerwise printed (Courtesy Spencer Wright)

Orienting parts off axis can also help improve surface finish. When a cylinder's axis is aligned in the XY plane, the top face will exhibit an undesirable stepped appearance; my earlier prototypes all had this feature. When a part is oriented off axis, the surface finish is generally more consistent.

I should note that none of these techniques is guaranteed to work in all cases. Layerwise has a lot of experience building a wide variety of geometries, and has developed a sense of how to anticipate and deal with issues as they come up. I got the impression that the techniques they used on my part are things they've used in the past, but each design is different and even a tried-and-true method of dealing with one design isn't guaranteed to work well on another.

The Layerwise team also put a lot of care into generating mesh supports. Like most of the metal AM industry, Layerwise uses Materialise Magics for their final build prep, and they've developed expertise in exploiting the software in creative ways. I'm not able to share a detailed description of the supports Layerwise created for my part, but I can say (and anyone in the industry could confirm) that they were needed in four areas:

- Underneath the part to anchor it to the build plate.
- Inside the saddle clamp cylinder.
- Inside the window in the centre funnel area.
- Inside the seatmast clamp bolt boss.

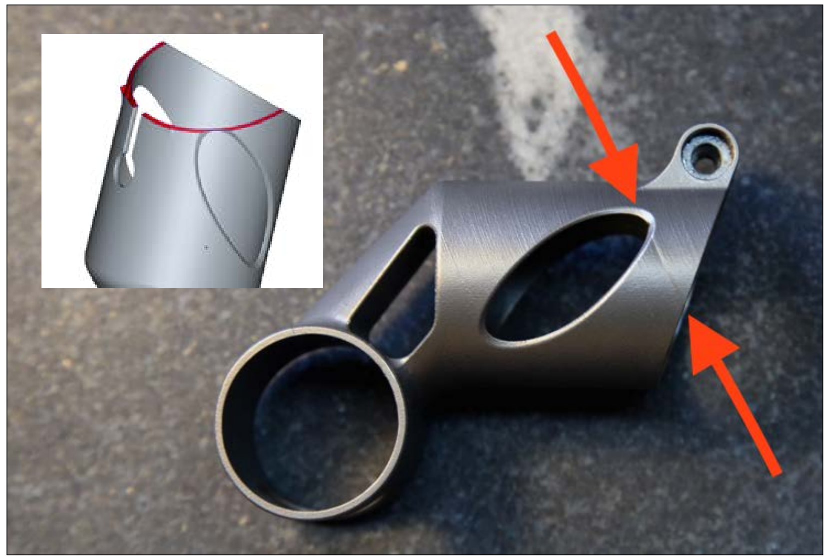


Fig. 6 Details of the flaw in Layerwise's first build (Courtesy Spencer Wright and Layerwise/3D Systems)

Fig. 7 Layerwise's second build setup (Courtesy Layerwise/3D Systems)

Fig. 8 The second Layerwise build of the part (Courtesy Spencer Wright)

Layerwise took great care to orient the part such that it didn't require support structures inside the hidden voids in its centre section. This is something that designers and project engineers alike need to think about as a part heads into production.

Not only can powder bed fusion not make fully sealed voids (if you printed a sealed sphere, the entire centre would be full of trapped, un-melted powder at the end of the process), but many geometries will require support structures in areas where they're difficult or impossible to remove.

For instance, a Klein bottle could be printed in metal, but no matter how you oriented it, there would likely always be support structures stuck inside its fat end. Because of the angles in my part, it was possible to avoid this, but a different design might not fare as well (Fig. 5).

The first part Martijn printed was a big step forward. The build completed successfully without collapsing. However, a new problem arose. The windows on the seatmast clamp area caused the two "leaves" of that cylinder to twist as they were built. By the time the window closed back up, they had become misaligned, and a witness was clearly visible where they joined back together (Fig. 6). The part had a clear flaw and it wouldn't be acceptable for production.

In the next build, Martijn added a curved, perforated disc to each of the seat mast cylinder's windows, keeping them aligned as they grew (Fig. 7). The part that resulted was a full success, printing with clean, smooth surfaces and good near net dimensions (Fig. 8).

Considering how much support material needed to be added back into the seatmast clamp area just to get it to build properly, I'm struck again with how inefficient my design is. The windows in the sides of the part are meant to reduce both weight and cost, but a bunch of energy is put into supporting them and then cleaning the temporary supports out again. Instead of windows, I could just as well have replaced the walls with a lattice structure that would both decrease mass and be self-supporting during the build process, bringing the part's cost down.

This hammers home a point that has plagued my design process: Without knowing and, optimally, having input into how a part is going to be oriented and supported during its build, designers are doomed to creating inefficient designs. Designing for manufacturing requires an intimate knowledge of the manufacturing process, including direct access to detailed information about how the part will be oriented and supported. But in most designer/service provider relationships today, that information comes well after many of the important design decisions have been made, if it comes at all. As a result, it often takes a large investment, both in time and money, just to prove whether Additive Manufacturing can possibly be used to create the part at hand and once that's been proven, many additional iterations are sure to be needed.

This is a key problem in today's additive manufacturing supply chain: while parts are usually designed in a solid modelling environment (often Autodesk Inventor or Solidworks, each of which cost between $5–10,000), builds are oriented and supported in Materialise Magics SG+, which costs an additional $15-20,000. As a result, independent designers are stuck with a disjointed process, which requires costly iterations and lots of communication with the service bureau who's preparing the part to be built.

Regardless, at this point in the process, it didn't make sense to redesign the seatmast clamp area to reduce supports. Martijn's build had a very high likelihood of completing successfully, and it was time to put it to the test. It worked!

Post-processing

After printing it, Layerwise did a bunch of post-processing before sending the part to me. This included:

Stress relief

First, the entire build plate was stress relieved. Layerwise's stress relief process is proprietary, but a typical process [1] would involve putting the build plate in a furnace and bringing it to 600°C over a period of an hour, then holding it there for three hours before turning it off. In theory the furnace is either argon purged or vacuumed, but in practice it may contain small amounts of oxygen too. Layerwise says that the vast majority of the stress relief that they do is performed in a vacuum, but argon is typically used on prototype parts.

Removal from build plate

Then the parts were removed from the build plate. Like most shops I've spoken to, Layerwise uses wire EDM, though band saws are also common.

Removal of support structures

At this point, each customer's part is separated and processed on its own. Supports are removed by a totally unsexy manual process, often involving wrenches, picks, and mallets.

Clean up

Where support structures have been removed additional clean-up is usually necessary. On prototype parts, Layerwise makes extensive use of rotary grinding bits.

Fig. 9 Preparing to tap the threads (Courtesy Spencer Wright)

Fig. 10 The part assembled and ready to test (Courtesy Spencer Wright)

Grinding IDs

The inner diameters of my part were both ground to their final size. Layerwise told me that this process was 100% manual, and I was blown away at the precision and consistency of the surface finish.

Shot peening

Any remaining features were micro shot peened with a nonabrasive ceramic medium.

Tap threads

At this point Layerwise sent me the part. Still to be done, however, was to tap the female threads in the seatmast bolt boss.

Herein lies an important point: metal 3D printing does not, in general, produce usable mechanical features like threading. In conventional manufacturing, threading is often just another step on the same machine: mills and lathes can both easily create female threads. But with metal Additive Manufacturing, threading almost always requires secondary processing. As a result, the design files that are loaded into Magics only contain plain-bore through holes; any threading specifications must be documented (and manufactured) separately.

So, the part that I received simply had a 4.2 mm hole in it; it was up to

Fig. 11 The part in EFBE's testing rig (Courtesy EFBE)

Fig. 12 The part, covered in penetrating dye (Courtesy EFBE)

me to cut the M5 female threads. "No problem," I thought. I've got a tap handle right at my desk, and am more than comfortable using it. At this point, I became painfully aware of what's called alpha case. Alpha case is a very hard, brittle layer of oxygen rich titanium in a part's surface (an interesting study on alpha case depth is published [2]); it's the result of the titanium having been processed at high temperatures in environments where oxygen is present. And as I tapped the hole in the first part that Layerwise printed me, I realised that it's very, very difficult to cut (Fig. 9).

In order to make my job easier, I purchased a set of custom progressive taps from Widell Industries. Progressive taps cut threads in three steps, increasing the thread depth as they go. As a result, the cutting force required is generally much lower. Even using progressive taps, I was shocked at how difficult tapping the second part was. It was incredibly slow going, and produced a lot of heat. I used cutting fluid liberally, and 45 minutes later was done.

I should note here that titanium is a hard metal regardless of how it's processed. Moreover, alpha case is preventable; in this case, it's simply the result of the stress relief process being done in a furnace that contains some trace oxygen. Annealed titanium 6/4 has a typical Vickers hardness of about 349 [3], but when a part has been stress relieved in an oxygenated environment, that number might jump to more than 412 [2]. By comparison, 4130 steel and 6061-T6 aluminium, both of which are used extensively in the bicycle industry, have Vickers hardnesses of around 207 [4] and 107 [5], respectively. In future prototypes, I would probably specify that the stress relief should happen in a full vacuum; that would at least make the tapping a bit easier.

Regardless, the part was finally ready to assemble (Fig. 10). After a total of eight build iterations, I could finally have the part tested—and learn whether my underlying design worked.

Testing at EFBE Prüftechnik

To help understand if my design would handle real world performance requirements, I worked with EFBE Prüftechnik, a German bicycle and component testing facility. EFBE tested the part to ISO 4210–9:2014, 4.5 (Fig. 11). That test entails:

1. Clamping the seatmast topper onto a 34.8 mm pillar angled at 73°, and fitting a dummy saddle rail into the saddle clamp.
2. Applying 100,000 cycles of a test force of 1230 N, at a distance of 70 mm to the centre of the rail clamp, with the saddle rail tilted down/backwards by 10°.
3. Applying a vertical static load of 2050 N to the centre of the saddle rail clamp.

Marcus Schröder, Managing Director of EFBE, put my part through the dynamic test first. It passed.Before he went through the static load test, Marcus asked whether I wanted to make sure I got an intact part back, or if I would rather find the failure mode in the static test. In the latter scenario, he would apply the maximum force his rig could handle and see if he could get the part to break, allowing me to redesign it accordingly. Wanting to know as much about my design as possible, I chose the latter option.

Marcus's test fixture was capable of applying 3750 Newtons to the part. My part withstood the whole thing. Marcus also used penetrating dye to confirm that the part didn't have any micro fractures, and it came back negative (Fig.12). The part had met and exceeded the requirements for parts like it.

It's worth noting that this test is simply that: a test. It's meant to simulate real world conditions and guarantee that the part meets generally accepted standards. But it simulates those conditions only generally; manufacturers of these kinds of parts will often have their own in-house spec that to tune the characteristics they optimise for. But in general, a designer needs to choose a test, and then optimise his design such that the part fails just beyond the test's requirements. If I trust the ISO specification implicitly then it stands to reason that I should remove more material from the part; after all, it passed the test with a wide margin.

Regardless, my part could be further optimised. What I've done to date was prove a basic concept: That metal powder bed fusion can be used to make thin walled bicycle parts. The question is: Can I make it commercially viable?

Cost

With the current design and an order quantity of ten pieces, the as-printed parts cost about $500 to make. Meanwhile, the most expensive commercially available seatmast topper I'm aware of costs $300, and the fanciest seatpost I've ever seen was under $600.

Now, there are a number of interesting things to note here. First, I'm able to buy in fairly low quantities. It's not unreasonable for me to purchase parts in batches of ten, which is about as low as any non-stock commercial product in the world and much lower than most products that involve forging, casting or CNC machining. If I can sell my part at a high end price point, then it wouldn't take much cost reduction before I've got a reasonable margin, even with a strikingly low order volume. Also, there are a number of ways that I can reduce cost on this part:

- Even keeping the part's design the same, I can reduce the cost by 25–40% by doubling the layer thickness. This will result in a rougher surface finish, but it's possible that the difference will be acceptable.
- A significant amount of time and effort can be saved by redesigning the underlying model so that the inner diameters need very little, or even zero, post processing. It's unclear exactly how much work this will take, but it could reduce the price significantly.
- Moreover, the entire part can be redesigned in order to reduce both the end mass *and* the amount of support structures necessary. Both of these have a big effect on price, though it will be time consuming to find an optimal design.

All of this assumes that I stick with a laser powered process. Electron Beam Melting, which I've been experimenting with in parallel, might reduce cost further.

Fig. 13 The new seatpost design, printed in EBM titanium by Addaero (Courtesy Spencer Wright)

Electron Beam Melting options explored with Addaero

Last December, when I visited MicroTek in Cincinnati to learn about surface treatments, Tim Bell made a suggestion, "Why not try EBM as well?" Within the US job shop market, Electron Beam Melting is almost an afterthought. While there are many dozens of shops offering (and reselling, I'm sure) DMLS services, only a handful do EBM, and in general they tend to cluster even closer to a single industry.

The closest of these to me is Addaero Manufacturing, which I first contacted in April. Since then, they've printed two iterations of prototypes for me. A few observations:

- EBM's surface finish is, for sure, noticeably rougher. This poses some interesting aesthetic questions (how much do consumers care about having a smooth, shiny part?), but there are practical matters as well. Rough finishes tend to create stress risers, which can result in significantly lower mechanical strength and fatigue life.
- Because the process produces lower thermal gradients during the build, EBM generally results in much lower residual stress

- in the printed part. This makes the orientation and support structures somewhat easier to deal with.
- EBM allows for parts to be nested in three dimensions, while DMLS parts can only be built one layer deep. As a result, the economies of scale with EBM could be more dramatic.

There's also the matter of part design. As my product has developed, I've become increasingly convinced that my part's design is ill suited for the process. Especially as I move to EBM, there are advantages to designing parts with lightweight lattice structures as opposed to thin walled tubes (Fig. 13). My part is already approaching the limit for minimum wall thicknesses that are possible with DMLS, but EBM requires even coarser features. By thickening some regions and removing others altogether, it's likely that I can create a part that's lighter, stronger, and easier to build all at once.

An engineer's view of the metal AM industry

I didn't start out with an intense desire to sell 3D printed bike parts. I simply wanted to test the technology and chose the best application I could think of. Neither did I intend in any real way to make a splash in the metal AM industry; I saw myself as an engineer trying to explore a new technology. But, because of the approach that I've taken and because of the intelligent, hardworking people that I've been lucky to have collaborated with, two surprising developments have come to pass.

The part

The more I learn about the economics of AM, and the more I work to optimise my part for the process, the more I believe that my choice of applications was savvy. My part is far from perfect, but there's little doubt in my mind that 3D printed titanium bike parts are not just possible to create, indeed I think they will prove to be commercially viable - at least for high end customers and quite possibly at scale as well.

As a result, I'm continuing to develop both the design and the business model that will be required to market, manufacture, and distribute it and other designs like it. This is uncharted territory. Despite extensive research, I'm not aware of any standard commercial products that are made by metal powder bed fusion today, and I'm interested and excited to forge a new path.

The process

But more significantly, I believe that the metal AM industry is doing a poor job of developing new markets and applications for the technology - and I want to change that. Like any industry, metal AM has developed haphazardly. Early on, each player grabbed whatever cards were closest and developed a strategy only after seeing the hand they drew.

But unlike other advances in manufacturing in the past century, AM offers the chance for the product development process to be reinvented. Between the enthusiasm generated by consumer 3D printing and a renewed interest in hardware and logistical problems among young engineers, we have today a unique chance to imagine and execute on a new paradigm in the way that engineered products come to life. However, the most advanced efforts in the field remain behind trade secrets and even where information is shared, it's often by one-to-one means (like email) as opposed to one-to-many (such as industry blogs), and in static formats (like PDFs) as opposed to flexible and commentable ones (like forums and comment boards).

And so as I develop my own parts, I'm using my product development process as a case study for ways that other teams, in industries much more advanced than cycling, can find ways to work together on shared problems. I believe that there's a better way for OEMs, machine manufacturers, and job shops alike to develop their products and processes. The technology at hand which promises to be powerful, but is still in the very early stages of true industrialisation and reliability, deserves better than the protective, incremental system that the industry has developed into so far.

In the coming months, I look forward to developing and sharing product development processes, both old and new, with the most forward thinking firms in the industry. If you're interested in pushing the industry forward in a meaningful way, or are just entering it and looking to learn more, get in touch at pencerw.com/gemba.

Author

Spencer Wright is a designer, manufacturing researcher, and blogger. In addition to building bike parts, he's currently working on a big new metal AM venture in New York City. You can read more of his work at pencerw.com/gemba

References

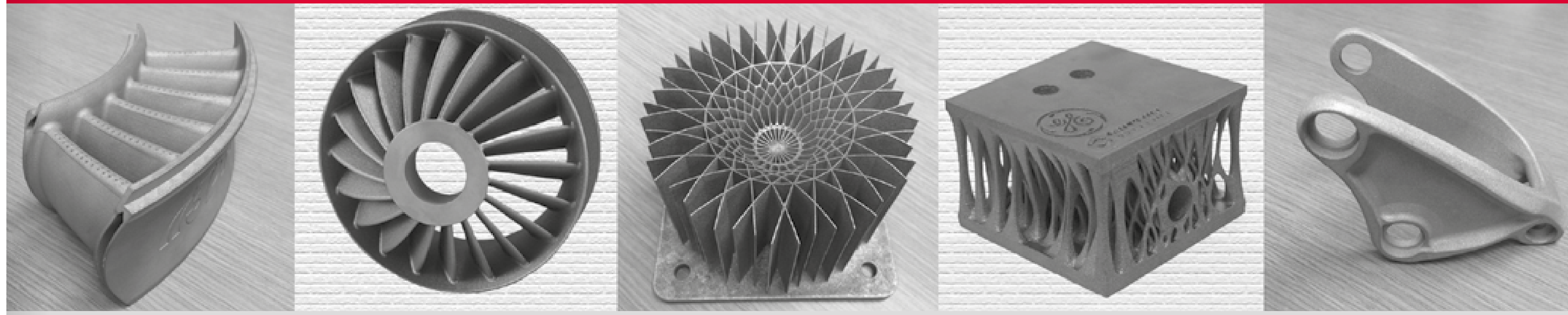
[1] Heat Treatment of Titanium Alloy Parts, Standard AMS2801B http://standards.sae.org/ams2801b/

[2] R Gaddam *et al*, Study of alpha-case depth in Ti-6Al-2Sn-4Zr-2Mo and Ti-6Al-4V, 7th EEIGM International Conference on Advanced Materials Research, IOP Science

[3] Titanium Ti-6Al-4V (Grade 5), Annealed, as published on ASM Aerospace Specification Metals Inc, http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MTP641

[4] AISI 4130 Steel, normalised at 870°C (1600°F), as published on ASM Aerospace Specification Metals Inc, http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=m4130r

[5] Aluminium 6061-T6; 6061-T651, as published on ASM Aerospace Specification Metals Inc, http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061t6



Developments in the Additive Manufacturing of titanium at PM Titanium 2015

The PM Titanium 2015 conference, held in Lüneburg, Germany, from August 31 to September 3, 2015, was the latest in the series of international conferences specifically focused on the processing, consolidation and metallurgy of titanium. As Dr David Whittaker reports for *Metal Additive Manufacturing* magazine, the ambition to apply titanium AM components in critical applications continues to drive researchers to further understand the influences of processing parameters on achieved microstructure and on the relationships between microstructure and mechanical properties.

PM Titanium 2015, the third in the international series of conferences on Powder Processing, Consolidation and Metallurgy of Titanium, was held at the Leuphana University in Lüneburg, Germany, from August 31 to September 3, 2015. The conference attracted an attendance of over 130 delegates from 27 countries. Encouragingly for an area of technology where, to date, the high level of R&D activity has not yet been matched by significant market penetration, several delegates from potential end-users were present, representing the aerospace, biomedical and consumer products sectors.

Within the ten technical session programme, two sessions were devoted specifically to the Additive Manufacturing of titanium and relevant papers also appeared in other sessions. This article reviews selected papers from the programme, all related to the processing of Ti-6Al-4V.

A consideration which is of high significance with regard to the viability of the use of Additive Manufacturing for safety-critical applications is the development of robust knowledge on the influences of processing parameters on achieved microstructure and on the relationships between microstructure and mechanical properties.

The reviewed papers all touch on this consideration by addressing the development of numerical simulation approaches to the modelling of the phase transformations as the melt pool is cooled during the Selective Laser Melting (SLM) process, the influence of post-build heat treatment

Fig. 1 Delegates at the PM Titanium 2015 conference in Lüneburg

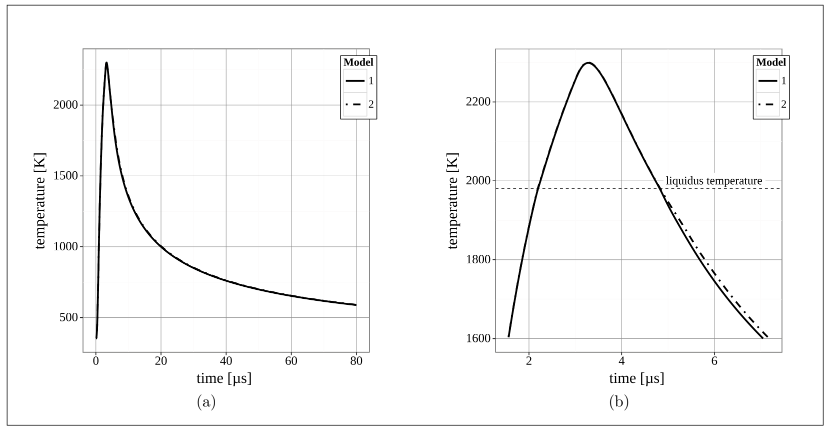


Fig. 2 Temperature evolution predicted at the centre of the laser beam, 5 µm beneath material's free surface of the initial configuration. The calculation is performed for the nucleation and growth approach (Model 2) and the commonly used approach (Model 1). (a) shows the overall temperature evolution over time. (b) shows the details during melting and solidification, revealing the differences between both models [1]

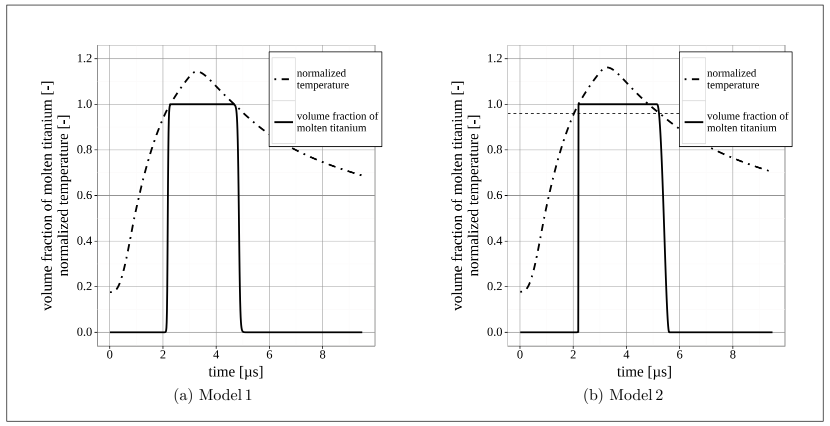


Fig. 3 Comparison of the volume fraction of molten titanium versus time and normalised temperature versus time for both phase transformation models predicted at the centre of the laser beam, 5 µm beneath material's free surface of the initial configuration [1]

on mechanical properties of material fabricated by Electron Beam Melting (EBM) and the effect of a surface hardening treatment on wear resistance and bulk mechanical properties of bars produced by SLM.

Multi Phase Field simulation of the Selective Laser Melting of titanium alloy

Peter Holfelder (Technical University of Munich, Germany) and his co-authors Jinming Lu, Christian Krempaszky and Ewald Werner, also Technical University of Munich, reported on work to develop numerical simulation methods to study the influence of process parameters on microstructure during the Selective Laser Melting (SLM) of Ti-6Al-4V.

To gain a better understanding of SLM, many experimental and simulative studies have been reported in the literature over the past two decades. Nevertheless, the process is still not fully understood due to the many inter-relationships of relevant physical effects that must be taken into account and due to the small timescales involved in the laser-material interaction.

In SLM, the metal powder is locally fully melted by a laser and cools down by self-quenching, by free convection of shielding gas and by thermal radiation from the free surface. This thermomechanical treatment of the material and, hence, the microstructure evolution differs substantially from those in conventional processing routes, such as forging, casting or milling. All of the mechanisms defined above were covered by the model presented.

In this model, a major area of novelty related to the proposal to use a CalPhad-based Multi Phase Field (MPF) model to describe the microstructure evolution induced by laser-material interaction. In contrast to the previously published and more conventional approaches, the nucleation and growth processes occurring during the relevant phase transformations are explicitly taken into account on the basis of free enthalpy. This allows a more detailed analysis of high cooling rates on the evolving field quantities.

The description of the phase transformation kinetics conventionally adopted is a fixed relation between phase fraction and temperature, for instance taken from measurements at cooling rates frequently near equilibrium conditions. In this commonly used approach, the phase fraction depends exclusively on the temperature. This simplified approach was included in the reported work, as a basis for comparison with the nucleation-and-growth approach, and was designated as Model 1. The second simulation set-up (Model 2) considered the nucleation and growth processes explicitly.

To demonstrate the principle of the Multi Phase Field approach, the phase transformation simulation was limited to the β-phase to molten phase transformation of Ti-6Al-4V and vice versa. The temperature evolution, evaluated at a selected point located at the centre axis of the laser beam, 5 µm beneath the material's free surface, is plotted in Fig. 2. In Fig. 3, the evolution of the volume fraction of molten titanium and the evolution of the temperature (normalised to the liquidus temperature) are shown for both models.

For both models, the overall behaviour of the temperature evolution is similar during the heating and cooling periods, see Fig. 2a. During the heating period, the temperature vs. time curves are identical. However, during the cooling period, they differ significantly from each other, as soon as temperature falls below the liquidus temperature (approximately 1980 K), see Fig. 2b.

The different temperature evolutions during the cooling period originate from the dissimilar descriptions of phase transition in the two models. Fig. 3a shows that the volume fraction of the molten titanium becomes 1.0 as soon as the temperature at the selected point exceeds the liquidus temperature and is zero if the temperature falls below the solidus temperature. Fig. 3b shows a different but more credible behaviour, because molten titanium is super-cooled, a phenomenon which is observed for many materials.

Knowing that Model 2 allows for super-cooling, the difference in temperature evolution during the cooling period can be explained by the higher thermal conductivity of β-titanium compared to that of molten titanium below the liquidus temperature. Therefore, the heat fluxes decrease when the selected point and its surrounding is in the molten state and the temperature falls below the liquidus temperature. Consequently, the selected point cools down more slowly, which can be seen in the detailed view of the temperature evolution (Fig. 2b). The delay of the β/molten titanium phase transition during the cooling period, shown in Fig. 3b, is caused by nucleation (and growth and the associated incubation time during the nucleation of β-titanium) and the finite interface velocity.

> *"Despite the current uncertainties, the chosen approach is able to provide a better understanding of microstructure evolution during SLM"*

During the heating period, the assumed small wetting angle for the nuclei of molten titanium leads to a high nucleation rate per cell when the transformation temperature is exceeded. This high nucleation rate leads to a nearly instantaneous transformation from β-titanium to molten titanium. Therefore, the temperature vs. time curves for the two models are indistinguishable.

The authors concluded that the nucleation-and-growth model provides a thermodynamically motivated description of the phase transformations during melting and re-solidification and that this model can capture the effect of super-cooling of molten titanium leading to a different temperature evolution compared with the commonly used approach, which assigns the phase fraction to a temperature value. Therefore, this model is physically reasonable for high cooling rates, because the incubation time of nucleation is considered.

The proper choice of particular material parameters, e.g. the interface mobility, is challenging, but could be performed by inverse analysis of measured relationships between phase fraction and temperature. Despite the current uncertainties, the chosen approach is able to provide a better understanding of microstructure evolution during SLM than the commonly used approach.

The influence of the chemical composition on the free enthalpies can be predicted by the CalPhad method. Adding the CalPhad method to the proposed model allows the study of the influence of the material chemical composition on the phase transformation. Furthermore, the model can be extended to simulate the growth of single grains to allow a deeper insight into microstructure evolution during the SLM process.

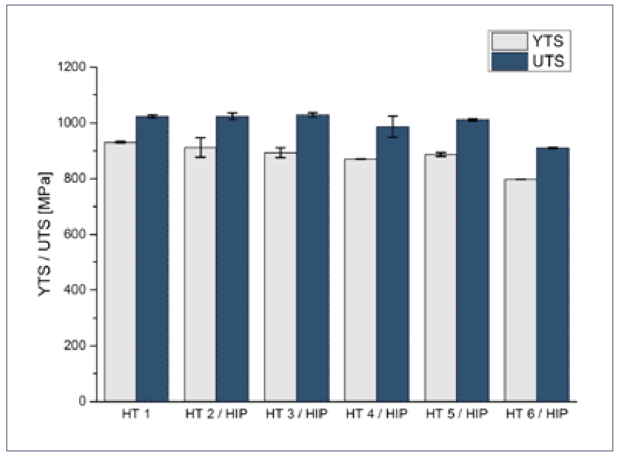


Fig. 4 Tensile yield strength (YTS) and ultimate tensile strength (UTS) of heat treated specimens built by EBM [2]

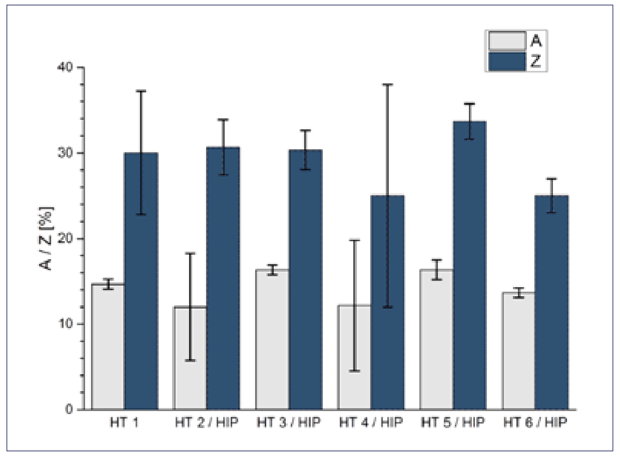


Fig. 5 Elongation at rupture (A) and reduction of area (Z) of heat treated specimens built by EBM [2]

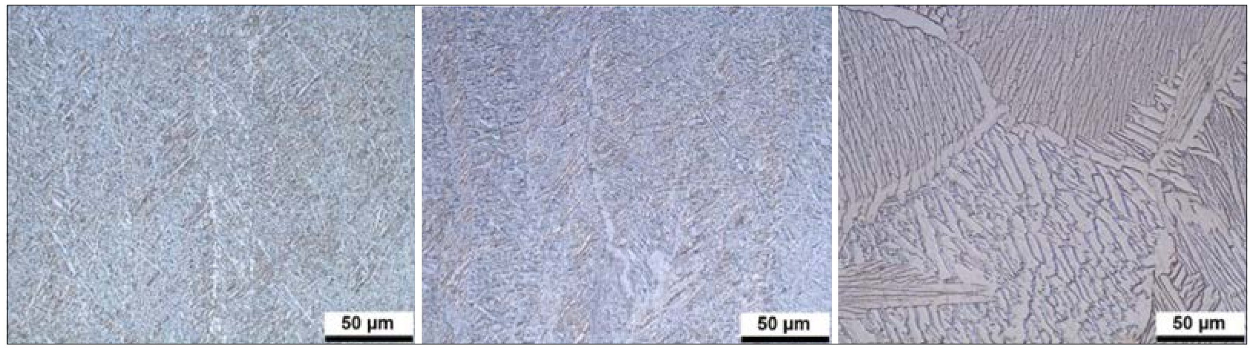


Fig. 6 Optical micrographs of heat treated samples built by EBM. (a) HT1. (b) HT3/HIP. (c) HT6/HIP [2]

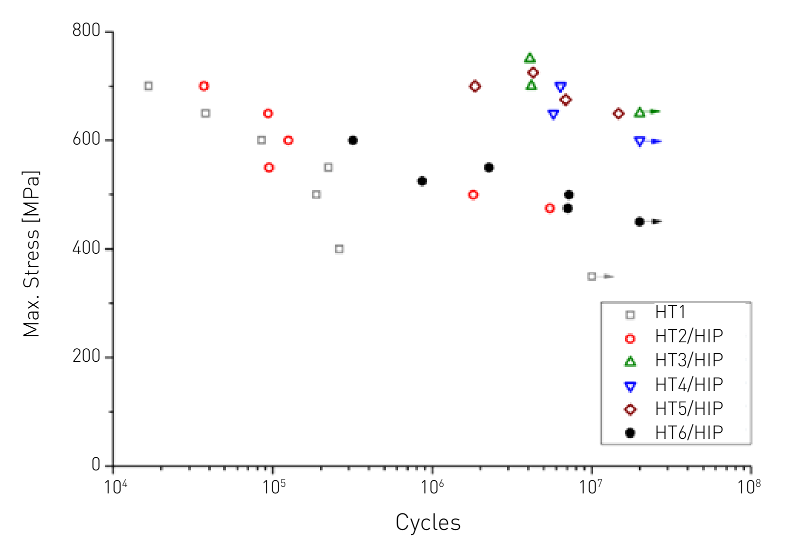


Fig. 7 High-cycle fatigue behaviour of heat treated specimens built by EBM. Data points with arrows mark specimens without rupture (run-out) [2]

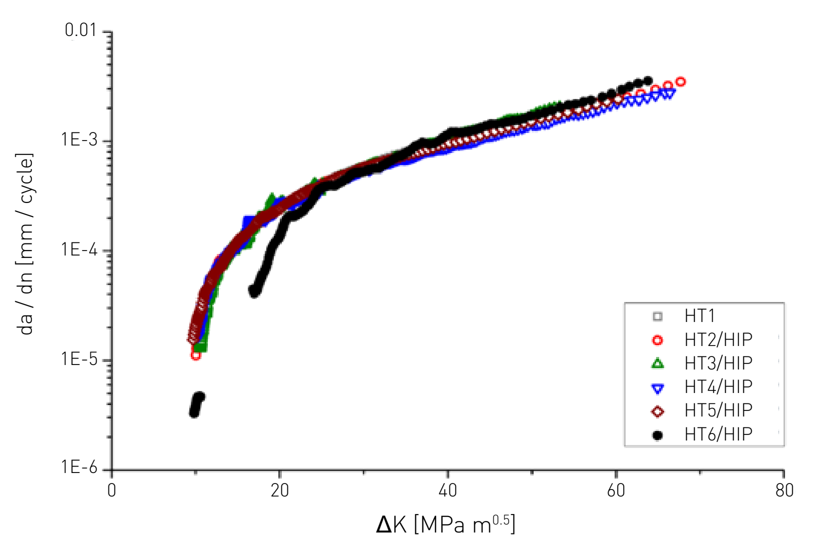


Fig. 8 Crack growth of heat treated specimens built by EBM [2]

Mechanical properties of heat treated titanium alloy fabricated by Electron Beam Melting

Alexander Kirchner (Fraunhofer IFAM, Dresden, Germany) presented a paper on the influence of post-build heat treatment on mechanical properties of material fabricated by Electron Beam Melting (EBM) on behalf of his co-authors Burghardt Kloden, Thomas Weissgarber and Bernd Kieback (also Fraunhofer IFAM, Dresden) and Achmin Schoberth, Daniel Greitemeier and Sarah Bagehorn (Airbus Group Innovations, Munich, Germany).

The advantages associated with powder bed Additive Manufacturing of titanium components are well recognised: the high freedom of design enabling the fabrication of structurally optimised, lightweight parts; the dramatic reductions in lead times; the improved utilisation of expensive material and the capacity for a high degree of product customisation.

However, for applications in safety-critical parts, certainty regarding the achieved static and fatigue strength is also mandatory. This is a challenging issue in view of the complex influences of build parameters, heat treatments and surface quality.

In the reported work, Ti-6Al-4V specimens, built by EBM, were subjected to heat treatments adapted to various application scenarios. Sample blanks were oriented in the build space such that the direction of subsequent mechanical testing coincided with the build direction (z-axis). These sample blanks were subjected to heat treatments between 650°C and 1050°C, designated as HT1 to HT6 in ascending order of treatment temperature. Treatments HT2 to HT6 also included Hot Isostatic Pressing (HIP) treatments with pressures up to 200 MPa and durations ranging from 0.2 h to 2 h, with the aim of removing residual porosity. Test samples, for tensile testing, high cycle fatigue testing and crack growth rate determinations, were machined from the blanks.

As the powder bed and the parts are kept at a temperature around 700°C during the EBM build process and are then cooled down slowly, the as-built parts have effectively been subject to an annealing treatment and dense specimens combine UTS of more than 1000 MPa with good ductility. A post-build heat treatment at 650°C (HT1) delivers virtually identical static properties to the as-built condition at a UTS of 1023 +/- 5 MPa and an elongation of 14.7 +/- 0.6%. Heat treatments at temperatures above 700°C produce very marginal changes in static tensile properties (see Figs. 4 and 5). For instance, treatment HT3/HIP gives a UTS of 1029 +/- 8 MPa and an elongation of 16.3 +/- 0.6%. The treatment at the highest temperature (HT6/HIP), in fact, produced a significant drop in UTS to 910 +/- 2 MPa.

The drop in UTS at high treatment temperatures can be correlated with observed microstructural changes. As can be seen in Fig. 6, the structure of HT1, tempered at the lowest temperature, is a very fine basket-weave pattern. The maximum thickness of the α-platelets is about 3 µm. Upon increasing temperature, the α-phase thickness grows slightly, especially along the prior β grain boundaries. Sample HT3 /HIP contains a few α-platelets of up to 8 µm in thickness. Specimen HT 6/HIP, tempered at the highest temperature, exhibits a distinct coarsening of the α-phase with plate thickness up to 15 µm and the initiation of globularisation.

In contrast to the static properties, significant increases in fatigue resistance can be generated by combining HIP and thermal treatments. As shown in Fig. 7, specimen HT1, heat treated at the lowest temperature, reached the fatigue limit of more than 10^7 cycles at 350 MPa. This agrees well with the published value of 340 MPa for as-built samples. Reducing any remaining porosity by HIP first lifts the "knee" above 10^6 cycles, as can be seen for sample HT2/HIP. HIP treatments at higher temperatures (HT3 to HT5) lift the S-N-curve to higher stress levels with a fatigue limit at approximately 600 MPa. In the case of HT3/HIP, a run-out at a stress level of 650 MPa was even observed. A further temperature increase leads to a reduction in HCF stability, as can be seen for HT6/HIP. In comparison, the fatigue limit of chemically polished, double vacuum-arc remelting forging stock, has been quoted in the literature as 550 MPa. Very similar values of 500 to 550 MPa have been quoted for machined, SLM-fabricated Ti-6Al-4V.

On the other hand, the treatment at the highest temperature (HT6/ HIP) has been observed to

> *"In contrast to the static properties, significant increases in fatigue resistance can be generated by combining HIP and thermal treatments."*

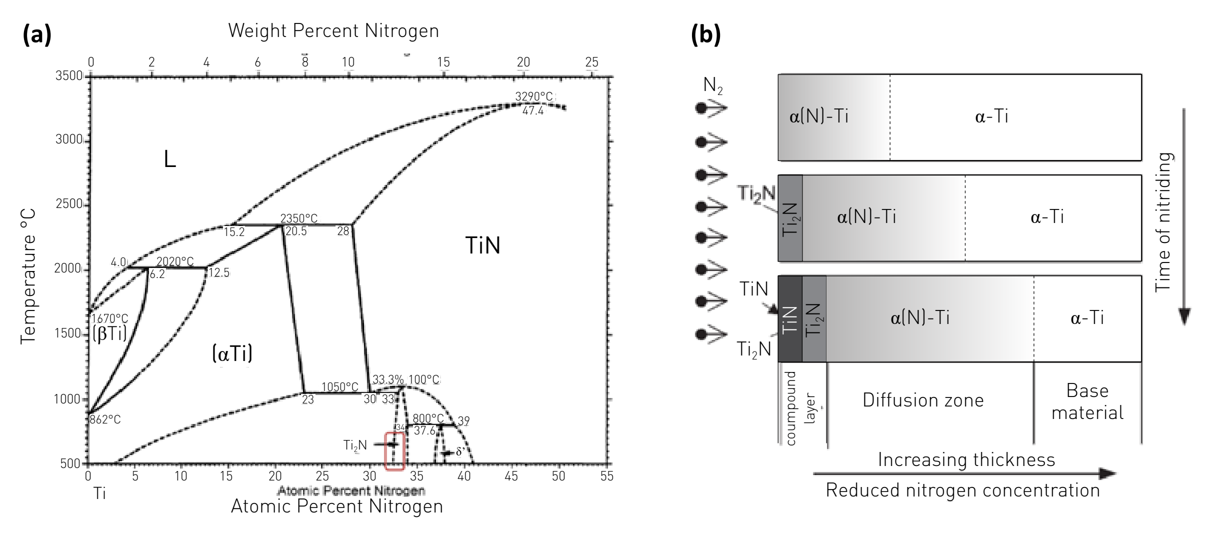


Fig. 9 (a) Ti-N phase diagram , (b) Diffusion process in Ti alloys [3]

GN Trial	GN Temperature	GN Time	Average Microhardness	Yield strength	UTS	EL	Surface N_2
	°C	hrs	HV	MPa	MPa	%	wt%
			370	1032	1226	6.9	
1	800	4	505	986	1036	4.6	8.5-8.8%
2	900	4	582	885	912	2.9	12-13%
3	900	5	574	875	956	5.2	15-16%
4	900	6.5	660	855	878	2.5	11-18%
5	1030	3	610	765	775	1.2	12-20%

Table 1 Gas nitriding trials with different nitriding processing conditions and mechanical properties of gas nitrided Ti64 bars produced by SLM (compared with the as-built, untreated condition) [3]

generate beneficial effects in terms of crack propagation rates. The crack propagation rates of the EBM-built samples are plotted in Fig. 8. The results coincide with each other except for HT6/HIP. This implies that the temperature increase from HT1 to HT5/HIP does not influence crack propagation noticeably. At a stress intensity range ΔK of 20 MPa√m, a crack growth rate of 2.5×10^{-4} mm/cycle was observed. This value is in good agreement with the data for solution treated and overaged Ti-6Al-4V exhibiting a bimodal microstructure. The data presently available shows that the plane strain fracture toughness KIC exceeds 50 MPa√m for all heat treatments.

HT6, however, causes a distinct retardation of crack growth at ΔK below 20 MPa√m. From data points at very low rates of crack growth a threshold of 10 MPa√m can be estimated. This is higher than the threshold value of 3.5 MPa√m cited for SLM-fabricated Ti-6Al-4V in the as-built state.

The fracture surfaces of samples HT1 to HT5/HIP are smooth, whereas the fracture surface of HT6/HIP features a higher roughness. High roughness of the fracture surface is linked to crack closure in titanium with a large α-colony size. This, together with the lower tensile yield strength, leading to a larger plastic zone at the crack tip, is responsible for the reduced crack propagation rate observed in sample HT6/HIP.

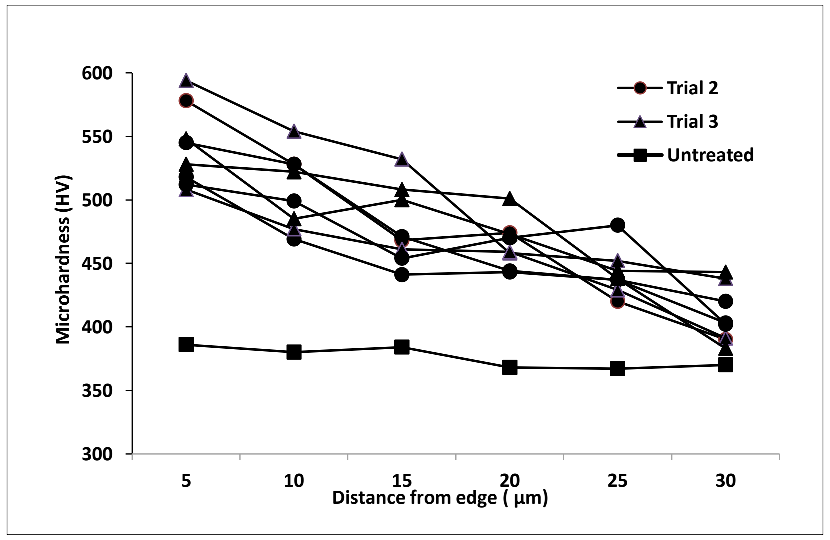


Fig. 10 Microhardness profiles through the cross-sections of Ti-6Al-4V bars produced by SLM and gas nitrided at 900°C for 4 and 5 hours (Trial 2 and Trial 3 in Table 1) [3]

Influence of gas nitriding of titanium alloy bars made by Selective Laser Melting

A paper presented by Stella Raynova, University of Waikato, New Zealand, on behalf of the authors Aamir Mukhtar, Peter Franz, Warwick Downing and Graeme Smith (TiDA Ltd. New Zealand) and Ben Jackson (University of Waikato), studied the influence of a gas nitriding treatment on the mechanical properties of Ti-6Al-4V bars produced by Selective Laser Melting.

SLM offers a number of advantages compared to conventional production techniques such as a reduction in production steps, high material use efficiency and near net shape production capability. The layer by layer building processes in SLM enables the production of parts with a high geometrical complexity, allowing a greater freedom of design.

However, the unique conditions during the SLM process can also give rise to problems. Because of the short interaction times and accompanying highly localised heat input, large thermal gradients exist during the process. These lead to the build-up of internal stresses, attributed to shrinkage during cooling. The rapid solidification also leads to segregation phenomena and the development of non-equilibrium phases (columnar growth).

To overcome these problems and strengthen SLM parts, different heat treatments (i.e. stress relieving, annealing) and thermo-chemical treatments have been applied. One candidate thermo-chemical treatment, gas nitriding, has been extensively studied for wrought titanium alloys and it has been observed that a surface phase of α(N)-Ti is created, which impedes the movement of dislocations or defects at the surface and provides a layer of significantly different mechanical properties than the bulk material. Ongoing gas nitriding forces the diffusion of α(N)-Ti from the surface into the unsaturated matrix.

Between 200°C and 500°C, nitrogen is present as α(N)-Ti only in the first hundred nanometres with an average concentration of 30at%, as highlighted in the Ti–N Phase Diagram (Fig. 9a). With higher treatment temperatures, a "compound layer" is formed at the surface as the nitride begins to nano-crystallise preferentially to Ti_2N and subsequently to TiN. An increased depth of the diffusion zone (consisting mainly of α-Ti solid solution enriched with precipitated nitrogen) can also be observed on increasing treatment duration. Fig. 9b shows the influence of time on the structural state of the surface layers during gas nitriding of wrought titanium alloys.

Fig. 11 Gas Nitriding of Ti-6Al-4V knives produced by SLM [3]

In the reported study, several heat treatments were investigated to find suitable nitriding processing parameters to strengthen SLM Ti-6Al-4V parts and gas nitriding was then combined with an adapted heat treatment below the β-transus temperature for interstitial hardening.

SLM parts were placed in a vacuum sintering furnace, heated to an elevated temperature with a heating rate of 10°C/min and furnace cooled to room temperature and high purity nitrogen gas was introduced with a fully controlled gas flow regulator. Gas nitriding trials were carried out over the temperature range from 800°C to 1030°C and for times from 3 hours to 6.5 hours (see Table 1).

The creation of a compound layer of Ti_2N and TiN during the gas nitriding of the SLM titanium alloy parts was confirmed by X-ray Diffraction (XRD) Analysis and Energy Dispersive Spectroscopy (EDS). The depth of the diffusion layers created by the treatments for 4 and 5 hours at 900°C was assessed through the use of micro-hardness plots and was demonstrated to be around 30 µm (Fig. 10). The property data in Table 1 demonstrate that the surfaces of the SLM Ti-6Al-4V bars after gas nitriding showed remarkably high values of microhardness (>600 HV) as compared to untreated SLM bars, making the material condition a candidate for applications demanding high levels of wear resistance.

In all cases, the tensile properties of the gas nitrided samples were inferior to those of the untreated SLM bars. However, the treatments at temperatures below the β-transus (e.g. 900°C) minimised this loss in tensile properties and provided levels acceptable for many applications. On the other hand, nitriding above the β-transus temperature (e.g. 1030°C) gave significantly lower tensile properties.

The improved wear resistance of SLM Ti-6Al-4V gas nitrided below the β-transus temperature, in combination with useful levels of tensile properties, promises to open up a range of applications and this was demonstrated through one specific example. The requirements of the "Rescue Knife" (Fig. 11), supplied by Victory Knives (New Zealand) to the Americas Cup Safety Team (2013), were for a state-of-the-art,

Photos from PM Titanium 2015 (Courtesy Dr Thomas Ebel)

light-weight, small knife, with high corrosion and wear resistance, that was strong enough to cut through marine ropes. These goals were achieved using Selective Laser Melting of Ti-6Al-4V alloy powder followed by surface hardening using gas nitriding.

References

[1] P Holfelder *et al.*, A Phase Field approach for modelling melting and re-solidification of Ti-6Al-4V during selective laser melting, as presented at PM Titanium 2015, August 31 to September 3, 2015 Lüneburg, Germany

[2] A Kirchner *et al.*, Mechanical properties of Ti-6Al-4V fabricated by Electron Beam Melting, as presented at PM Titanium 2015, August 31 to September 3, 2015 Lüneburg, Germany

[3] A Mukhtar *et al.*, Mechanical behaviour of gas nitrided Ti6Al4V bars produced by Selective Laser Melting, as presented at PM Titanium 2015, August 31 to September 3, 2015 Lüneburg, Germany.

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PM Titanium 2015 Conference Proceedings

For anyone seeking greater detail on the reviewed papers or access to the wider range of papers, relevant to Additive Manufacturing of titanium and titanium alloys, the full proceedings of the conference will be available in early 2016. Those with an interest in obtaining a copy of the proceedings can register their interest by e-mailing Thomas Ebel: thomas.ebel@hzg.de

To invest or not to invest: Understanding the business cases for entering the Additive Manufacturing arena

With such intense levels of interest in Additive Manufacturing, the pressure for businesses to adopt the technology can be high. Expectations, however, need to be managed and the business opportunities and challenges need to be understood. As Onno Ponfoort and Chris Krampitz explain, the dilemmas for any company looking to move into this arena range from fully understanding the advantages that the technology presents to ensuring that those tasked with the project, as well as potential customers, have the necessary technical training.

Additive Manufacturing is at the heart of the digital manufacturing revolution. Being able to produce individualised, tailored products, on demand and on location, spurs the imagination of everyone, children and adults, the technologically savvy and business professionals alike. But is the impact of AM indeed as great as some reports may suggest? This article looks at the potential impact of AM on the various stages in the value chain. It also addresses some key areas of development that need to be tackled before more wide spread use of AM can be expected.

Big promises

The technology holds a number of promises for industry. Making use of the layer-by-layer production method that the different AM techniques have in common allows for complex forms and improved designs previously unthinkable. When describing the benefits this can bring there are generally five categories of advantages given (Fig. 1).

Lower costs

AM supports the manufacturing of parts directly from the digital file (CAD/CAM) without having to manufacture a mould or die to form the part, or cut the part from a solid block of material as in milling.

When AM machines are sited at or near the location of use of the parts, transportation costs can be reduced. Clearly, the materials to be used in the AM machine (powder, wire etc.) need to be on-site, so some transportation costs will still be incurred. The ability for local and on demand production may also help minimise the number of parts held in stock, reducing warehouse space needed. Any of these aspects can lead to a decrease in capital required.

Better design

'Complexity for free' is a phrase used to indicate the fact that more complex

Lower costs	Better design	Customisation	Sustainability	New business models
No tooling or cheaper tooling	Complexity for free	Ergonomics	Less waste	Prototyping & Small Series
Less transportation	Added features (cooling, isolation, structures, conductivity, etc)	Interfaces with other products	Light weight	Shorten lead time or time-to-market
Lower warehousing	Hybrid materials	Body contours (external & internal)	Less fuel consumption	Supply chains (on demand, on location)
Less working capital	Light-weight	Aesthetics	Efficient supply chains	Services
Less waste	Less assembly by integrated design	Use specific variations	Life Cycle Analysis	Co-creation / home creation

Fig. 1 Overview of benefits of Additive Manufacturing (Source Berenschot)

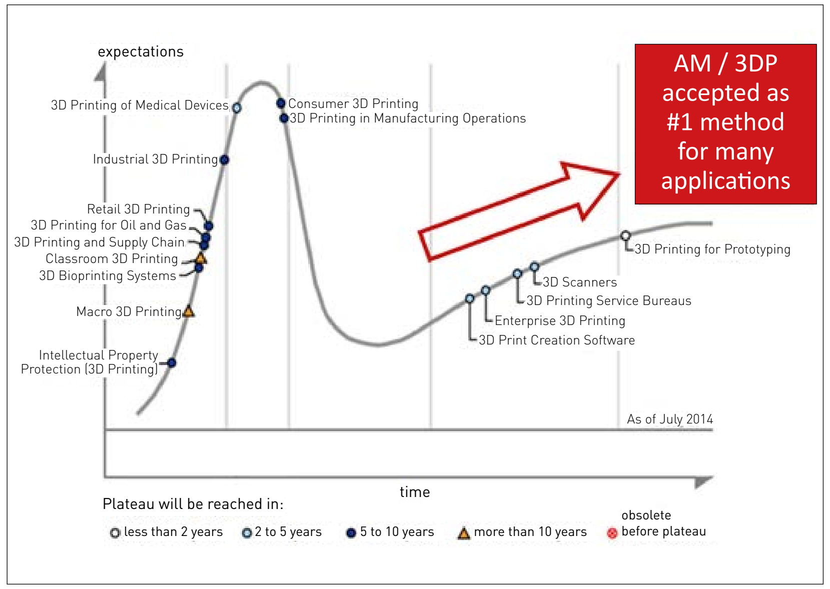


Fig. 2 Gartner Hype cycle with additions by Berenschot (Courtesy Gartner Inc.)

designs can be produced without adding further production costs. An AM machine produces the desired parts layer-by-layer, adding material where needed. This allows for new shapes and forms, for example manifolds with channels situated to optimally cool during production or prostheses with surface structures to stimulate bone grow-in. Topology optimisation allows for an optimal balance between material used and structural requirements to be met.

> *"...significant benefits can be found by producing lightweight components in the aerospace and automotive sectors"*

Customisation

Conventionally, customised or individualised products are either hard to produce or very expensive. Personalised tools or prostheses perfectly matching the individual body contours, for example, are often impossible to manufacture or take many hours of design and handcrafting to produce. Small series of parts or products are often too expensive to produce, as the costs for an expensive mould need to be amortised over a small number of parts, making the final product too expensive to sell.

Additive Manufacturing allows the production of complex, individual parts, making customisation economically viable in a number of applications.

Sustainability

The initial thoughts people have when thinking about AM and sustainability have to do with the additive nature of the production method. Instead of taking away material with methods like milling or cutting, thereby producing waste, AM only uses the material required to produce the part. This is not entirely true, as often support structures are required to print a part, which are removed and discarded during finishing. Often, a like-for-like comparison of the energy used to produce one part via AM versus traditional manufacturing can be unfavourable for AM.

On the other hand, significant benefits can be found by producing lightweight components in the aerospace and automotive sectors, with for example a positive effect on the fuel consumption of an aircraft. Typically a 'life cycle analysis' is required to determine the actual environmental benefit of AM over traditional manufacturing techniques.

New business models

Additive Manufacturing certainly allows for shorter time to market. Design, engineering and prototyping can benefit from greatly reduced time frames. Concurrent engineering offers possibilities to execute different design strategies next to each other, ultimately leading to a more optimal end result. The potential for smaller series, increased customisation and local production already allows for new, distributed manufacturing models to be used and ways in which local SME's are able to compete with global industrials in previously unthought-of ways will be created.

A number of these promises may not be too far-fetched or that far away. The Gartner Hype Cycle (Fig. 2) indicates a number of Additive Manufacturing related technologies and innovations and their readiness for use. Whereas some applications might still take some time or are uncertain to be achieved, such as the wide acceptance of consumer home printing of functional products, a number of innovations are already becoming mainstream. AM for prototyping is today one of the preferred methods used by industry and the number of service bureaus where you can have designs printed and finished is increasing dramatically. 3D scanning and 3D creation software are on the rise offering possibilities to quickly adjust standard designs to individual needs.

Investing in AM: A manufacturer's dilemma

With all these benefits, why is industry not jumping on the AM bandwagon more forcefully? Unfortunately some barriers still exist. On the one hand, technological advances are still required with regards to size and speed. The building envelope of metal parts is still somewhat limited, particularly in relation to metal powder based processes, and build speed is limited. This means that rapid prototyping is possible, building one piece or small series is viable, but the mass production of parts is still some way off.

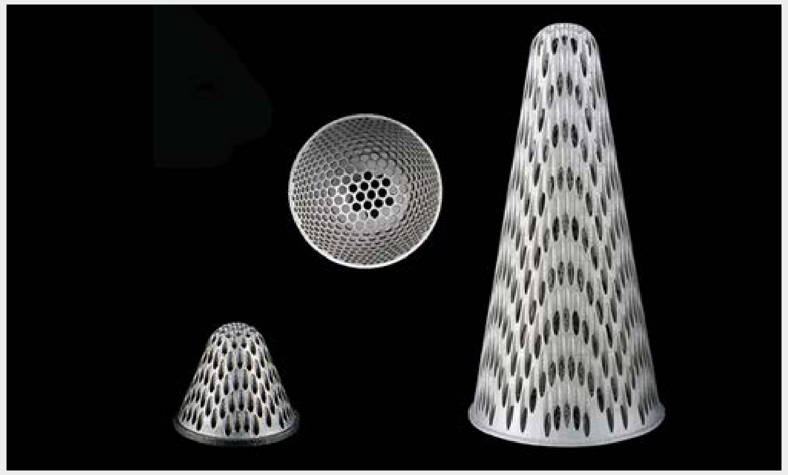
Another aspect to mitigate is the uncertainty of many industrialists with regards to AM. Metal AM machines require a substantial investment and the immediate need for these machines is not felt by all manufacturers. Combined with the tendency of industrial companies to shy away from outsourcing production activities they normally view as their own competence, investments in AM are often postponed. This is, in our opinion, a wrong choice as it means that these companies are starting to fall behind those already pursuing AM. In view of the rise in the number of service providers, we fortunately see this trend reversing.

Another uncertainty is the aspect of meeting quality and safety standards in an environment where industry norms and standards for AM have not been agreed upon by bodies such as ASTM and ISO. Questions such as: How can I reap the benefits of the AM technology and ensure that products meet standards and regulations? How will I secure that parts will be accepted by my customers? Will insurers underwrite my business and evaluate the risk exposure as acceptable? are realistic.

No review of the dilemmas facing the industry would be complete without considering education. AM requires a new way of thinking about design, engineering and doing business, when you want to use the technology to the fullest. Currently no comprehensive and all-encompassing curriculums are available, neither in regular education (schools, universities) nor as a form of continuous education for machine operators or craftsmen.

Even though the dilemmas described are realistic and challenges remain, waiting to enter the fray is, in our view, not an option.

Case study: Croft Filters



Croft Filters, a leading filter manufacturer based in Warrington, UK, produces filtration components for multiple industries using a range of subtractive techniques including CNC punching and machining. The company identified a significant opportunity in using Additive Manufacturing technology to reduce energy usage and produce components that could not be created using any other method.

AM allows the design of filters with aligned and uniform apertures which leads to a decrease in the pumping energy required to perform a specific function. With fewer pressure drops and higher flow rates, Croft's filters are now up to 30% more energy efficient. Additionally, AM requires less labour and supports faster production. Integration of parts and less assembly was required, something not possible with existing technologies.

Product development and design

The most important aspect for product development and design is the form freedom that AM gives when designing a part or product. Better design can lead to performance breakthroughs and product solutions that were simply not possible before. To make the most of these possibilities, new design principles and analysis tools are needed to support rapid prototyping and rapid testing.

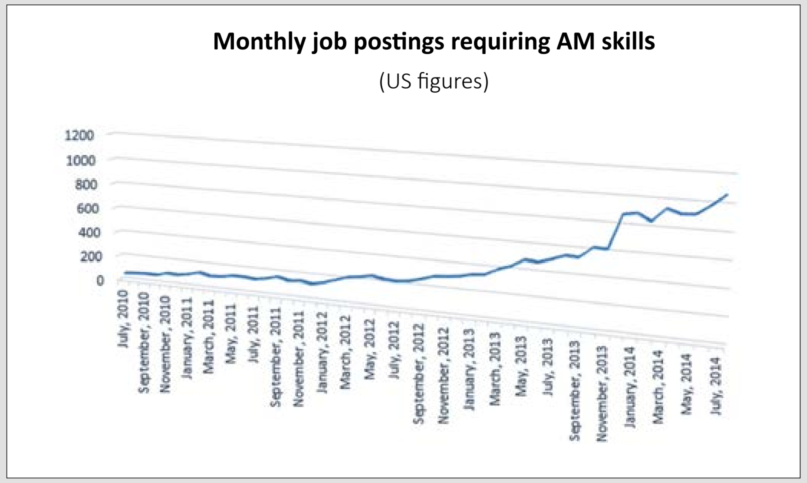
Traditionally designers have been educated to "design for production", making sure that the product designed can indeed be produced and post processed using the manufacturing method selected. This often leads to limitations in the design possibilities. AM allows for "design for function" with fewer manufacturing constraints. Using simulation software, early design verification is also possible.

AM requires less labour and supports faster production. It allows for the integration of parts with fewer assembly steps, something not always possible with existing technologies. AM will therefore lead, and in a growing number of cases already leads to, better solutions and better performance, lower costs, shorter lead time and reduced time to market. To reap these benefits, engineers, designers and their clients

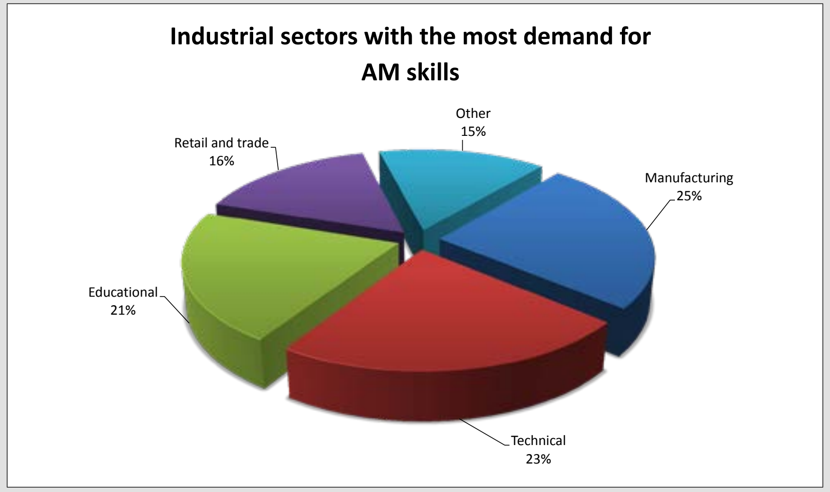
Overcoming the knowledge gap: the need for AM specific education

The numerous examples of the application of AM indicate that change is about to come and this will be the point that the digital manufacturing revolution gets into full swing. An important hurdle to overcome is, however, the availability of skilled employees for a wide variety of positions. Not only is there a shortage of engineers with AM proficiency, but a shortage of professionals with business, legal and organisational backgrounds is observed. If no action is taken the skill gap is expected to widen and could reach two million educated workers in the US in the next decade alone. Many initiatives are now therefore making efforts to train students and professionals alike.

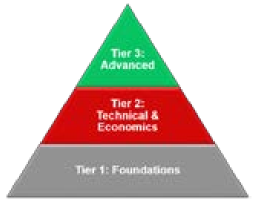
Some initiatives can be found in schools and Universities. These address the education of untrained students. Most workers found in the research and developments centres and factories cannot be reached by these initiatives. To close the gap these professionals need to be trained in the possibilities of what AM has to offer. The training curriculum that UL (Underwriters Laboratories) developed focuses on those professionals, with a three-tiered comprehensive programme.



Job postings requiring AM skills in the US, July 2010 - July 2014. 1370 jobs were posted in February 2015



Demand for AM jobs by sector, February 2015

	**Tier 3**	Builds competency to successfully fabricate metal, polymer composite, and ceramic parts, from AM design setup to part build to post-processing to quality assurance
	Tier 2	Builds technical and economics competency to optimise AM designs, to select the best manufacturing technology, to manage the quality and safety and to manage capital investments
	Tier 1	Delivers essential information to begin working in the AM industry, for example technologies, materials, key issues

Summary of the contents of the AM Training Curriculum of UL (Source UL.com)

Tier 1: Foundation
The foundational program helps participants identify the various AM technologies and their benefits/limitations. Students learn to understand the hardware and software for digital file management, define the basic AM processes and the basic safety and quality considerations.

Understand the factors to determine manufacturability of existing designs for AM and the application of 'Design for Additive Manufacturing' principles form a key element of the Tier 2 technical courses. Also aspects as component design, gaining a working knowledge of the process to select manufacturing technology and material combinations and approaches to assess conformance (quality & safety) of AM are taught.

Tier 2: Economics
This economics based curriculum focuses on understanding, justifying and monitoring investments in AM. Using real life cases, participants gain a working knowledge regarding production efficiency, product development, supply chain management and business modelling for AM.

Tier 3: Advanced operations
Here, advanced training helps students gain proficiency in operating various AM metal, plastics and ceramic machines at a state-of-the-art level. After this, the qualified operators understand the process requirements (from design preparation to quality assurance), regulatory requirements, industry standards.

All modules of the UL training curriculum can be concluded with an exam. Those that passed all exams receive a certificate of proficiency. To date the UL curriculum is the only curriculum supported by America Makes and the Additive Manufacturing User Group (AMUG).

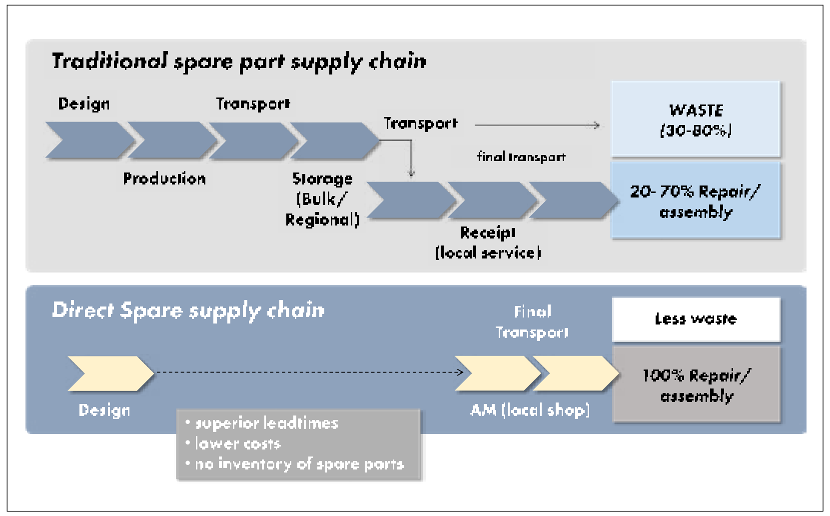


Fig. 3 Schematic overview of Traditional vs Direct AM supply chain (Source Berenschot in Direct Spare project, 2012)

need to have an open mind to product design and discuss the requirements of the product rather than being inflexible about specifications. Often alternate designs, other materials or new production methods can meet demands.

Production efficiency

AM allows for small series production via the direct manufacture of parts. The possibility to integrate a number of parts from an assembly into the design, thus producing products with fewer parts, brings many benefits. There are fewer parts to order, there is less assembly and less risk during build-up, all of which can improve quality. In many cases it can also lead to time savings, energy savings and process improvements. An example of this part integration can be seen in the Havells – LayerWise case study overleaf. These are just some indications of the possibilities to lower costs and realise timing benefits with AM, compared to the existing production setup.

Making optimal use of AM for production efficiency means taking a fresh look at the make or buy decision. Often the AM machine required is not owned by the traditional supplier, or the knowledge about the production process and requirements is not available with your regular supply chain partner.

Supply chain

On demand and on location production are catchphrases often used when discussing the benefits of AM. On a larger geo-political scale, government officials even talk about reshoring manufacturing, with all the macro-economic benefits associated with that. When more mature and further developed, AM could indeed lead to lower stocks, distributed manufacturing and local production of spare parts. Ultimately this would mean faster repair, less scrap, cost savings and environmental benefits.

In reality this might be a bridge too far for now. A project that compared an AM supported supply chain to a traditional supply chain route gave interesting results (Fig. 3). It was hoped that AM would allow the production of parts on demand, when and where required. But the 'dream situation' depicted was unable to achieve this for the particular parts selected. The component could be printed, but the cost of developing a new AM specific design file, the qualification procedure for the alternative material required to print, and administrative aspects of registering a new part prevented AM from being an economically viable solution to print the part.

In other situations, however, those extra costs could be absorbed and lead to a positive business case. For

Case study: The Havells gas burner

Havells Sylvania is a producer of armatures, light bulbs and lighting control. For the production of their halogen light bulbs, Havells combines a glass tube with a filament wire and halogen gas. The quartz glass bulb is closed using a burner that heats it to extreme temperatures of about 2000°C. Havells experienced problems with the quality and durability of this burner unit.

The V-shaped burner has integrated machine milled cooling channels to enable temperature control. The inlet and outlet channel of the cooling circuit are welded to the burner, as is also the gas supply tube. The inset image shows the original burner assembly (top)which consists of over 20 parts. It has a working life of about six months at which time leakage occurs in one of the welded joints. This causes shut downs in production. All of the 64 burners in the production line are exchanged for new ones.

3DS LayerWise and Havells investigated the possible benefits from the design freedom provided by metal AM to improve the burner design and overall production efficiency. One of the big challenges for LayerWise in this project was assuring that all unexposed powder is removed from the burner after production, especially the unexposed powder inside the burner tubes. 3DS LayerWise succeeded in designing a new burner, that is additively manufactured as one piece. The new burners have proven to be as effective as the traditional burner, with the added benefit of having a far longer life time. The 64 burners installed are running for over one year now, preventing downtime and lowing maintenance and repair activities and costs at Havells

Gas burner design (Source 3DS Layerwise)

instance, when a ship with perishable cargo has to wait for a part to be sent from far away and thus cannot sail for three weeks, the economics are completely different. The cost of losing the cargo can, most of the time, easily be offset by spending some thousand euros on the design and Additive Manufacturing of a spare part, even if just a temporary one. These situations ask for an integral view of the business case, instead of a part versus part comparison.

Reaping the benefits

Additive Manufacturing is often regarded as a disruptive technology. We do not support this view, but see AM as an additional tool in the toolbox of industry. In some cases AM will be the preferred way of working, in other cases AM supports the shorter time to market for new products that are designed using AM, but produced using traditional manufacturing methods. In other cases AM offers a temporary solution, to bridge the time between the breakdown of a part and the arrival of the original spare.

In any case the use of AM will grow. In the near future many more materials will be available to print. Both metals and polymers will be offered with characteristics meeting customer demand. Ceramics and bio-materials will also find their way to mainstream AM.

Initially, as in every developing market, actors in the industry perform a wide variety of activities for many customer groups in diverse industries. When the market grows, and the demand becomes more specified, it is impossible to satisfy the need of every customer with a one-size-fits-all solution. Smart companies already active in the AM industry, or newcomers, dare to focus on a specific niche in the market. The success factors you need to meet for a client in the B2C arena requiring an enabling service differ considerably from the success factors of a surgeon asking for a prosthesis.

The AM industry is rapidly maturing. Both equipment and material manufacturers and the companies they serve understand that industry standards need to be met, using safe and secure tools and machines, operated by qualified personnel. By-standers will soon become laggards, as developments move fast. But for those hopping on the AM train soon, there is still plenty of space to help lead the industry to higher grounds.

Authors

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Director Strategy Digital Manufacturing at UL Inc., based in Northbrook IL, USA. He has over 20 years of experience innovating manufacturing technologies and materials, and is the driving force behind the comprehensive AM Training Curriculum UL has developed recently.

Hoeganaes Corporation: A global leader in metal powder production targets Additive Manufacturing

The growth in metal Additive Manufacturing has attracted a wide range of companies to enter the market to supply metal powders, however few have the track record of Hoeganaes Corporation in the production of powders for industrial parts production. In the following article the company reports on the development of gas atomised titanium powders for metal AM, along with the its ambitions to introduce more cost effective water atomised powders that have the potential to help the industry move towards higher volume production.

Hoeganaes Corporation is a recognised global leader in the production of metal powders for the production of structural components, with six metal powder manufacturing facilities in the United States, Europe and Asia. The company recently completed a $5 million investment in its Innovation Center in Cinnaminson, New Jersey, USA, with the primary purpose being the development of a new generation of advanced metal powders for Additive Manufacturing. State-of-the-art equipment, including a new gas atomisation facility, has been installed in the new Innovation Center as the company makes progress towards its goal of the development of long-term, sustainable production of high-quality cost effective powders for metal Additive Manufacturing.

Commenting on the main drivers behind the expansion into powders for metal Additive Manufacturing, Hoeganaes' Global Director of Business Development for Additive Manufacturing, Richard Kallee, told *Metal Additive Manufacturing* magazine, "Hoeganaes Corporation continually benchmarks new technology for the use of metal powders. Following an evaluation of the technical challenges and market expectations, metal powders designed specifically for AM were identified as a growth market. Based on this analysis, we developed a strategy for the supply of powders for Additive Manufacturing."

Fig. 1 Exterior view of the Hoeganaes Innovation Center in Cinnaminson, New Jersey

Fig. 2 Production facility at Hoeganaes' Innovation Center

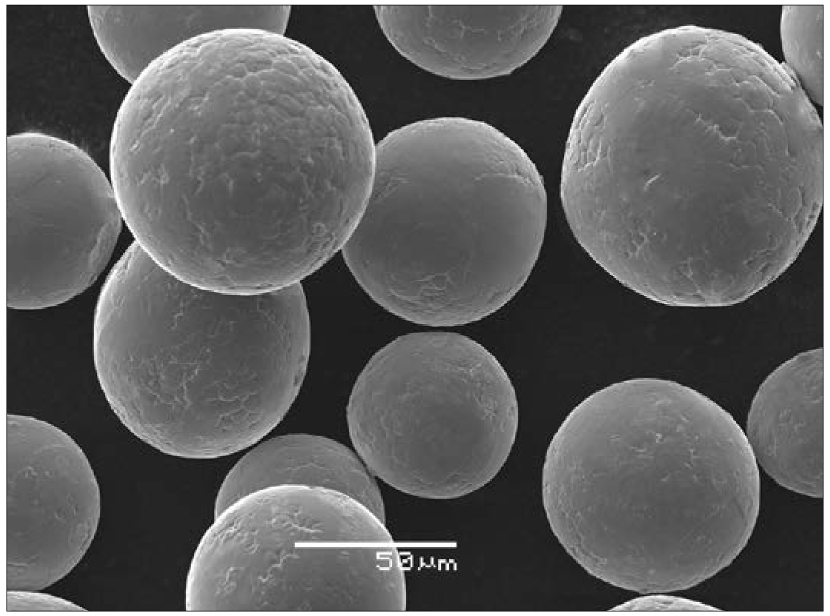

Fig. 3 Micrograph of AncorTi gas atomised titanium powders for Additive Manufacturing

Hoeganaes believes that the combination of its new Innovation Center and long track record in metal powder production puts it in a strong position to serve the growing metal AM industry. Mike Marucci, Vice President for Advanced Engineering, commented, "We believe that the biggest advantage that the Innovation Center provides is the people. Hoeganaes has been a leading powder manufacturer for decades and our Innovation Center has people that have worked in developing powders driving various markets for more than 40 years. Additionally, a new wave of engineers are now in the process of working with various AM platforms to better support our customers. These people and their experience provide a formidable support team for launching products into a new market such as AM."

The new Innovation Center not only includes water and gas atomisers, but also state-of-the-art AM production equipment and a laboratory that includes advanced image analysis systems and scanning electron microscopy as well as mechanical and chemical testing. Marcucci stated, "Hoeganaes is working with several industry leaders on materials development for selective laser melting, electron beam melting, and binder-based AM technologies. However, as AM process development will be primarily part-specific, we believe our customers will work on developing the process to suit their product and Hoeganaes can provide the support to develop the powder properties and ideal alloys required."

Titanium powders for AM

Thanks to high levels of interest from the aerospace and medical sectors, titanium is proving to be one of the leading materials behind the surge in the growth of metal Additive Manufacturing. Additive Manufacturing is recognised as a key technology that can take advantage of titanium's unique properties such as its high strength to weight ratio, excellent corrosion resistance and biocompatibility, whilst bypassing the high cost of machining complex shapes from wrought material. Titanium powder, however, is challenging to produce and metal Additive Manufacturing not only requires powder with extremely high levels of purity, but also powder with specific shape and size specifications to enable the stable and repeatable production of the highest quality parts.

Hoeganaes introduced its AncorTi™ titanium powder earlier this year. AncorTi is a gas atomised spherical Ti6Al4V powder for Additive Manufacturing applications, however it is also suitable for Metal Injection Moulding (MIM) and Hot Isostatic Pressing (HIP) processing. Titanium's high strength to weight ratio, corrosion resistance and biocompatibility makes it a perfect candidate to manufacture parts for aerospace, medical, chemical and marine applications. "Ti6Al4V is the most commonly used titanium alloy and is offered by Hoeganaes in a range of particle sizes and purities including those that meet ASTM specifications. Of course, all our products are subjected to rigorous quality testing," stated Marucci.

Hoeganaes is currently offering AncorTi in Grades 5 and 23, with three particle size distributions engineered for Selective Laser Melting (SLM) and Electron Beam Melting (EBM) AM platforms and customer applications. Commercially Pure (CP) titanium is also available.

"We are currently focused on supplying the aerospace and medical markets with our AncorTi products. We see both of these industries as the main drivers of metal AM manufacturing and we are excited to collaborate with them to develop a new standard for these powders and processes," stated Kallee. "Our experience of meeting the high demands for quality in the automotive industry gives us a decided advantage in supplying mission-critical materials to these markets. To that end, Hoeganaes will be AS9100 certified by the end of 2015."

Quality control in Additive Manufacturing

When it comes to metal Additive Manufacturing processes, Hoeganaes believes that there needs to be a much more holistic approach to understanding and improving process quality. "It is crucial to have a comprehensive understanding of the complete process chain, from powder manufacturing through to AM processing and product performance evaluation," stated Kallee. "Since Hoeganaes has over fifty years of experience in the development of metal powder for part production, our research engineers have the depth of understanding to develop optimal manufacturing methods for AM powders, from melting and atomising through to shape control, screening and classification."

Hoeganaes has identified a number of key quality issues that needed to be addressed by the industry in relation to the metal powders used in AM. The issues include unexpected alloy inclusions, gas inclusions, particle size variations and alloy content deterioration. The company has also cited storage and transportation dependent shelf life variations, as well as humidity and climate variation, as important factors.

These issues, state Hoeganaes, can cause inconsistent spreadability in powder bed AM systems, leading to process instability, inclusions or pores, gas entrapments causing pores directly or indirectly by laser scattering in smoke, and certain element inclusions causing crack initiation sites during fatigue cycling.

Grade	Al	V	C	Fe	N	H	O	Ti
Grade 5	5.50-6.75	3.50-4.50	0.08 Max	0.40 Max	0.05 Max	0.015 Max	0.20 Max	Bal.
Grade 23	5.50-6.75	3.50-4.50	0.08 Max	0.40 Max	0.05 Max	0.015 Max	0.13 Max	Bal.

Table 1 AncorTi Ti6Al4V chemical analysis (weight %)

Laser Particle Size Analysis (micrometers)			
Particle Size	Grade A	Grade B	Grade C
d_{10}	7-17	29-34	48-58
d_{50}	27-37	41-46	68-87
d_{90}	40-50	55-60	97-125

Table 2 Particle Size Distribution of AncorTi Ti6Al4V (particle size measurements were performed using Sympatec Laser Particle Size Determination)

> *"It is crucial to have a comprehensive understanding of the complete process chain, from powder manufacturing through to AM processing and product performance evaluation"*

Hoeganaes indicates that it has already developed standardised tests for issues such as powder internal porosity, powder cleanliness (i.e. non-metallic inclusions), contamination, flowability and shape.

"All of these process developments will help support the advances that are being made in 3D platforms for printing metals. As machine processing times continue to improve and new technologies are introduced for in-process inspection, we believe that it is essential that metal powder producers also maintain rapid product development at the vital powder end of the equation."

Ferrous powder grades: reducing costs with advanced water atomisation technology

Hoeganaes has been involved in the gas atomisation of metal powders since the 1960s, making alloys for applications such as thermal spray, powder coating, brazing and filters.

Since the late 1990s, however, the company has produced finer powders that were conventionally made by gas atomisation through a proprietary high-pressure water atomisation process. As water causes surface oxidation during the atomisation process, which is removed from the powders during a post process, the technology is most suitable for iron-based material in the automotive industry.

Generally, gas atomised powders have been preferred for Additive Manufacturing because of the spherical nature of the particulate.

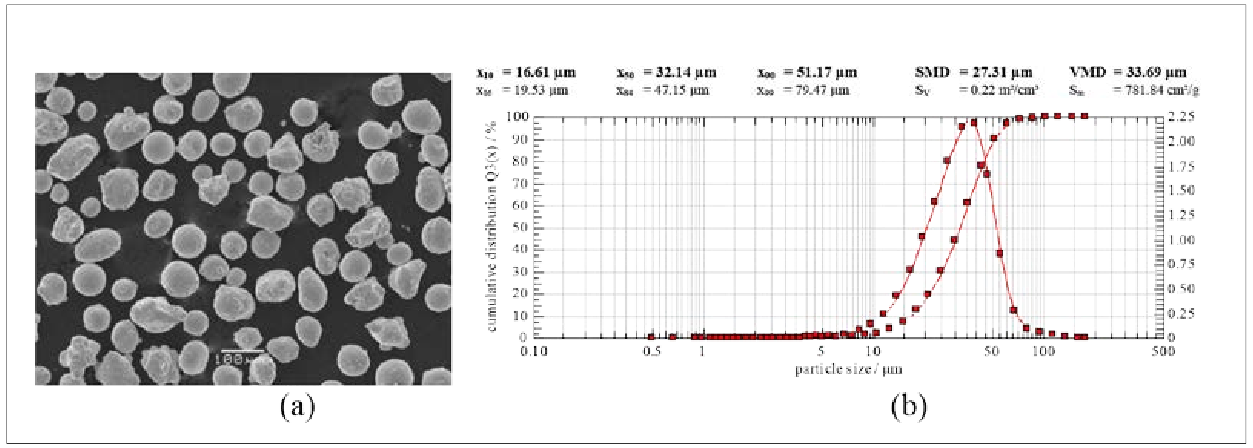

Fig. 4 (a) SEM image of water atomised iron powder and (b) typical particle size distribution of iron powder for Additive Manufacturing [1]

Water atomisation is, however, the most common and economical technique to produce metal powders. Water atomisation, due to the rapid cooling rate, produces powders that are irregular in shape. In addition, the high water pressures impact more energy into the molten metal stream leading to the rough shape of the powder particles. This irregular shape is less desirable for AM because it increases the flow time and possibly reduces the packing density. However, if a low water to metal ratio is used in the water atomisation process, along with a high pressure, a spherical powder with a particle size distribution optimised for Additive Manufacturing can be produced [1].

Hoeganaes works with its customers to determine the correct parameters necessary for a powder to allow it to work for each manufacturing platform. The company has seen powders from 15 micron to 60 micron, both irregular and spherical, all successfully used in AM processes. It believes that the key is to ensure the economics exist from powder production through to part production and the successful introduction of a final product to market. "The key is to work together to determine the characteristics of the powder that work best," stated Kallee.

"Hoeganaes is currently supplying a range of water atomised powders to the AM industry as the various AM processes require powders with different properties, including powders that are nearly as spherical as gas-atomised powders. In general, water atomised powders are lower cost than gas atomised powders, but each application is different and the AM industry is still defining the optimum particle size and properties. Eventually, this will dictate the final value of water atomised powders based on the yield that can be achieved," stated Marucci. "Many powders that had been gas atomised are now made through this process, such as powders for Metal Injection Molding and Metal Matrix Composites, and now some powders for Additive Manufacturing."

Outlook

As a leading supplier to the global automotive industry, Hoeganaes is keen to advance the development of water atomisation technology for AM iron powders and it has launched research programs with key customers. However, Hoeganaes states that the business cases for automotive applications require a step-change improvement in processing to make the commercial benefits of water atomisation substantial enough to drive the market beyond low volume production.

Marucci concluded, "We have the powders, technology, quality systems and people to work on demanding application programs with world class customers, both for gas atomised powders such as titanium and for advanced water atomised powders. We are already established as a market leader in metal powder production, with the knowledge base, global network and commitment to high-quality, sustainable AM powder. We believe that this makes us an ideal solution provider at the forefront of this innovative and rapidly growing AM industry."

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References

[1] Development of Atomized Powders For Additive Manufacturing, Christopher T. Schade and Thomas F. Murphy, Hoeganaes Corporation, Cinnaminson, NJ, USA, Chris Walton, Hoeganaes Specialty Products, Cinnaminson, NJ, USA. As presented at the 2014 MPIF World Congress on Powder Metallurgy and Particulate Materials, Orlando, USA, May 18–22 2014. Available to download from www.gkn.com/hoeganaes

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Size and shape optimisation of metal powders for Additive Manufacturing

The consistency of metal powder particle size, shape and flow is essential for those companies looking to move to serial production of high quality components. The correct characterisation of powders enables the necessary quality control to ensure powder behaviour is predictable and repeatable from batch to batch. Dr Paul Kippax, Product Group Manager, Malvern Instruments, and Dr Robert Deffley, Research & Development Manager, LPW Technology, report on the process undertaken at LPW to ensure its powders meet customer expectations.

As the Additive Manufacturing industry matures and transitions from prototype manufacture to commercial production, attention to the properties of metal powders used in AM is growing. Amongst the most important considerations is the identification of powders that will process efficiently in a given machine. Securing a consistent supply of such material can be a challenge, but is crucial for profitable operation in the long term as organisations adopt AM for serial production, and imperative in sectors such as the biomedical and aerospace industries where the use of certified materials is necessary to meet stringent standards for quality and safety.

LPW Technology is a global leader in the development, optimisation and supply of metal powders for AM, and relies heavily on characterisation technology to meet evolving and increasingly exacting customer requirements. This article looks at how the company uses particle size and shape measurement systems from Malvern Instruments to provide the information needed to support the quality control and assurance of AM powders.

The requirements for Additive Manufacturing

In its early years, AM was known for the manufacture of prototypes, primarily using polymer powders. However, during the last decade,

Fig. 1 The Mastersizer 3000 from Malvern Instruments uses the technique of laser diffraction to measure particle size distributions from 10 nm up to 3.5 mm

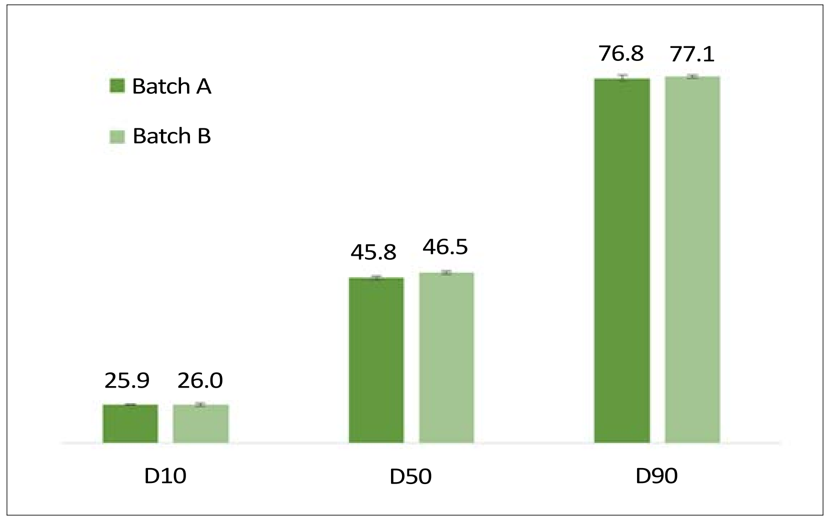

Fig. 2 Particle size data for the two batches of AlSi10Mg show close similarity

AM applications in commercial-scale manufacturing have become increasingly routine. The biomedical, automotive and aerospace sectors have all recognised the advantages of this technology for the production of high value, intricate and/or bespoke components, and have begun to use AM in the full-scale production of high specification metal components.

> *"The quality of AM processes relies heavily on powder properties such as flowability and, to a lesser extent, packing density"*

The quality of AM processes relies heavily on powder properties such as flowability and, to a lesser extent, packing density, since during manufacture, powder must flow freely from a feed hopper, then disperse across the working surface rapidly and evenly in a layer just tens of microns thick. A poorly flowing powder can severely compromise manufacturing efficiency by increasing the frequency of plant shutdowns and/or impacting the quality and integrity of the finished component. An inconsistent powder supply translates directly into variable product quality which is always undesirable, and is, in some instances/sectors, simply unacceptable.

However, achieving acceptable performance can be challenging. Most AM metal powders are necessarily fine (median particle size (Dv 50), in the range of 20 to 60 microns), to deliver regular, smooth layers of the required depth and the necessary detail in the final component. Such fine powders typically exhibit relatively poor flow properties though using particles that are regular and spherical can be a helpful in improving flow behaviour. Reproducible and reliable powder characterisation is critical to the identification of powders which will process successfully within a particular machine, which may have a unique spreader and rake design.

LPW Technology applies various processing steps for both sizing and shaping, to precisely control AM powder production and ensure the consistency of supply, to certified standards where required. A battery of characterisation techniques enables rigorous quality control to the very close tolerances required in serial production to ensure powder performance is repeatable from batch to batch. Particle size, shape and flow measurement are essential elements of the company's analytical strategy.

An analytical strategy for AM powders

Sieve analysis is one of the earliest techniques developed for particle size measurement and remains in use for metal powders; indeed, sieving is also deployed as a processing step so the test is a good representation of the processed powder. LPW Technology applies sieve analysis to coarser metal powders as part of material acceptance testing, but it is a relatively slow and low resolution method that struggles to deliver the reproducibility (especially below 45 microns) associated with newer, highly-automated alternatives. Sieve analysis classifies particles according to the sieve aperture dimension and equivalent sphere diameter, which tends to correspond to the particles' second-largest rather than their primary dimension. This means that shape can have a pronounced effect on size results and create a source of error. Elongated particles, for example, may be classified by sieve analysis as having a finer particle size distribution than that calculated using alternative methods.

Laser diffraction particle size analysis is a fast and fully automated method, with a dynamic range that comfortably covers the sizing requirements for AM metal powders. LPW Technology values laser diffraction for its high throughput, which is particularly valuable in routine QC. The technique reproducibly quantifies the amount of fine material present within powders, an assessment which is challenging for sieve analysis due to the problems associated with fine meshes and the cohesivity of fine powder. Fines can have a pronounced effect on packing behaviour and flow properties, so accurately quantifying their levels is essential. However, as with sieving, laser diffraction results are influenced by particle shape, since the size calculations underpinning the technique are based on the assumption that particles are spherical.

To complement these size analysis methods, automated imaging systems can be used to measure powder size and shape distributions by capturing individual images of particles. Modern systems can capture and process tens of thousands of images within minutes and are therefore able to rapidly produce statistically-relevant size and shape distribution data, which can elucidate differences in powder behaviour. Many metal powders are produced by atomisation processes, in which the thermal conductivity of the molten metal plays an important role in determining the speed of cooling and consequently the shape of the solidified particle. In addition, collisions between molten/semi-molten particles affect their shape with the fusion of particles giving rise to agglomerates and satellites of irregular shape.

The following case study shows how LPW Technology has used laser diffraction and automated analytical imaging techniques to understand the flow property differences between two different metal powders used in AM.

Case study: Exploring the flow properties of AlSiMg powders

Aluminium-Silicon-Magnesium (AlSiMg) alloys are popular in AM due to their ability to produce components with a good strength to weight ratio. A number of different AlSiMg alloys are commercially available, and these vary considerably in their physical characteristics. In this study a comparison of the properties of two batches of commercially available AlSiMg powders was carried out in order to predict their suitability for AM processes.

The two samples tested were taken from two different batches of AlSi10Mg, Batch A and Batch B, which were produced using two different gas atomisation methods. In the first round of testing, a Hall flow meter was used to assess the flow properties of each sample. The Hall flow meter is used to measure the time taken for 50 g of powder to flow through an opening with specific dimensions. The results (Table 1) show that while Batch A flows under standard test conditions, Batch B does not. These data suggest that Batch B does not flow sufficiently well to deliver acceptable performance in the manufacturing environment.

A laser diffraction particle size analyser, the Mastersizer 3000 from Malvern Instruments (Fig. 1), was used to produce particle size data for each sample. The particle size distribution recorded for the two

Fig. 3 Shape data for the two samples were collected using the Morphologi G3 from Malvern Instruments

Laser Power (W)	Batch A: Time (s)	Batch B: Time (s)
Result 1	80.8	WNF
Result 2	79.3	WNF
Result 3	79.9	WNF
Average	80.0	WNF
Equipment: Hall Flow Meter		

Table 1 Hall flow meter results show that one batch of AlSi10Mg, Batch A, flows while the other, Batch B, does not (WNF = will not flow)

	Elongation		HS Circularity		Convexity	
	Batch A	Batch B	Batch A	Batch B	Batch A	Batch B
Min	0	0	0.189	0.162	0.755	0.694
Max	0.5	0.5	1	1	1	1
Mean	0.122	0.154	0.943	0.933	0.996	0.996
D[n, 0.1]	0	0.014	0.84	0.818	0.964	0.973
D[n, 0.5]	0.09	0.113	0.962	0.962	0.992	0.994
D[n, 0.9]	0.288	0.361	0.992	0.992	0.997	0.998

Table 2 Shape metrics for Batch A and Batch B highlight differences between the two AlSi10Mg powders

samples is highly reproducible (Fig. 2) and indicates that both samples are similar in terms of particle size. So, why the difference in flowability?

Shape data for the two samples were then collected using a Morphologi G3 automated image analyser from Malvern Instruments (Fig. 3). Table 2 shows the generated metrics for each sample, including circularity, convexity and elongation.

These three parameters quantify different aspects of the shape of the particles (circularity/ elongation) and the smoothness of the particle perimeter (convexity). The closer the circularity of a particle to 1, the more spherical it is. Elongation is based on the ratio of the longest to shortest dimensions of the particle, with values closer to 1 indicating long, thin, needle-shaped particles. The above results therefore show that the particles in Batch B are less spherical than those in Batch A.

Particles with convexity close to 1 have a smooth outline while those that are more irregular have a value closer to 0. The results therefore also suggest that the Batch A particles are also slightly smoother than the Batch B particles. Images gathered during automated image analysis confirm the results and provide greater insight into the nature of the two powders and the differences between them.

Analytical imaging was therefore able to explain the observed differences in flow behaviour between the two samples of AlSiMg powder. The results show how relatively subtle differences in metal powder properties can result in a 'pass or fail' in suitability for AM applications. The poor flow rate of Batch B makes it ill-suited to routine AM despite its perceived similarity to the Batch A sample.

In conclusion

The flowability of powders used in AM is critical, and is directly impacted by both particle size and shape. Fine particles are particularly significant because of their potential impact on both packing behaviour and flow properties, which directly affect the density and strength of a finished component.

Laser diffraction particle size analysis is a useful technique for the characterisation of AM metal powders, as it gives a rapid, high-throughput particle size and particle size distribution measurement. This technique provides the resolution required to accurately quantify all the size fractions present, right down to the level of fines. However, in the case of some metal powders, it is only when shape data is provided that an understanding of differences in flow behaviour is unlocked. Here, automated imaging acts as a powerful complementary technique, providing the statistically significant shape data needed to secure a consistently high-performing powder.

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www.rapdasa.org

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

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

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

Additive Manufacturing Meetings Torino
November 18-19, Torino, Italy
www.additive-manufacturing-meetings.com

2016

APS Meetings
February 3-4, Lyon, France
www.apsmeetings.com

PM 16 International Conference
February 18-20, Pune, India
www.pmai.in/pm16

Additive Manufacturing Users Group Conference
April 3-7, St. Louis, Missouri, USA
www.additivemanufacturingusersgroup.com

Hannover Messe
April 25-29, Hannover, Germany
www.hannovermesse.de

PM China 2016
April 27-29, Shanghai, China
www.cn-pmexpo.com

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

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

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

Additive Manufacturing and 3D Printing International Conference
July 12–14, Nottingham, UK
www.am-conference.com

AM3D Additive Manufacturing + 3D Printing Conference & Expo
August 21–24, Charlotte, USA
www.asme.org/events/am3d

3D Print
October 4-5, Lyon,France
www.3dprint-exhibition.com

6th International Conference on Additive Manufacturing Technologies AM 2016
October 6–7, Bangalore, India
www.amsi.org.in

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

MS&T 2016 - Additive Manufacturing of Composites and Complex Materials
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