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FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

POWDER INJECTION MOULDING INTERNATIONAL

in this issue

Company visit: Alliance MIM
PIM at World PM2016
Binder Jetting AM for PIM producers

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Publisher & editorial offices
Inovar Communications Ltd
2 The Rural Enterprise Centre
Battlefield Enterprise Park
Shrewsbury SY1 3FE, United Kingdom
Tel: +44 (0)1743 454990 Fax: +44 (0)1743 469909
Email: info@inovar-communications.com
www.pim-international.com

Managing Director and Editor
Nick Williams
Tel: +44 (0)1743 454991
Email: nick@inovar-communications.com

Publishing Director
Paul Whittaker
Tel: +44 (0)1743 454992
Email: paul@inovar-communications.com

Consulting Editors
Professor Randall M German
Associate Dean of Engineering, Professor of Mechanical Engineering, San Diego State University, USA

Dr Yoshiyuki Kato
Kato Professional Engineer Office, Yokohama, Japan

Professor Dr Frank Petzoldt
Deputy Director, Fraunhofer IFAM, Bremen, Germany

Dr David Whittaker
DWA Consulting, Wolverhampton, UK

Bernard Williams
Consultant, Shrewsbury, UK

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

Advertising
Jon Craxford, Advertising Director
Tel: +44 (0) 207 1939 749, Fax: +44 (0) 1743 469909
E-mail: jon@inovar-communications.com

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POWDER INJECTION MOULDING INTERNATIONAL

For the metal, ceramic and carbide injection moulding industries

PIM shines brightly at World PM2016

The PIM industry can look back on the World PM2016 Congress and Exhibition with a mix of positive memories and optimism for continued growth.

Whilst some concern was expressed at PM2016 in relation to future applications for conventional Powder Metallurgy applications in the rapidly evolving automotive sector, the confidence of the PIM industry's technology and materials suppliers was clear to be seen. Impressive exhibition stands and upbeat announcements in relation to new products and applications combined to offer a positive outlook for the coming years.

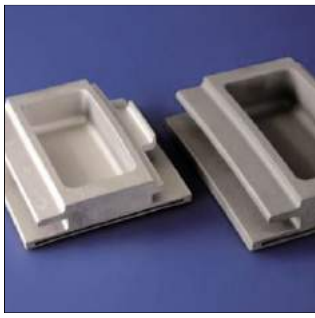
The social highlight for PIM industry leaders was of course the International MIM party, now a firmly established part of the PM World Congress schedule since the inaugural party at PM2012 in Yokohama. This year's event was larger than ever and provided the opportunity for some outstanding networking and relationship building, all in a very relaxed environment.

The next World PM event takes place in Beijing, China, from September 16–20, 2018. Given the dramatic growth of PIM in China over the last ten years, there can be no doubting the huge interest that there will be in our technology at the event. This will also be the first time that a PM World Congress has been held in China and, based on conversations with the organisers in Hamburg, it is clear that this will be one of the most eagerly anticipated PM events of recent years.

Nick Williams
Managing Editor

Cover image
A view of the MIM production hall at Alliance MIM, France

December 2016



In this issue

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Industry News

To submit news for inclusion in *Powder Injection Moulding International* please contact Nick Williams, nick@inovar-communications.com

2C MIM automotive component wins 2016 EPMA award

The European Powder Metallurgy Association (EPMA) organised its 2016 Powder Metallurgy Component Awards to coincide with the World PM2016 Congress & Exhibition, Hamburg, October 9–13, 2016. These awards were open to members of the association who manufacture components made by conventional Powder Metallurgy, Metal Injection Moulding, Hot Isostatic Pressing and Additive Manufacturing. The winners were presented with their awards during the event's opening Plenary Session.

Metal Injection Moulding featured prominently in the overall list of competition entries, however it was a two-material (2C) MIM automotive component that won the award in the MIM category. Developed by Schunk Sintermetalltechnik GmbH, Germany, the 2C-pin is the first serial part worldwide produced by the Metal Injection Moulding of two different materials, in this case 316L stainless steel and the cobalt-base alloy Stellite 12.

By using this cutting edge MIM technology it was stated that a critical customer problem was solved, namely combining wear resistance in a wide range of temperatures with weldability in one complex part. The challenge and innovation was to modify two different alloys to get close to the same sintering behaviour. Cracks are therefore avoided and a continuous gradient in chemical composition can be achieved between the two components instead of an abrupt joining zone. The judges stated that Schunk has opened a new area for MIM applications with this technology, with the promise of significant growth potential. The part has densities that range from >7.6 to >8.2 g/cm^3. Tensile strength was reported as ranging from >500 to >1000 N/mm^2, Yield Strength ranges from >200 to >900 N/mm^2, Product Hardness ranges from 120-180 HV to 440-540 HV and Elongation was stated as ranging from >50 to >2.

www.schunk-sintermetals.com

A two-material (2C) MIM automotive component manufactured by Schunk Sintermetalltechnik GmbH, Germany

World PM2016: Metal Injection Moulded smartphone housings produced in exhibition hall

At the World PM2016 Congress and Exhibition, Hamburg, Germany, leading injection moulding machine manufacturer Arburg GmbH & Co KG demonstrated the cost-efficient production of smartphone housings using Metal Injection Moulding. The technology is increasingly being used in the smartphone sector as a production-efficient and cost-effective alternative to conventional machining processes. A hydraulic Allrounder 470 S (Fig. 1) was used to produce the green compacts for smartphone back covers (Fig. 2) in a cycle time of around one minute. "The booming international smartphone market offers huge potential for Powder Injection Moulding," stated Arburg's PIM expert Hartmut Walcher. "We're receiving more and more enquiries from this segment at international trade fairs. As a result, we've now established a joint venture with BASF for an innovative PIM application that was seen for the first time at the World PM2016 fair. This enables significant cost savings in comparison with conventional machining processes."

This innovative application for Metal Injection Moulding was implemented jointly with BASF, whose latest Catamold feedstock system was used for production. In addition to the back housing, the changeable hot-runner mould, featuring liquid temperature control, is also designed to produce a closed or four-part frame for smartphone housings. In order to minimise part distortion at a wall thickness of around 1 mm, the mould temperature is dynamically controlled to ensure a constant green density throughout the entire part.

Dynamic mould temperature control is required because of the significantly higher thermal conductivity of the MIM feedstock compared to thermoplastics. A linear MULTILIFT SELECT robotic system removed the moulded green compacts and set them down on a slide rail.

www.arburg.com | www.basf.com

Fig. 1 Production of the smartphone frames underway in the World PM2016 exhibition hall

Fig. 2 MIM is increasingly being used in the smartphone sector as a production-efficient and cost-effective alternative to conventional machining processes (Photo: Arburg)

Registration opens for the MIM2017 Metal Injection Moulding conference

Registration has now opened for the MIM2017 International Conference on Injection Molding of Metals, Ceramics and Carbides. The event, which takes place from February 27th to March 1st 2017 at the Hilton Orlando Lake Buena Vista, Florida, is the only international conference dedicated to Powder Injection Moulding. The conference, in combination with a tabletop exhibition, will, once again highlight the latest advances in the PIM industry.

Dan Messina, Technical Services Manager at the Metal Powder Industries Federation (MPIF), stated, "The MIM2017 conference is ideal for industry professionals looking to broaden their knowledge of PIM technology and this year there is a focus on enhancing attendee understanding of how PIM can work alongside metal Additive Manufacturing. If you're a product designer, engineer, consumer, manufacturer, researcher, educator or student, then we hope to see you there."

In addition to the conference, Prof Randall M. German, FAPMI, San Diego State University, will present a tutorial on Powder Injection Moulding on Monday, February 27. This will provide a basis for determining options, uses, properties, applications and opportunities for cost-effective PIM manufacturing.

MIM2017 is sponsored by the Metal Injection Molding Association (MIMA), a trade association within Metal Powder Industries Federation. MIMA's objectives include improving and promoting the products of the Metal Injection Molding industry as well as promoting the investigation, research and interchange of ideas among its members.

www.mim2017.org

Plans underway for Ceramitec 2018

The leading international trade fair for the ceramics industry, Ceramitec, will take place from April 10-13, 2018, in parallel with Analytica, an international event for laboratory technology, analysis and the biotechnology sector. The events will take place at the Messe München exhibition centre, Munich, Germany.

With this new set-up, state the organisers, visitors to Analytica will now also be able to go along and talk to the exhibitors at Ceramitec, all in one visit. In turn that enables exhibitors at Ceramitec to reach new target groups of visitors and expand their business networks.

Around 600 exhibitors from all over the world making use of Ceramitec as a showcase for presenting their latest machinery, equipment, systems and processes, including technical ceramics, CIM and PM.

www.ceramitec.de


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Catamold®evo: BASF launches its next generation feedstock system at World PM2016

Germany's BASF SE, the market leader in feedstock for Metal Injection Moulding, announced its next-generation MIM feedstock system at the World PM2016 Congress and Exhibition, Hamburg, Germany. The system, called Catamold® evo, improves on the flowability of the feedstock, thereby allowing for more complex and challenging shapes to be moulded. The new evo line represents an evolution of the company's well-known Catamold feedstock system. The formulation retains its compatibility with existing Catamold based debinding and sintering equipment and signals BASF's commitment to its widely-used POM-based catalytic process.

Dr Sven Fleischmann, Global Product Manager Catamold, told *PIM International*, "The new Catamold evo series is the next generation of Catamold feedstocks and is based on an improved formulation. This allows our customers in various industries improved production efficiency in extended application fields." Fig. 1 shows the melt flow index of Catamold evo versus the standard Catamold material.

The first Catamold evo materials are being launched in Q4 2016 and are reported to include Catamold evo 17-4PH, Catamold evo 316L and Catamold evo 304 stainless steels. Low alloy steels are scheduled for launch in 2017. BASF stated that target applications for the new feedstock system in the 3C sector include connectors for consumer electronics, smartphone frames and bodies and SIM card trays. In the automotive industry target applications were identified as rocker arms, levers and gear shift fingers.

BASF, headquartered in Ludwigshafen, Germany, is the world's largest chemical company with 2015 revenues in excess of €70 billion. The company's Catamold feedstock system transformed the fortunes of the MIM industry when it was launched nearly thirty years ago. In 2012 the company announced plans for a dedicated MIM feedstock production facility at its Kuanyin site in Taiwan and today this plant has a production capacity in excess of 5,000 tons per year.

www.catamold.de

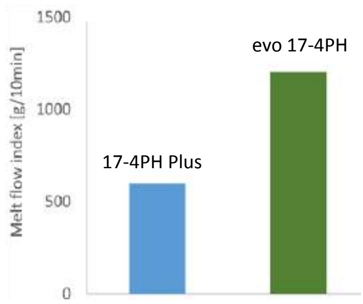

Fig. 1 BASF's new Catamold evo feedstock offers improved flowability over the original system

Epson Atmix launches high sintered density 316L stainless steel powders for MIM

Epson Atmix Corp., Hachinoke-shi, Aomori-ken, Japan, is a leading producer of ultra-fine (-20 µm to sub-micron particle size) metal powders using its high pressure water atomisation technology. The company introduced a new 316L stainless steel grade power at the World PM2016 Congress and Exhibition in Hamburg, October 9-13, which the company states achieves near full density (99.5% or higher) in sintered Metal Injection Moulded components.

The company believes that the newly developed powder achieves density levels which would be impossible using conventional MIM technology and allows the production of mirror surface finish on MIM parts after polishing such as the watch case shown in Fig. 1.

The company also introduced a 316L stainless steel granulated powder in Hamburg which allows the conventional powder die compaction and sintering of ultrafine powders to very high densities and with excellent mechanical properties and dimensional tolerances. A double gear made from the new granulated 316L powder having diameters of 8 mm and 31 mm respectively is shown in Fig. 2.

Epson Atmix is currently also constructing a new factory for superfine alloy powders, excluding amorphous alloy powders, which are used in the production of high-performance precision Metal Injection Moulded components for numerous sectors including automotive, 3C, wearable products and medical devices.

www.atmix.co.jp

Fig. 1 High-quality mirrored surface on a MIM 316L casing using Epson Atmix's new ultrafine powder grade

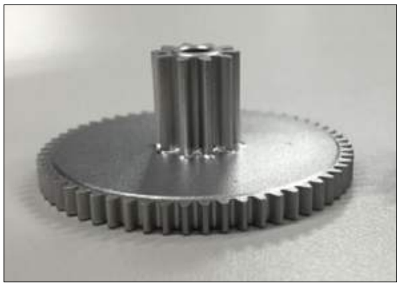

Fig. 2 Double gear made from granulated ultrafine powders developed by Epson Atmix Corp.

Rado unveils new PIM Ceramica designed by Konstantin Grcic

Luxury watchmaker Rado, based in Lengnau, Switzerland, and part of the Swatch Group, celebrated another milestone during this year's edition of Vienna Design Week held in early October 2016, with the launch of the new Rado Ceramica designed by internationally renowned industrial designer Konstantin Grcic. Grcic's new design gives the watch a contemporary look while retaining the geometric shape for which the original Ceramica, first introduced in 1990, was known.

Like the original upon which it is based, the new Rado Ceramica is a high-tech ceramic watch manufactured by Ceramic Injection Moulding using ultra-fine zirconium-oxide powder mixed with colouring pigments and binder to create a granulated feedstock. This feedstock is then injection moulded at high pressure prior to debinding, sintering and a lengthy finished process in order to achieve the desired surface finish. Rado was a pioneer in the use of CIM for watch applications.

The linear bracelet silhouette of the original has evolved into a more classic watch shape, with the gently curved edges of the monobloc case being a design cue. Advances in technology, together with Grcic's vision, stated Rado, have given rise to this combination of form and material which can be found in the eleven models that make up the new Ceramica collection.

Selected models of the new Ceramica, previously best known for their high gloss iteration, now come in a matt finish. "In my opinion, the matt finish brings out the form of the watch much stronger," stated Grcic.

www.rado.com

Rado's new Ceramica watch designed by internationally renowned industrial designer Konstantin Grcic

PIM tungsten Langmuir probes tested in nuclear fusion project

The EUROfusion project is a Europe-wide consortium established in 2014 to find the most efficient way of realising fusion electricity by 2050. One of the research projects currently underway is 'Tungsten (W) Environment in Steady State Tokamak' (or WEST) which is intended to become one of EUROfusion's test benches for tungsten components under conditions to be found in the International Thermonuclear Experimental Reactor (ITER). One application envisaged for tungsten is for small Langmuir probes, which are required to deliver precise data such as temperature, density and electric potential from a harsh fusion environment.

The diagnostic Langmuir probes need to survive high power and steady state particle bombardment inside tokamaks without being a risk for machine operation in the event of damage. Not only will the diagnostics provide essential data, the use of tungsten Langmuir probes bolted onto an actively cooled divertor target is considered to be a technical solution suitable for the ITER divertor probe system. As a result, the feedback from the tungsten probes in WEST research is expected to provide input into the ITER design decision.

A recent report published in *Fusion in Europe* (No. 2, 2016) states that WEST researchers were at first struggling to find a technical solution to design the Langmuir tungsten probes, which are about the size of a paper clip. However, collaboration between two European research centres at the Institute of Applied Materials, Karlsruhe Institute of Technology's (KIT), Germany, and the Department de Recherches sur la Fusion at CEA in Cadarache, France, resulted in Powder Injection Moulding (PIM) being used at KIT to produce 70 Langmuir tungsten probes for the tokamak WEST project.

Steffen Antusch, from the Institute of Applied Materials at KIT, stated in the report that the PIM Langmuir probes, which are 25 mm long, 17 mm tall and only 2 mm deep (Fig. 2) had to be produced to strict tolerances in order to comply with the diagnostic requirements of the probes. Producing the small PIM diagnostic probes proved difficult but not impossible thanks to KIT's long standing experience in tungsten PIM. The effort was supported by two industrial partners, Rodinger Kunstoff-Technik GmbH, Germany, which produced the tools for the Powder Injection Moulding of the green moulded parts and Plansee SE, Austria, which specialises in processing refractory metals and high performance materials, finalised the components for WEST.

www.euro-fusion.org

Fig. 1 The ITER site under construction in October 2016 (Photo ITER Organisation/EJF Riche)

Fig. 2 PIM tungsten Langmuir probes have to deliver precise data from a harsh environment

PM2016: Successful International MIM Party welcomes nearly 200 guests

The latest International MIM Party took place in Hamburg, Germany, on October 12th, 2016. The event was held in parallel with the World PM2016 Congress and nearly 200 participants from 21 countries attended. Following the land-based barbecue at the International MIM Party at World PM2014 in Orlando, the 2016 party returned to the marine-based theme of the inaugural MIM Party in Yokohama in 2012.

The venue this year was Rickmer Rickmers, a three masted barque sailing ship that is now permanently moored as a museum ship near Hamburg's Cap San Diego. The ship, which dates back to 1896, was first used on the Hong Kong route carrying rice and bamboo before being used on South American routes. This international heritage served as a fitting venue for such an event, which attracted both part producers and suppliers from around the world.

Prof Dr Ing Frank Petzoldt, Deputy Director of Fraunhofer IFAM and Chairman of the German-language MIM Expertenkreis (MIM Expert Group) told *PIM International*, "Networking has become such a vital activity in modern business life. What we wanted to achieve with this party was to create a memorable networking opportunity especially for all the international MIM people who were attending the World PM2016, where they could meet in a relaxed and hospitable atmosphere to talk to their friends, business partners and customers, enjoy good food and have an evening of fun."

"We tried to invite everybody involved in MIM who was planning to attend the congress and also as many of their customers as were willing to travel to Hamburg. These special evenings just for the MIM community have become an important networking occasion for members of the different international MIM associations and we hope that they will become a permanent addition to future PM world congresses."

The party was jointly hosted by the MIM Expertenkreis and the EPMA with the support of: Arburg GmbH & Co KG, BASF SE, Carpenter Powder Products GmbH, Cremer Thermoprozessanlagen GmbH, Elnik Systems LLC, SIGMA Engineering GmbH and LÖMI GmbH. Thanks also go to Dagmar Fischer for organising such an enjoyable event.

www.mim-experten.de

www.epma.com








Photos: Anja Burmeister-Timpe

EPMA celebrates a successful World PM2016 Congress & Exhibition

The German city of Hamburg played host to the World PM2016 Congress & Exhibition event, 9-13 October 2016. The 'World Series' event, organised and sponsored by the European Powder Metallurgy Association (EPMA), made for a truly international experience with participants attending from over sixty countries, including the Far East, Africa and the Americas.

The appeal of the World PM2016 event meant that it attracted over 400 oral and poster presentations and the EPMA reported a strong attendance in excess of 1900 participants. The event also included a sell-out exhibition with over 200 booths covering companies from all parts of the PM supply chain.

Dr Lionel Aboussouan, EPMA Executive Director, stated, "Hamburg will be well remembered within Powder Metallurgy circles for a positive and successful World PM event. We would like to thank all the EPMA supporters who, over the last five years, have helped to create a first-rate World PM event in Europe. We would also like to thank our sponsors BASF, Höganäs AB, Linde AG, Makin Metal Powders UK, Rio Tinto QMP, SACMI Imola SC and Taylor & Francis Group; our Keynote speakers Oliver Schauerte, VW and Roland Käppner, ThyssenKrupp; the Technical Programme Committee and Michael Krehl, this year's Congress Chairman."

Former EPMA President Dr Cèsar Molins was recognised with the association's 2016 Distinguished Service Award during the PM2016 Opening Ceremony. Molins is Director General at AMES SA, a leading international Powder Metallurg component producer with seven plants in four countries.

www.epma.com

EPMA Executive Director Lionel Aboussouan welcomes delegates (Photo Andrew McLeish)

Volkswagen's Dr Oliver Schauerte speaking in the opening plenary session (Photo Andrew McLeish)

Plansee offers range of new high temperature hot zones

Plansee has announced it is offering a range of new hot zone systems suited for high temperatures over 1,000°C. Three newly developed equipment packages are said to cover the differing requirements of plant operators. In addition, an online configurator now gives potential buyers immediate access to prices, energy consumption values and equipment features.

In a furnace, the hot zone is crucial for the temperature distribution, the cleanliness of operations and the energy consumption of high-temperature processes. Plansee states that it does not support the one-size-fits-all approach and has therefore developed its Basic, Premium and Enerzone hot zone packages that are specifically designed to meet differing customer requirements.

"Our engineers have listened very carefully to the customers – leading furnace manufacturers as well as end users – and have taken into account all of their requirements in the new hot zones. Every nozzle, shield and shielding layer has already proved its value in practice," stated Dr Bernd Kleinpass, who is responsible for the Thermal Processes Market Unit at Plansee.

Plansee's hot zone packages that are specifically designed to meet differing customer requirements

In the Basic hot zone package the main materials are pure molybdenum and steel. This package is designed for moderate application conditions and frequency of use. The Premium hot zone includes various design features and a number of material alloys that permit a particularly long service life and dimensional stability. Even after a very large number of cycles and at very high temperatures, it is reported that there is no deformation or cracking evident.

Plansee recommends its Enerzone package to customers who place the most exacting demands on their furnaces. This system is said to excel through its long-term durability and offers unrivalled energy-efficiency thanks to many additional layers of shielding and its lightweight construction. "The same applies to hot zones as it does to cars: The right equipment depends on the way you want to use it. 'Basic' is the hot zone for the daily drive to work and 'Enerzone' is the sports car for the highest performance," added Kleinpass.

Plansee hot zones are available for new systems or as replacement units. A state-of-the-art simulation procedure also makes it possible to test how the hot zones will function during live operation before they are used in production. Plansee stated that this service is of vital importance to customers whose processes push their hot zones to the very limits.

www.plansee.com/hotzones

Submitting news..

To submit news to *PIM International* please contact Nick Williams:
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SZS to expand MIM production with new continuous furnaces in 2017

Shin Zu Shing Co. Ltd. (SZS) is a leading manufacturer of precision springs, stamped parts and hinge assemblies made by technologies that include Metal Injection Moulding, stamping and machining. The company, which is headquartered in New Taipei City, Taiwan, is planning to expand its MIM production capacity by over 30% by adding two new continuous debinding/sintering furnaces. These are expected to come into operation in the second half of 2017, stated a report in *Digitimes* (November 22, 2016). The report adds that SZS already has 33 batch furnaces for MIM and that the company estimates that the new continuous furnaces will each add the capacity of six to seven batch Metal Injection Moulding furnaces.

Shin Zu Shing Co., Ltd. manufactures and sells MIM hinge assemblies for use in notebook and tablet PCs, LCD monitors, as well as MIM components for communication, computer and consumer products. The company states that motivation to expand MIM production capacity was through leading OEMs increasingly adopting MIM hinges for notebook computers as well as the use of MIM parts in other 2-in-1 notebooks, wearable and handheld devices.

www.szs.com.tw

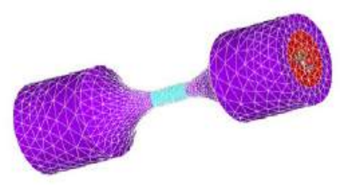
Stage 3 of ultrasonic fatigue testing of hardmetals in the gigacycle regime project to be launched

The EPMA has announced it will launch a further club project on 'Ultrasonic fatigue testing of hardmetals in the gigacycle regime (UFTH): Stage 3', in partnership with TU Vienna, Austria, and CEIT San Sebastian, Spain.

The UFTH Stage 3 will first complete the UFTH 2a project, where a testing rig and procedure for ultrasonic fatigue testing by three-point bending was developed and built, by testing an additional set of samples. It will also evaluate a new testing strategy based on brazed hardmetal-steel testing specimens.

Participation in the project is open to all organisations. A full description and registration to the UFTH Stage 3 project is available from the EPMA website.

www.epma.com



FE simulation of the hardmetal-steel resonance test specimen

New 17-4PH stainless steel multi-tool made using Metal Injection Moulding

Christian Reed, an inventor, engineer and US Army veteran, came up with the idea for a compact, finger-driven multi-tool whilst on deployment in Afghanistan. Working together with MIT Engineering and more than fifty revisions of the multi-tool later, Outsourcing Technologies LLC based in Boston, Massachusetts, USA, is now producing a unique and robust stainless steel GRIPsher multi-tool which can be used for a wide variety of applications. These include bottle opener, wire cutter, hex wrench, knife, flat head and Phillips screw-driver. Glow-in-the-dark jaws at the base create the Hexgrip System which allows an easy and fully adjustable way to secure hex screw bits in one cutout and hex bolts and nuts in the other cutout, which is at a 20 degree angle for easy use.

The GRIPsher multi-tool

The initial 316L stainless steel multi-tool designs were produced from machine cut samples and additively manufactured metal parts were used for prototype testing of the tool's functionality. Later, 17-4 PH stainless steel was tested with greatly improved results. For mass production of the multi-tool's individual components, CNC machining was first tried. However, machining was ruled out due to fixturing complexity and the amount of small end mills that would be needed to mill each part. The designers began to explore Metal Injection Moulding and soon realised it would be a great fit for this product. The unspecified MIM manufacturer that produces the components now uses three moulding tools; one family mould for the left and right arm, one family mould for the knife and file tools and a plastic injection mould for the green jaws at the bottom.

www.outstech.com

Wittmann Battenfeld plans for sustained growth

Wittmann Battenfeld, a supplier of injection moulding machines, robotics and auxiliary equipment head-quartered in Kottingbrunn, Austria, experienced double-digit growth of 19.5% in sales in 2015 but expects a more sustainable growth of around 9% in 2016.

President and CEO Georg Tinschert, speaking at his company's press conference at K 2016 in Düsseldorf, stated that in order to meet growing demand the company will undertake ambitious expansion projects including adding 1300 m^2 to its production area giving it the capacity to produce around 4,800 robotic systems per year. The company had already expanded its material handling facilities with the completion of a new building in October 2016. Further expansion of production space with an additional 2600 m^2 is scheduled to be completed by Autumn 2017.

The company introduced a number of new developments at K 2016 including its fast-cycling all electric EcoPower Xpress 400 injection moulding system, with first deliveries planned for Q3 2017. The all electric machine uses highly dynamic drive axes for injection as well as closing and opening allowing for fast movements and ultimate control accuracy. Also featured were the next generation Unilog BB controllers that combine powerful software and the 'Condition Monitoring System' (CMS) which applies sensing technology to predictive diagnostics with the goal of optimising moulding machine availability and efficiency.

www.wittmann-group.com ■

India's PM17 set for New Delhi

The Powder Metallurgy Association of India's (PMAI) PM17 International Conference on Powder Metallurgy and Particulate Materials & Exhibition is scheduled to take place from February 20-22, 2017, in New Delhi. The event will once again bring together an all topic technical programme and an international trade exhibition.

Delegate registrations for the event can now be submitted online at the PM17 conference website. The organisers also state that a limited number of pre-fabricated (2 m x 3m) stands are available to PM parts manufacturers and suppliers of materials, services and equipment to the PM industry. The venue for the event is the 5-star Pride Plaza Hotel.

www.pmai.in/pm17 ■

USD Powder receives Fachmetall Powder Metallurgy Qualification Award

Fachmetall GmbH, a Powder Metallurgy and wrought materials metallurgical laboratory based in Radevormwald, Germany, has presented its 2016 PM Qualification Award to USD Powder GmbH, Meinerzhagen, Germany, a supplier of unique gas-water combined atomised metal powders.

USD Powder GmbH is a supplier of special alloy powders under the brand name iPowder® for applications in Metal Injection Moulding and metal Additive Manufacturing. The prize was awarded to USD Powder for the successful alloy development of MIM steel powders for rolling contact fatigue and cold working applications.

USD Formteiltechnik GmbH, the parent company of USD Powder GmbH, is a supplier of structural steel components made by various manufacturing techniques including PM and MIM. Thorsten Klein, Managing Director of USD Powder GmbH, received the award on behalf of the company from Fachmetall's Managing Director Holger Davin.

With its annual presentations of the international PM Qualification Award, Fachmetall GmbH aims to draw attention to companies with outstanding Powder Metallurgy and Quality Management activities.

www.fachmetall.de

www.usdpowder.com

Euro PM2017 Congress & Exhibition heads to Milan

The European Powder Metallurgy Association (EPMA) has announced that its Euro PM2017 International Conference and Exhibition will be held in Milan, Italy, October 1–4 2017 at the MiCo–Milano Congressi. The event will cover all aspects of Powder Metallurgy.

"In addition to the main technical programme, there will also be a number of special interest seminars covering all the main strands of the Powder Metallurgy industry, EPMA working group meetings and workshops on key topics of relevance to the industry," stated Lionel Aboussouan, EPMA Executive Director.

The Euro PM2017 exhibition will take place in parallel to the technical sessions and will provide a showcase for the global Powder Metallurgy industry. Euro PM2017 will also include a number of social events.

Those wishing to present either an oral or poster paper at Euro PM2017 should submit abstracts before January 18, 2017.

www.europm2017.com

Milan is the location for the EPMA's Euro PM2017 International Conference and Exhibition (Photo EPMA / © Beatrice Preve)

Multi-frequency vibrating sieves for screening ultrafine powders

Fine, spherical metal powders having narrow particle size distributions are often essential in Powder Injection Moulding in order to achieve higher packing density, which in turn lowers binder content in the moulding feedstock. Additionally, finer powders in the as-moulded parts enhance sintering. To obtain particle size distributions in the range from 30 µm to 60 µm powder producers have used ultrasonic sieving techniques and/or air classification, but, for ultrafine metal powders down to 6 µm and below, which are often required for PIM, existing sieving techniques have not been found cost effective.

The Virto Group/Cuccolini of Reggio Emilia, Italy, is a long established manufacturer of screening and particle separation equipment for all forms of particulates used in a variety of industries ranging from food, pharmaceuticals, metal powders, heavy aggregates and mining. Virto displayed one of its ScreenX Multi-Frequency Vibration (MFV) sieving machines at World PM2016 in Hamburg, which the company stated is able to significantly increase sieving capacity and particle size separation efficiency even for problematic particulates down to 6 µm.

Asad Bilal, Business Development Manager at Virto/Cuccolini told *PIM International* that the ScreenX MFV equipment has had particular success with fine particle separation of metal powders both at high and lower volumes to a size of less than 10 µm with an efficiency of 99%. He stated that the ScreenX MFV sieving machine achieves far greater capacities for fine and difficult materials due to its patented multi-frequency vibration technology that accelerates the mesh by up to 500 G. This is said to be a 10,000% increase in mesh acceleration compared to standard sieving methods. Bilal said that the 500 G acceleration increases both the amplitude and frequency of the vibration and so doing overcomes mesh blinding, pegging and agglomeration by harnessing the power of resonance to achieve efficient and high capacity wet or dry screening of ultrafine powders.

Fig.1 Multi-frequency vibration sieving machine built by Virto-Cuccolini

Material	Mesh (micron)	Capacity (kg/hr)
Aluminium	6	42
Iron	20	67
Tungsten	25	355
Gold	7	20
Titanium	15	70
Stainless steel	22	106
Copper	40	49

The sieving capacity of a 650 mm diameter Screen X MFV machine

The ScreenX MFV sieving equipment, an example of which is shown in Fig. 1, is offered in rectangular or circular configuration with the circular version available from 650 mm diameter to 1200 mm diameter. Table 1 shows the sieving capacity of a 650 mm diameter machine for different fine and ultrafine metal powders. The company also produces single frequency vibrating sieving machines for all standard separation of powders down to 50 µm particle size.

www.virtogroup.com

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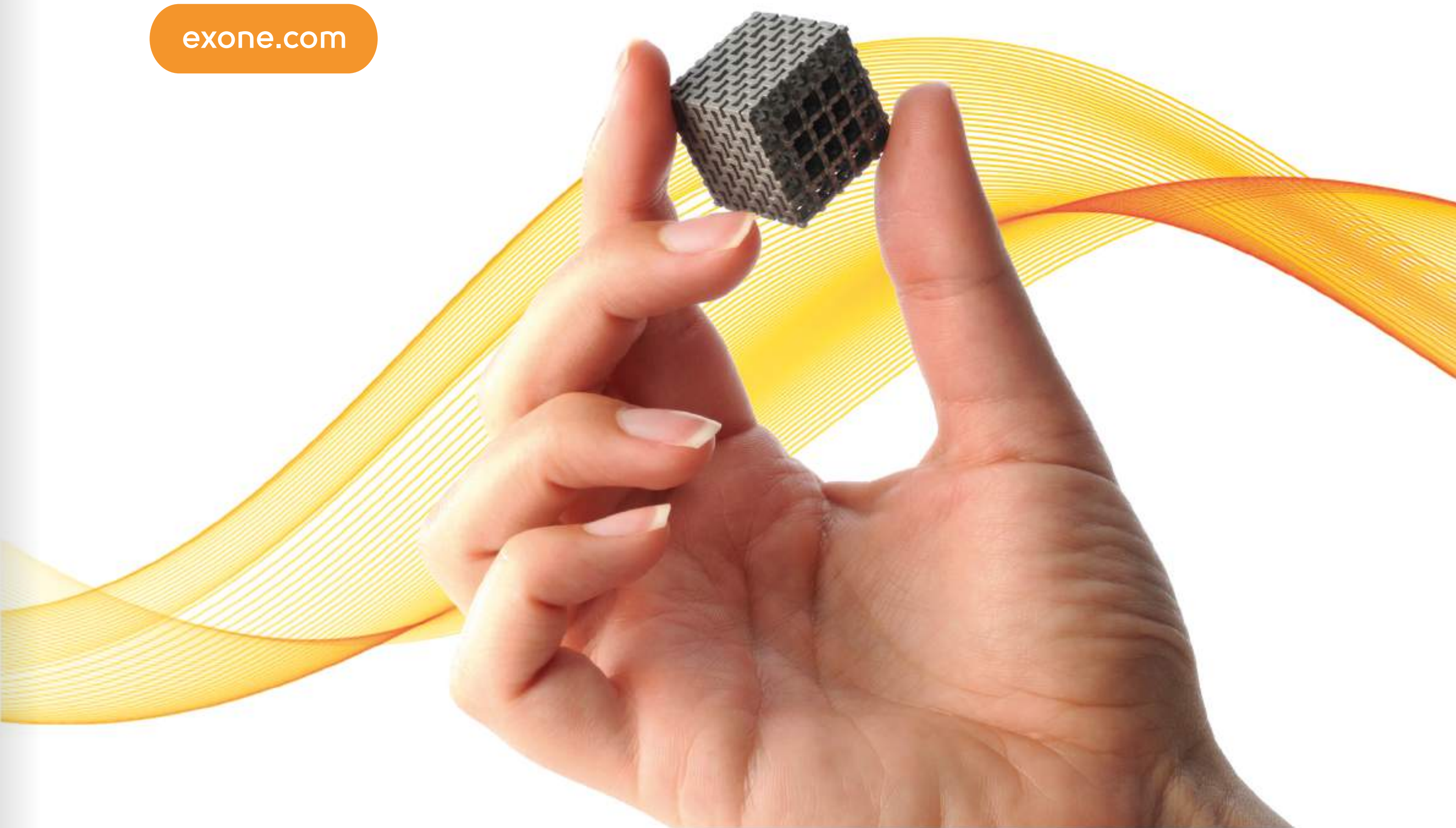

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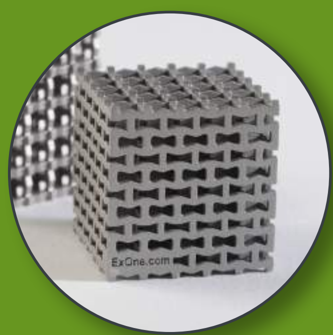

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Xjet announces ceramic 3D printing capabilities

Ceramic parts made using XJet's NanoParticle Jetting™ technology

XJet Ltd., an Additive Manufacturing company pioneering NanoParticle Jetting™ technology, has announced the addition of ceramic inkjet 3D printing to its line of Additive Manufacturing capabilities. The ceramic 3D printed parts were on display for the first time at the formnext exhibition in Frankfurt, Germany, in November 2016.

NanoParticle Jetting (NPJ) technology was first unveiled at the RAPID Show in Orlando, Florida in May 2016 and the developers claim that it offers unprecedented levels of details, surface finish and accuracy, producing high quality parts with any geometry.

"After many years of research, we are excited to have reached this milestone of development, producing another high quality material through NanoParticle Jetting," stated Hanan Gothait, CEO and Founder of XJet. "NPJ is a truly disruptive technology as it offers a totally new level of fine details, material properties and simple clean operation without the need to design or remove complex support structures."

"The expansion of NanoParticle Jetting to include ceramics will allow XJet to address an even wider range of applications such as dental, medical and specific industrial applications," added Dror Danai, Chief Business Officer, XJet. "At formnext we demonstrated how the usage of ink-jet technology will encourage more industries to look at Ceramic AM as an option for both customised parts and relatively large scale manufacturing of small parts." XJet's technology was initially launched for the processing of metals. The powders, as well as the support material, are loaded easily by hand into the XJet system using cartridges, eliminating the need for powder handling.

www.xjet3d.com

World PM2016: Case studies highlight the diversity of PIM applications

In addition to the many technical papers presented at the World PM2016 Congress in Hamburg covering technological developments in Powder Injection Moulding, a Special Interest Seminar was also organised which focused on presentations by PIM industry experts on a number of case studies that highlighted the growing diversity and success of PIM applications.

Mimecrisa, Spain

Mimecrisa is one of Europe's leading Metal Injection Moulding companies and is also a subsidiary of Ecrimesa, an investment casting producer established in Santander, Spain, in 1964. The MIM operation, also located in Santander, was established in 1989 after the realisation that a number of parts produced by Investment Casting (IC) could be manufactured more efficiently and to a better quality at lower cost by MIM. This was especially the case for small parts (<20 g), although there were also found to be many overlapping MIM and IC parts in the 20 to 100 g weight range. Mimecrisa has additionally seen a growing tendency to produce MIM parts exceeding 100 g in weight where the complex shape can be injection moulded to near final shape to avoid costly machining of IC parts.

Manuel Caballero, Technical Manager, at Mimecrisa, said that the company was the first MIM producer to install a continuous MIM debinding and sintering furnace delivered by Cremer Thermoprozessanlagen in 1994, to which three further continuous lines have been added as well as vacuum and controlled atmosphere batch sintering furnaces. MIM part production is currently around 1.5 million pieces/month for a wide range of markets including locks, tools, automotive, textile machinery, medical, aerospace and defence with the latter making up around a third of MIM part production. Over 80% of MIM part production is exported to more than 20 countries. The materials portfolio at Mimecrisa-ranges from low alloy steels FN02 and

Fig. 2 The gun underbarrel produced by MIMECRISA in MIM-8740 steel provided the customer with considerable cost savings

Fig. 1 This thin-walled stainless steel part used in a laser surgery machine illustrates the complexity of shape that can be achieved by MIM

Fig. 3 One of the heaviest MIM parts produced by MIMECRISA is this 200 gr Fe-8NiC-HT+ZnNi part for a professional power tool using a ceramic injection mould as a setter for improved alignment during sintering

FN08 through to 316L and 17-4PH stainless steels to tool steels and heat resistant alloys.

Caballero gave some examples of where MIM has succeeded in providing cost savings. The first was a thin-walled cosmetic surgery device weighing 65 g produced in 316L stainless steel and used in the head of a laser surgery machine (Fig. 1). One of main difficulties found at the time of developing this part was correct mould design, especially when ejecting the part from the mould without breaking the most fragile areas. It also required fine tuning of the electric moulding machine used to produce the green parts and it was necessary to support the green parts during sintering to avoid cracks. Caballero said that the company was able to produce this MIM part competitively in relatively short production runs by eliminating secondary machining and welding operations. The MIM part also offered better mechanical properties.

The second MIM part described by Caballero was an underbarrel used in a hand gun (Fig. 2). He said that this component, which weighs 160 g, highlights the complexity of shape and size possible by MIM. As with the previous case study, the success of this part was due to advanced mould design. It was also necessary to establish a suitable MIM debinding and sintering process to prevent distortion and cracking in the finished parts. The MIM underbarrel part is produced from MIM-8740 steel hardened and tempered to a hardness of 32-36 HRC. This part has provided significant savings in terms of manufacturing costs to the customer, especially by eliminating machining operations.

One of the heaviest MIM parts in production at Mimecrisa weighs 200 g and is used in a professional power tool (Fig. 3). Caballero stated that the company used a MIM-Fe8NiC-HT+ZnNi material to produce this long MIM part in batches of 2000 to 5000 pieces. A special Ceramic Injection Moulded sintering support was produced in-house to stabilise the MIM part during thermal debinding and sintering and maintain alignment.

MIMest, Italy

A further case study involving the production of a Metal Injection Moulded key plate using an austenitic manganese steel, or Hadfield steel as it is commonly known, was outlined by Marco Cazzolli from MIMest SpA, Pergine Valsugana, northern Italy.

This type of steel, which is based on the composition Fe-13.4Mn-1.01%Si-1.3C, is characterised by its stable austenite microstructure at room temperature, its high work hardenability through TWIP (twinning induced plasticity) and high wear and impact resistance. Its main uses include hammers for rock drilling, railroad frogs, power shovel teeth and parts subject to high impact loads.

Cazzolli stated that MIMest has been in production of MIM parts since

Fig. 4 MIM key plate produced for reinforced doors using Hadfield steel

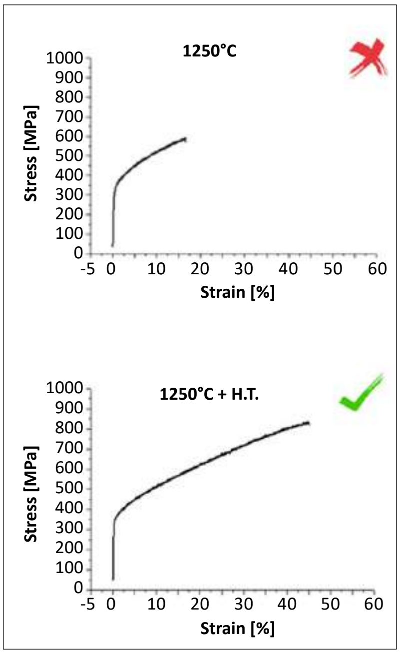

Fig. 5 Properties of the MIM Hadfield steel samples sintered at different conditions

2005 using both Arburg and Battenfeld injection moulding machines and a TAV batch furnace to process a range of alloys including steels, stainless steels, titanium alloys and nickel-base superalloys. The MIM key plate (Fig. 4) presented in this study was previously produced by machining sliced pieces of AVP steel rod to final shape. Heat treatment was necessary to obtain the final hardness required for the key plate, which is used in reinforced doors.

The customer sought cost savings by eliminating both the machining and heat treatment operations and turned to MIMest to investigate the suitability of producing the part by Metal Injection Moulding for this application. A Hadfield steel grade powder was produced by gas atomisation and the alloy powder was mixed with a proprietary binder to obtain the injection moulding feedstock. After moulding, debinding was done in H_20 at 50°C followed by secondary debinding at 600°C for 1 hr to reach a presintered state in the material. Cazzolli said that initial tests with MIM pieces sintered at 1250°C provided unexpectedly low properties in terms of tensile strength and elongation. Raising the sintering temperature to 1300°C for 1 h increased the density from 7.33 g/cm^3 to 7.44 g/cm^3 and a post sintering heat treatment for 30 min. at 1000°C followed by rapid cooling in pressurised nitrogen increased the properties to the level of cast Hadfield steel (Fig. 5).

One of the quality control issues faced by MIMest was the dimensional variation of the MIM key plates during liquid phase sintering, especially those parts in the outer zones of the sintering furnace close to the heating elements where there could be overshooting of the temperature cycle. Cazzolli stated that this required a small adjustment to the sintering cycle based on the weight control of the different batches of green injection moulded parts.

Functional tests using a 4 mm diameter drill bit and an applied load of 15 kg showed better performance of the MIM Hadfield steel compared with the AVS steel previously used (Fig. 6). The MIM Hadfield steel also had good ductility.

Further reports on MIM case studies and the status of MIM in China, Japan and India also presented at the MIM Special Interest Seminar in Hamburg, will be published in a forthcoming issue of PIM International.

www.epma.com
www.ecrimesa.es
www.mimest.com

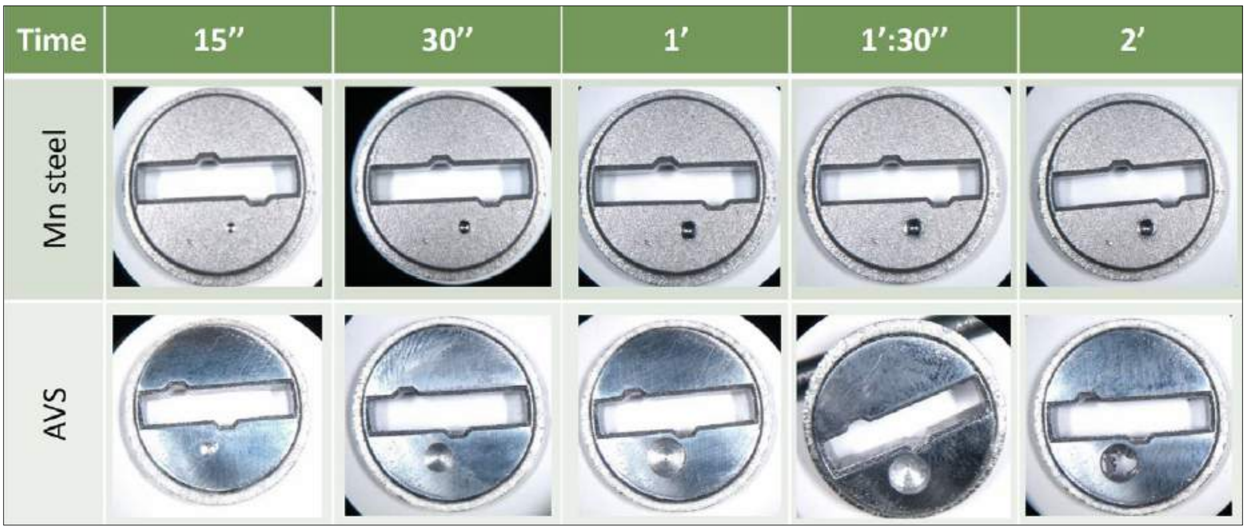

Fig. 6 Functional tests of MIM Hadfield steel (top) and the previously used machined AVS steel (bottom). Bottom right photo shows the good ductility of the MIM key plate

Autonomous optimisation reduces particle segregation in MIM

At the World PM2016 Congress and Exhibition in Hamburg, Germany, Sigma Engineering GmbH introduced a new approach to minimise particle segregation in Metal Injection Moulding. Simulation is a well-established tool in MIM, as it accurately predicts flow and thermal related effects in the green part moulding. In recent years, Sigmasoft® Virtual Moulding has developed a number of new features to predict particle segregation, one of the most common problems associated to MIM.

Particle segregation causes surface defects and once the green part is sintered, the differences in density lead to inhomogeneous shrinkage and therefore to warpage. Particle segregation is mainly a process driven effect caused by shear. Therefore, process parameters and part gating are critical.

Timo Gebauer, Sigma's Chief Technical Officer, demonstrated how autonomous optimisation can be used to reduce the appearance of particle segregation. Fig. 1 shows particle concentration for a very simple part. Three scenarios are considered: on the left, the part is filled with a short filling time. The part in the centre was simulated with a long filling time, and the right part shows the particle concentration for the short time, but with a different gate position. For each variation the segregation pattern is quite different.

"To understand the problem it makes sense to run various simulations in a Design of Experiments (DOE). This can help figuring out the correlations of the different boundary conditions and the influence on the observed result," explained Gebauer. In the optimisation, an even particle distribution is the main goal and both filling time and gate geometry are varied in a first study. As seen in Fig. 2, the difference in particle concentration diminishes with increasing filling time and there is a minimum achieved with a given offset to the middle plane of the part for the gate position.

To make the simulation feasible for an industrial part and mold, an approach called 'autonomous optimisation' is used. Using a similar strategy to the one previously described, the problem is solved in parts through several optimisation generations. This reduces the amount of calculations necessary to find an optimum solution. Sigma's congress presentation explained in further detail how this approach was used to minimise particle segregation in real products.

www.sigmasoft.de

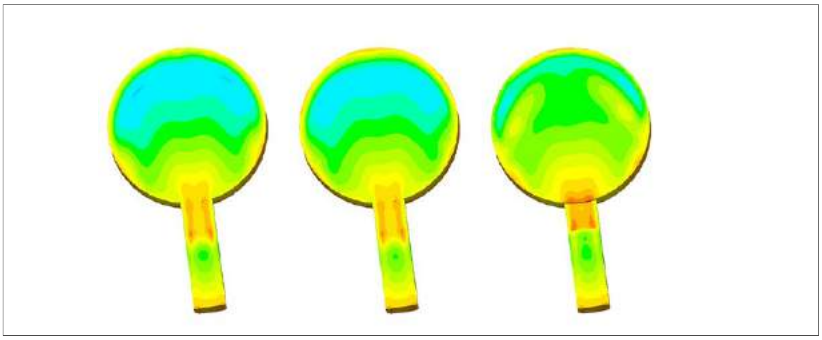

Fig. 1 Three different particle concentrations on the part surface at different filling times and gating positions

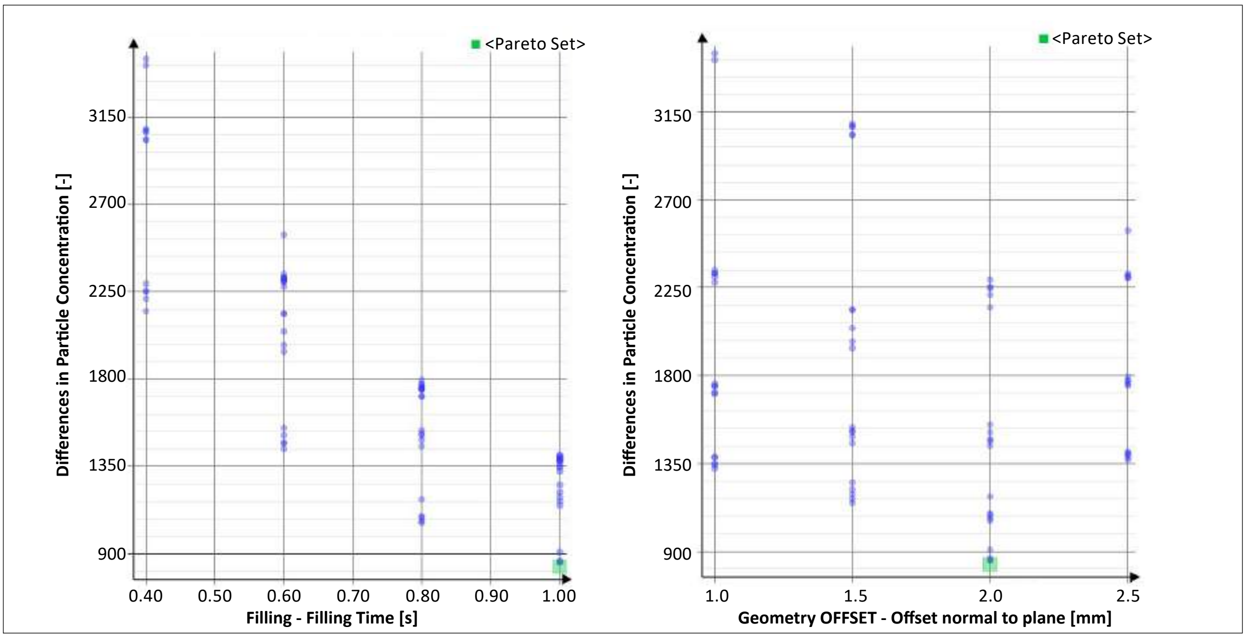

Fig. 2 Influence of filling time and gating position over the particle concentration gradient. The minimum gradient (optimum solution) is shown in green

EPMA 2017 Powder Metallurgy Summer School heads to Grenoble

The European Powder Metallurgy Association (EPMA) has announced that its next Powder Metallurgy Summer School will take place in Grenoble, France, June 19 – 23, 2017. The popular course is open to young scientists, designers and engineers looking to gain a broader knowledge and understanding of the Powder Metallurgy process and applications.

The five day residential event consists of a range of lectures given by PM experts drawn from both industry and academia and will be held at the Grenoble Institute of Technology (Grenoble INP). Topics to be covered will include the manufacture of metal powders, powder compaction, MIM, modelling, sintering, Hot Isostatic Pressing and Additive Manufacturing. Participants will be able to discuss and solve problems as well as get hands-on experience of various PM processes.

Grenoble Institute of Technology will host the 2017 Summer School

The Summer School is designed for young graduate designers, engineers and scientists from disciplines such as materials science, design, engineering, manufacturing or metallurgy. Graduates under 35 and who have obtained their degree from a European institution are eligible to apply. Registration to the Summer School will open in early 2017.

www.epma.com

Ceramics Expo: registration opens

North America's largest manufacturing and engineering event for the technical ceramics industry takes place from April 25-27, 2017 in Cleveland, Ohio. Ceramics Expo will once again feature a diverse range of exhibitors and a twin-track technical conference.

Worldwide industry leading companies including Morgan Advanced Materials, CoorsTek, McDanel and Hitachi High-Technologies will be exhibiting as well as hundreds of smaller technology and materials suppliers.

A parallel conference offers three days of free sessions, focusing on various ceramic and glass applications and manufacturing processes. This free-to-attend conference will feature over 60 speakers discussing trending topics including Additive Manufacturing.

www.ceramicsexpousa.com

American Axle & Manufacturing announces acquisition of Metaldyne Performance Group

American Axle & Manufacturing Holdings, Inc. (AAM) and Metaldyne Performance Group Inc. (MPG) have announced that the companies have entered into a definitive merger agreement under which AAM will acquire MPG for approximately $1.6 billion in cash and stock, plus the assumption of $1.7 billion in net debt. The transaction has been unanimously approved by the boards of directors of both companies and is anticipated to close in the first half of 2017 subject to shareholder and regulatory approval and other customary closing conditions.

"AAM's transformational acquisition of MPG brings together two complementary Tier 1 organisations to create a company with greater scale and increased diversity across products, customers and end markets," stated David C. Dauch, AAM's Chairman and CEO.

"MPG's expertise in complex, highly-engineered powertrain components and its global footprint will be tremendous assets to AAM. We are excited about the powerful industrial logic in this combination that will allow us to create additional value for our customers and other key stakeholders. Together, we are forming a company with increased earnings potential and enhanced cash flow generation that will allow us to rapidly reduce leverage while fuelling growth and delivering value to our shareholders," added Dauch.

AAM is a world leader in the manufacturing, engineering, design and validation of driveline and drivetrain systems and related components and modules, chassis systems, electric drive systems and metal-formed products. In addition to locations in the United States (Michigan, Ohio, and Indiana), AAM also has offices or facilities in Brazil, China, Germany, India, Japan, Luxembourg, Mexico, Poland, Scotland, South Korea, Sweden and Thailand. AAM has approximately 13,000 employees globally.

MPG is a leading provider of highly-engineered components for use in powertrain and suspension applications for the global light, commercial and industrial vehicle markets. The company has a global footprint spanning more than 60 locations in 13 countries across North America, South America, Europe and Asia with approximately 12,000 employees. Production capability includes conventional and powder forged component production as well as Metal Injection Moulding.

Under the terms of the agreement, each share of MPG's common stock will be converted into the right to receive $13.50 per share in cash and 0.5 share of AAM common stock. Upon closing of the transaction, AAM's shareholders will own approximately 70% of the combined company and MPG's shareholders will own approximately 30%.

www.aam.com

www.mpgdriven.com

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Hönbacher Str. 10
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Fax +49 3675 / 7484-44
email: info@fct-anlagenbau.de
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Alliance MIM: France's MIM leader prepares for opportunities in the aerospace sector

Besançon, the capital and commercial hub of the Franche-Comté region in eastern France, is the heart of the French watchmaking industry and home to CETEHOR, a highly regarded research institution specialising in watchmaking technologies. The area, situated close to the Swiss border, has a long tradition of fine mechanical and metalworking industries. On this fertile ground prospers France's only MIM producer, Alliance MIM SA. Dr Georg Schlieper recently visited the company and reports exclusively for *PIM International* about its approach to MIM technology and new markets.

Alliance MIM SA was established in 1995 in Saint-Vit, a small town near Besançon, by three companies with activities in the watchmaking industry. Two of the companies, Richemont Group and Louis Lang SA, were Swiss whilst the third company, Jean-Louis Burdet SAS, was French. These companies had discovered the potential of Metal Injection Moulding and decided to invest in this technology in order to meet their requirement for small, complex, precision parts. They hired Dr Jean-Claude Bihr, a mechanical engineering and materials science researcher who at that time was finishing his PhD thesis on the development of Metal Matrix Composites by Powder Metallurgy technology and put great trust in him to build the new company.

In all other respects the founding companies were competitors in the watchmaking market. The formation of such an alliance to develop and commercialise MIM technology was the inspiration behind the name of the new company, which at the start was solely devoted to MIM technology. The company has since also added Ceramic Injection Moulding capabilities. Each of the three founding companies owns a 30% share of Alliance, with the remaining 10% owned by Bihr, the General Manager. Remarkably, Alliance is still the only commercial MIM parts manufacturer in France.

From the beginning, Alliance adopted BASF's Catamold process. This uses a feedstock based on a polyoxymethylene (POM) binder and a catalytic debinding process in which the POM binder is decomposed at a temperature of 110–140°C with the addition of highly concentrated nitric acid. The vapours of nitric acid degrade the POM binder into formal-

Fig. 1 Alliance's modern factory building in Saint-Vit, France

Fig. 2 The toolshop at Alliance supplies around fifty new MIM and CIM tools each year

dehyde which is further degraded by a natural gas burner.

With the technical support of BASF, Bihr's background in powder technology and an initial customer base provided by the three parent companies, Alliance was built on solid foundations. Debinding furnaces were installed according to BASF specifications and investment in injection moulding machines and sintering furnaces was made.

"*Sometimes two or more different parts are moulded in one tool if they belong to the same end product and are always required in identical quantities.*"

Feedstocks were initially purchased solely from BASF, however additional suppliers are now also called upon for special materials, for example.

MIM production at Alliance

Alliance has an in-house tool shop operated by fifteen employees and equipped with modern EDM and CNC machinery. This supplies approximately fifty tool sets per year for metal and ceramic injection moulding (Fig. 2). In addition, the tool shop delivers jigs and fittings for secondary processes such as sizing or polishing. Thus, with the exception of heat treatment, Alliance is self-sufficient for the entire process chain.

"Soon after we started our business we learned that our customers expected us to react quickly on new projects and the production of high quality tools was a central part of this," stated Bihr. "With our own tool shop we are able to best serve our customers at an affordable cost."

Multi-cavity tools with up to eight cavities are usually used at Alliance in order to reduce the cost of injection moulding. Besides combining several identical cavities in a tool, sometimes two or more different parts are moulded in one tool if they belong to the same end product and are always required in identical quantities. This route reduces the price of the tooling and, as an example, one firearm that Alliance supplies components for contains four different MIM parts that are all moulded in the same tooling.

Alliance has 17 injection moulding machines with clamping forces ranging from 35 to 220 tons, however the standard is 50 tons (Fig. 3). Almost all moulding machines are equipped with six-axis robotic arms, which automatically remove the parts from the mould and place them on trays for debinding. Sintering is done in vacuum and atmosphere

Fig. 3 The injection moulding machines at Alliance are typically fitted with 6-axis robots for highly efficient production

batch type furnaces (Fig. 4). As the feedstock for CIM is designed for a solvent debinding process in water, a suitable solvent debinding unit and a sintering furnace for ceramics are also installed.

The markets served by Alliance require medium quantities of parts. Delivered annual quantities usually range from several thousand to 100,000, with an average of about 30,000 parts per year. Such volumes require a flexible strategy in the organisation of the factory.

Bihr stressed the point that Alliance does not keep inventories. "You will not see many parts in our plant," he stated. "We want our parts to be shipped out to our customers, not to lie around in the factory." To achieve this, an extremely efficient organisation is required including a well-considered arrangement of the machines on the shop floor and a clear flow of material. Each order is produced on customer demand and each production lot is accompanied by a card with essential information about the processing sequence and the actual status of work. When a processing step is finished, the parts are picked up within thirty minutes and transferred to the next operation site. In conjunction with a fast twenty minute tool change, this scheme speeds up the material flow in the factory, is very flexible and ensures the shortest possible time to delivery. "We can produce 500 parts per order or even less and still make a profit," Bihr stated.

In addition to the card system that has been adopted from Toyota, a computer system with easily understood symbols illustrates to the operators at each work station where defects or flaws might occur and what to observe.

Secondary operations are another strong pillar of Alliance's business. According to Bihr, 30 to 50% of Alliance's turnover is generated by secondary operations. These include turning, five-axis milling, sizing, laser welding, mechanical and laser engraving. Surface finishing operations such as sand blasting, lacquering, barrelling and polishing are available in-house as well. Alliance also delivers assemblies of parts.

Alliance's management concept

Bihr is particularly proud of his innovative management concept that he developed in close cooperation with his co-worker and Human Relations Manager, Caroline Trudel. Whilst he is an excellent engineer and aware of the importance of technical expertise, he is also convinced that business success relies more on the cooperation of people than on technical expertise of individuals. His management concept includes an emphasis on frequent contact with both customers and suppliers that involves a broad range of the company's employees. The company's structure is characterised by an extremely flat hierarchy, with the management team consisting of Bihr himself and a handful of sectoral managers for the technical and

Fig. 4 Debinding and sintering furnaces

Fig. 5 Alliance's open plan main office area

commercial business units. Each employee has direct access to the General Manager whenever they have a concern.

In 2015 Alliance moved into a newly erected building with 3700 m^2 of floor space, the design of which reflects the company's management concept. A word that appropriately describes the philosophy of the building as well as the management concept is transparency. Visitors entering the building pass through an entrance hall and then enter a spacious main office (Fig. 5) where the commercial and technical activities are concentrated. Large windows allow a view into the central meeting room and the design department. The layout of the offices is intended to support communication among employees on all levels. Spontaneous meetings are encouraged with an informal meeting area located in the centre of the office.

Currently, Alliance has 125 employees. Since many companies in the region use traditional stamping, punching and machining processes for the manufacture of metal components the area offers a lot of well-trained metalworkers. However, as Bihr pointed out, some are rooted in these traditional technologies and are reluctant to accept new processes. It can therefore be difficult to select staff who fit into such a forward looking company and technology.

In line with the company's philosophy of promoting employee responsibility, Bihr believes that it is important in the course of job interviews to ensure that candidates are mentally flexible and open for change. "We want to employ brains rather than hands," stated Bihr, "We don't want candidates who just do their job in a routine way, as they have always done, without thinking about what they are doing and without being ready for change."

Likewise, open communication and close cooperation is sought with the customers. A separate room is reserved for technical project discussions and problem solving within teams, either with the company's engineers or in cooperation with customers. Interaction between people is regarded as the key to long-lasting and mutually rewarding customer relations.

"MIM technology is not yet well-known in many design offices and we have to learn in cooperation with our customers how we can best develop and manufacture their parts," stated Bihr. "Today only half of our customers design their parts for MIM from the start. The other half design their parts for conventional manufacturing technologies and we have to find out, in a cooperative manner, how we can offer them a better solution in terms of cost and performance with MIM. In this process we are very open to discuss the options that MIM can offer. Personal contact is essential for successful interaction - this cannot be done by telephone and email."

"We want to make our technology wider and bigger," stated Bihr, "and hiding is not the way to make a business grow." His ambition is to get his entire staff involved in the learning process that is associated with the launch of each new part. Bihr is aware that MIM technology can only prosper with competent and committed people. He sees his most important task in educating his employees in this way. The more knowledge is accumulated in the company, the better the quality of the products that are developed. He is convinced that employees who fully understand and appreciate what they are doing are better motivated, less absent and deliver better quality than uninformed workers.

Jean-Claude Bihr is also concerned about the environmental aspects of manufacturing. "It is a fact that the world population will continue to grow", he stated. "Limited energy and material resources are one side of the problem, but air and water pollution are also key issues. Our technology is green, we do not produce any significant waste, we save raw materials and we do not pollute the environment. MIM is therefore a technology of the future."

Markets and products

Alliance primarily serves four market segments; aesthetic consumer products, firearms and technical components, medical/dental products and aerospace applications. Aesthetic parts for consumer products are the core of Alliance's expertise. These include parts for watchcases and watch straps, parts for eyewear applications, components for luxury leather goods and pens. A number of examples are shown in Figs. 6 and 7. These products are typically characterised by extremely finely polished and glossy surfaces.

Fig. 6 Parts for watch straps and cases

Fig. 7 MIM parts for luxury leather goods

Fig. 8 MIM parts for an orthodontic mouth rinsing device

Fig. 9 MIM parts for technical applications

Fig. 10 MIM parts for firearms applications

Approximately 20% of Alliance's annual turnover is generated by dental applications such as brackets, instruments for dentists and components for orthodontic devices. Fig. 8 shows an assembly of several MIM parts for the nozzle of a dental hygiene rinsing system.

Technical applications are extremely diverse and include parts for industrial robots, weaving machines, electronic devices and more. Some examples are shown in Fig. 9. A substantial part of Alliance's production goes into the firearm sector (Fig. 10)

Materials processed

Most parts for the watchmaking industry and other aesthetic applications are made from 316L stainless steel, a material that when polished has the necessary quality of surface finish. There has in recent years also been a growing demand from this market for titanium parts and as a result Alliance developed its capabilities to include Ti and Ti6Al4V. In many cases, the same watch parts that are made from 316L stainless steel are also produced from titanium for sports versions, for example.

Parts for orthodontic applications are also predominantly made from 316L stainless steel. The superior corrosion resistance of PM stainless steel adds to the benefits of the MIM process for the design of complex parts. Technical applications are usually served with high strength 17-4PH, FN08, 8620 and 42CrMo4 steels, often heat treated. The majority of MIM parts at Alliance weigh between 5 and 50 g, although there are also parts weighing less than 1 g such as dental brackets, as well as some larger parts.

In the last five years, Alliance has developed a new business sector serving the demand for luxury consumer products made from zirconia ceramics. Zirconia is required by Alliance's core aesthetic consumer products market and is produced in white, black and various colours. After polishing it exhibits a very attractive, glossy and scratch resistant surface. As previously reported in *PIM International* (Vol.9 No.3, p 53-60), a large number of high value watches feature CIM zirconia parts.

Opportunities in the aerospace sector

The aerospace industry poses new challenges for Alliance in terms of documentation and quality management certification. For certain applications, the company had to develop the processing of the high temperature resistant alloys Hasteloy X and Inconel 718. Some envisioned aerospace products are turbine blades up to 300 mm in length and alloys that cannot be cast or machined are on the horizon. There are also plans to develop in-house feedstock compounding for special alloys in order not to have to share specialist knowledge with third-party companies. In a first step, the powder is purchased and inspected at Alliance and then compounded by a feedstock maker, but in-house compounding remains a target. Aerospace applications are envisaged to make a major contribution to Alliance's turnover in the near future.

One extremely impressive aerospace component developed with French aerospace company Safran is the swirler shown in Fig. 11. Originally planned to be made by traditional machining, assembly and welding processes, the component shown is made by the co-sintering of four individual MIM parts.

"At the beginning the customer came to see us for the central part only as it was the most complex to mill. Through discussions about how the part was used it became clear that there would be significant benefits to producing all the parts by MIM and then assembling them just prior to sintering, during which they diffusion bond together - and it works!," stated Bihr.

The material is Hastelloy X and the diameter of the part is 47 mm. Such a part could potentially be produced by Additive Manufacturing but AM may have presented challenges in terms of supporting the parts, the accuracy of all the tiny holes and cost. The latter is a consideration as more than 1000 parts a year may be required.

Fig. 11 This highly complex Hastelloy X aerospace swirler components is 47 mm in diameter and consists of four sinter-bonded MIM parts

MIM versus Additive Manufacturing

Whilst Additive Manufacturing has in recent years caught the attention of the world as a 'revolutionary' technology that can deliver complex, 3D metal components, MIM has never benefitted from such intense media exposure. As demonstrated by the aerospace swirler component, Bihr believes that there are some potential areas of overlap that will present opportunities for MIM.

"There are some parts that can only be additive manufactured, but a lot of others can be prototyped using AM and then produced in series through MIM. There are challenges, however. Designers have understood in a fraction of a second what they can do with AM machines, but in the world of metal, people who understand plastic injection moulding are few and far between," stated Bihr.

"There is also the challenge that part 'creation' interests a lot of people, but 'production' not so much. This is why so many MIM companies are located where the world produces goods, such as China and India, and why AM technology is so strong in Europe and the USA, where so many people design and create products. AM is in the minds of many people linked to the digital world of Silicon Valley, whereas MIM is linked to industry. AM connects with creativity, MIM connects with cost reduction and production."

Bihr explained that what the two processes have in common is the powder and the fact that the part 'grows around its holes'. Metallurgically speaking, however, the two are quite different. In terms of microstructures, MIM is solid state and isotropic whilst AM is liquid state and directional. "Another big difference is the yield of powder, which is far better in MIM, a technology in which the surface definition is also much better. For me, and for small series production, a very interesting MIM-like technology is the printing of feedstock. With this, you have the freedom of pure AM and the metallurgy of solid state sintering," stated Bihr.

Marketing

Marketing activities focus on end-user exhibitions, in-house seminars and presentations at technical conferences. The main objective of these initiatives is to make the technology better known to end-users. The marketing activities are supported by sales representatives in the UK and in Switzerland and a representative in Hamburg, Germany, has recently joined the team.

The company exports 70% of its production to other European countries as well as further afield. In order to be competitive on the world market Alliance, with its high wages

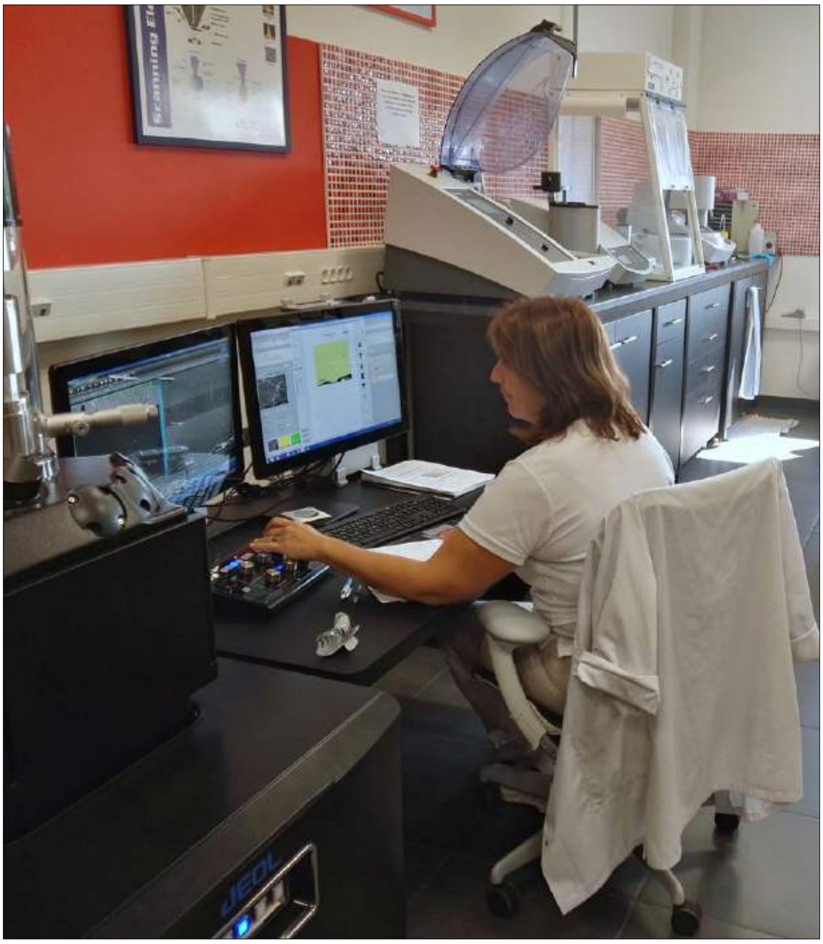

Fig. 12 Advanced SEM technology in Alliance's R&D laboratory

in comparison to many competitors, relies upon its extremely flexible and efficient manufacturing strategy.

Focus on R&D activities

Significant growth is expected in the future from innovative components for the aerospace industry. The potential of PM-based technologies to produce materials with outstanding and unique properties will further be exploited by Alliance. For this reason, the company has installed a sophisticated materials research laboratory which is extraordinarily well-equipped for a medium sized company such as Alliance. In addition to the standard materials testing devices such as metallography and hardness testers, there are instruments for analysing carbon, oxygen and nitrogen content and a scanning electron microscope is also available (Fig. 12).

Materials research is done in close cooperation with customers and from time to time with universities and research institutions. This is considered more efficient than publicly funded research on a European level. Whilst Bihr is unable to disclose further details of the topics of research projects, it is clear that the qualification of titanium for aerospace applications is high on the agenda. Bihr indicated that even entirely new PM alloys with unique combinations of properties may be developed by Alliance in the near future.

Outlook

Concluding, Bihr returned to the environmental credentials of MIM and CIM. "I believe that the future will come from green technologies, of which MIM is a leader. It not only uses less material, but its lower emissions in terms of by-products are also significant. The future can be seen with the achievements of a company such as Tesla, whose products people regard as cool and desirable because they are made with clean technology. I believe this is the future for MIM, but it won't be an easy journey!"

Contact

Dr Jean-Claude Bihr
General Manager
Alliance MIM SA
22, rue de l'Europe
F-25410 Saint-Vit
France
Tel. +33 3 81 87 52 49
Email: jean-claude.bihr@alliance-mim.com

Author

Dr Georg Schlieper
Harscheidweg 89
D-45149 Essen
Germany
Tel: +49 201 71 20 98
www.gammatec.com
Email: info@gammatec.com

World PM2016: PIM technical sessions review advances in novel titanium alloys for biomedical applications

The World PM2016 Congress and Exhibition took place in Hamburg, Germany, October 9-13, and attracted over 1900 participants and 200 exhibitors. Powder Injection Moulding (PIM) was one of the key themes of the Congress technical programme, with both researchers and manufacturers presenting their latest innovations. In our first report from the Congress Bernard Williams reviews a number of technical papers which focused on the development of novel titanium alloys for biomedical applications.

The Technical Programme of the World PM2016 Congress was made up of over 400 presentations in 69 sessions, including seven dedicated to recent and novel advances in materials for PIM. A half-day Special Interest Seminar also reviewed global PIM developments through case studies from around the world and trends in global PIM markets.

First generation α and β titanium alloys such as Ti6Al4V, Ti6Al7Nb and Ti5Al2.5Fe are already used in orthopaedic and biomedical applications because of their low density, superior biocompatibility, corrosion resistance and good mechanical properties, as well as low elastic modulus. In recent years second generation low-modulus near β and β type titanium alloys have been developed for biomedical applications in order to avoid the 'stress shielding' effect caused by the modulus mismatch between the titanium implant and the human bone. The following report reviews five of the papers presented on developments in novel titanium-based alloys produced by PIM and intended for biomedical applications.

Ti-29Nb-13Ta-4.6Zr alloy for MIM implants

Dr Eiji Endo and colleagues at Castem Co Ltd and Kindai University in Japan stated that whilst the existing pure Ti and Ti6Al4V alloy materials are already being used for medical applications, their use is limited by the mismatch of elasticity between implants and bones. Therefore in recent years low elasticity Ti alloys having properties closer to those of bone have been developed in Japan including one based on a Ti-29Nb-13Ta-4.6Zr composition, also known as TNTZ alloy. The authors have been studying the potential of

Fig. 1 World PM2016's Official Reception took place at the Handelskammer in Hamburg city centre

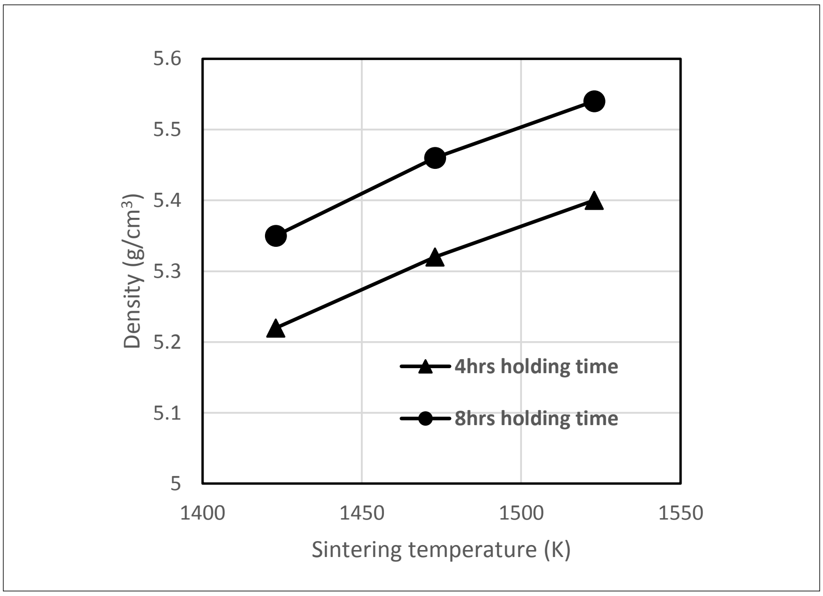

Fig. 2 Variation of density of the as-sintered Ti-29Nb-13Ta-4.6Zr alloy as a function of temperature and time [1]

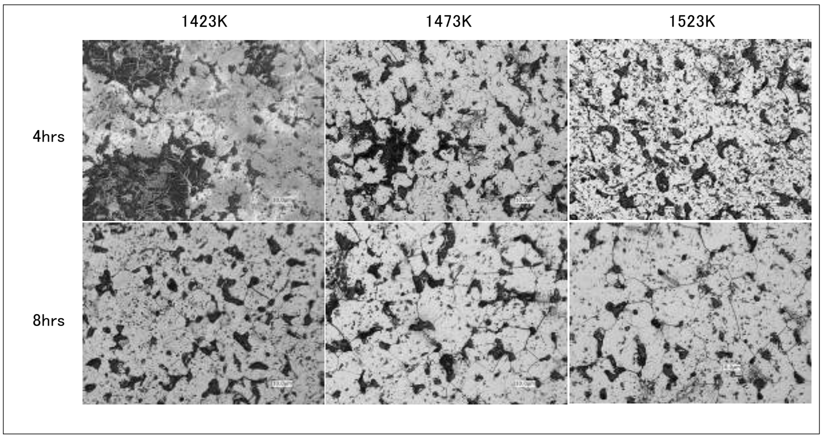

Fig. 3 Variation of the microstructure of the as-sintered alloy as a function of sintering temperature and holding time [1]

the MIM process for this TNTZ alloy, in particular the effect of sintering conditions on the microstructure and mechanical properties [1].

The authors used elemental powders to make up the target composition of Ti-29Nb-13Ta-4.6Zr, with each powder having a particle size of less than 45 µm. The powders were mixed with a polymer binder and the resulting feedstock was injection moulded followed by sintering at 1423 K, 1473 K and 1523 K in vacuum for 4 h and 8 h. The sintered specimens were cooled by introducing argon gas. The resulting as-sintered densities of the alloy as a function of temperature and time are shown in Fig. 2. Increasing sintering temperature to 1523 K and holding time to 8 h resulted in a relative density of 93%, which was the highest density achievable through sintering alone. However, increasing sintering temperature also led to grain coarsening in the Ti-29Nb-13Ta-4.6Zr alloy, as can be seen in Fig. 3. This shows the variation of microstructure in the as-sintered alloy as a function of sintering temperature and time. As a result, the sintered alloy consisted of a β phase when sintered at high temperature and for longer holding times.

The authors also reported on the influence of temperature and holding time on tensile strength and ductility, which depended on the density and microstructure of the Ti-29Nb-13Ta-

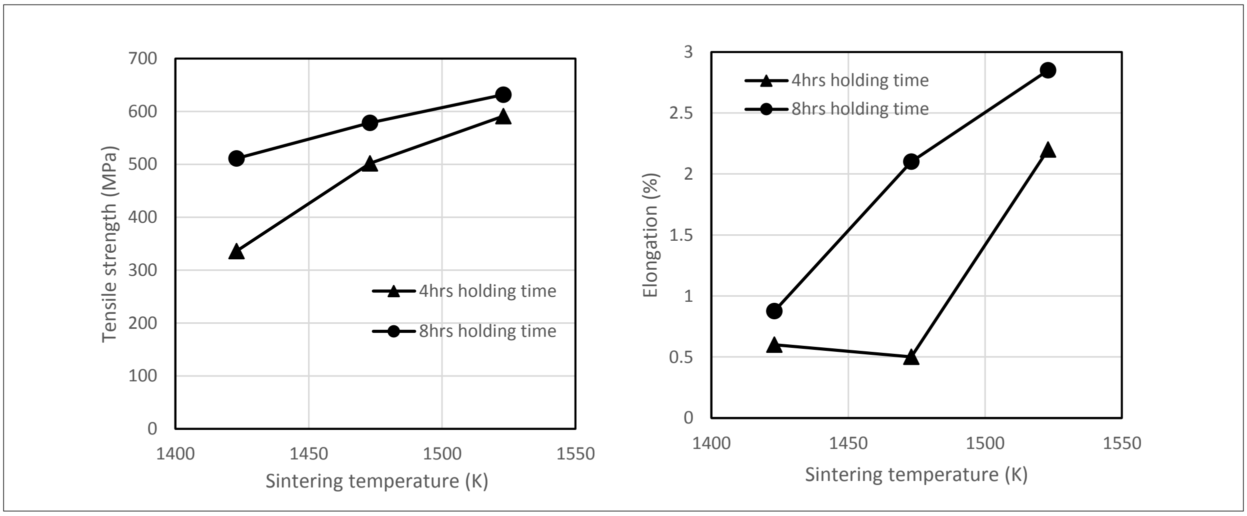

Fig. 4 Tensile and elongation properties of the as-sintered alloy at different sintering temperatures and holding time [1]

4.6Zr alloy. Ultimate tensile strength and elongation were highest for the alloy sintered at 1523 K and holding time of 8 h reaching 650 MPa and 3% respectively (Fig. 4). Young's modulus was found to be around 60 GPa which is similar to that of the equivalent grade of wrought alloy.

Low modulus near β Ti alloy for implant applications

J–E Bidaux and co-authors from the University of Applied Sciences and Arts of Western Switzerland undertook research to produce a low modulus near β Ti-13Nb-13Zr alloy by Metal Injection Moulding to replace standard Ti-6Al-4V for implant applications [2].

Powders used included spherical gas atomised Ti powder (D_v50 = 21 μm), angular Nb powders (D_v50 = 41 μm) and spherical gas atomised Zr powder (D_v50 = 35 μm). The binder consisted of 55% paraffin wax, 35% low density polyethylene and 10% stearic acid. Powder loading in the feedstock was 60 vol.%. Injection moulded tensile test specimens were debound first by removing the soluble part of the binder in heptane for 20 h at 50°C followed by thermal debinding and sintering in a single thermal cycle under argon at temperatures up to 1400°C. Some sintered specimens were encapsulated in an evacuated quartz ampule, solution treated in the β phase for 1 h at 800°C and water quenched by breaking the ampule under water. Some quenched specimens were further aged for 6 h at 500°C. Both quenching and aging treatments were performed according to ASTM F1713 standard.

Shape retention in the green and sintered specimens was found to be good, with linear shrinkage between the two states reported to be 13.8 ± 0.4%. Sintered density was 96.5% of T.D. The dissolved oxygen content in the sintered Ti-13Nb-13Zr alloy was, however, found to be high, exceeding the requirements of ASTM F1713. Table 1 shows the concentration of the interstitial elements and the high O_2 content in the sintered MIM samples, which was attributed to the high reactivity of Zr in the alloy. This, along with the presence of carbides at the grain boundaries, substantially influenced the elongation properties with plastic elongation of <1%. The authors stated that keeping the alloy free from carbides would require the carbon content in Ti-Nb alloys to be kept below 0.023 wt.%. This is much lower than for pure Ti and Ti6Al4V alloys.

Typical stress-strain curves for the as-sintered, water quenched and aged MIM Ti-13Nb-13Zr specimens are shown in Fig. 5. Table 2 compares the data obtained for the MIM Ti-13Nb-13Zr with reference data for the equivalent wrought alloy. The modulus of the as-sintered specimen

Material	O (wt.%)	C (wt.%)	N (wt.%)
Ti powder	0.160 ± 0.003	0.009 ± 0.004	0.010 ± 0.001
Nb powder	0.072 ± 0.002	0.002 ± 0.002	0.004 ± 0.001
Zr powder	0.174 ± 0.008	0.010 ± 0.001	0.007± 0.002
MIM Ti-13Nb-13Zr	0.33 ± 0.05	0.10 ± 0.02	0.032 ± 0.001
Wrought Ti-13Nb-13Zr	<0.15	<0.08	<0.05

Table 1 Concentration of interstitial elements in the Ti-13Nb-13Zr MIM alloy [2]

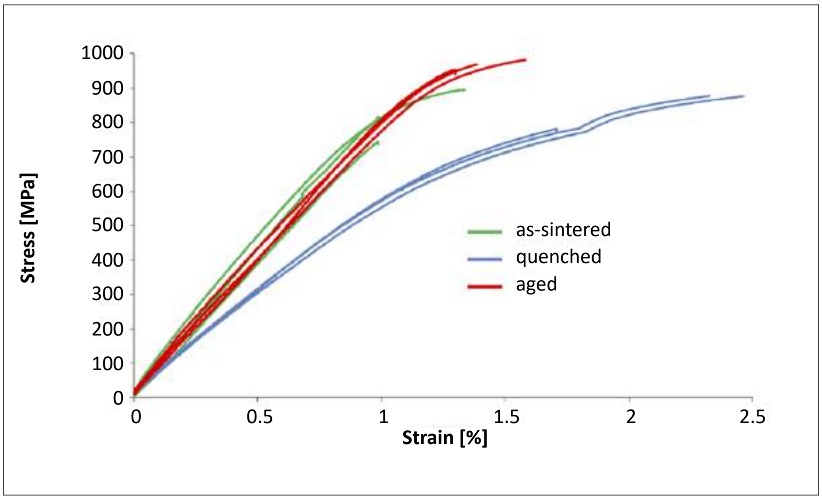

Fig. 5 Stress-strain curves from tensile tests of MIM as-sintered, water quenched and aged Ti-13Nb-13Zr samples [2]

Material	Condition	Young's modulus (GPa)	Yield strength (MPa)	Elongation (%)
MIM Ti-13Zr-13Nb	As-sintered	85 ± 5	842 ±20	<0.3
	Water quenched	58 ± 3	684 ± 19	< 1
	Aged	79 ± 5	951 ± 20	<0.4
Wrought Ti-13Zr-13Nb	Air-cooled	83 ± 2	599 ± 24	20 ± 3
	Water quenched	64 -77	433 - 554	21 - 29
	Aged	81 ± 4	864 ± 43	13 ± 3

Table 2 Tensile test properties of MIM Ti-13Zr-13Nb and wrought Ti-13Zr-13Nb specimens [2]

Powder	Oxygen [wt.%]	Nitrogen [wt.%]	Carbon [wt.%]
Ti-6Al-7Nb PIGA	0.098	0.002	0.003
Ti-6Al-7Nb EIGA	0.202	0.014	0.006

Table 3 Interstitial contents of Ti-6Al-7Nb gas atomised powders [3]

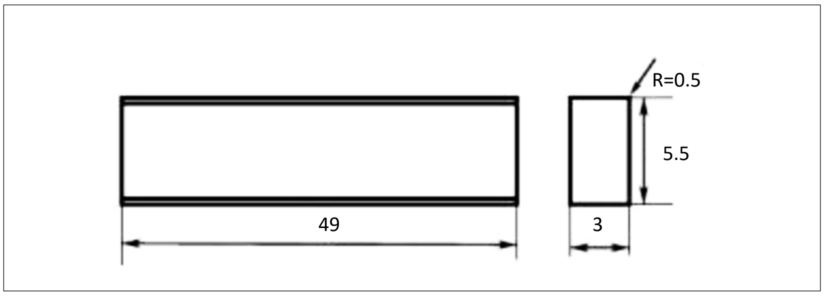

Fig. 6 Mould cavity geometry with dimensions for the fatigue MIM specimens [3]

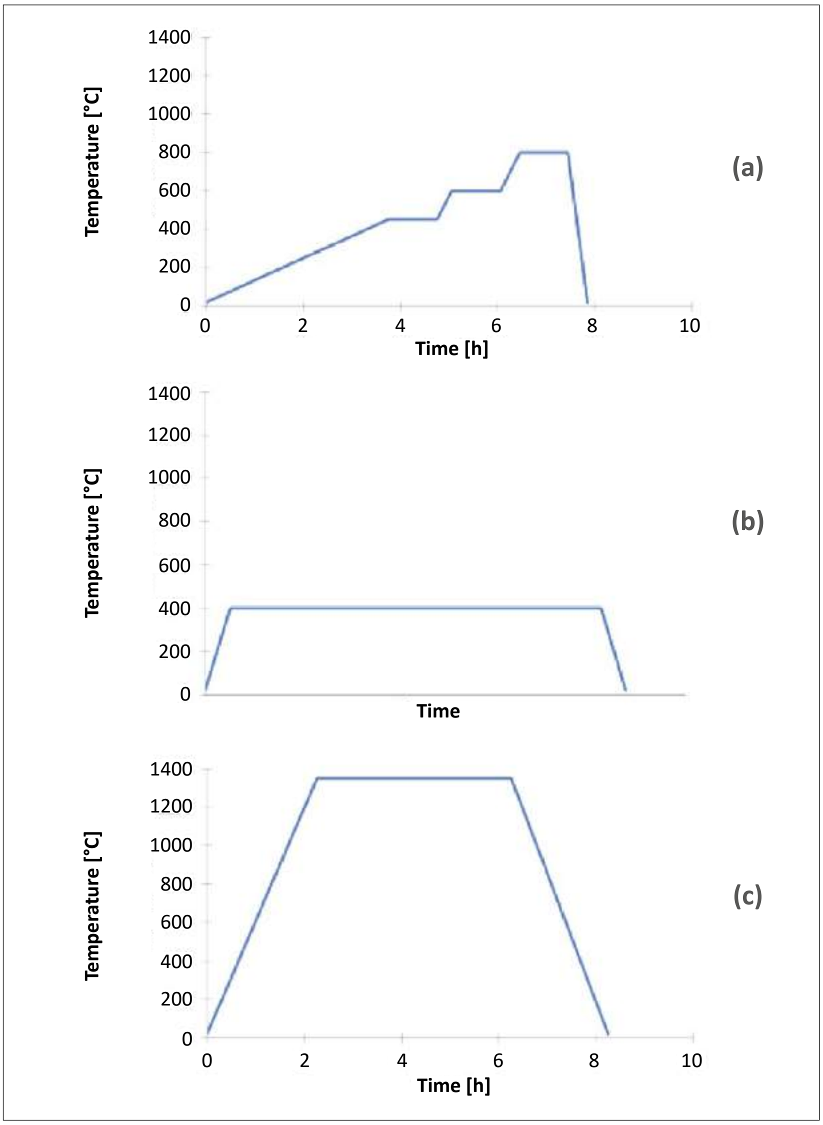

Fig. 7 Oxidation procedure for EIGA specimens: (a) pre-sintering (b) thermal treatment and (c) sintering [3]

is shown to be about 85 GPa. Water quenching allows a decrease of the modulus to 58 GPa, while keeping the strength high. Further aging provides the highest level of strength but the modulus returns to a value close to that of the as-sintered material, 79 GPa. The authors conclude that ductility is certainly the property that needs, as a priority, to be improved. Solutions to prevent excessive oxygen and carbon pick-up during processing must be found.

Fatigue behaviour of Ti-6Al-7Nb alloy

Ti-6Al-7Nb is an attractive alloy for load bearing medical implants because of its good biocompatibility and mechanical and dynamic properties. Alexandra Amherd Hidalgo at the Helmholtz-Zentrum Geesthacht, Germany, in conjunction with researchers at Höganäs AB, Sweden, and the University of Applied Sciences and Arts Western Switzerland, reported on work to determine the influence of interstitials such as oxygen, carbon and nitrogen on the tensile strength and fatigue properties of MIM Ti-6Al-7Nb specimens subjected to high cycle 4-point bending fatigue tests [3]. Two types of gas atomised Ti-6Al-7Nb powders having particle size <45 μm were produced at Helmholtz-Zentrum Geesthacht using Plasma Melting Induction Guiding Gas Atomisation (PIGA) and Electrode Induction Melting Gas Atomisation (EIGA). The interstitial contents of the two types of powder are shown in Table 3.

Injection moulding feedstock was produced by mixing the Ti-6Al-7Nb powders with 35.5 vol.% binder comprising ethylene vinyl acetate (EVA), paraffin wax and stearic acid. Two different geometries were used to produce (a) the tensile test specimens (dimensions according to ISO 2740) and (b) specimens for four-point bending fatigue with dimensions shown in Fig. 6.

The PIGA specimens were processed by a two step debinding operation involving solvent debinding in hexane at 40°C for 15 h, followed by thermal debinding at below 450°C in argon. Sintering of the PIGA specimens was done in a cold-wall furnace with Mo-shielding and tungsten heater, at a temperature of 1350°C under high vacuum for 4 h using yttria coated molybdenum sintering supports.

EIGA specimens were sintered so as to produce different interstitials content. Specimens were first pre-sintered, then thermally treated under oxygen-argon atmosphere, and finally sintered. The pre-sintering step was performed in a hot-wall furnace at 800°C under vacuum for 1 h using yttria coated molybdenum sintering supports. During thermal treatment, specimens were hung and exposed to oxygen (20%)-argon gas flow of 35 l/h and 1 bar for different times at a temperature of 400°C. Finally, specimens were sintered at 1350°C for 4 h under high vacuum. The oxidation procedure for the EIGA test specimens is shown in Fig. 7. All sintered MIM Ti-6Al-7Nb specimens had a 97% theoretical density. Four-point bending MIM specimens were shot peened using zirconia powder having particle size of 200 µm to ensure an appropriate surface quality for fatigue testing.

Tensile tests results of specimens containing different oxygen equivalent contents are presented in Table 4. An oxygen equivalent content change from 0.15 wt.% to 0.34 wt.% was found to increase the strength by 12% with ductility values around 14-16%. Specimens showed typical dimple fracture of MIM ductile materials. A drop of elongation from 16% to 6% was observed when the oxygen equivalent content exceeded 0.46 wt.%. This behaviour is mainly due to solid solution strengthening of the alpha phase. No significant grain size reduction was detected during microstructure evaluation excluding strengthening by a finer grain size.

The authors reported that fatigue resistance decreases with high interstitial contents with the fatigue endurance strength of MIM specimens at N = 10^7 decreasing from 450 MPa at 0.18 wt.% O_{eq} to 350 MPa at 0.50 wt.% O_{eq} (Fig. 8). The reduction in both low- and high-fatigue life regions is explained by the significant decrease of elongation resulting in a crack propagation resistance reduction and a more sensitive crack initiation stage.

They conclude that with respect to tensile strength it can be beneficial to

O_{eq} [wt.%]	Colony size [µm]	Tensile strength [MPa]	Yield strength [MPa]	Plastic Elongation [%]	Young modulus [GPa]
0.15	97 ± 10	751.2 ± 1.0	661 ± 2	14 ± 1	99 ± 5
0.34	77 ± 11	848.2 ± 2.9	738 ± 2	16 ± 1	107 ± 10
0.46	86 ± 3	879.1 ± 3.1	765 ± 10	12 ± 2	98 ± 6
0.46	84 ± 7	885.7 ± 2.1	767 ± 7	11 ± 2	98 ± 11
0.47	75 ± 8	879.3 ± 6.4	765 ± 8	8 ± 2	98 ± 7
0.52	85± 6	889.9 ± 2.5	782 ± 4	6 ± 2	108 ± 5
0.69	89 ± 9	913.8 ± 2.1	817 ± 2	2 ± 1	106 ± 3

Table 4 Average tensile parameters (n=5) of samples with different oxygen equivalent content [3]

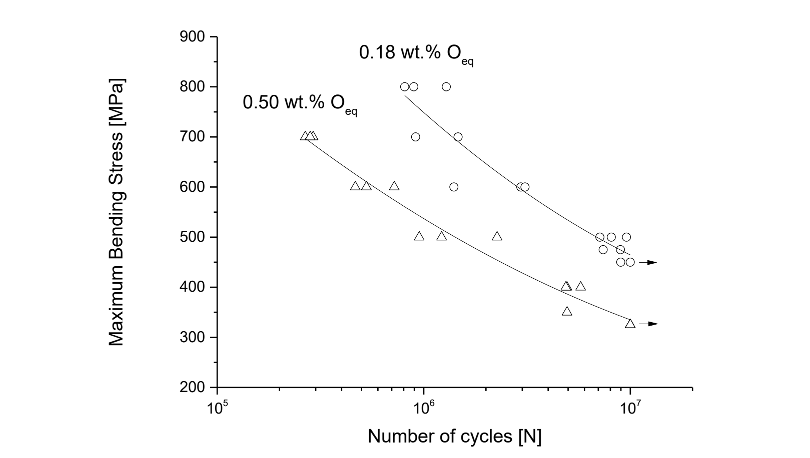

Fig. 8 S-N curve of MIM Ti-6Al-7Nb specimens containing 0.18 wt.% and 0.50 wt.% O_{eq} [3]

Item		Ti	Nb	Zr
Melting Point, °C		1670	2468	1850
Vendor		Phelly Mater.	Alfa Aesar	Alfa Aesar
Shape		Irregular	Irregular	Irregular
Particle size	D10	16.05	3.52	1.95
	D50	32.69	8.53	6.97
	D90	57.15	21.28	26.72
Pycn. Density, g/cm^3		4.51	8.42	6.53
Purity, %		Commercial Purity	99.9	99.9

Table 5 Powder characteristics of Ti, Nb, and Zr powders [4]

Sintering Conditions	Sintered Density g/cm³	Relative Density %	UTS MPa	Elongation %	Hardness HRB
1100-1 h	4.43	90.7	360	1.5	95.9
1200-1 h	4.63	94.8	596	4	108
1300-1 h	4.69	96.1	672	7.8	109
1400-1 h	4.76	97.5	701	9.1	110.9
1500-1 h	4.82	98.7	738	13.9	111.6

Table 6 Sintered densities and mechanical properties of PIM-Ti10Nb-10Zr alloys [4]

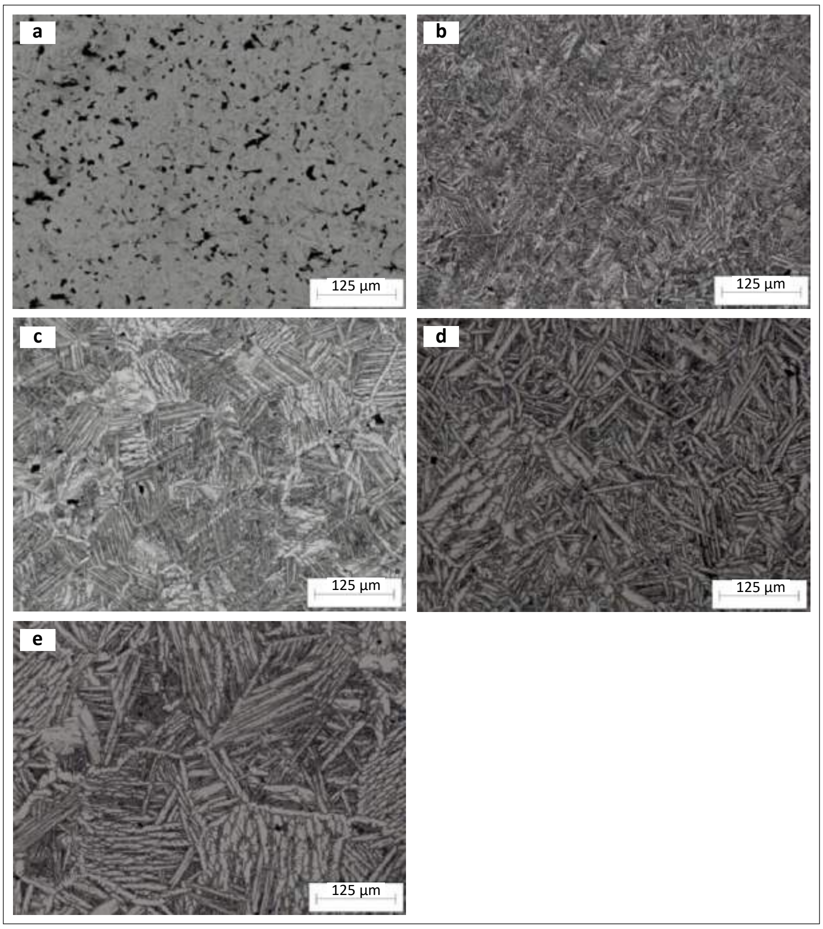

Fig. 9 Optical micrographs of PIM-Ti10Nb-10Zr samples sintered at (a) 1100°C – 1 h, (b) 1200°C – 1 h, (c) 1300°C – 1 h (d), 1400°C – 1 h and (e) 1500°C – 1 h [4]

allow high amounts of interstitials. However, ductility is negatively affected if a certain amount of interstitials is exceeded as are the fatigue properties. MIM Ti-6Al-7Nb does, however, seem to be slightly more tolerant to the presence of interstitials in terms of tensile properties compared with Metal Injection Moulded Ti-6Al-4V.

Mechanical properties and biocompatibility of MIM Ti-10Nb-10Zr alloy

Two poster papers by Isil Yemisci and Ozkan Gulsoy at Marmara University in Turkey, covered the powder injection moulding and mechanical properties of Ti-10Nb-10Zr alloy for biomedical applications. Their research also included the electro-chemical and biocompatibility of the Ti-10Nb-10Zr alloy.

The first paper by the authors covered the microstructural evolution and mechanical properties of β type sintered Ti-10Nb-10Zr alloy produced by MIM using elemental powders the characteristics of which are shown in Table 5 [4]. The Ti powder was an irregular shaped HDH Ti sponge powder having a particle size D_{50} = 32.69 µm; the Nb and Zr powders also had irregular shapes with particle sizes of D_{50} = 8.53 µm and D_{50} = 6.97 µm respectively. The elemental powders were mixed with a multiple-component binder consisting of paraffin wax, polypropylene, carnauba wax and stearic acid with powder loading in the mixture at 55 vol.%. Feedstock was prepared at 175°C with the binder melted first and then the powder blend added incrementally. The feedstock was injected moulded using a pressure of 12.5 MPa in a specially made injection-moulding machine to produce tensile (MPIF 50) test bars for MIM specimens.

Following a two-step solvent/thermal debinding operation, the green parts were pre-sintered at 900°C in argon for 1 h followed by increasing the temperature to 1100°C at incremental steps of 10°C/min and then final sintering at different temperatures up to 1500°C in vacuum. The densities and mechanical properties of MIM Ti-10Nb-10Zr obtained under different conditions are shown in Table 6. The sintered density, ultimate tensile strength, elongation and hardness were reported to be 99%, 738 MPa, 14% and 111.6 HRB, respectively when sintered at 1500°C for 1 h.

Fig. 9 shows the optical micrographs obtained for MIM Ti-10Nb-10Zr samples sintered at temperatures from 1100°C to 1500°C for 1 h. The sintered MIM samples were found to have a coarse acicular microstructure, revealing α grains with intergranular β-phase. The percentage of α-phase in the alloys was found to depend on the sintering conditions. A lower sintering temperature affects porosity and the amount of α-phase, which appears precipitated at the grain boundaries, darker than β-phase. Samples sintered at high temperatures and longer times possessed Widmanstatten microstructure, which consisted of α and β lamellae. The β grains were outlined by the α phase and contained several colonies of α and β lamellae. The colonies had α and β lamellae aligned in the same orientation. The β grains, α colonies and α phase thickness in the β grains had a significant effect on properties.

In a second paper Isil Yemisci and colleagues reported on their studies of the electrochemical properties and biocompatibility of the MIM Ti-10Nb-10Zr alloy sintered at 1500°C for 3 h in high vacuum [5]. Fig. 10 shows the optical micrographs of a Ti10Nb10Zr sintered sample which followed the description of the microstructure given in the first paper by the authors above. Cylindrical sintered samples polished to a mirror finish in alcohol, were subjected to electrochemical evaluation tests in two different environments: a salt solution (3.5% NaCl) and artificial saliva solution (ASS) using potentiodynamic polarisation. The critical parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}) and corrosion rate were evaluated from the polarisation curves. The researchers stated that according to Tafel curves the corrosion rate of MIM Ti10Nb10Zr samples in ASS is lower than in salty solution media which is due to the more aggressive environment constituted by the salty solution (Fig. 11).

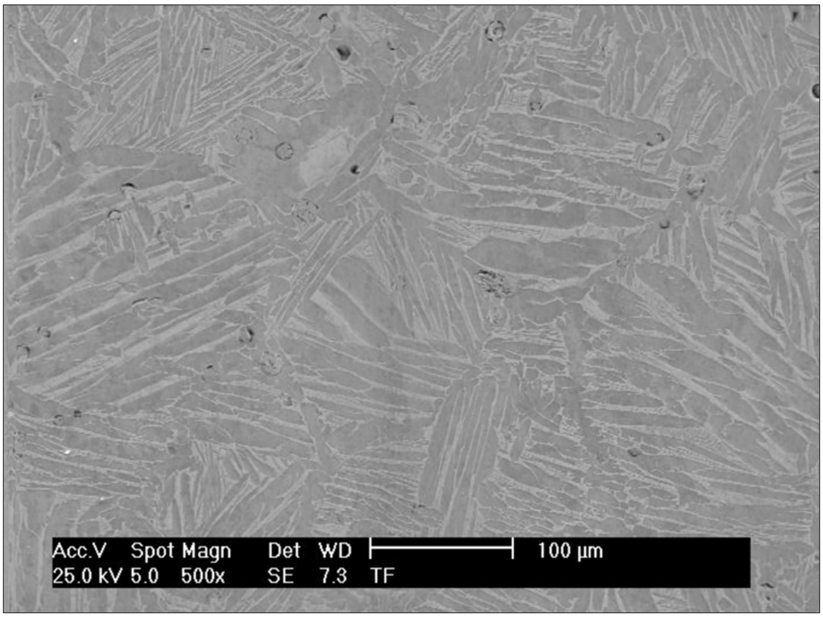

Fig. 10 SEM micrograph of Ti10Nb10Zr sample sintered at 1500°C for 3 h [5]

Bioactivity was also investigated to evaluate biocompatibility of the sintered MIM samples in a self body fluid (SBF). Surfaces after immersion in SBF and proliferation of cells were analysed using scanning electron microscope (SEM). SEM morphologies of the sintered sample surfaces after immersion in the SBF showed that, after seven days immersion, many globular apatite particles had grown onto the surface of the samples with the Ti10Nb10Zr alloy material scarcely observed on the surface and only Ca and P apatite particles seen on the biomaterial surface. With the increase of immersion time in SBF, the quantity and size of the apatite particles increased gradually. Table 7 shows the element concentration of the sintered MIM Ti10Nb10Zr sample in SBF.

The authors concluded that mechanical, corrosion and SBF immersion tests and results from SEM morphologies of the sample surfaces after immersion in the SBF for various times show that the Ca-deficient apatite is bone-like apatite with excellent bioactivity. The

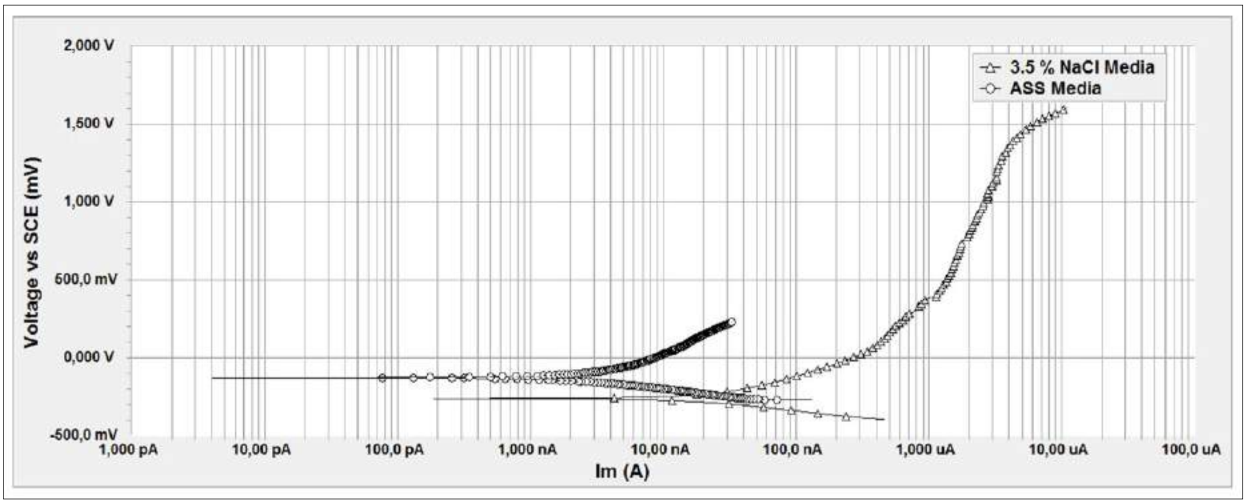

Fig. 11 Tafel curves for the Ti10Nb10Zr samples in salty and ASS media [5]

	Elements (wt.%)					
	Ti	Na	P	Cl	K	Ca
7 days	75.87	7.33	5.39	3.17	4.58	3.66
15 days	61.13	9.11	9.62	7.23	6.4	6.51

Table 7 Element concentrations of sintered Ti10Nb10Zr sample in SBF [5]

Ti10Nb10Zr alloys are high strength and good bioactive materials and are promising for application as biomedical materials. They further conclude that the results of cell culture show that the MIM Ti10Nb10Zr samples are well tolerated by the 3T3 mouse fibroblasts, which showed normal morphology and attached onto the samples over the incubation times.

References

[1] 'Effect of Sintering Conditions on Microstructures and Mechanical Properties of Ti-29Nb-13Ta-4.6Zr Alloy Fabricated by MIM Process', E Endo *et al*, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

[2] 'Powder Injection Moulding of low modulus Ti-13Nb-13Zr for implant Application'. J–E Bidaux *et al*, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

[3] 'Fundamental Understanding of the Influence of Oxygen on the Fatigue Behaviour of Ti-6Al-7Nb Alloys'. A Hidalgo *et al*, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

[4] Microstructural Evolution and Mechanical Properties of β-type Ti10Nb10Zr Alloy produced by Metal Injection Molding', I Yemisci, H O Gulsoy, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

[5] Powder Injection Moulded Ti10Nb10Zr Alloy for Bio-applications: Electrochemical Properties and Biocompatibility. I Yemisci *et al.* as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

Author

Bernard Williams
Consulting Editor
PIM International
Tel: +44 (0)1743 454990
Email: bernard.williams2@btinternet.com

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World PM2016: PIM as a route to high performance superalloy components for aero engines and gas turbines

In the second of his reports on Powder Injection Moulding presentations at the World PM2016 Congress held in Hamburg, germany, October 9-13, Bernard Williams focuses on high temperature (HT) alloys for applications in aero engines and land based gas turbines. As well as covering the use of PIM for well known HT nickel-base superalloys such as Inconel 713LC and Inconel 718 the report also includes the Powder Injection Moulding of a new class of HT alloys based on Nb-Si.

Influence of heat treatment on properties of MIM IN 713LC Ni-base superalloy

Nickel-base superalloys are an important class of materials for aero engines and land based gas turbines because of their combination of excellent properties at operating temperatures up to 950°C and superior corrosion resistance. IN 713LC, the composition of which is shown in Table 1 (overleaf), is normally used in the as-cast condition at high operating temperatures and there is almost no information published on relevant properties such as fatigue and creep behaviour of this material when produced by Powder Injection Moulding.

Katharina Horke (Rolls Royce Deutschland) and co-authors at the Joint Institute of Advanced Materials and Processes (ZMP) at Friedrich-Alexander-University Erlangen-Nürnberg, Germany, have undertaken research to evaluate the potential of the PIM route for the manufacturing of complex shaped components from IN 713LC alloy and specifically to study the effect of solution annealing followed by an ageing treatment on the tensile, fatigue and creep properties of sintered MIM IN 713LC [1]. This work was carried out within the framework of the BMWi (Bundesministerium für Wirtschaft und Energie / Federal Ministry for Economic Affairs and Energy) funded LuFo project RHinnoVer (funding code: 20T1111).

The as-sintered MIM IN 713LC test samples were produced by Schunk Sintermetalltechnik GmbH (Thale, Germany). As reference, cast and HIPed IN 713LC material was used. Sintered density of the MIM test pieces was greater than 99%. Solution annealing heat treatment of the test pieces was performed under high vacuum conditions (10^{-5} - 10^{-6} mbar) for two hours at 1220°C followed by rapid furnace cooling under flowing argon. Ageing was performed using two different time cycles at

Fig. 1 Congress Centrum Hamburg was the venue for World PM2016

Ni	Cr	Mo	Nb	Ti	Al	Zr	Mn	Si	C
Balance	11-13	3.8-5.2	1.5-2.5	0.5-0.9	5.5-6.5	0.05-0.15	≤ 0.25	≤ 0.5	0.03-0.07

Table 1 Chemical composition of Inconel 713LC according to SAE AMS5377 standard in wt.% [1]

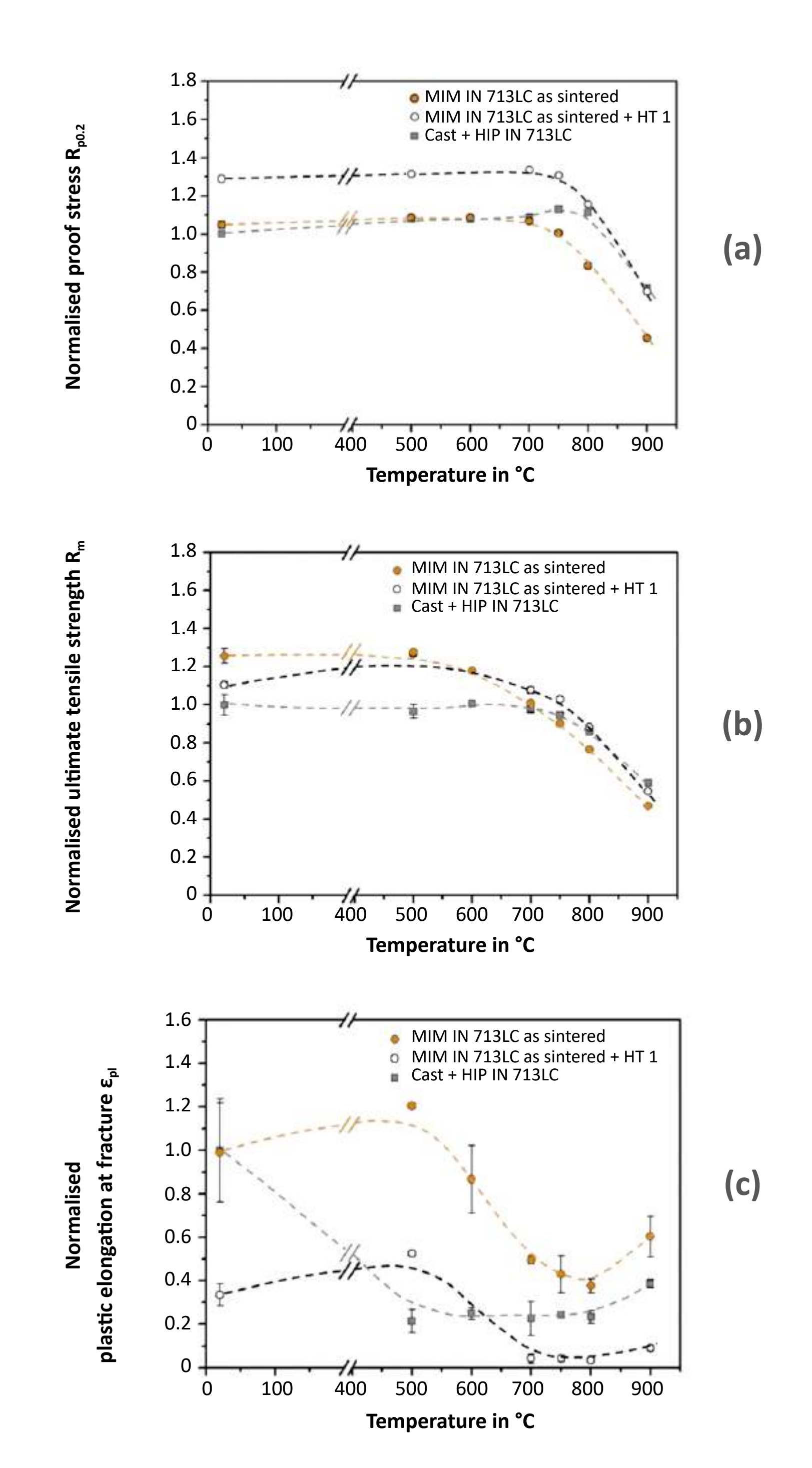

Fig. 2 Normalised (a) 0.2% proof stress, (b) ultimate tensile strength and (c) plastic elongation at fracture of as-sintered MIM IN 713LC, as-sintered and heat treated MIM IN 713LC and cast + HIP IN 713LC. The values were normalised to the values for R_m, $Rp_{0.2}$ and the elongation at fracture of the cast + HIP IN 713LC material at room temperature [1]

925°C – the first for 4 hours (HT 1) and the second for 16 hours (HT 2), both followed by air cooling. However, as the microstructures after both heat treatment cycles were very similar, only the 4 h cycle was used for mechanical testing of the MIM samples.

Horke reported that heat treated MIM IN 713LC is characterised by refined γ' size (refinement of the initial γ' edge length from approx. 0.6 µm to 0.3 µm) and increased carbide precipitation at the grain boundaries compared to as-sintered material. Accordingly, the mechanical properties of MIM IN 713LC material are influenced by the heat treatment. In Fig. 2 the influence of heat treatment on the ultimate tensile strength (R_m), the 0.2% proof stress ($R_{p0.2}$) and the elongation at fracture of MIM IN 713LC is plotted as a function of temperature. The tensile test data for as-sintered MIM IN 713LC and cast and HIPed IN 713LC are given as reference values. Compared to as-sintered MIM IN 713LC, R_m and $R_{p0.2}$ at elevated temperatures are increased after heat treatment which is attributed to refined γ' and carbide precipitation at the grain boundaries. However, the increase in strength is accompanied by a severe reduction in ductility. Compared to the cast + HIPed alloy, MIM IN 713LC exhibits higher strength for temperatures up to 700°C. The ductility of MIM IN 713LC in the as-sintered condition is higher than that of the tested cast + HIPed alloy. However, after heat treatment the ductility is lower for most test temperatures compared to the cast + HIPed reference material.

The applied heat treatments were also found to lead to an improvement of the time to rupture for the same applied stresses compared to as-sintered material in a temperature range from 700°C to 800°C, presumably due to grain boundary stabilisation against sliding.

For 500°C and 83 Hz test frequency rotating bending fatigue properties equivalent to as-sintered MIM IN 713LC material are obtained in the heat treated condition and both the as-sintered and heat treated variants show better fatigue behaviour compared with cast + HIP IN 713LC (Fig. 3). The improved fatigue properties were attributed to the much finer microstructure of the MIM alloy.

The authors concluded that a combination of PIM and heat treatment to produce high performance MIM Inconel 713LC materials can provide an opportunity for improvement of selected mechanical properties of this material.

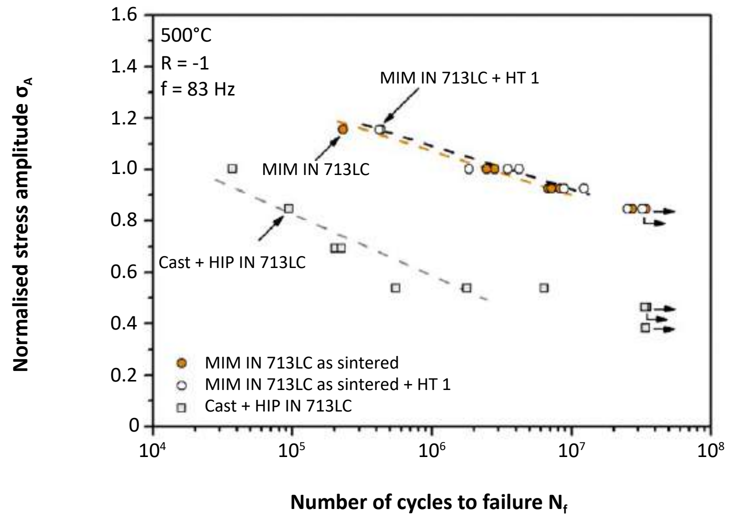

Fig. 3 Normalised S-N curve for rotating bending tests performed at 500°C with as-sintered MIM IN 713LC, as-sintered and heat treated MIM IN 713LC and cast +HIP IN 713LC reference material. The values were normalised to the highest applied stress for cast +HIP IN 713LC [1]

Nb-Si alloy powder tested for high performance turbine parts made by PIM

Marco Mulser (Fraunhofer IFAM, Bremen) and co-researchers at Karlsruhe Institute of Technology and the University of Birmingham, reported on the results of research carried out within the HYSOP project (EU 7th Framework Programme) to develop a new class of materials based on Nb-Si alloys capable of operating at higher temperatures than currently possible with nickel-base superalloys used in aero engines and land based gas turbines which are limited to around 1100°C [2]. A substantial increase in turbine materials operating temperature would permit either a combustion temperature increase of around 200°C or a significant reduction of cooling air flows (or a combination of these).

The authors stated that refractory alloys such as niobium-based silicide composites are promising materials for gas turbine applications because of their high temperature (HT) strength and reduced weight with Nb-Si alloys offering a density of about 7 g/cm³ which is significantly lower than the density of superalloys. These Nb-Si alloys consist of a ductile niobium solid solution (Nb_{ss}) matrix, which provides room temperature toughness, and an intermetallic silicide phase (Nb_5Si_3) that provides the HT strength. The required oxidation resistance at application temperature is provided by a coating.

The authors reported that Nb-Si powder having a nominal composition of Nb-20Si-23Ti-3Cr-6Al-4Hf (at%) was produced by electrode Induction Melting Gas Atomisation (EIGA) with the fine gas atomised (GA) powder fraction (<25 µm) used for the MIM feedstock. They also endeavoured to increase the yield of usable atomised powder for MIM by reducing the particle size of the coarser fraction (45-106 µm) through mechanically milling. Heptane was used as the milling agent. The particle size was reduced to 38 µm (d_{90}), but with a significant fraction of coarser particles remaining. Thus, the powder was sieved to <45 µm under inert gas. Fig. 4 shows the particle size distribution of the MM powder measured by laser diffractometry after sieving in comparison to the fine GA powder fraction. The fine fraction (<25 µm) GA powder consists of smooth spherical particles, whereas the MM <45 µm powder has irregular shaped particles. The carbon content in the MM powder increased significantly (0.80%) which the researchers attributed to the use of heptane as a milling agent. The oxygen content of the MM powder at 0.51% also increased during milling. However, C and O_2 pick up during sintering of the MM samples was found to be rather small.

The resulting GA and MM powders were mixed separately with a multi-component binder containing polyethylene, waxes and stearic acid with powder loading at 62 vol.% for the MM powder to achieve adequate flowability for injection moulding and 70% powder loading for the fine spherical GA Nb-Si powder. Injection moulded parts were first debound by solvent extraction of the wax ingredients, followed by thermal debinding (1 h at 600°C in argon) and sintering (3 h at 1525°C in high vacuum) which were carried out in a combined debinding/sintering furnace. The MIM samples were surrounded by getter material of pre-sintered coarse Nb-Si powders to prevent oxidation on the sample surface during sintering. The authors stated that the MM powder feedstock could be injection moulded without issues whereas

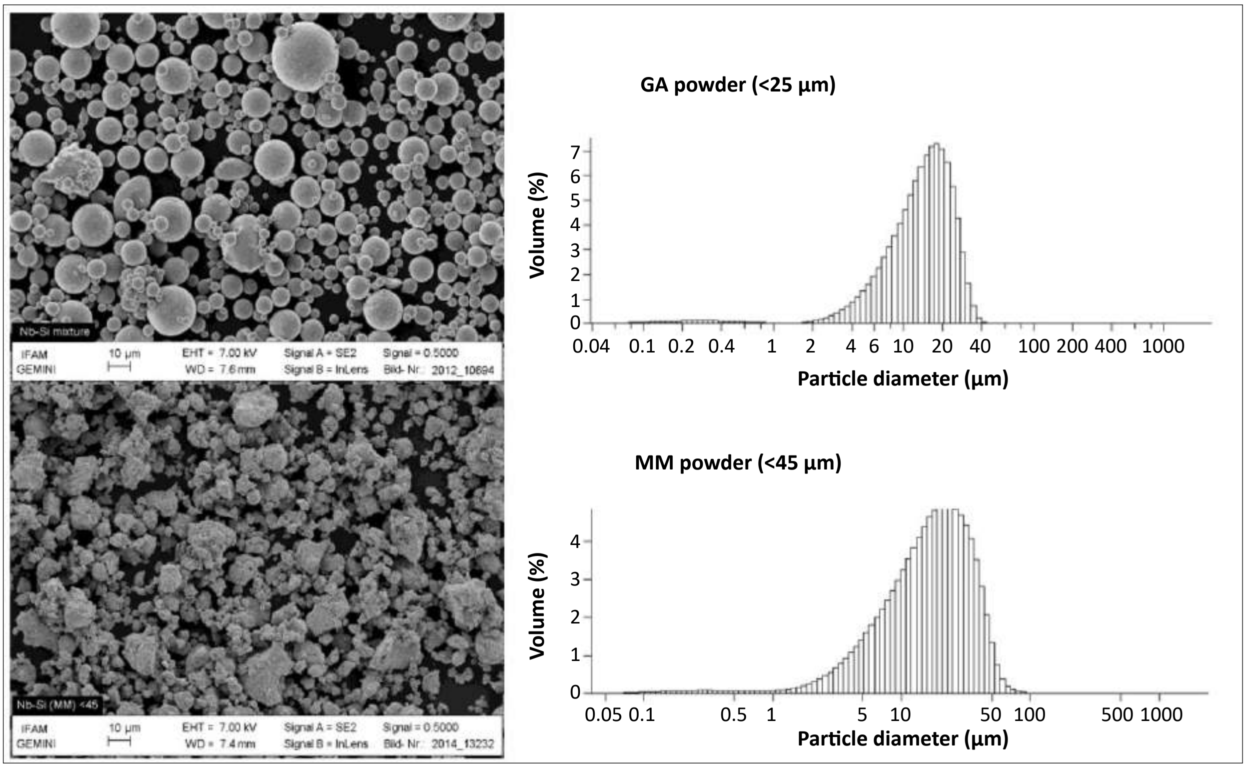

Fig. 4 SEM image and particle size distribution of the gas atomised (GA) and mechanically milled Nb-Si alloy powder [2]

the GA powder feedstock exhibited phase separation during moulding. Also the MM powder feedstock showed much better shape retention during debinding and sintering than the GA powder feedstock. This was explained by the fact that the sintering of Nb-Si alloy starts at around 1300°C giving better part stability through the interlocking of the irregular shaped MM powder particles in the brown parts.

The as-sintered MIM samples from MM Nb-Si powder reached a density of 6.79 g/cm³ which equates to a relative density of 99.1% (Fig. 5). After additional HIPing the density reached 6.81 g/cm³ (99.4%). The density values obtained for the MM powder are comparable to those achieved with the GA powder.

The compressive strength of the as-sintered samples of GA powder was about 620 MPa, which increased after additional HIPing to about 650 MPa as can seen in Fig. 6. However, the researchers stated that the measured values are comparable to those of the single-crystal superalloy CMSX-4 with a reported compressive strength of 570 MPa at 1000°C. Regarding the specific mechanical properties (strength divided by density), the as-sintered values (91 Nm/g) and the HIPed values (99 Nm/g) of Nb-Si are significantly higher than for CMSX-4 (66 Nm/g) due to the lower density of Nb-Si compared to CMSX-4 (8.7 g/cm³).

"the results...provide a solid basis on which to develop PIM debinding and sintering processes for geometrically complex shaped components for high temperature turbine parts"

The authors concluded that the results of the project to-date provide a solid basis on which to develop Powder Injection Moulding debinding and sintering processes for geometrically complex shaped components for high temperature turbine parts. A demonstrator part shown in Fig. 7 was successfully produced by PIM using both the GA and MM powders, although as mentioned shape retention was much better in the MM feedstock compared with the GA powder feedstock. The as-sintered and additionally HIPed MIM samples of the MM powder show comparable values to the samples from GA powder with respect to microstructure, residual porosity and density. The increase in carbon and oxygen content during milling of the MM powder and its impact on the mechanical properties at elevated temperatures will be further investigated.

Microwave and field assisted sintering of MIM Inconel 718 superalloy

Inconel 718 is a nickel-chrome superalloy which shows high strength and creep resistance at elevated temperatures in addition to good corrosion resistance. However, this superalloy is difficult to machine, which imposes dimensional limits and often results in a significant loss of machined material in order to obtain the desired finish shaped component. Metal Injection Moulding is capable of volume production of complex near-net shape Inconel 718 components with low loss of material and with mechanical properties close to those of the machined parts. In the sintered condition the microstructure of the Inconel 718 has been reported to be composed of a γ matrix reinforced by a γ' phase Ni_3 (Al, Ti) and a γ'' phase Ni_3 (Nb, Ti). These two intermetallic phases are said to be responsible for the increase in hardness and the good mechanical properties of the alloy at high temperature.

Olivier Dugauguez and colleagues at the Université de Franche Comté, Besancon, France, and the Universidad Carlos III de Madrid, Spain, have compared conventional MIM sintering with microwave and Field Assisted Hot Pressing (FAHP) in order to reduce the time and energy needed for this important MIM processing step [3]. The authors describe field assisted hot pressing (FAHP) as a method derived from hot pressing where the powder is introduced into a graphite die (punches and matrices) and subjected to a combination of uniaxial pressure and a high intensity electric current. The combination of pressure and electric pulses accelerates the sintering and consolidation processes and thereby reduces the time needed to achieve near full density components. The shorter sintering time can also limit grain growth achieving microstructures which can bring improved properties.

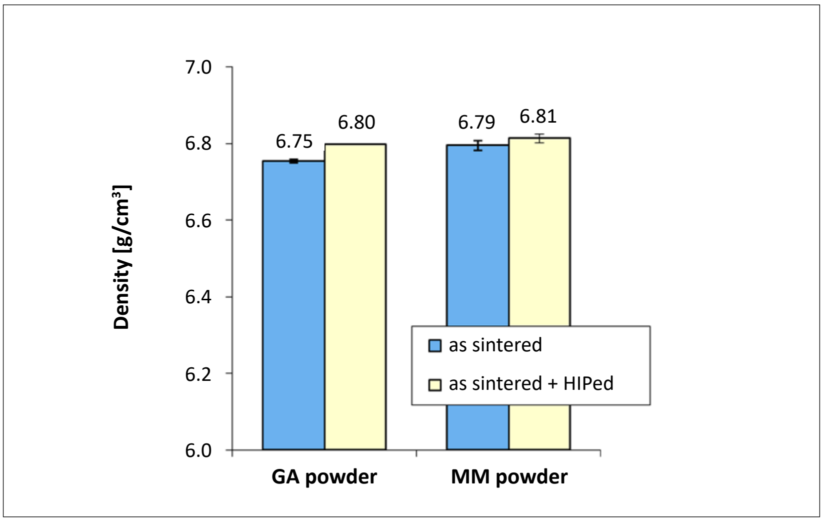

Fig. 5 Densities of MIM samples of the GA and MM powder before and after subsequent HIPing [2]

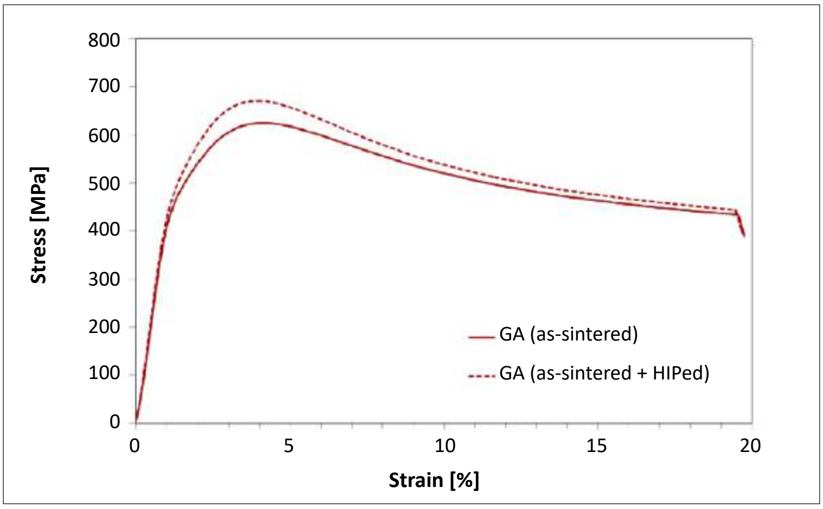

Fig. 6 Stress-strain curves from compression tests of MIM samples of the GA powder at 1000°C [2]

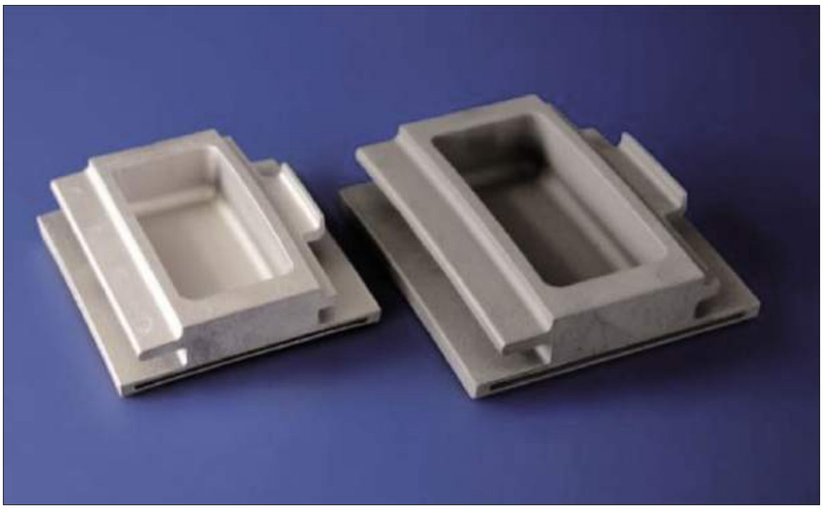

Fig. 7 MIM high temperature turbine demonstrator part (left: as-sintered; right: green part) [2]

Method	Conventional	Microwave	FAHP
Temperature	1290°C	1300°C	1250°C
Dwell time	120 min	60 min	10 min
Density	96.70%	95.8%	94.50%
Hardness	211.3 ± 3.4	191.2 ± 15.8	256.3 ± 5.7

Table 2 Comparison of the conventional, microwave and FAHP sintering methods and properties obtained [3]

Microwave sintering has been used to process ceramics and composites where the heating of the moulded parts is by the movement of the charged particles inside the material (ions, dipoles) created by the microwaves. The microwaves are able to penetrate the porosity of the injection moulded parts and offers a faster sintering compared with conventional sintering. By increasing the heating rate microwave sintering also has a positive effect on grain size distribution in the sintered parts and consequently also the mechanical properties. The authors have reported on their results comparing both FASP and microwave sintering with conventional sintering specifically on the effect of different heating rates on the obtained microstructures and properties.

"By increasing the heating rate microwave sintering also has a positive effect on grain size distribution in the sintered parts and consequently also the mechanical properties"

The Inconel 718 (Ni-19Fe-19Cr-3Mo-0.5Al-0.9Ti-5.3Nb) powder used in the study was produced by gas atomisation and comprises particle size volume fractions D_{10}, D_{50} and D_{90} of 3.53 µm, 6.24 µm and 10.97 µm respectively. The binder used to produce the feedstock comprises CAB (cellulose acetate butyrate) and PEG (Polyethylene Glycol), Stearic Acid (SA) and Phenothiazine (PTZ). Debinding is first done by immersing the green parts in distilled water at room temperature for 48 h to remove the PEG. They are then dried in an oven at 50°C for 5 h. The CAB is removed by thermal debinding at 500°C for 3 h in argon.

The density of the MIM Inconel 718 samples sintered conventionally in a high vacuum furnace at 1290°C for 2 h was the highest at 96.7% as shown in Table 2. Fig. 8 shows the dilatometric curve for the Inconel 718 alloy and the evolution of shrinkage during sintering. The authors stated that the first decrease in height of the samples was at 160°C which corresponded to the thermal debinding of the CAB; the second decrease started at around 1090°C which was the beginning of sintering.

In the sintering of the MIM Inconel 718 using FAHP the PIM sample was consolidated in a Gleeble 3800 equipment by applying an alternating current of 50 Hz going through the punches under vacuum. The PIM sample is composed only of powder barely held together with a small amount of polymer binder. The heating rate of the sample is fixed at 50°C/min until the desired temperature is reached. A dwell time is applied at 600°C when a minimum pressure of 5 MPa is applied and is maintained until the cooling is completed. The shrinkage of the sample is measured via the displace-

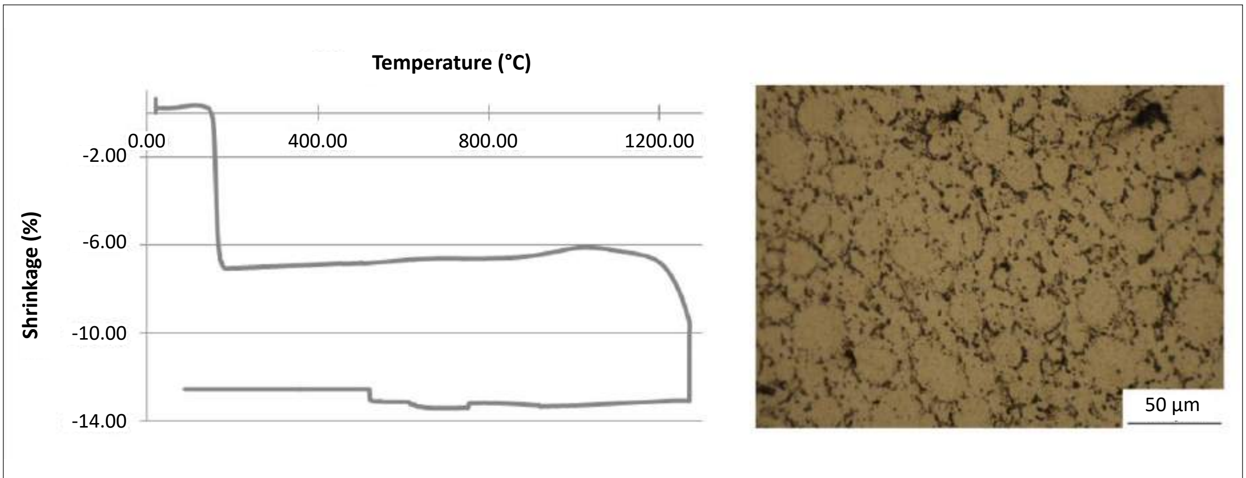

Fig. 8 Dilatometric curve of Inconel 718 sintered at 1200°C for 2 h [3]

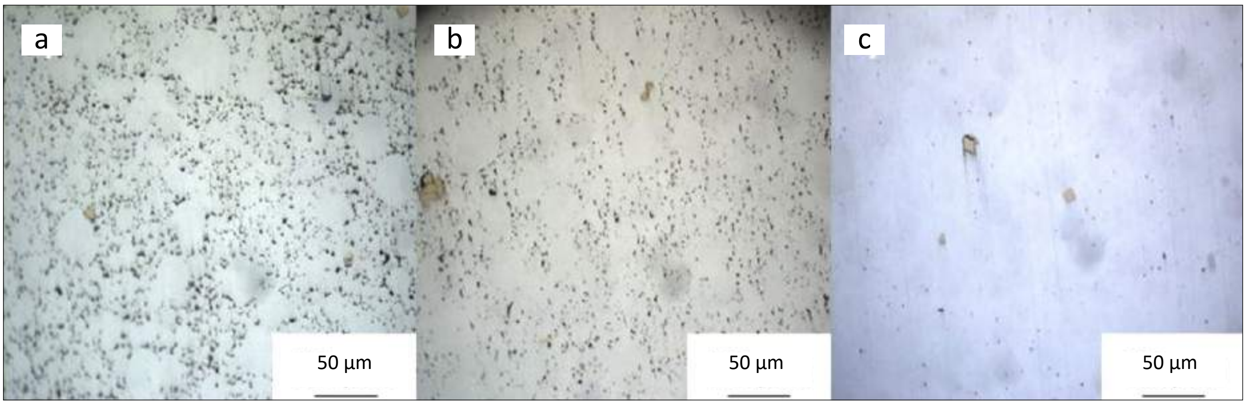

Fig. 9 Optical Microscopy images of the samples sintered by FAHP at (a) 1100°C, (b) 1200°C and (c) 1250°C [3]

ment of the punches. The application of pressure during FAHP allowed the sintering temperature to be reduced to 1250°C at which the highest density of 94.5% was reached. Fig. 9 shows the porosity which can still be observed but with a well developed microstructure. The authors believe that the density can be improved by adjustment of heating rate and dwell time during sintering. FAHP gave the best result in terms of hardness and also reduced sintering time.

Microwave sintering was done in a furnace developed by Sairem where the PIM sample is introduced into a chamber comprising a quartz tube positioned with the help of an alumina tube in front of the microwave source. The power of the microwaves was set to between 0.10 and 3.0 kW. The power of the microwave source is increased in line with 100°C/min temperature increases until around 1300°C. Density reached was 95.8% and Fig. 10 shows the microstructure of the microwave sintered sample after sintering times of 30 min and 60 min with longer time resulting in a more homogeneous microstructure. The relatively low hardness level was said to be due to cracks found on the sintered surface which the authors attributed to too high a heating rate during debinding and also to the formation of hot points inside the sample during microwave sintering.

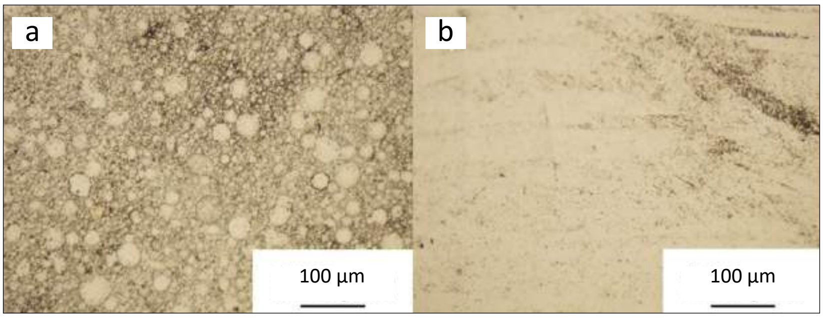

Fig. 10 Optical microscopy images of the PIM samples sintered by microwave during (a) 30 min and (b) 60 min. [3]

References

[1] 'Influence of Heat Treatment on Tensile, Fatigue and Creep Properties of Nickel-base Superalloy IN 713LC Fabricated by Metal Injection Moulding', K Horke *et al*, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

[2] 'MIM for HT Turbine Parts: Gas Atomized versus Mechanically Milled Nb-Si Alloy Powder', M Mulser *et al*, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

[3] 'Effect of Microwave and Field Assisted Sintering on the Mechanical Properties of Inconel 718 MIM Samples'. O Dugaugue *et al*, as presented at the World PM2016 Congress, Hamburg, October 11-14, and published in the Proceedings by EPMA, Shrewsbury, UK.

Author

Bernard Williams
Consulting Editor
PIM International
Tel: +44 (0)1743 454990
Email: bernard.williams2@btinternet.com

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ExOne: Customised and low volume 316L stainless steel firearms components using Binder Jetting technology

ExOne® Binder Jetting 3D printing technology offers Metal Injection Moulding (MIM) producers an effective route to overcome the challenges of low volume and customised component production where tooling costs make conventional production unviable. The technology has the added advantages of being able to use existing MIM furnaces for sintering and, thanks to recent system enhancements, standard MIM grade powders. In the following article the team from The ExOne Company (ExOne) highlights recent innovations along with the use of the technology by US custom firearms component specialist Wicked Grips.

Wicked Grips, a firearm components manufacturer in Davison, Michigan, USA, wanted to offer its customers a unique product in an ever changing market. The company defines itself as a true custom shop where customers can get high quality products that are one of a kind. Owner, Ed Strange, knew that this would require the ability to maintain low inventories in order to offer a greater variety of products. Typically, Wicked Grips relies on conventional manufacturing methods such as MIM, stamping and Investment Casting to produce parts. These methods, however, limit Wicked Grips' ability to offer diversity in products because of the high cost of tooling, startup costs and the required quantities for production. This led Strange to contact ExOne and explore the capabilities of Binder Jetting 3D printing and how this technology would fit into his company's process.

Wicked Grips wanted to continue to use non-corrosive materials for its products and ExOne had recently released new machine enhancements that enabled the use of standard MIM industry materials. This combination allowed ExOne to produce Wicked Grips products using 316L stainless steel, one of the most popular MIM materials in the firearms sector (Fig. 1). This austenitic material is known for its superior corrosion resistance properties and is also widely used in the automotive and medical industries.

316L parts produced using the ExOne® process therefore enable the production of low volume and prototype quantities of parts that traditionally would have been produced through MIM. In addition, designs are able to be made more

Fig. 1 Recoil spring plugs manufactured by Wicked Grips using ExOne® Binder Jetting technology and MIM-grade 316L stainless steel powder

Part design considerations	
Max. length	114 mm
Min. length	10 mm
Corner radius	Max as design allows
Chamfer	>0.1 mm
Wall thickness	>1.5 mm
Holes	>0.38 mm depending on hole length
Accepted file formats	STL, STEP

Table 1 Part design consideraions in Binder Jetting

Material properties	ExOne 316L
Ultimate tensile strength (ATSM E8)	75 ksi (517 MPa)
Yield strength (0.2% offset)	31 ksi (214 MPa)
Elastic modulus	24 msi (165 GPa)
Elongation at break	34%
Hardness	74 HRB
Relative Density	96%+
Density	0.28 lb/in³ (7.7 g/cm³)

Table 2 Typical material properties using ExOne® 316L

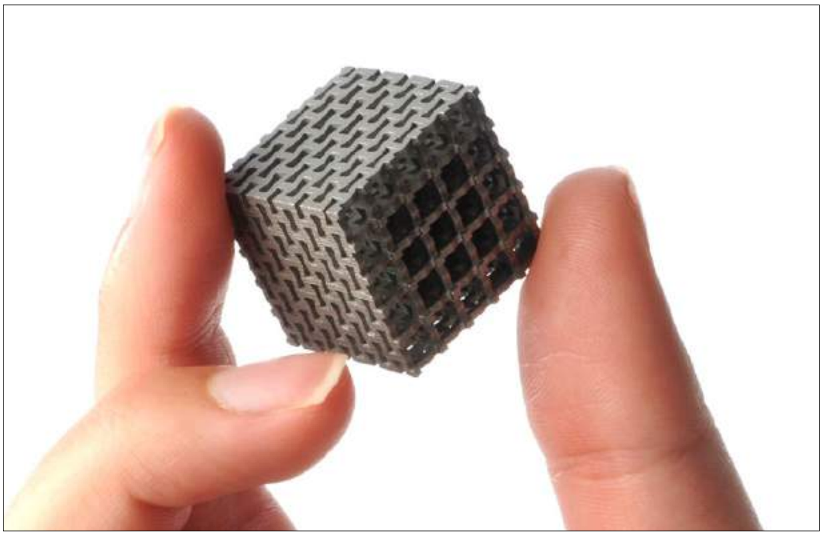

Fig. 2 An example of a highly complex ExOne® 316L stainless steel part

complex than traditional MIM (Table 1, Figs 1, 2).

ExOne 316L stainless steel parts have properties comparable to MIM parts, with ultimate tensile strength exceeding 75 ksi (Table 2). Parts produced using ExOne® technology are able to be used in production equipment or functional prototypes.

In order to offer customised parts, Wicked Grips had to alter their established design approach. Customisation had been limited using traditional manufacturing methods. The constraints of these traditional methods not only controlled part design, but also affected the quantities required to be ordered. With ExOne Binder Jetting, Strange and his team were able to use software such as Maya to create parts that were artistic and functional without the limitations that they previously experienced.

Strange explained, "ExOne gave our small business the ability to prototype and produce small runs of highly detailed parts at a fraction of the time and cost normally associated with this sort of production" (Fig. 3, Table 3). ExOne® metal 3D printing technology has now been used to print a wide range of intricate personalised back panel covers and recoil spring plugs in industry grade materials for firearm manufacturers with considerable savings on initial set-up and tooling costs.

Binder Jetting as a complementary technology to MIM

The challenges associated with Wicked Grips parts are familiar to those operating in a wide range of industry sectors. There is an increasing need for the ability to produce smaller lot sizes and wider variations of components with shorter lead times. MIM manufacturers can now augment their existing capabilities by offering smaller quantity runs. In addition, MIM manufacturers can take advantage of ExOne® Binder Jetting to print prototypes. Such flexibility reduces the number of mould iterations needed to finalise designs. The Binder Jetting process also offers the opportunity to provide the manufacturer and end-user with more complex parts than is possible with MIM. The possibility for part producers to use the same sintering furnaces for both their MIM and 3D printed parts is also a considerable attraction of the ExOne® process.

Printing with standard MIM powders

The 316L powder used in ExOne® Systems is the same powder that is commercially used for MIM applications. With MIM, the powder is held together with a binder. However,

Fig. 3 A firearm back panel cover manufactured by Wicked Grips using ExOne® Binder Jetting technology and MIM grade 316L powder

whereas MIM has a high percentage of binder content, parts produced using Binder Jetting have less than 1% binder content. By using the same powders as MIM, similar sintering furnace profiles are able to be used and similar properties are able to be achieved.

The freedom of part development without moulds

Since Binder Jetting involves directly printing the green part, the creation of moulds for compaction or injection moulding is unnecessary. This results in significant cost savings for both prototypes and low-volume production runs. Binder Jetting also overcomes some of the limitations in regards to part size in conventional Powder Metallurgy and MIM processes. Though controlling geometries and tolerances due to distortion with increased part size is an evolving challenge, Binder Jetting 3D printing is able to consistently produce parts larger than conventional MIM production.

Recent machine enhancements improve flexibility and resolution

Significant machine improvements were needed to enable the dispensing and forming of standard MIM grade powders. Whilst in MIM feedstocks the metal powder is pre-mixed with a binder to enable it to flow, Binder Jetting does not have this characteristic. Instead, Binder Jetting requires the powder to be dispensed and spread without the binder being combined with the powder in advance. ExOne's recent improvements in powder dispensing now allow non-flowing powders to be dispensed. With the improvements in spreading and compacting, density uniformity across the build volume has been improved. In addition to standard MIM powders, these latest machine improvements also allow users to print virtually any material that can be held together with ExOne® binder.

Since ExOne is capable of printing a wide range of materials, the company is now also able to offer powder feasibility testing to analyse the printability of a customer's powder. The customer then receives a report which includes particle size

Traditional methods	Start up	Order quantities	Turnaround time
Stamping, casting, CNC, MIM	\$10,000-\$15,000	Min. 2,000 - 5,000 pcs	Months
ExOne Metal 3D Printing	**Start up**	**Order quantities**	**Turnaround time**
Binder Jetting	No fees	No minimum	Weeks

Table 3 Cost advantages versus conventional manufacturing

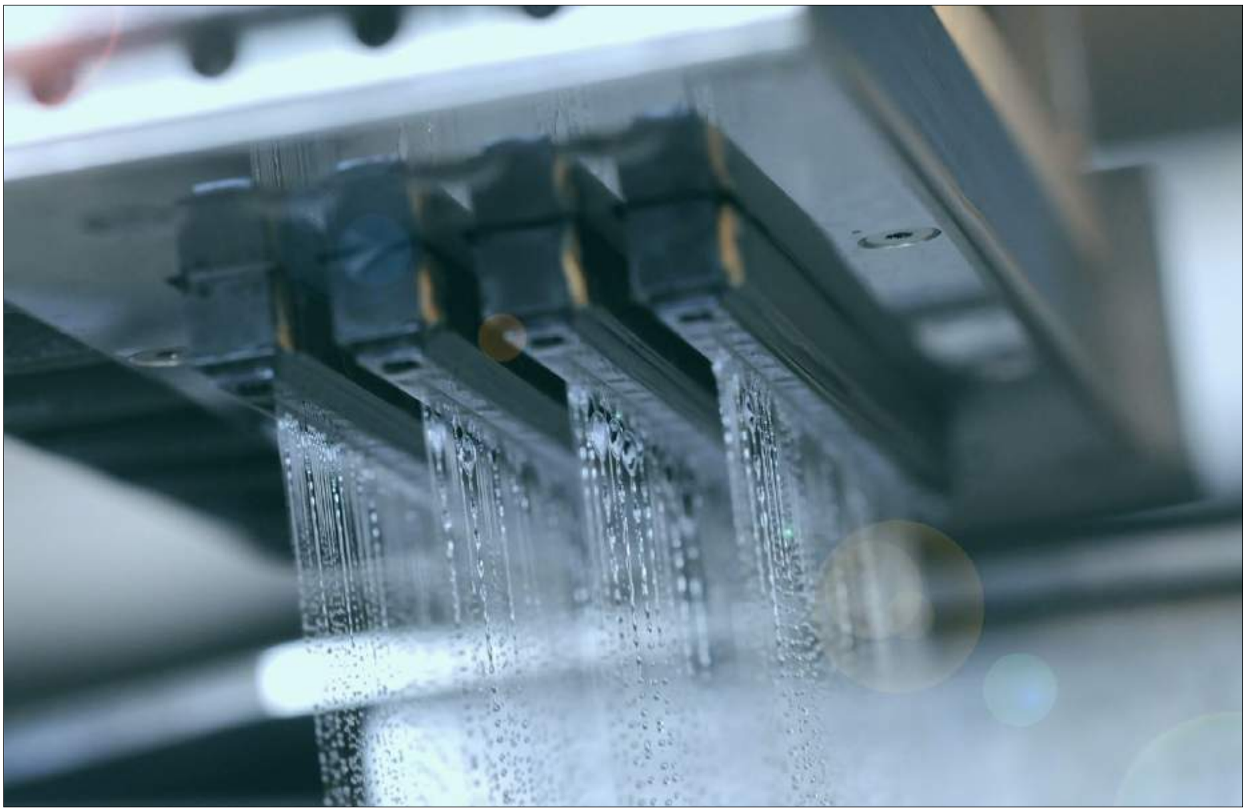

Fig. 4 Recent enhancements to ExOne® technology have enabled parts to be produced with improved resolution and decreased surface roughness

analysis, powder shape and size, powder flow properties, analysis of powder-binder compatibility and recommendations for the best path to printing. Based on the results from these initial steps, ExOne may work with the customer to develop parts to be printed through its R&D department.

Printhead and binder system

Further machine enhancements to ExOne® printhead and binder systems have enabled parts to be produced with improved resolution and decreased surface roughness. One of these enhancements included print heads which disperse smaller droplets (Fig. 4). By utilising smaller droplets, along with finer powders, the voxel (the result of the integration between the powder and binder) was able to be made smaller and thus a higher resolution is achieved. Additionally, with continuously improved binder formulations, part surface roughness can be decreased.

Benefits of fine powder recoater enhancement

With the company's recent fine powder recoater enhancement, the dispensing and spreading of finer powders that typically are not able to be processed by 3D printing are now available. This feature also now allows users to work with a wider variety of materials traditionally used in powder forming techniques, such as a number of ceramics. This also includes non-spherical powders, low density powders, etc.

Wicked Grips future with Binder Jetting

Wicked Grips stated that with the capability to offer highly customised and low volume production through 3D printing it will continue to expand its product offerings thanks to an ability to access its inventory 'on demand'. Additional business development benefits, it was stated, also come from the ease of prototyping new, innovative products. The company is now offering glock panels and coil spring plugs with multiple design elements thanks to the flexibility of the ExOne® process and the ability to produce one-off parts.

ExOne offers full 3D printing contract services through its Production Service Centres (PSCs) around the world. This allows customers the ability to print parts as well as access additional services such as R&D materials development. ExOne recently added a new Elnik vacuum sintering furnace to increase contract manufacturing capacity at its North Huntingdon, PA, USA, facility.

Contact

Part Production and Development:
Brandon Cary, Industrial Sales and Marketing Specialist Email: brandon.cary@exone.com.

System Sales:
Laurie Gredence, Inside Sales
Email: laurie.gredence@exone.com.

www.exone.com

The ExOne process

ExOne® Binder Jetting is an Additive Manufacturing process in which a liquid binding agent is selectively deposited to join powder particles. Layers of material are then bonded to form an object. The printhead drops binder into the powder. The job box lowers and another layer of powder is then spread and binder is added. Over time, the part develops through the layering of powder and binder.

Fig. 5 An ExOne Innovent® system and control screen

Powders

The ExOne® process is compatible with several types of powders which allows customers to use powders that fit their process.

Powder dispensing and spreading

Powder is held in a hopper on the machine in order to be dispensed throughout the printing process. A counter-rotating roller is then used to compact and level the surface, leaving a smooth surface for printing.

Binder Jetting

After spreading powder, binder is deposited onto the print bed using the printhead. Dispensing between 450 and 900 drops per inch, the printhead traverses the bed to dispense binder only in the desired areas. The Binder Jetting process relies on proprietary ExOne® binders that are designed for certain powders and applications.

Curing process

Depending on the binder, the 3D printed parts are cured. The build box is placed in an industrial curing oven at around 200°C for 2-12 hours. The curing process strengthens the binder, allowing the part to be handled.

De-powdering

During the de-powdering process, a vacuum is used to remove bulk powder and air is used to clear fine features on the part. The unprinted powder that is removed from the build box is then sieved and returned to the machine for future production runs, resulting in the recyclability of powder.

Sintering

Parts produced with Binder Jetting can be sintered or infiltrated depending on the material printed or the desired material properties using an industry standard furnace. The infiltration process results in the porosity of the part being filled with bronze due to capillary action. Parts that are sintered shrink as the powder particles are bonded together, producing a highly dense part. ExOne® 316L parts are sintered to high density.

Finishing

After completing the sintering process, parts can be machined, coated or blasted to attain desired finishes.

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