Vol. 10 No. 2 JUNE 2016

FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

POWDER INJECTION MOULDING INTERNATIONAL

in this issue

Company profile: Zoltrix

PIM: A toolmaker's perspective

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Subscriptions
Powder Injection Moulding International is published on a quarterly basis as either a free digital publication or via a paid print subscription. The annual print subscription charge for four issues is £135.00 including shipping.

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Printed by
Cambrian Printers, Aberystwyth, United Kingdom

ISSN 1753-1497 (print)
ISSN 2055-6667 (online)

Vol. 10. No. 2 June 2016

This magazine is also available for free download from www.pim-international.com

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Powder Injection Moulding International

For the metal, ceramic and carbide injection moulding industries

Fresh perspectives on the world of PIM

By all accounts the global PIM industry is continuing to progress at a tremendous pace. Recent market reports suggest that sales have moved past the $2 billion mark and that within four years they will exceed $3 billion. Such reports of growth appear to be supported by news of substantial investments in production capacity around the world, as well as a steady expansion of the materials that can now be processed by Powder Injection Moulding.

One company that is continuing to expand and significantly increase production capacity is leading Chinese MIM producer Zoltrix Material International Limited. Despite reports of over-capacity in the Chinese MIM industry, we report how Zoltrix is driving forward with expansion, technological innovation and market diversification (page 45).

A fresh perspective on what is happening in the MIM industry can always be gained by talking to key figures in the supply chain. In this issue leading US-based PIM toolmaker Dynamic Engineering presents its vision of an industry that is on a rapid growth track and a technology that is being used for ever more sophisticated projects (page 53).

There is also growing evidence that titanium MIM is finally coming of age, with numerous MIM producers around the world now reporting to be in commercial production. One technology leader is Praxis Technology, a company that has already achieved considerable commercial success with Ti-6Al-4V MIM parts. We report on the company's development of higher performance Ti MIM materials with improved tensile strength and creep resistance (page 63).

Nick Williams
Managing Editor

Cover image
A selection of MIM parts manufactured by Zoltrix Material International Limited

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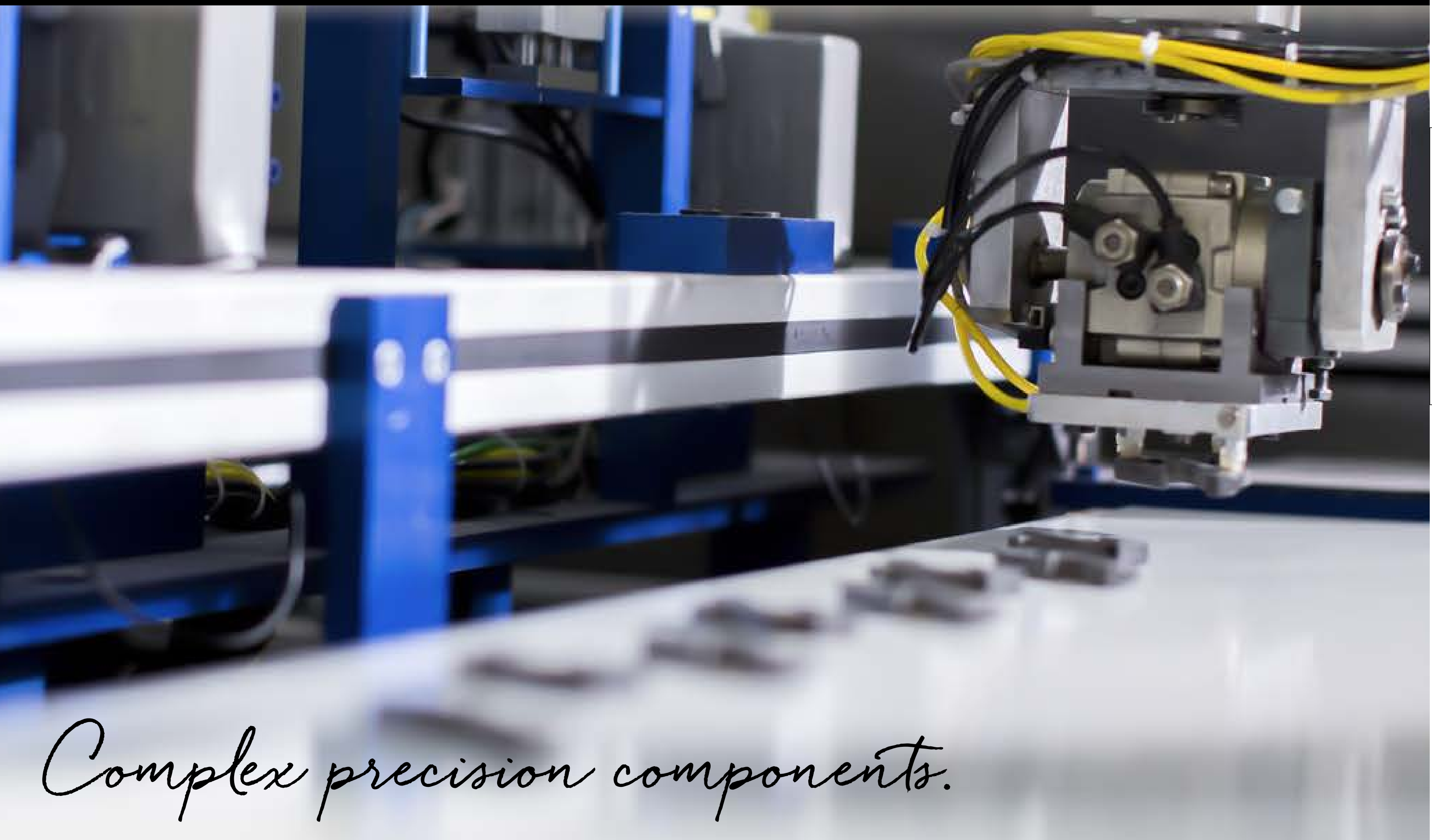

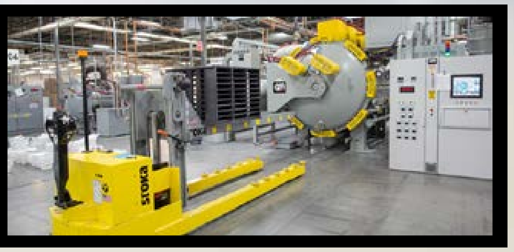

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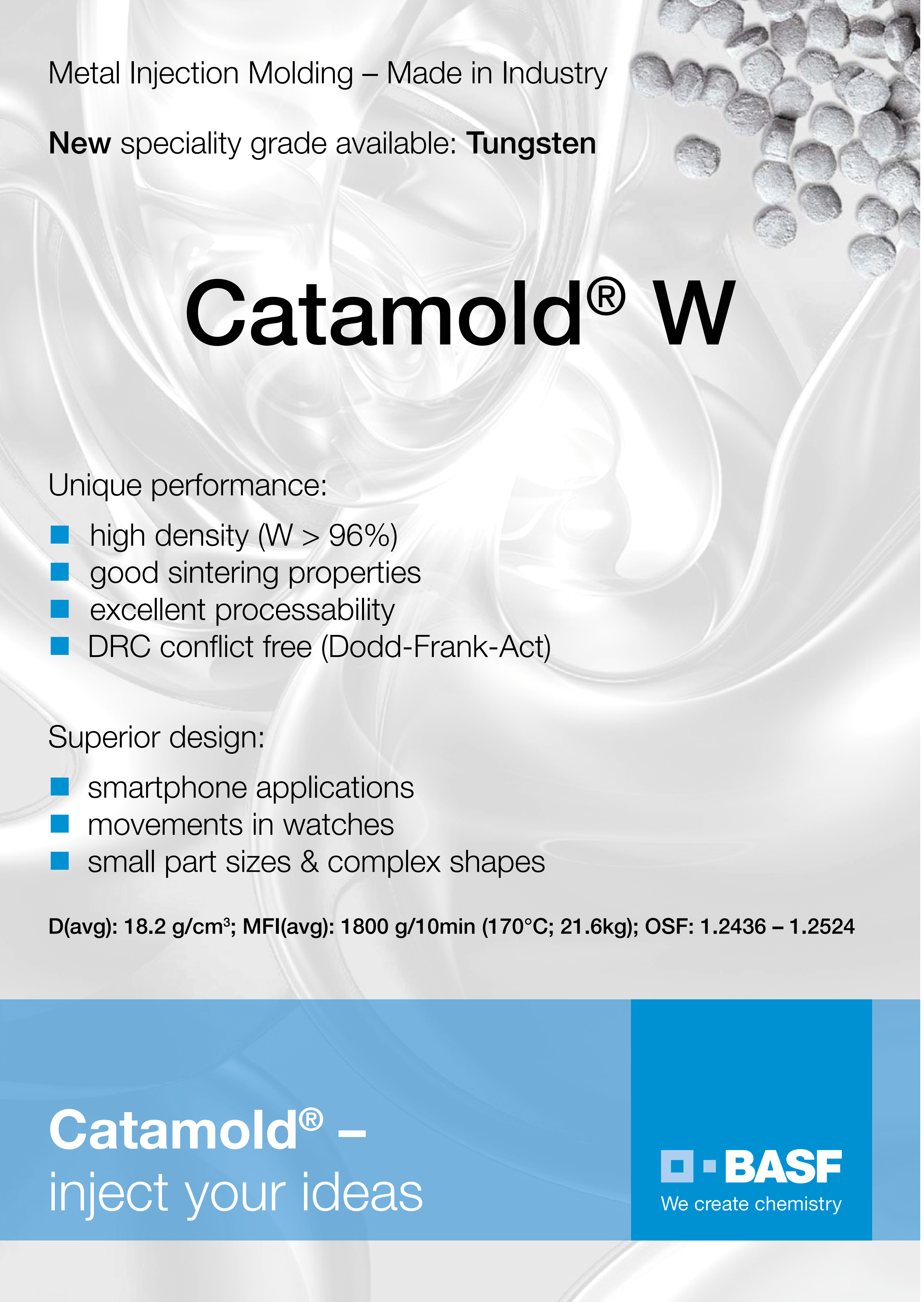
Powder Injection Moulding International

In this issue

Regular features



Industry News

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

World PM2016: Global PIM suppliers, manufacturers and researchers prepare to meet in Hamburg

The Technical Programme for the World PM2016 Congress & Exhibition has just been published by the European Powder Metallurgy Association. The event, which takes place in Hamburg, Germany, from October 9-13, 2016, includes more than 450 keynote, oral, poster and special interest presentations.

Metal Injection Moulding features prominently in the programme, which covers the whole spectrum of Powder Metallurgy, from conventional structural PM components to Additive Manufacturing, hard materials, diamond tooling and Hot Isostatic Pressing. The full technical programme consists of some 70 technical sessions, seven keynote paper award winners and five special interest seminars.

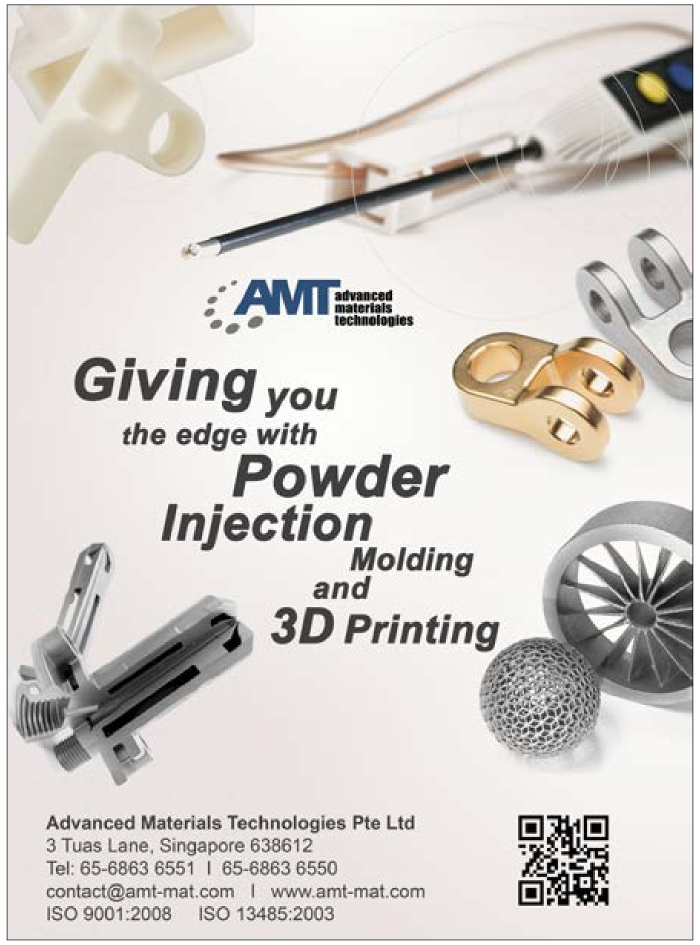
Dr Michael Krehl, World PM2016 Congress Chairman, stated, "Due to the high volume and quality of the abstracts submitted to the event, the Steering Committee took the unanimous decision to increase the number of technical sessions during the congress, which will make for an extensive programme covering all areas of Powder Metallurgy."

Congress Centre Hamburg will be the location for the World PM2016 Congress and Exhibition

A major exhibition will run in parallel to the technical sessions. Congress Centre Hamburg's Hall H will host the four-day exhibition, making it, stated the EPMA, the largest international Powder Metallurgy focused exhibition in 2016. The exhibition area features over 150 companies representing all aspects of the Powder Metallurgy supply chain. Up-to-date information on the technical programme, exhibition floor plan and details of how to register are available on the World PM2016 Congress & Exhibition website.

The September issue of *PIM International* will be widely distributed at PM2016 and the team at Inovar Communications looks forward to meeting visitors at our stand 199.

www.worldpm2016.com



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Demcon focuses on Metal Injection Moulding for high-tech industrial systems and medical devices

Demcon MIM, based in Oldenzaal, The Netherlands, is a subsidiary of Demcon, a company established in Enschede in 1993 to produce and supply products for high tech systems, industrial systems and medical devices.

The company claims that it is distinctive in the Metal Injection Moulding field for its in-house developed, environmentally friendly feedstock. This feedstock, states the company, has been optimised to result in a more robust process to produce high quality Metal Injection Moulded parts.

MIM parts manufactured by Demcon

The company's MIM production lines are equipped with machine vision solutions for 100% quality control and a coordinate measuring machine is available for sample control of shape and dimensional tolerances.

The company also licenses the process to produce its feedstock as well as supplying licences for MIM production know how, production control, automation and quality assurance. Rob Egberink, Managing Director of Demcon MIM, stated that the company can set up dedicated production lines with automatic robotic part handling.

www.demcon-mim.nl

MIM computer hinges in the limelight

According to *DigiTimes*, sources within the Apple supply chain claim that the next generation of the company's ultra-thin MacBooks will have Metal Injection Moulded hinges. US firm Amphenol, which also supplies specially designed hinges for the Microsoft Surface Pro tablets, is reported to have joined Apple's supply chain to produce these MIM hinges.

Whilst the use of Metal Injection Moulding for the production of hinges for laptops and netbooks is by no means new, these reports reflect the ongoing trend in the use of Metal Injection Moulding for the manufacture of complex, high strength components for the consumer electronics industry.

www.digitimes.com

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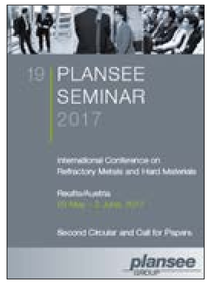
Micro's MIM technology eliminates secondary operation medical device

Micro, based in Somerset, New Jersey, USA, is a full-service contract manufacturer of precision medical and surgical components, complete devices and finished class-critical impact devices. The company also claims to be one of the world's largest manufacturers of titanium and stainless steel ligation clips, class critical implant devices, blades, scissors, stapling and biopsy devices as well as laparoscopic, endoscopic, and arthroscopic minimally invasive surgical instruments.

Included in the company's manufacturing capabilities are MIM and CIM and a recent success story involved the partnering with a major surgical device company to develop a PIM component for a new medical device using a challenging, implantable grade material. The component was originally designed to be produced by stamping, however, this would have required a costly secondary sharpening operation. Micro's MIM process was able to produce a finished component with an ultra-sharp 0.127 mm (0.005 in.) radius tip requiring no secondary sharpening operation.

www.micro-co.com

Call for Papers issued for the 19th Plansee Seminar 2017



A Call for Papers has been issued by organisers of the 19th Plansee Seminar, the International Conference on Refractory Metals and Hard Materials, taking place at the headquarters of the Plansee Group in Reutte, Austria, from May 29 – June 2, 2017.

Authors are invited to submit abstracts for papers to be presented in either lecture or poster format. All papers must contain unpublished results that are of current interest and abstracts should clearly outline the aim of the work and the methods employed, as well as the major results and conclusions. The deadline for submission of abstracts is September 9, 2016.

The presentations at the Plansee Seminar will include all areas where products based on Refractory Metals and Hard Materials play an important role, or where they are promising alternatives to present material solutions.

www.plansee-seminar.com

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Report sees continuing high growth in global Powder Injection Moulding markets

BCC Research, the market research company based in Wellesley, Massachusetts, USA, has issued a new report on the current growth, potential future growth and changes that are taking place in the global Powder Injection Moulding markets. The report updates that published in 2014 (see *PIM International*, March 2014, page 16). The latest report is the third PIM market research survey done by BCC since 2004 when it first reported the global market for Metal Injection Moulding to be around $383 million with expected growth to $571 million by 2009. The reported figure for 2009 turned out to be $985 million.

BCC Research states that by 2014 the global PIM market had more than doubled from the 2009 figure, reaching $2 billion, and that sales should reach $3.1 billion by 2020. This would see compound annual growth rates (CAGR) of 7.6% over the next few years. PIM sales in Asia in 2014 were estimated at $798 million and this figure is forecast to rise to nearly $1.3 billion by 2020, a CAGR of 7.9%. North American sales for PIM were said to have reached $492 million in 2014 and are forecast to reach $790 million by 2020, a CAGR of 8.2%.

The report also looks at the supply side of a number of metal and alloy powders used in Powder Injection Moulding, providing market data where available. The titanium powder market in particular is covered in some detail, with applications for Metal Injection Moulded titanium said to be growing strongly in the aerospace segment. On the application side, the report covers MIM manufacturers with detailed market analysis of various segments such as firearms, medical and dental products and the watch industry. The computer, communication and consumer electronics market is also discussed. Numerous lists of customers that import products in these market segments are provided, which should help MIM manufacturers grow their market base in a targeted geographical manner.

Finally, the report looks into some of the technical aspects of the industry and discusses the technical trends, current challenges and breakthroughs and potential future directions the industry will take. A chapter has been devoted to analysis of US patents related to the MIM industry with trends in various sub-categories discussed.

www.bccresearch.com

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Japan's Atect promotes high performance PIM parts at Engine Expo

Powder Injection Moulding specialist Atect, based in Higashiosaka-shi, Osaka, Japan, demonstrated at the Engine Expo, Novi, Michigan, USA, how its approach to Powder Injection Moulding has helped to develop new high performance products for the automotive sector.

The company used the event to promote its high-performance CIM heat sinks for thermal control solutions for high-heat applications such as insulated-gate bipolar transistor (IGBT) systems on hybrid intelligent power modules.

The company also promoted its low-inertia, high-accuracy MIM turbocharger rotor with extra-thin wall blades for downsizing turbo applications to achieve higher fuel efficiency. The company states that its PIM technology is able to achieve intricate shapes with difficult-to-machine materials such as Inconel, titanium and ceramics. The process eliminates any secondary machining process and enables a one-piece design, offering a unique single-step thermal debinding system for accurate dimensions, along with extremely thin wall designs. It has also developed a binder for optimal flowability, eliminating most common defects.

www.atect.co.jp

Tudor introduces CIM watchcase and bezel

Leading Swiss luxury watchmaker Tudor has for the first time launched a watch with a case and bezel manufactured from high-tech ceramics. The parts, states the company, are manufactured in a new in-house Powder Injection Moulding facility. The Ceramic Injection Moulded case and bezel are used on the Fastrider Black Shield watch.

The ceramic used is a very fine zirconium dioxide powder of less than 1 micron particle size, which is mixed with both a binding agent that allows it to be moulded and pigments that result in final desired colour. After debinding and sintering, the parts are precision machined using diamond tools to give the case and bezel their final shape.

www.tudorwatch.com

The CIM watch case manufactured by Tudor

Kistler introduces leading-edge process monitoring system for injection moulding

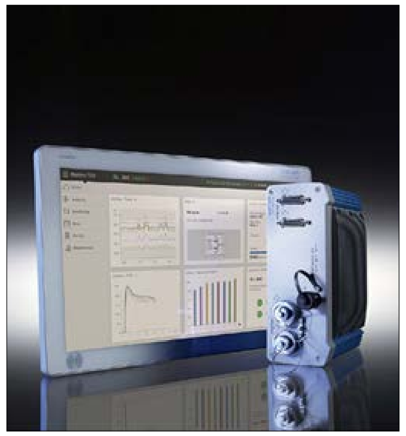
Kistler Gruppe, headquartered in Winterthur, Switzerland, is a global supplier of dynamic pressure, force, torque and acceleration measurement technology for the injection moulding industry. The company recently introduced its newest product, the ComoNeo process monitoring system. This is used for cavity pressure-based analysis, optimisation, monitoring and documentation of the injection moulding process with good part/bad part separation.

The compact system is reported to meet industrial standards and is easily configured. It also features simple connection technology and integrates flexibly into different product environments. Kistler states that ComoNeo is easy to operate, with the profiles of cavity pressures able to be monitored in real-time with visualisation on the capacitive Multi-Touch display, making it easy to identify process fluctuations.

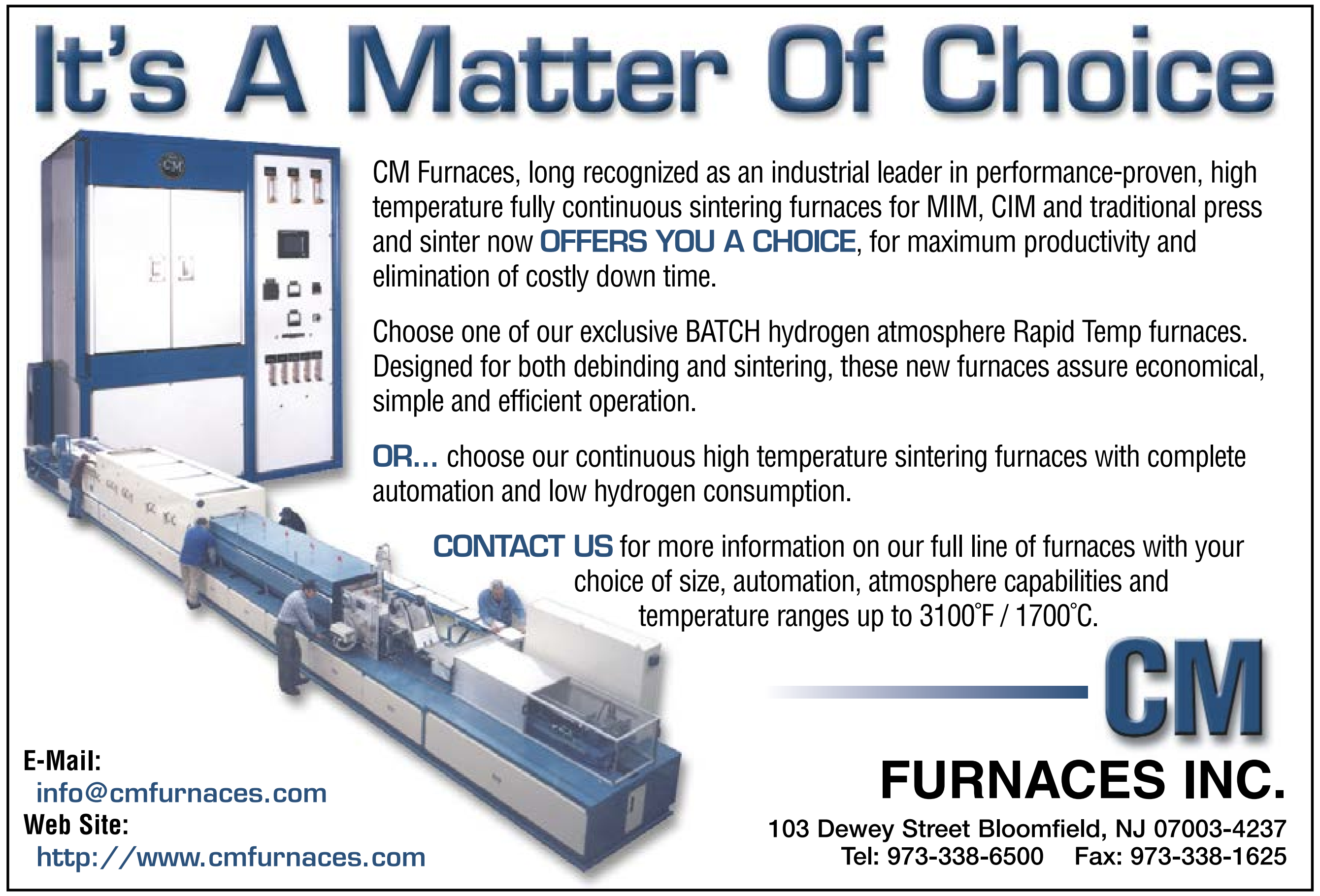
Integrated data storage allows recording of curve histories of at least 50,000 cycles. Curve superimposition and a host of other useful functions, such as changeable colour schemes to display curves, cycle comments, cursor functions, etc., allow detailed analysis directly on the injection moulding machine.

A production mode includes clear displays showing production progress and scrap rate, as well as intelligent mechanisms for the automatic detection of interruptions to production and the declaration of a defined number of cycles as scrap on restarting. As well as part quality, ComoNeo can monitor process stability and give warning signals in case of process fluctuations.

www.kistler.com



Kistler's new ComoNeo process monitoring system for injection moulding offers cavity pressure-based analysis, optimisation, monitoring and documentation of the injection moulding process with good part/bad part separation



Rado unveils new ceramic watches

Rado, based in Lengnau, Switzerland, is a pioneer in the use of Ceramic Injection Moulding for watch production. The company has further developed its use of high-tech ceramics with three further ceramic watches in the True family range.

The True Open Heart is produced in either matt or polished white zirconium oxide and is produced in a limited run of 500 individually marked pieces.

The multi-coloured True Colours collection features timepieces in three high ceramic colours; rich chocolate, navy blue and dark green. The 40 mm monobloc ceramic case fastens to the wrist with a matching Nato strap.

A further watch, the Rado True Thinline Skeleton is limited to an exclusive run of 99 watches and is engineered from polished black ceramic. It has a slim profile of just 7 mm.

Rado's Ceramic Injection Moulded watches are manufactured from ultrafine, high purity zirconium oxide powder. Pigments are then added to the powder to set its colour. These are then mixed together with a polymer binder which acts as a moulding aid. The melted feedstock is injected under high pressure into a precision mould, which is designed to the final shape of the ceramic watch piece. The polymer binder is then removed using a chemical process and the pieces undergo sintering at 1450°C, during which they shrink by around 23%. The finished parts are fully dense and reach a hardness of 1250 Vickers.

Finally, critical dimensions are reworked with a diamond wheel. The pieces can then be polished, with a perfect high-gloss finish taking several days to achieve. Rado also applies a patented plasma carburising process to fully finished white ceramic pieces. Here CIM components are placed in a specially designed plasma furnace where the gases, activated by a plasma discharge at 20,000°C, trigger a chemical reaction that changes the composition of the ceramic. This results in a change of colour from white to a unique metallic grey.

www.rado.com

Rado's Ceramic Injection Moulded multi-coloured True Colours watches

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Technologies for titanium powder reviewed at Titanium Europe 2016

New sources and technology for producing titanium and titanium alloy powders suitable for Metal Injection Moulding and Additive Manufacturing (AM) were revealed in presentations given at the Titanium Europe 2016 conference held in Paris, April 18-20. Neill McDonald of MetaFensch, Institut de Metallurgie du Val de Fensch, a publicly funded R&D centre in Lorraine, reported in his presentation that a pilot and semi-industrial scale plant has been established at his centre to produce fine titanium powder using an Electrode Induction Gas Atomisation (EIGA) furnace capable of using up to 100 mm diameter electrodes. He stated that the pilot scale facility can provide suitable quantities of powder to facilitate tests and to produce titanium powder in small batch series.

Tekna, a world leader in industrial plasma technology based in Sherbrooke, Quebec, Canada, also produces pure titanium and titanium alloy powders. Dr Romain Vert stated in a presentation that the company's inductively-coupled plasma (ICP) process has the capability to produce and/or recycle high quality titanium-based powder materials. Tekna has also developed a proprietary classification process specifically for removing ultrafine particles within a powder, allowing the re-use of powders in MIM and AM that would otherwise be out of specification in terms of powder purity and flowability.

Dr Matthias de Sousa, R&D Manager at Silimelt, a producer of metal and ceramic powders based in Talence, France, reported on the production of high reactivity TiAl powders used in MIM and AM. These powders are normally produced using crucible-free EIGA or the Rotating Electrode Process (REP) with quite large particle size distribution (from 5 to 300 micron). Silimelt cooperated with ALD Vacuum Technologies, Germany, to develop a two-step process for fine TiAl powder production using EIGA. The first step produces powder with around 55% of the particles sized below 100 micron and only 22% below 50 micron. The second step involves the plasma fragmentation of oversized (>100 µm) TiAl powders in order to convert coarse powders into finer ones. Up to 50% of the starting powder above 100 micron can be converted into finer powders after in-flight plasma treatment.

www.titanium.org

Submitting your news...

To submit news to *PIM International* please contact Nick Williams: nick@inovar-communications.com

Bodycote becomes first company in Europe to pass MedAccred audit

Bodycote has announced that its facility in Derby, UK, has received MedAccred accreditation. MedAccred, administered by Performance Review Institute, is an industry managed approach to ensuring critical manufacturing process quality throughout the medical device supply chain. Bodycote Derby is the first facility in Europe to earn the MedAccred accreditation.

Bodycote Derby offers heat treatment and Hot Isostatic Pressing (HIP) services to the medical device and implants markets in Europe. MedAccred establishes stringent consensus audit criteria based on industry and specific OEM requirements that ensure compliance and quality.

Joe Pinto, Executive Vice President and Chief Operating Officer of the Performance Review Institute, the organisation which administers the MedAccred program on behalf of the medical device industry, sent his congratulations to the team at the Bodycote Derby facility. "We are delighted that Bodycote has the honour of becoming the first company to receive an accreditation from MedAccred in Europe. To be the first in anything demonstrates a high level of foresight and commitment to a long term strategy. The MedAccred audit is challenging and, in achieving accredited status, Bodycote's Derby facility has proven it has the capability to meet and exceed the requirements of its medical customers. The entire team should be proud of their success."

www.bodycote.com

PIM International website updated

After several months of development Inovar Communications is pleased to announce the launch of a new website for *PIM International* magazine. Hugo Ribeiro, Production Manager at Inovar, stated, "This new format brings www.pim-international.com fully up-to-date with the latest website design concepts and back-end technology. Visual improvements include a much larger site area with more readable fonts and a bolder magazine-like presentation content."

The site is now fully dynamic, reflecting the growing use of tablets and smartphones for web browsing. The site's search facility has also been updated, allowing search results to include content from our PDF magazine archive. The site also offers advertisers larger, more functional banner options.

www.pim-international.com

Arburg Innovation Centre opens at Karlsruhe Institute of Technology (KIT)

The inauguration ceremony for the new Arburg Innovation Centre (AIC) at Karlsruhe Institute of Technology (KIT), Germany, took place on April 11, 2016. KIT is one of the largest research and teaching institutions for science and engineering in Europe with a strong track record in Powder Injection Moulding. In their addresses, the head of the Institute, Prof. Jürgen Fleischer and Arburg Managing Director Technology and Engineering, Heinz Gaub underscored the importance of the new facility for the cooperation between research and business.

The new Arburg Innovation Centre is high-tech and modern in appearance and the 60 m^2 of floorspace accommodates two Freeformer Additive Manufacturing systems, one Allrounder injection moulding machine, a free-standing six-axis robotic system and several workstations.

Heinz Gaub (left) Prof. Jürgen Fleischer (right) officially opening the AIC facility (Photo: Arburg)

Gaub emphasised the value of uncomplicated cooperation between KIT and Arburg. "We came up with the idea for this Innovation Centre together and then turned it into reality," he stated. Commenting on the successful cooperation, Gaub added, "After all, the AIC not only looks good, but is also backed up by a great deal of expertise." It was stated that the Institute for Production Science at Karlsruhe Institute of Technology is an ideal research and cooperative partner for Arburg and for this reason the company was happy to support the idea of the Innovation Centre.

Prof. Fleischer referred to the long-established collaboration between KIT and Arburg, which started at the beginning of the new millennium. He went on to state that the Innovation Centre bridges the gap between the scientific acquisition of knowledge and the establishment of market viability. "Here, we can see science and industry working hand-in-hand in a professional venture," said Prof. Fleischer.

KIT seeks to exploit its unique position as both a major national research centre and a state university. It is is organised into five divisions: Mechanical and Electrical Engineering; Biology, Chemistry, and Process Engineering; Informatics, Economics and Society; Natural and Built Environment; Physics and Mathematics. It has a staff of around 9,300 and 25,000 students.

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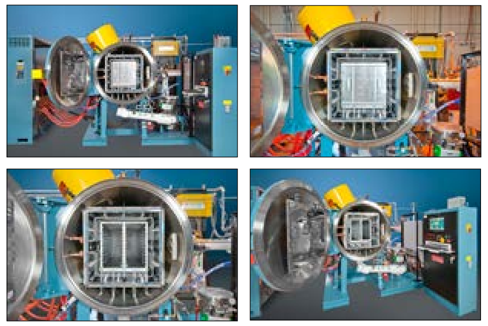

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MIM grade ultrafine gas atomised powders from Atomising Systems

Powder proiduction underway at Atomising Systems Limited

Atomising Systems Limited, Sheffield, UK, has announced that significant research and development work has been undertaken on its gas atomiser systems to address the increasing market for ultrafine gas atomised powders. Following work to improve the tundish system, the 200 kg batch capacity gas atomiser has now been upgraded with a high power gas heater allowing much higher atomising gas temperatures to be achieved.

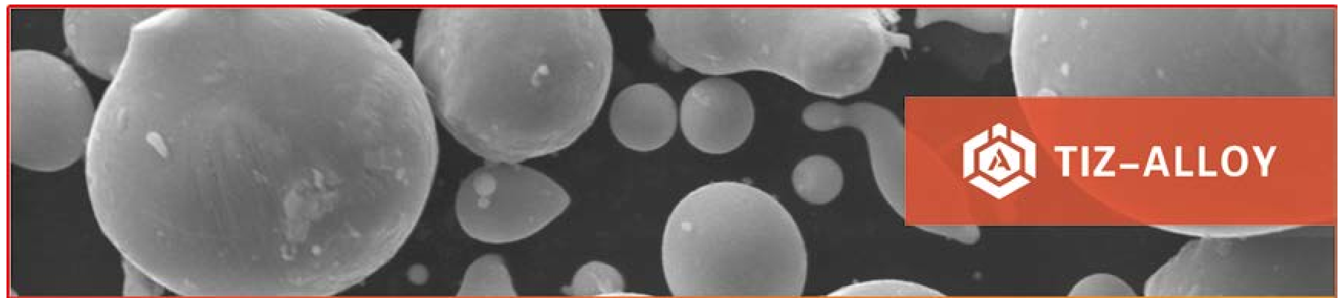
Coupled with extensive work on ASL's gas atomising nozzle system, the upgrades enables the production of stainless steels with a median particle size of less than 20 microns. Further investment in uprated sieving and classification systems also allows ASL to undertake powder separations from over 100 microns down to less than 5 microns. With these upgrades ASL states that it has more than doubled its production capacity for the finest grades.

It was announced that the company's quality control laboratory has also received a significant boost with a new Malvern Mastersizer, a total oxygen determination instrument, a compaction press and tensometer for green determination of water atomised powders and an XRF chemical analyser. All are now in operation, assuring the quality and consistency of the ultrafine gas atomised powders.

"While a massive increase in orders for water atomised powders has kept us very busy, we have not neglected to develop our capability to serve our gas atomised powder clients with new grades for Metal Injection Moulding, Additive Manufacturing, Hot Isostatic Pressing and thermal spray processes amongst others. These investments are already proving to be extremely beneficial," stated Simon Dunkley, ASL's Managing Director.

"This QC laboratory investment of well over £200,000, coupled with the recruitment of extra laboratory staff, ensures ASL can provide a QC service exceeding that expected by our demanding clients."

www.atomising.co.uk



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Elnik launches new laboratory-sized MIM furnace

Elnik Systems LLC., a market leader in the production of vacuum sintering furnaces for Metal Injection Moulding, has launched a new laboratory furnace for MIM part and process development. The furnace has a useable volume of 16 litres and a footprint of 252 cm x 196 cm x 324 cm including the afterburner. Stefan Joens, Vice President of Elnik Systems, told *PIM International*, "Over the last five or more years we saw the need to develop a true laboratory sized Metal Injection Moulding furnace that offers all the same functionality and testing parameters as a full sized production furnace. With the development of the MIM3001L laboratory furnace, we have answered the demand for a furnace that can provide real test results that are similar to those of a production furnace. It provides its users with the ability to scale up to production processing without having to 'reinvent the wheel' when it comes to scaling up production and switching to one of our full sized furnaces."

The new MIM3001L laboratory furnace from Elnik Systems

The system is designed so that once a successful profile has been developed for a particular part or material, it is easy to move that same profile to a full sized production furnace. Joens stated, "The only real adjustment needed would be the amount of gas usage throughout the profile to accommodate the additional size and material of a production sized load."

The MIM3001L lab furnace was developed to offer the same advanced functionality as its larger production sized furnace family members and this furnace incorporates many of the features found on Elnik's popular MIM3000 series furnaces. This includes the utilisation of a similar retort gas plenum construction that allows for shortest distance gas flow with even gas flow per process shelf. Users have the ability to program any segment with hydrogen, argon, nitrogen or forming gas. "Utilising mass flow controllers for both hotzone and retort locations allows the user to have ultimate control," stated Joens.

All the control thermocouples in the furnace use Elnik's proprietary AccuTemp™ control functionality, allowing the furnace to achieve very tight temperature control in each of its heating zones. This, stated Elnik, provides the user with the ability to reach high part densities by being able to program the furnace to run very close to the material's solidus temperature without overshooting.

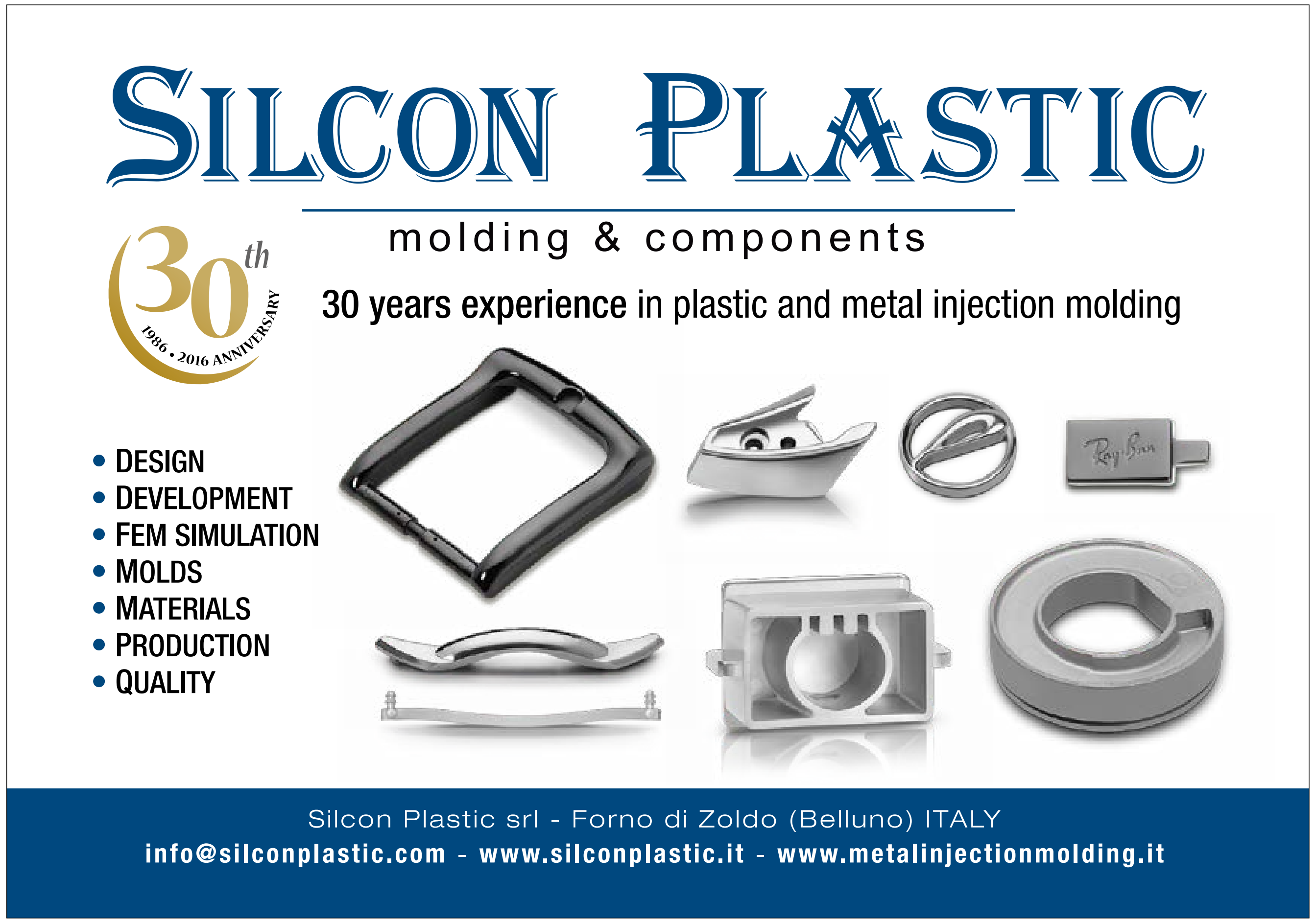
The furnace's control system uses the same Excel based program builder as the larger MIM3000 system, making it simple and easy for a user to program the furnace with any control parameter they see fit. As the furnace has the ability to operate under a hydrogen environment at partial vacuum pressure, Elnik has incorporated all its standard safety features to ensure proper customer safety.

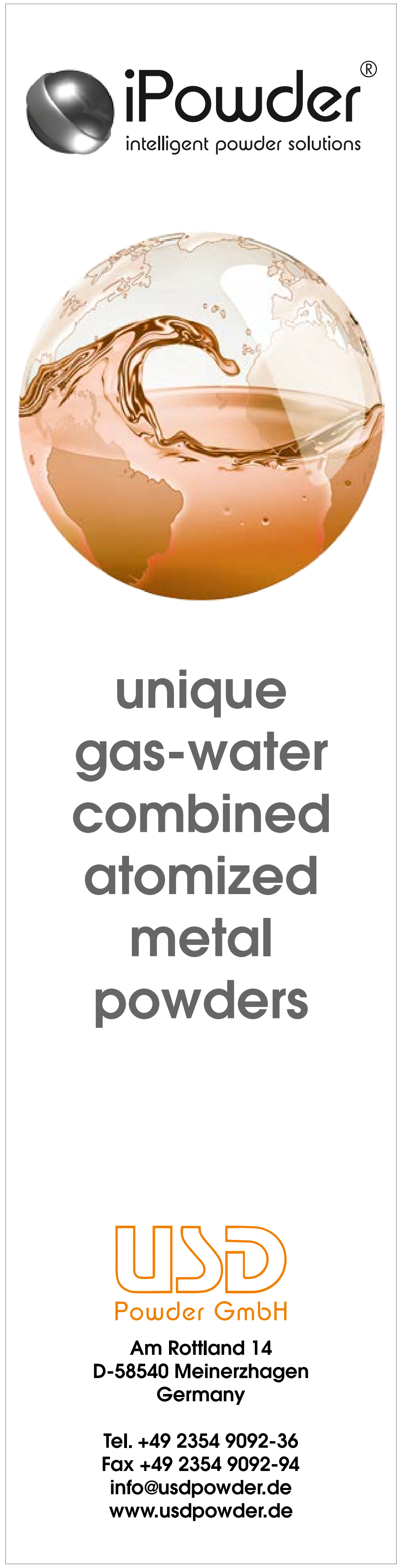
The furnace is designed to operate at up to 1,600°C under vacuum. It is supplied ready to be outfitted with a diffusion pump for high vacuum processing, with typical vacuum ranges being 1x 10^{-5} or 10^{-6} mbar. There are also numerous ports to outfit SAT or TUS thermocouples for process control and analysis.

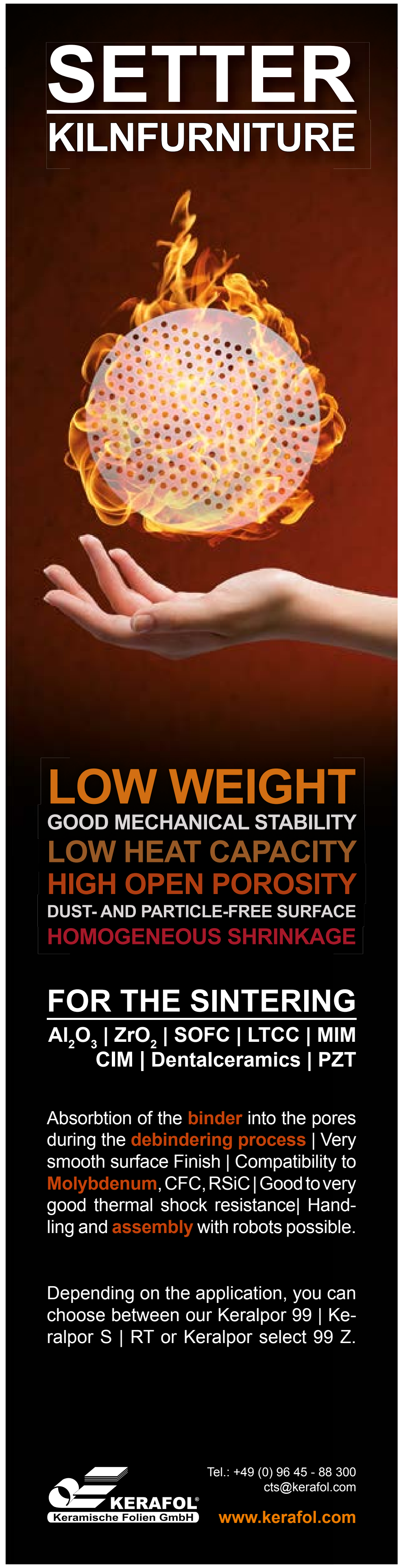
"The usability and functionality of the MIM3001L furnace makes it the ideal laboratory furnace to be used at universities, research and development organisations, feedstock manufacturers, small batch MIM part makers and any MIM part maker that is looking for a furnace to perform reliable test runs. As with any of our furnaces, usability and flexibility were part of the groundwork when developing this Lab furnace," stated Joens.

www.elnik.com

Interior view of the new MIM3001L laboratory furnace







PM China 2016: China's largest PM exhibition continues to grow

PM China 2016, China's largest international Powder Metallurgy exhibition, took place at Shanghai's Everbright Convention and Exhibition Center from April 27-29. The event attracted more than 360 exhibitors from around the world, making it the largest event in the series to-date.

PM Expo's Maggie Song told *PIM International*, "The successful combination of a wide range of exhibition booths, expert tutorials and a parallel technical conference succeeded in attracting the attention of high numbers of international and local visitors."

Exhibitors from China included materials, equipment and parts suppliers covering technologies including conventional Powder Metallurgy, Hot Isostatic Pressing and Metal Injection Molding. International industry suppliers present included leading companies from USA, UK, Germany, Italy, Sweden, Switzerland, India, Singapore and Japan.

"We believe that many new business deals were done and a lot of new contacts were created through this effective networking platform. Visitors from home and abroad were satisfied with the wide range of display," stated Song.

As in previous years, Metal Injection Moulding technology was prominent in both the exhibition hall and the conference. On April 26th Prof. Randall M. German, San Diego State University, presented a one-day MIM tutorial. This was followed on April 27th by the 2016 Shanghai International MIM Symposium, which featured presentations from Chinese and international speakers.

PM China 2017 will take place from April 26-28, 2017 at the Shanghai Everbright Convention and Exhibition Center, with the organisers already reporting high demand for space.

www.cn-pmexpo.com






Ampal expands its aluminium powder production facility

Ampal, Inc., a wholly owned subsidiary of United States Metal Powders, Inc. (USMP), formerly United States Bronze Powders, Inc. (USBP), has announced the expansion of its aluminium powder production facility in Palmerton, Pennsylvania, USA, along with the acquisition of an adjacent industrial property.

Ampal, a producer of aluminium powder, was founded in 1968 and its parent company, USBP, in 1918. Ampal moved its production facility from Flemington, New Jersey to its current location in 1982. The company has grown to be the largest US producer of aluminium powder. The newly purchased property will facilitate the company's expansion by providing warehouse space and a new location for its R&D team which will be relocated from Flemington. The team has developed aluminium alloy powders for MIM and AM.

Once completed, the expansion is expected to create fifteen new jobs for a total employment at Ampal of over 40 people. "After operating successfully for more than three decades in Palmerton, this expansion provides an opportunity to create new job opportunities and to continue to drive our growth in the aluminium powder business. We are proud of our team of highly talented employees at Ampal today," stated K Clive Ramsey, President of Ampal and USMP. "We look forward to continuing our strong ties to the local community and are pleased to be creating new employment opportunities."

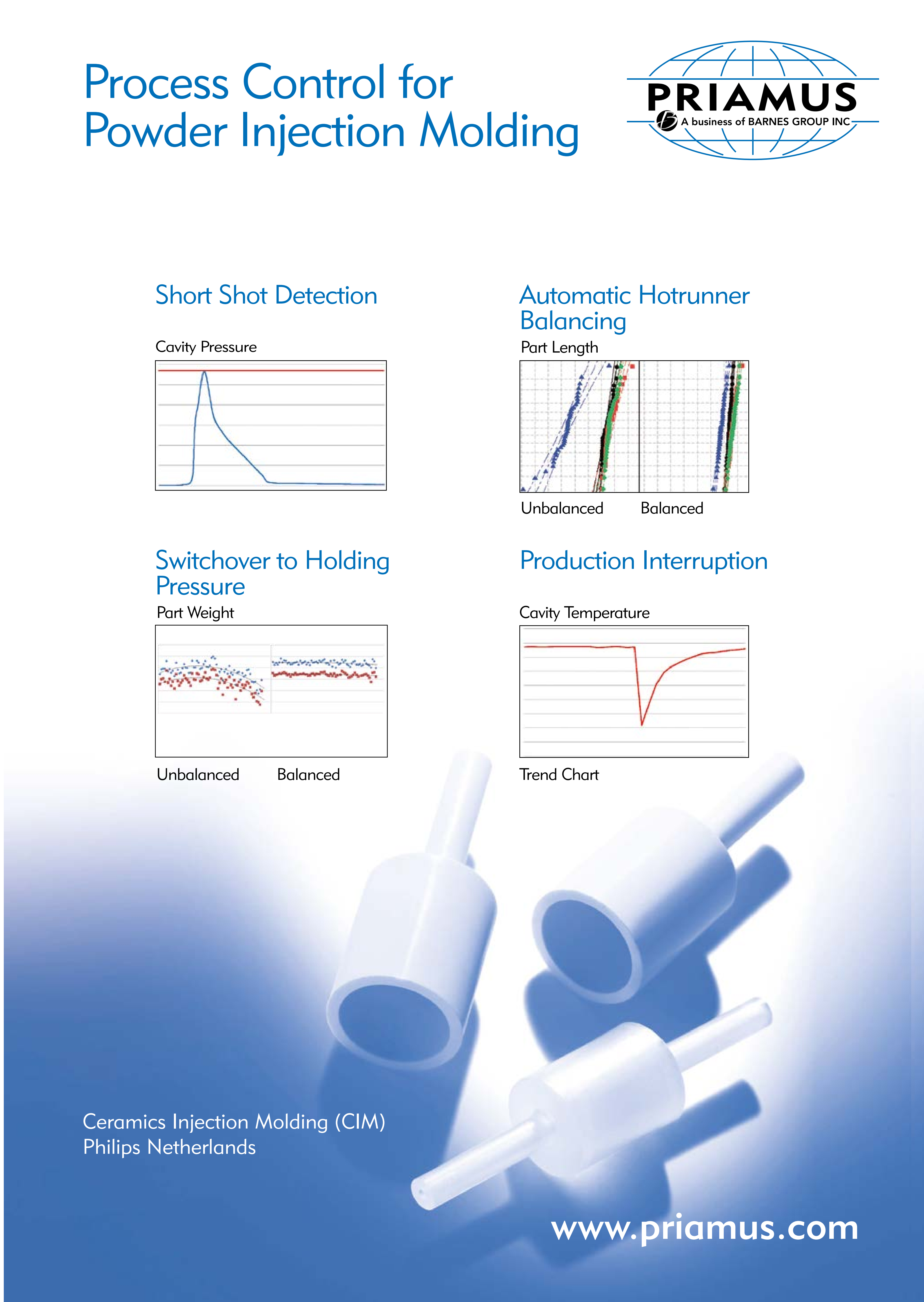
www.ampal-inc.com

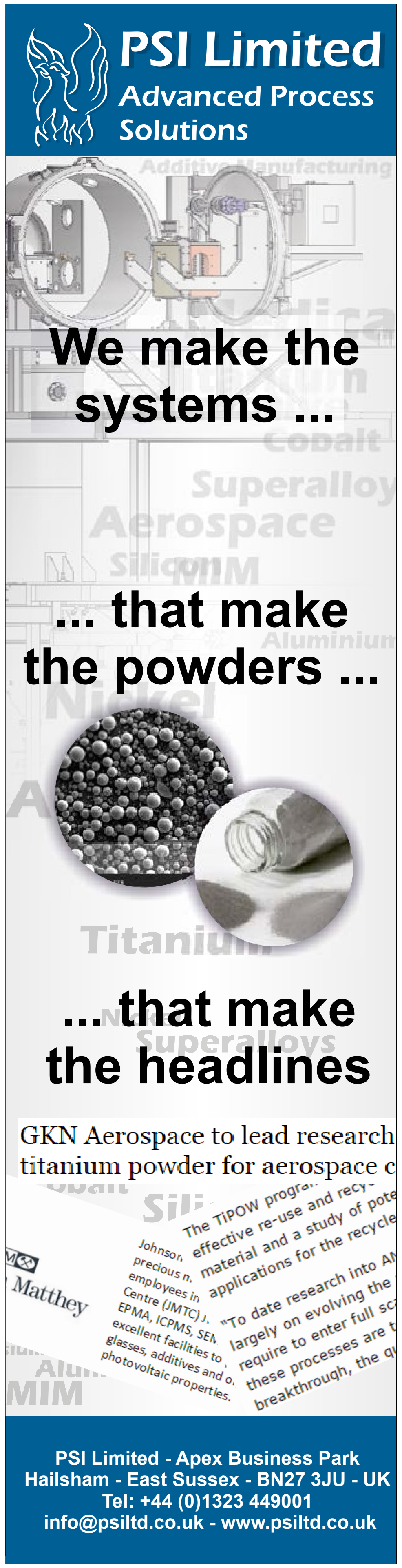
Phillips-Medisize completes MIM expansion

Phillips-Medisize Corporation has announced the completion of its MIM plant expansion on the company's Menomonie, Wisconsin, campus. The 4650 m^2 facility has now been expanded twice the past three years to support continued growth.

The facility houses numerous injection moulding machines, four continuous debind and sintering furnaces and multiple batch furnaces. Matt Jennings, Chairman and CEO of Phillips-Medisize Corporation said, "We believe this expansion, with the addition of another continuous debind and sintering furnace, also allows us to service more new and existing customers with the largest capacity for MIM in North America."

www.phillipsmedisize.com





Aluminium Metal Injection Moulding promises new opportunities for industry

Although Metal Injection Moulding has worked very well for many decades for a wide range of metals and alloys, the process has always proved to be unsuitable for aluminium. However, researchers at the Technical University Vienna (TU Wien) have now succeeded in developing a Powder Injection Moulding process for aluminium which can be used to manufacture complex-shaped, weight saving components in a material-efficient manner. This, it was stated, will be of particular interest for sectors in which weight-reduction plays an important role, from the automotive industry to aerospace and space technology.

The team at the Institute of Chemical Technologies and Analytics at TU Wien has been researching sintering technologies for many years and has worked together with some of the world's leading Powder Metallurgy companies in the field with great success. "The raw materials in Metal Injection Moulding are fine metal particles that react with the oxygen in the air and are therefore usually coated with a thin oxide layer," explained Dr Christian Gierl-Mayer. In conventional Metal Injection Moulding, the metal powder is first mixed with a binder in order to make it mouldable and this is then injected into a mould. The resulting semi-finished product, known as a green part, is then heated in a sintering furnace. In this way, the binder substance is removed and, at high temperatures, the oxide layer is reduced. The metal grains come into direct contact and join to form a solid metal body.

However, a problem arises if aluminium is used, as the oxide layer surrounding the aluminium particles can only be removed at extremely high temperatures. At the same time, aluminium has a relatively low melting point, which restricts the maximum sintering temperature. It is therefore impossible to remove the oxide layer on the aluminium powder before the entire metal piece has melted.

The binder material, which bonds the metal powder in the PIM feedstock, is also removed by thermal processes, which only occur at increased temperatures. The overlapping of the temperature ranges for binder removal and sintering means that residues of the binding agent are incorporated into the sintered workpiece if aluminium is processed using the same technique as for other metals.

TU Wien has now succeeded in finding a solution to this problem. The key is in creating the correct atmosphere in the sintering furnace. A low-oxygen environment is usually used to prevent the complete oxidation of a metal powder. By contrast, with aluminium, an oxygen-rich atmosphere has been found to be beneficial. "The aluminium oxide layer of the particles is so thick that the particles are protected from complete oxidation. At the same time, the oxygen aids the combustion of the carbon contents of the binder material," explained Gierl-Mayer.

After this first step, the oxygen atmosphere is replaced by nitrogen and the temperature is increased further. With the additional help of magnesium, the aluminium oxide layer is finally broken and reduced. A liquid phase occurs and the aluminium particles are sintered to form a solid metal piece. "This method allows us to separate the two process steps; the removal of carbon residue and the sintering of the aluminium particles, thereby enabling both steps to run to completion for the first time," explained Christian Gierl-Mayer.

The Powder Injection Moulding process enables complex shapes to be manufactured, which cannot be realised in any other way, or only with great effort. The aluminium powder is relatively inexpensive, which means that even large components, by PIM standards, can be produced at a reasonable cost. In mass production, savings of up to 50% can therefore be expected on materials and weight compared with conventional production.

There are many potential industrial uses for this new aluminium sintering method. Gierl-Mayer stated, "Sintering processes with other metals have already asserted themselves in many areas of industry, with Austrian companies taking the lead globally in this field." The low density of aluminium makes it of particular interest for many applications, including in the automotive industries and aerospace engineering, for example, where weight reduction is important. It was also suggested that this aluminium sintering method could open up new opportunities in the areas of machine tools and watches.

A green aluminium MIM part, left, and the sintered part on the right

A patent application has been submitted for the new technology.

www.tuwien.ac.at

In *PIM International* Vol. 6 No. 4 TU Wien published "Carbon removal as a crucial parameter in the PIM of aluminium alloys." Download a copy from www.pim-international.com

Priamus offers improved process control technology for Ceramic Injection Moulding

Cavity pressure and cavity temperature sensors located in an injection mould are key components for process monitoring and process control in injection moulding. This is because they are flush mounted in the cavity and come in direct contact with the material. This allows the sensor to get the best material readings and determine whether the quality of the part is within the required limits.

Because sensors are highly sensitive pieces of measuring equipment, it is important to keep the face of the sensors in good condition. In many cases however, this is a problem with abrasive, highly filled and chemically corrosive melts that gradually damage the sensor front. The lifetime of the sensors is therefore limited with such applications.

Priamus System Technologies AG, headquartered in Schaffhausen, Switzerland, has therefore developed a new patent filed procedure in order to manufacture the sensor front from an extremely hard and chemically resistant material which extends lifetime of the sensor significantly. Alternative methods such as thin layers of Titanium Nitride or chromed surfaces, state the company, have not proved themselves in the past. This is because they did not withstand the wear from abrasive materials, the surfaces were washed away, or because the outline of the sensor front could not be mapped. The consequence was a visible mark on the moulded part.

Cavity temperature sensors with hardened sensor fronts are successfully being used in such highly abrasive conditions. These applications have proved that, even under extreme conditions, significantly longer lifetimes can be achieved. Priamus states that these new sensors can be used with highly filled materials or with ceramic melts without having to worry about damage to the sensor front.

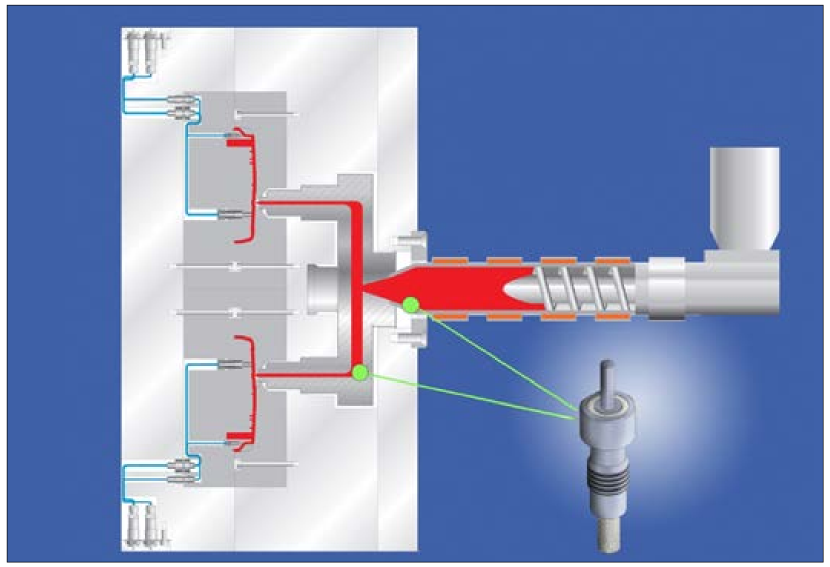
Priamus' existing range of products has been extended with a new line of heavy duty cavity temperature sensors that can be used at mould temperatures up to 320°C. This is a 120°C increase from the 200°C limit of the standard temperature sensors. These heavy duty sensors use robust steel braided connecting cables which were designed for the use in rough and industrial environments and can be ordered with the hardened sensor front for use with an abrasive material.

As a further new development, the company has introduced a melt temperature sensor for use in the machine nozzle or in the hotrunner manifold. This sensor has been especially designed for the temperature measurement of plastic melts under high pressure, which is why it is provided with a special seal. The ambient temperature at the place of installation can permanently reach 450°C. The sensor is delivered with a hardened sensor front as standard in order to withstand highly filled melts.

Priamus states that its highly sensitive and responsive cavity temperature sensors are applied in numerous other process control applications based upon melt front detection. An example was given as the automatic opening or closing of valve gates. Placed flush with the mould surface, cavity temperature sensors register the arrival of the melt front within milliseconds, outputting the melt front arrival signal instantaneously to a controller.

The company states that its new sensor technologies are well suited to application in the CIM industry.

www.priamus.com



Priamus offers a range of wear resistant sensors for application in abrasive prosesses such as CIM

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Arburg targets specialist Taiwanese manufacturers with new subsidiary

At Arburg's new subsidiary in Taiwan: Subsidiary Manager Michael Huang (left) and Arburg's Overseas Sales Director Andrea Carta (right). The company aims to secure and strategically expand Arburg's local presence (Photo: Arburg)

Injection Moulding machine manufacturer Arburg GmbH + Co KG has established its own subsidiary in Taiwan. The company, which is the market leader in injection moulding equipment for Powder Injection Moulding, states that the founding of the subsidiary is an important milestone for the further expansion of its global network and activities in Asia. Located in Taichung, the new subsidiary is ideally positioned in an important, strongly growing industrial region of Taiwan.

Arburg is well established in the Taiwanese market, having had an agent there in the form of C & F International Corp. since 1981. By taking on the sales and service employees from its former partner, the company states that expert customer support can be further expanded in future.

Andrea Carta, Arburg's Overseas Sales Director, stated, "Due to Taiwan's great importance as an innovative market with many high-end companies, we are taking prompt action to secure and strategically expand our local presence there. By taking on many sales and service employees from our former trading partner, the same extensive knowledge and familiar local contacts will continue to be available to our customers in the future. Another reason for founding our own organisation is that we wish to provide our customers with even more support in their internationalisation process. This can only work smoothly, however, if we have our own location in Taiwan. Numerous Taiwanese Arburg customers are turning to the People's Republic of China, but also to Southeast Asia. And these important decisions are taken in Taiwanese company headquarters."

There is a large number of specialist manufacturing companies in Taiwan that have been using Arburg technology for a long time. Many of the company's Allrounder machines are not only used in medical technology and electronics production, but also in Taiwan's major Metal Injection Moulding and Ceramic Injection Moulding industries. Carta stated, "With our technology, our applications and our turnkey solutions, we want to continue growing not just in specialist areas, but also in standard fields such as thermoplastic processing, for example. So not only will we take over the infrastructure in Taiwan, we will undertake a targeted expansion by broadening our service offering, for instance, and with application technology consulting. To achieve this, we will work closely together with the experts at the company headquarters."

The new subsidiary's premises cover an area of around 550 m^2 and the showroom offers space for three Allrounders, complemented by training rooms and an extensive spare parts store. "We greatly value comprehensive application technology consulting and a broad service offering. At our premises, our customers can run tests and configure sample moulds, but they can also benefit from in-depth application technology consulting and receive training on all aspects of Arburg technology," explained Michael Huang, Subsidiary Manager.

Arburg stated that its cooperation with C&F will initially continue. As well as selling the necessary peripheral processing equipment, the former trading partner will also continue to take care of some key accounts from the injection moulding field. However, the new Arburg subsidiary will completely take over the work of the after-sales service. This will ensure continuity in support for the Taiwanese market in every respect. Carta explained, "We have had a very good, trusting partnership with our trading partner C&F since 1981. We are extremely grateful for the work they have done. However, both Managing Directors wish to retire in the medium term. Therefore, by planning this transition with a view to the long term, we wish to expand our own capacities in the country, so that we can also continue to provide our customers with perfect support in future."

www.arburg.com

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MIM2016 conference attracts record attendance, 2017 dates announced

The Metal Powder Industries Federation (MPIF) has reported that it was a record setting year for its annual Metal Injection Moulding conference, with over 160 delegates in attendance at MIM2016. The conference was held in Irvine, California, USA, from March 7-9 and attracted delegates representing nearly one hundred companies from twelve countries.

A Powder Injection Molding Tutorial, held prior to the main MIM2016 conference, attracted over 45 attendees. The tutorial, presented by Prof. Randall German, provided a basis for determining options, uses, properties, applications and opportunities for cost-effective PIM manufacturing.

Thirty-one companies showcased their products and services during the tabletop exhibition and networking reception that followed Tuesday's presentations. This provided visitors with the opportunity to meet and network with key representatives of the complete MIM supply chain, from materials to injection moulding, debinding and sintering equipment.

During the conference delegates enjoyed the California sunshine and heard about some of the most recent advancements in the Metal Injection Moulding industry. Keynote Presenter Jean-Claude Bihr, Alliance MIM, France, opened the conference by discussing the environmental and cost impacts of manufacturing technologies, as well as MIM's role in green technology.

Delegates also had the unique opportunity to attend a tour and reception at a nearby Arburg Technology Center (ATC). Next year's conference will take place in Orlando, Florida, from February 27 to March 1, 2017.

www.mpif.org

MPIF Standard 35 for MIM parts: 2016 Edition now available

The Metal Powder Industries Federation (MPIF) has just published the 2016 edition of its "*Standard 35 - Metal Injection Molded Parts*". Developed by the Metal Injection Moulding parts manufacturing industry, each section of this updated 38-page standard is clearly distinguished by easy-to-read data tables (Inch-Pound and SI Units) and explanatory information for materials listed.

This standard provides design and materials engineers with the latest engineering property data and information available in order to specify materials for components made by the MIM process.

Available in print and digital formats, it is an essential resource for all involved in the MIM process including quality assurance/laboratory staff and sales representatives. Publication of the 2016 edition of this standard renders the 2007 edition, and prior editions, obsolete.

This latest edition includes new materials and mechanical property data for heat treated MIM-440 stainless steel. It also includes data on the following materials that had been previously published as addenda on the MPIF website:

- Copper: MIM-Cu, as sintered, including CTE data
- Low-alloy steel: MIM-4140, quenched and tempered

The standard is available for $50.00 as a PDF for immediate download or in print format. The PDF and print edition can be purchased together for $70.00

www.mpif.org

Platinum powder from Cooksongold

Cooksongold, Birmingham, UK, has announced the addition of platinum to its range of metal powders. The powder was launched in collaboration with the Platinum Guild International (PGI), an organisation funded by leading South African platinum producers and refiners. Cooksongold's Pt/Ru alloy was specifically developed for Additive Manufacturing, however the company states that the powder range is also suitable for other applications including MIM.

The 950 Pt/Ru powder will be added to Cooksongold's existing portfolio, which consists of 18k 3N yellow gold, 18k white gold, 18k 5N red gold and Brilliante 925 silver. Further new powders, such as base metals and other carat gold alloys, are currently being developed

www.cooksongold.com

High Strength, low cost ß-type Ti-Mn alloys produced by MIM and cold rolling

Titanium alloys are widely used in the aerospace, chemical, energy and biomedical industries because of their high specific strength (ratio of strength to density), good corrosion resistance and good biocompatibility. They allow very strong thin walled parts to be produced and Ti alloys retain their high strength at temperatures up to 600°C. However, there is concern over the long term availability of some of the alloying elements (ie. vanadium, niobium, and tantalum) used for Ti-15-3 and other existing ß-type Ti alloys and efforts are being made to look for other candidate alloying elements.

Manganese (Mn) is considered to be a strong candidate as a ß-stabiliser for new, high strength ß-type Ti alloys because of its abundant availability, but there have been few studies of ß-type Ti-Mn alloys with Mn content higher than 10 mass%. Ken Cho and colleagues at Osaka University, Tohoku University, the Industrial Research Institute of Shizuoka Pref., Kansai University and the Egypt-Japan University of Science and Technology, report in a paper published in *Journal of Alloys and Compounds* (Vol.664, 2016, 272-283) on work done to develop a low cost, ß-type Ti-Mn alloy containing 13 mass% produced using Metal Injection Moulding. They state that in conventional Ti alloys processed by arc melting and cold crucible levitation melting various hot or cold working procedures are needed followed by heat treatments to refine the coarse initial grain diameter of >100 µm to below this level.

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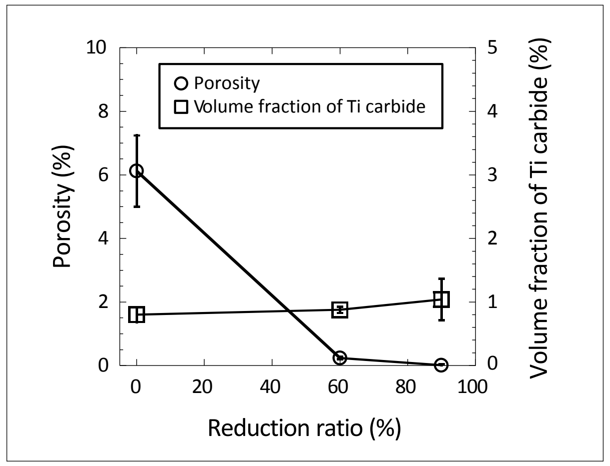


Fig. 1 Influence of cold rolling on porosity and volume fraction of Ti carbide in Ti-13Mn as a function of reduction ratio (From paper 'Improvement in mechanical strength of low cost ß-type Ti-Mn alloys fabricated by Metal Injection Molding through cold rolling', by: K. Cho, et al Journal of Alloys and Compounds Vol.664, 2016, pp272-283)

Using MIM technology it is possible to control the grain diameter to lower than 100 µm because the starting powder used for MIM is less than 50 µm. The resulting finer grain diameter in the MIM ß-type Ti-Mn alloy was expected to give improved strength. However, it is also known that porosity in sintered MIM Ti-Mn alloys can have a detrimental effect on mechanical properties. It was, therefore, proposed to use cold rolling as an effective way to reduce porosity, or to change pore shape, for improving strength.

Gas-atomised pure Ti powder and fine Mn powders having particle size <45 µm were premixed then kneaded with an organic binder to produce the MIM feedstock. The ß-typeTi-13Mn feedstock was then injection-moulded into rectangular specimens having a length, width and thickness of approximately 80, 10, and 4 mm, respectively. Extraction debinding using vaporised n-hexane was conducted to partially remove the binder and the specimens were then sintered at 1100°C for 8 hr. The sintered parts were subjected to solution treatment (ST) at 900°C for approx. 33 min in vacuum, followed by water quenching. The sintered MIM Ti-13Mn parts were cold rolled at a reduction ratio of 60% or 90% at room temperature in air. Fig.1 shows that at 90% reduction ratio porosity in the MIM Ti-13Mn parts was reduced from 6.10% to 0.01%. The Ti carbide in the alloy is also fragmented during cold rolling. The cold rolled and solutionised MIM Ti-13Mn consisted of a ß-phase and a deformation induced athermal ω phase to improve strength.

Alloy	Ultimate tensile strength, σ_B (MPa)	0.2% proof stress, $\sigma_{0.2}$ (MPa)	Elongation (%)	Vickers hardness, *Hv*	Young's modulus, *E* (GPa)
Ti-13Mn$_{ST}$	888 ± 3	827 ± 19	0.9 ± 0.1	279 ± 13	96 ± 4
Ti-15V-3Al-3Sn-3Cr	800	750	17	255	83
Ti-6Al-4V ELI	850-950	710-850	10-15	310-350	105-115

Table 1 Comparison of mechanical properties of MIM Ti-13Mn and wrought Ti-15V-3Al-3Sn-3Cr and wrought Ti-6Al-4V alloys (From paper 'Improvement in mechanical strength of low cost ß-type Ti-Mn alloys fabricated by Metal Injection Molding through cold rolling', by: K. Cho, et al Journal of Alloys and Compounds Vol.664, 2016, pp272-283)

As can be seen in Table 1, the mechanical properties, including the ultimate tensile strength and 0.2% proof stress, of the solutionised MIM Ti-13Mn are higher than both solutionised wrought Ti-15-3 and the thermo-mechanically treated wrought Ti-6Al-4V. Vickers hardness and Young's modulus of Ti-13Mn are also improved but elongation is lower. The high strength of Ti-13Mn is attributed to the solid solution strengthening by oxygen and also to the presence of the nanometre-sized athermal phase (precipitation strengthening) and fine Ti carbide (dispersion strengthening). However, the ω phase and Ti carbide also contributed to the lower elongation properties of Ti-13Mn. Fig.2 shows (a) tensile strength and (b) elongation of Ti-13Mn as a function of cold rolling reduction ratio along with comparisons for values of wrought Ti-15V-3Al-3Sn-3Cr and Ti-6Al-4V. ■

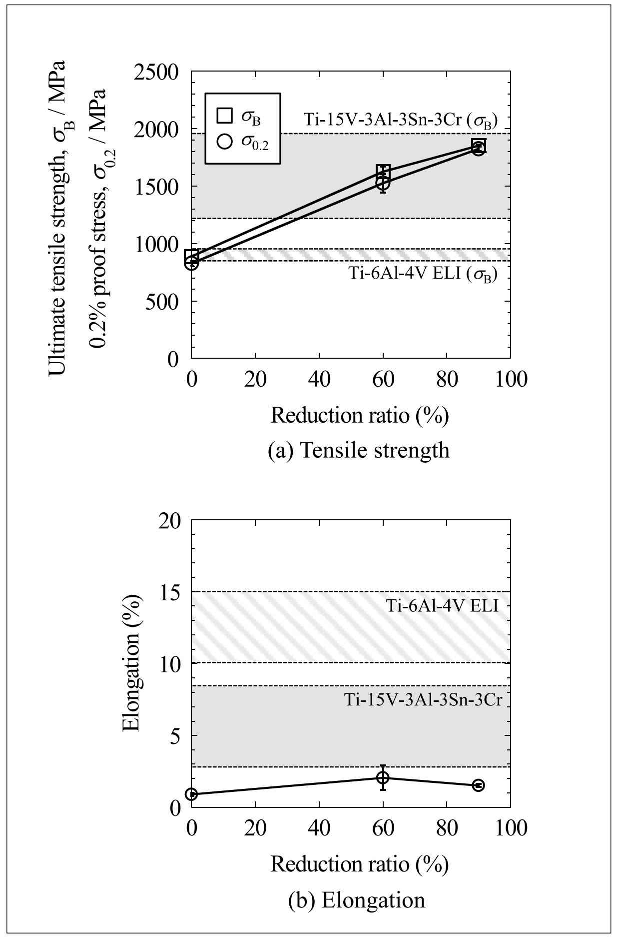
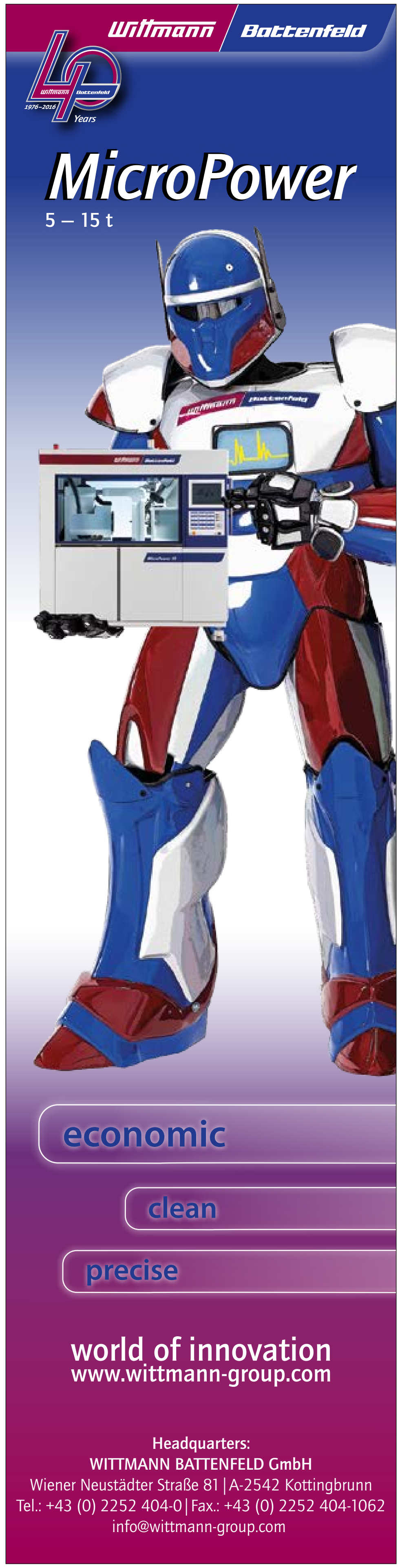


Fig. 2 (a) tensile strength and (b) elongation of Ti-13Mn as a function of cold rolling reduction ratio along with wrought Ti-15V-3Al-3Sn-3Cr and wrought Ti-6Al-4V alloys (From paper 'Improvement in mechanical strength of low cost ß-type Ti-Mn alloys fabricated by Metal Injection Molding through cold rolling', by: K. Cho, et al Journal of Alloys and Compounds Vol.664, 2016, pp272-283)



Defects and properties of PIM ultra-fine silicon nitride powders

Silicon nitride (Si_3N_4) ceramics are widely used as high performance bearings, in engine turbochargers and in other structural applications requiring light weight, low thermal expansion coefficient, high strength, good shock resistance and good corrosion resistance in high temperature environments. A number of production processes can be used to produce Si_3N_4 but for parts requiring high precision and complex shape then Ceramic Injection Moulding in combination with gas pressure sintering is said to be the preferred method. However, problems exist when using ultra-fine Si_3N_4 powder for CIM primarily in preparing a feedstock having low viscosity with a higher solids loading and controlling defects in moulding and debinding.

Xian-feng Yang and co-researchers at the Changsha University of Science and Technology (Changsha) and the Tsinghua University (Beijing) sought to overcome these problems by developing PIM feedstocks using ultra-fine Si_3N_4 – composite powder mix containing 6wt.% Y_2O_3 + 2wt.% La_2O_3 as a sintering aid. Their work was reported in the *International Journal of Minerals, Metallurgy and Materials* (Vol. 22, No. 6, June 2015). The ultra-fine α-Si_3N_4-phase powder had a median particle size (d50) of 0.34 µm. The Si_3N_4 – Y_2O_3 - La_2O_3 powder was mixed with a PP:PE:wax = 10:10:80 mass% binder plus 6wt.% stearic acid as surfactant. Fig. 1 shows the shear viscosity of the feedstock at different solid loadings. As can be seen the feedstock with 50 vol.% solid loading or lower shows good flowability. Thus whilst a lower solid loading can lead to greater shrinkage during debinding and sintering, this may be preferred in the case of Si_3N_4 parts having thin walls where good mould filling and safe demoulding are the primary concerns.

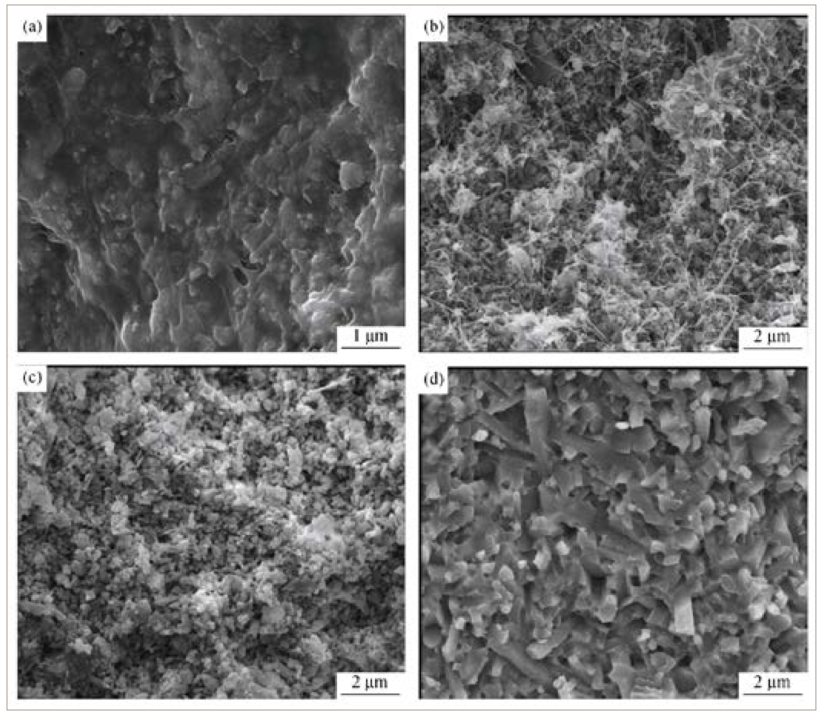


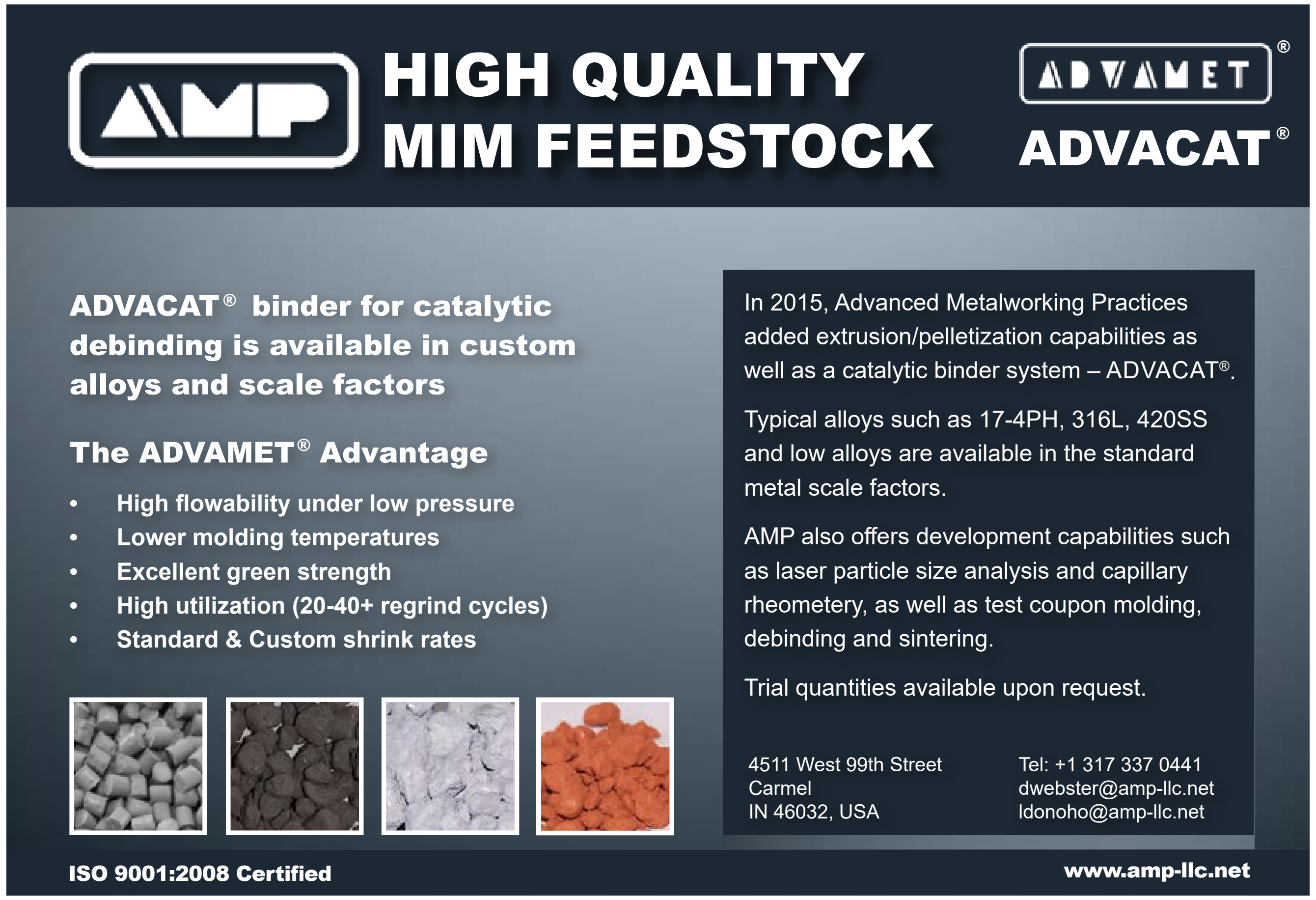
Fig. 1 Shear viscosity of the Si_3N_4 – Y_2O_3 - La_2O_3 feedstock with different solid loadings. (From paper: 'Injection molding of ultra-fine Si_3N_4 powder for gas pressure sintering' by Xian-feng Yang, et al. International Journal of Minerals, Metallurgy and Materials Vol.22, No.6, June 2015, pp654-658)

Sample	Density (g·cm^3)	Shrinkage %	Vickers hardness GPa	Strength MPa	Fracture toughness (MPa·m$^{1/2}$)
Green body	2.21	-	-	-	-
Solvent debound body	1.73	0	-	-	-
Brown body	1.69	10.4	-	-	-
Sintered body	3.23	20.5	16.5	980	7.2

Table 1 Properties of PIM Si_3N_4 composite powder during debinding and sintering. (From paper: 'Injection molding of ultra-fine Si_3N_4 powder for gas pressure sintering' by Xian-feng Yang, et al. International Journal of Minerals, Metallurgy and Materials Vol.22, No.6, June 2015, pp654-658)

The researchers produced both ball and bar injection moulded shapes, the latter used for bending strength tests and measuring 3 x 4 x 35 mm. The injection moulded pieces were first debound in a solvent for 4 hr at 40°C to remove approx. 50wt.% of the wax. The authors stated that using higher temperatures during solvent debinding increases the risk of cracking or deformation in the parts because of the softening of the backbone binder. Thermal debinding was then performed in a vacuum furnace at temperatures up to 900°C to degrade and remove the residual polymer binder, followed by sintering in a gas-pressure sintering furnace at 1795°C for 3 hr under N_2 pressure of 8 MPa.

Table 1 shows the properties of the sintered Si_3N_4 – Y_2O_3 - La_2O_3. Sintered density was 3.2 g/cm^3, hardness was 1650 GPa, and fracture toughness was 7.2 MPa·m$^{1/2}$. Total shrinkage from the green body to the sintered body is 20.5%. Defects in Ceramic Injection Moulded parts using ultra fine powders are said to be greater in number than with other forming methods. These include welding lines, blistering during solvent debinding, cracks around the injection gate and external and internal cracks in the sintered parts. Defects detected during the production process are traced to improper injection parameters, mould design, debinding parameters, residual stress, or inhomogeneous composition distribution in the green body leading to crack formation during sintering. ■



Acoustic vector hydrophone incorporates μPIM piezoelectric sensor

Researchers at Pohang University of Science and Engineering (POSTECH), Korea, the Korean Agency for Defence Development (Jinhae-shi), and Mahindra Ecole Centrale in Hyderabad, India, have explored the use of Powder Injection Moulding to develop a piezoelectric AHC tranducer for use in underwater acoustic vector hydrophones. Jun Sae Han and colleagues recently reported on their research into producing the microscale PIM AHC transducer in the journal *Smart Materials and Structures* (Vol.24, November 2015, 13pp). It showed the piezoelectric AHC transducer to comprise four main parts as can be seen in Fig.1: the high aspect ratio hair cell (31), three mechanoreceptors (32), polymeric sphere (33), and three fixing legs (34), designed for attachment to a printed circuit board (PCB).

Fig.2 (a) and (b) indicates the side and top view of the microscale AHC transducer in order to present the working principle. The authors stated that when the acoustic wave is propagated from the source, the AHC transducer follows the acoustic velocity of the media. As a result of the acoustic wave, hydrodynamic force is induced on the polymeric sphere by the radiation and the sound pressure. The hydrodynamic force causes a moment and this moment induces a reaction force on the mechanoreceptors.

The authors emphasised the need to be able to produce the PIM piezoelectric ceramic structure with precise dimensions. The three mechanoreceptors should meet the 3 μm dimensional tolerance, in order for each to have the same piezoelectric performance, and the hair cell should be placed in the centre of the device without tilting or twisting. The authors, therefore, designed the injection mould for the piezoelectric AHC structure to use specially designed gate systems. This involved a cylindrical gate which was used to inject the PIM feedstock through each rectangular mechanoreceptor to fabricate exactly the same size mechanoreceptors. The ejection pin was designed in the centre of the hair cell to eject the high aspect ratio structure without ejection problems. The authors reported that incomplete or non-uniform filling was avoided by optimising the injection moulding parameters. It was found that the dielectric property of the mechanoreceptors showed an acceptable 8% deviation compared to the dielectric property of the reference PMN-PZT ceramic powder.

In producing the PIM AHC transducer, synthesised PMN–PZT piezoelectric powder was used having the composition Pb(Mg, Nb)O_3-Pb(Zr, Ti)O_3 of irregular shape, particle size D_{50} of 0.52 μm, and with dielectric constant ($\varepsilon^T_{33}/\varepsilon_0$) 3731. The PMN–PZT powder was mixed with a binder comprising 57.5 wt.% paraffin wax, 25 wt.% polypropylene, 15 wt.% polyethylene and 2.5 wt.% stearic acid. Solid loading was 47%. Injection moulding was done at 60 MPa injection pressure at 160°C with the mould held at a temperature of 55°C. The moulded parts were debound using solvent and thermal debinding and sintering was done in a closed crucible to reduce Pb loss through evaporation at 1300°C sintering temperature and 3 hr hold time in air to reach full density. Fig. 3 shows the AHC transducer structure at each stage of the PIM process.

The dielectric property of the sintered material was found to be 85% of the reference PMN–PZT ceramic powder. The authors state that a high density in the PIM part leads to higher piezoelectric performance. Larger grains in the microstructure will also bring superior piezoelectric performance because larger grains reduce the mismatch of domains. The avoidance of vaporisation of Pb during sintering is a significant controlling factor as this can dramatically reduce piezoelectric properties.

After sintering, silver paste was deposited as electrodes on the top and bottom of the mechanoreceptors. A precise poling jig was designed to apply the voltage for each mechanoreceptor at the same time. The sintered structure is attached to a jig by using the cylindrical gate. The upper and lower pin system is contacted with the silver electrodes of the mechanoreceptors.

The researchers concluded that by using PIM technology they were able to successfully incorporate microscale sintered PMN-PZT AHC hydrophone structures onto electric PCBs and package them into the brass body of acoustic vector hydrophones. The packaged acoustic vector hydrophones were able to measure underwater acoustic signals from 500 to 800 Hz with -212 dB of sensitivity. ■

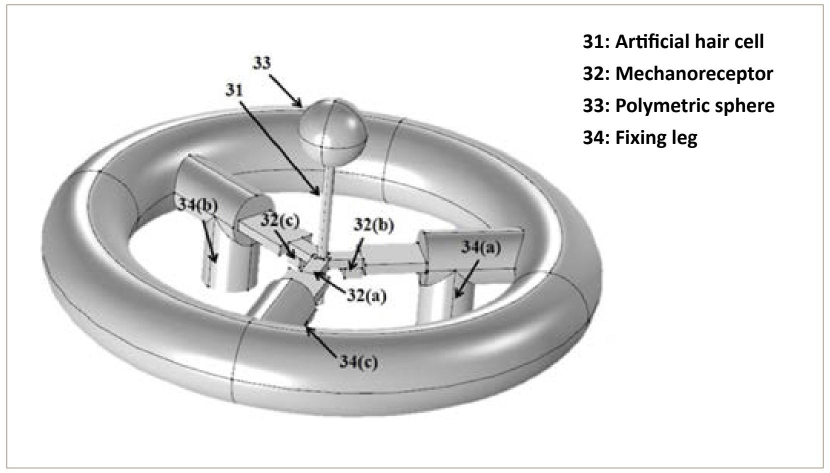


Fig. 1 Conceptual design for the microscale PIM piezoelectric AHC transducer. (From paper: 'Bio-inspired piezoelectric artificial hair cell sensor fabricated by powder injection moulding' by Jun Sae Han, et al Smart Materials and Structures Vol.24, No,12, 2015, 13pp)

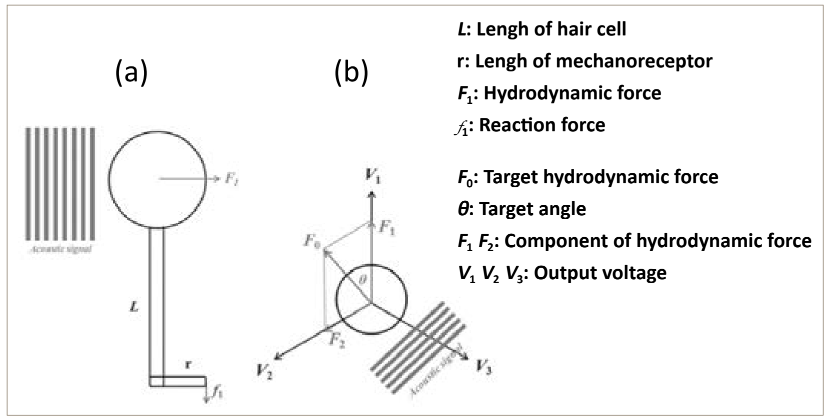


Fig. 2 Working principle of AHC vector hydrophone (a) side view (b) top view. (From paper: 'Bio-inspired piezoelectric artificial hair cell sensor fabricated by powder injection moulding' by Jun Sae Han, et al Smart Materials and Structures Vol.24, No,12, 2015, 13pp)

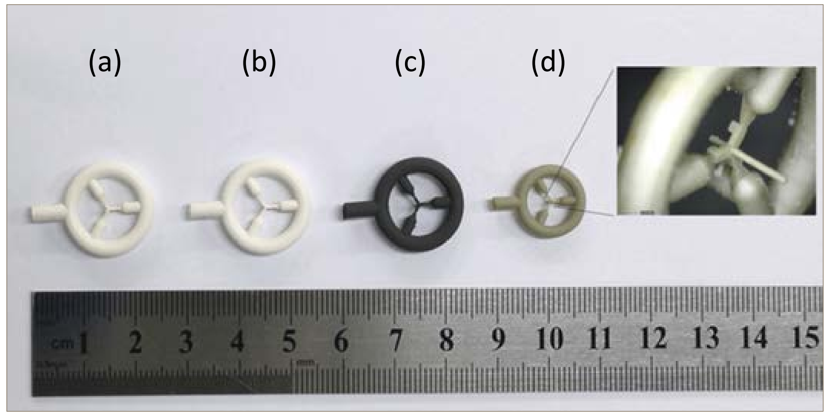


Fig. 3 AHC structure at each stage of the PIM process: (a) injection moulding, (b) solvent debinding, (c) thermal debinding, (d) sintering. (From paper: 'Bio-inspired piezoelectric artificial hair cell sensor fabricated by powder injection moulding' by Jun Sae Han, et al Smart Materials and Structures Vol.24, No,12, 2015, 13pp)

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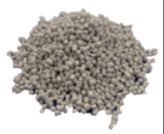
M1	106.43	1.80	0.9655	382	510
M3	42.16	1.84	0.9677	398	510
M4	256.81	3.74	0.9588	378	510
C1	645.72	1.43	0.9833	346	510
C7	244.98	1.34	0.9924	335	510
CS13	1024.23	1.29	0.9190	367	510

M1 : Improves deformation and cosmetic rejections
M3 : Minimize impurity residue and porosity for perfect surface



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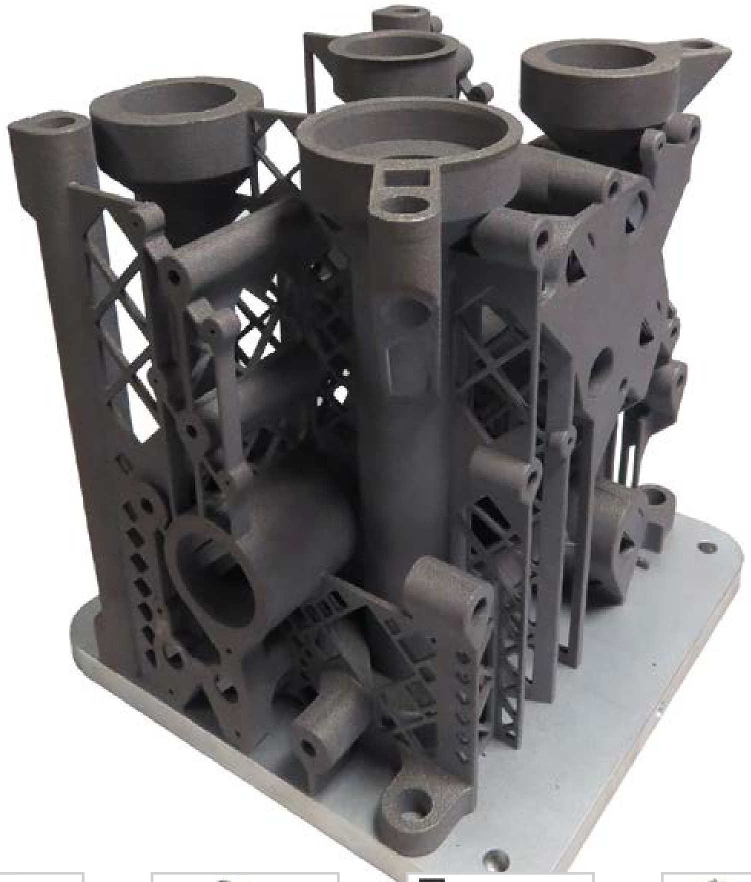

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Zoltrix: Leading Chinese MIM producer increases capacity and targets new international markets

China's Metal Injection Moulding industry has grown tremendously over the past decade, in part as a result of the huge demand from the consumer electronics sector. In the following article, *PIM International*'s Nick Williams profiles one of the country's leading MIM producers, Zoltrix Material International Limited. Zoltrix, a company with a strong track record in the high volume production of aesthetic components for the consumer electronics and luxury markets, is now increasing capacity in order to grow its presence in the automotive, medical and smart wearable sectors.

In the timeline of the MIM industry's global development, it is widely understood that the technology's rapid development in China took place in large part over the last decade, whilst, in North America, Europe and Japan, the industry started to achieve commercial success as early as the 1990s. With every rule, however, there is the exception and MIM parts producer Zoltrix Material International Limited is such an exception.

Zoltrix's history in Metal Injection Moulding can be traced back to 1990, when its Hong Kong based parent company, Chung Nam Watch Company Limited, took the first steps on its journey towards implementing MIM technology in order to fulfil its internal requirements for watch components. By 1992 small scale production was underway and in 1995 the company moved MIM production to a new site in the Nansha district of Guangzhou, Southern China, having correctly anticipated the growth in demand for MIM parts. The facility (Fig. 1) was significantly expanded in 1998, the year in which the company invested in its first continuous sintering furnace. The introduction of Metal Injection Moulding, along with advanced surface treatment technologies, enabled the company to manufacture high precision watch components with excellent aesthetic qualities. To this day, aesthetic components remain an important part of the business.

The history of Chung Nam Watch can be traced back to the foundation of the Chung Nam Company in 1935 by Chong Ching Um and his wife in Hong Kong. Today, the Chung Nam Group of companies has global

Fig. 1 The Zoltrix MIM factory in the Nansha district of Guangzhou, China

Fig. 2 Zoltrix operates more than 250 injection moulding machines for MIM production, many with automation to facilitate high volume production

interests that include high-technology manufacturing, watchmaking, retail and fashion.

Zoltrix is today a part of CN Innovations (CNI), a business of the Chung Nam Group of companies that was established in 2006 with investment from the Chung Nam Watch Company Limited. CNI's activities not only cover metal components processing, but also include the production of touch panels, cover glass and coatings for electronics, the development of both battery-based electric vehicles and hybrid vehicles, advanced laser ablation, micro deposition systems and micro-bio reactors for medical applications. The company's ambition is to be a leading international material science company, offering a range of technology and supply chain solutions to industry. Although headquartered in Hong Kong, the company's main production facilities are located at sites in Mainland China including Shenzhen, Guangzhou and Suzhou. CNI employs over 11,000 people.

Component production technologies at CN Innovations

As well as Metal Injection Moulding, CN Innovations' operations feature a number of other metal processing technologies for the production of precision metal parts. These technologies include metal stamping, hot and cold forging, CNC machining, laser welding and subassembly. There is also extensive expertise for surface finishing, including decorative and functional PVD coating, polishing, hairline brushing and sand blasting.

This comprehensive range of technologies is used to produce cases and components for internationally renowned watchmakers, smart device vendors and contract manufacturers. Watch components are produced from a number of materials including aluminium, stainless steel, titanium, zirconium and metal matrix composites.

Metal Injection Moulding technology at Zoltrix

In 1998, in addition to expanding MIM production capacity, Zoltrix's management team made the decision to change the MIM business from a captive operation to one seeking external market opportunities. This change was driven by a small management team of four led by Kevin Liu, formerly General Manager of Zoltrix and now Group Chief Engineering Officer. The other management team members are Eric Chong (formerly Sales and Marketing, now Group Sales and Marketing Officer), Cliff Lee (Operations) and PC Chan (Research & Development). This core team still remains in place and the company believes that the experience that has been built up over many years has allowed the business to overcome many challenges and places it in a strong position for the future.

The change from a captive MIM operation came at a time when MIM was enjoying significant growth in a number of major markets including computer hardware, consumer electronics, mobile phones and car parts. In parallel with strong growth, the company maintained a focus on technology development and quality standards, achieving ISO9001 in 2001, ISO14001 in 2004, QS9000 in 2005 and TS16949 in 2008. During this period Zoltrix grew to become one of the largest MIM manufacturing operations in China. The company told *PIM International* that in the coming months it also expects to be certified to the medical device standard ISO13485.

Today, Zoltrix operates one of the world's highest capacity MIM facilities, with more than 250 injection moulding machines in use. (Fig. 2). The high volumes of green parts produced by this large number of machines are processed in six continuous sintering furnaces (Fig. 3), with a further three continuous furnaces to be installed by the end of 2016. Additionally, a number of vacuum sintering furnaces are used for the processing of special materials and to help balance the changing volume demands of different customers.

Zoltrix manufactures and maintains all tools in-house, including high complexity multi-cavity tools for small, high volume components (Figs. 4-6). Kevin Liu told *PIM International*, "Keeping our tool production in-house helps to ensure quality of the products and allows us to provide the best service to customers. Importantly, in-house tool making also provides a high level of design security for the customer. By developing tooling in-house we are also able to provide timely design feedback to customers for the whole chain of service, from tool making to cosmetic finishing and PVD."

Zoltrix uses imported catalytic-based feedstock, believing that this offers many advantages over in-house feedstock preparation. PC Chan stated, "Stable manufacturing is the prime strategy behind our operations and this backed up by a reliable feedstock system and advanced

Fig. 3 Continuous MIM debind and sintering furnaces in operation

Fig. 4 A view inside the tool maintenance area at Zoltrix

Fig. 5 Tool production at Zoltrix

Fig. 6 Tool production equipment at Zoltrix

Fig. 7 The surface finishing of MIM parts

equipment." It was indicated that feedstock consumption for the coming 12 months may increase by up to 50% on the past year thanks to the addition of the new continuous furnaces.

The main materials processed by Zoltrix are 316L and 17-4PH stainless steels, which the company states are produced in equal proportion. Parts from these two material types enjoy the highest production volumes, ranging from hundreds of pieces to several million pieces per day. In addition to stainless steels, low alloys steels, tool steels, tungsten and ceramics are also produced. Looking to the future, Zoltrix is seeing growth in titanium MIM. PC Chan commented, "Titanium is used in daily production and we are sure that titanium MIM will become even more important to us as we have a strong presence in the market for cosmetic MIM parts. Tungsten is also important for the future and, thanks to its weight, it is useful for functional parts and parts with complex internal features." The company also confirmed that aluminium MIM is under development.

High production volumes and rising labour costs mean that automation has been embraced in the company's operations. PC Chan commented, "Automation applied in Metal Injection Moulding makes the process much more cost effective as it reduces the heavy cost of manual labour. Applying automation in our operations has the additional advantage of improving operational stability and thereby improving quality."

Given the company's expertise in the production of aesthetic components, secondary operations are a crucial part of Zoltrix's MIM capabilities (Fig. 7). Secondary processing capabilities include automatic sandblasting, polishing and tumbling, continuous spray painting, PVD coating, stamping and laser welding/marking. Such operations are not limited, however, to surface technologies. CNC machining, stamping, over-moulding and the production of sub-assemblies are also available within Zoltrix.

A recent development, driven in part by the desire to further improve the surface finish of Metal Injection Moulded components, is the addition of Hot Isostatic Pressing (HIP) technology at Zoltrix. Chan explained to *PIM International*, "We are now bringing MIM + HIP technology into production. Some of our main customers are from famous brand watches and with this technology products can reach 100% density. We can therefore ensure a perfect aesthetic appearance using this technology combination. This process is especially useful for ceramic components."

A total solutions provider

CNI believes that it is in a strong position to be regarded as a total solutions provider by its customers, not only because of the scale of its Zoltrix MIM operation, but because it is able to offer a number of different manufacturing technologies to suit a specific application.

Eric Chong told *PIM International*, "It's quite natural that we offer customers the full range of our design and manufacturing solutions, as we aim to promote CNI's services as a whole. We welcome early supplier involvement from customers, especially when we can be involved in a product's conceptual design phase. We always introduce the best fit manufacturing processes and try to simultaneously educate new customers in the use of Metal Injection Moulding."

Where MIM is chosen, the focus remains on providing a total solution to customers. Eric Chong added, "We work closely with customers to truly offer a one-stop service in MIM, from materials selection to tool making, MIM processing, cosmetic treatments such as PVD and then finally sub-assembly. For cosmetic MIM applications in particular, we try to understand the needs of our customers and have the expert knowledge that is required in order to process high volumes of cosmetic components. We believe that this makes us unique in the market."

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Fig. 8 Highly polished MIM stainless steel watch parts manufactured by Zoltrix

The consumer electronics sector

The consumer electronics sector accounts for a high proportion of MIM production at Zoltrix. The company's expertise in what it describes as "touch and look" components, using experience gained producing parts for the watchmaking market (Fig. 8), put it in a strong position to win business when the market for smartphones and tablets took off, resulting in a surge in demand for MIM components, many with both mechanical and aesthetic requirements. Components include device casings, bezels, buttons, hinges and trims as well as internal components.

Kevin Liu told *PIM International*, "Zoltrix was the first company to bring cosmetic MIM to the China mainland market. This market is challenging as high sintered densities are required to enable polishing and fulfil the aesthetic demands of customers. However, our strong research and development capability, technical improvements and capital investments helped gain customer confidence and satisfaction. Because of such a history, Zoltrix is now a world-class cosmetic MIM house."

Despite the attraction of extremely high production volumes, this sector also brings significant challenges for MIM parts producers. Orders are often placed by OEMs and contract manufacturers at short notice and with minimal lead times. As a result, stated Cliff Lee, the only way to deal with this market is to have spare capacity reserved for such situations. "To maintain sustainable mass production with flexibility according to customers' fluctuating volume requirements is the major challenge in this sector, so spare capacity has to be reserved. Frequent design changes in the development stage are another challenge, particularly when providing fast responses to customers on our design feasibility studies. Shortened product life cycles are also presenting the industry with challenges."

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Fig. 9 A selection of MIM parts manufactured by Zoltrix, including a demonstration turbocharger rotor

Looking to the future of this sector, Cliff Lee commented, "MIM parts will be around for a long time as the technology is much more cost effective compared to stamping and forging for complicated 3D shapes. There is no competition from other technologies because of the unique position of MIM – it is the only technology that can produce millions of complex, high quality, near net-shape parts per day. In addition, the technology can enable the efficient production of designs that in some cases would be impossible to make with processes such as CNC machining."

Other markets

Whilst consumer electronics remain the company's largest market, Zoltrix operates in a number of other sectors, many of which it believes offer significant growth potential. Opportunities are still seen in the watchmaking sector, where the growth of smartwatches and wearable devices is resulting in the demand for very complex components that are ideally suited to MIM. "MIM is perfect for watch applications such as watch cases as the technology can at once deliver complex interior features and a highly polishable exterior. This provides flexibility to the designer and more efficient production. The smartwatch sector is also similar to the consumer electronics sector with regard to production volumes, commented Cliff Lee." Other markets with an aesthetic requirement include jewellery parts, eyewear components and accessories for the luxury goods market (Fig. 10).

Zoltrix states that it also supplies MIM components to other markets including automotive and medical devices, the latter including hearing aids and microsurgical instruments (Fig. 11). In 2012, Zoltrix received a Supplier Excellence Award from a leading international implantable hearing solutions company.

The company believes that its experience of supplying high volumes of components to the consumer electronics sector has put it in a good position to grow the sales of products to the automotive components market, where the demands in terms of quality, traceability and reliability are critical. The company stated that it is also exploring the commodity sector for new opportunities.

The current status of MIM in China

Commenting on the current status of MIM in China, Eric Chong stated that although the industry was growing well, there was currently overcapacity in the market. "The current situation in China is that MIM component supply capacity exceeds demand, so we are very mindful to pick the right MIM products. Our strategy is to keep on collaborating with customers on project developments and win business with our high technical capabilities and on-time delivery."

Commenting on the understanding and awareness of MIM in China, Eric Chong stated, "The technology's growth in China has been impressive and awareness of MIM technology has improved substantially. There are, however, many customers who still misunderstand the technology, for example believing that the price of conventional PM is comparable to the price of MIM. The domestic market in China needs more education in MIM technology."

In sectors such as consumer electronics, MIM technology has become sufficiently established that many products could now be regarded as commodity items. Commenting on this, Kevin Liu told *PIM International*, "Many MIM products became what we could call commodity items around three years ago. This is no longer a premium process; on the contrary, more and more people are starting to use MIM for high volume commodity components. This is of course a benefit to MIM manufacturers with high production capacities."

Outlook

It is clear from the current capacity expansion at Zoltrix that there is confidence in the future growth of the MIM market. The company stated that sales in 2016 are expected to be higher, in double digits, than the previous year. Given the investments in capacity, as well as in technologies such as HIP and automation, it is clear that Chinese MIM producers such as Zoltrix are now more than capable of competing with the leading producers in other world regions.

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Fig. 10 Decorative MIM parts produced by Zoltrix

Fig. 11 Small surgical device components manufactured by Zoltrix

Fig. 12 Cases for mobile phones made by stamping that demonstrate the various PVD coatings that can be applied at Zoltrix

ABSTRACT SUBMISSION DEADLINE: SEPTEMBER 30, 2016

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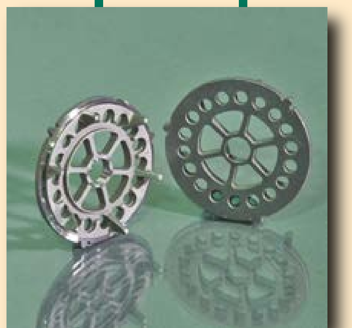

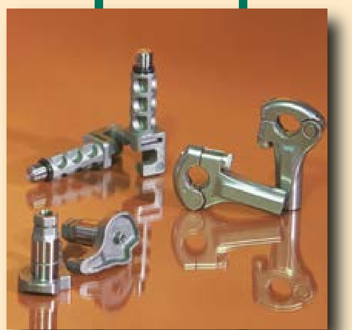

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Dynamic Group: A toolmaker's perspective on the challenges and opportunities in PIM

Toolmakers are in a unique position in the PIM process chain, with decisions that are made when designing and manufacturing a new PIM tool having a major influence on the technical and economic success of a part. As the following article reveals, toolmakers specialising in PIM not only have to be able to work at the cutting edge of what is technically possible, but they are also in a position to gauge the growth of the industry and the technology. We profile leading PIM toolmaker Dynamic Group and share the company's unique perspectives on the development of the PIM industry.

Dynamic Group, originally named Dynamic Engineering, was founded in 1977 by two toolmakers as a contract manufacturer and injection mould provider. In 1988, a customer who was impressed with the company's injection moulds asked if they would like to try making tools for a relatively new and promising technology: Metal Injection Moulding. Twenty-eight years later, Dynamic continues to supply that same customer, and many more, with state of the art PIM tools.

Despite having continually produced PIM tools for decades, between 2013 and 2015 the company's output of PIM tools more than doubled, reaching 110 shipped tools during 2015. The company operates out of two facilities in Minneapolis, Minnesota, USA. The first is a 1,500 m^2 mould manufacturing and precision machining facility with a staff of fifty full time tooling employees. The second facility, covering some 2,100 m^2, houses a plastic injection moulding and contract manufacturing facility as well as the company's headquarters. The company is FDA registered and ISO 13485 and ISO 9001 certified.

The growth of PIM at Dynamic

The story of Dynamic's dramatic recent growth in the PIM tooling market offers a unique perspective and focus on emerging trends in the industry. Brian Kalina, one of three second-generation owners and Dynamic Group's Vice President of Operations, explained to *PIM International* the company's place in the market prior to its growth. "For many years, prior to about 2013, our reputation in the market and our size brought us a pretty consistent flow of fairly standard PIM tool work. A little more than half the tools we made

Fig. 1 Part of Dynamic Group's injection mould manufacturing facility in Minneapolis showing various wire EDM machines

Fig. 2 From left to right: Joe McGillivray (CEO), Steve Kalina (President), and Brian Kalina (Vice President of Operations)

each year were for the PIM market. At that time, our experience in building PIM tools allowed almost all of them to flow through the shop in the same way as any other tool would. However, we also almost always had one or two very difficult to manufacture PIM tools that we would be working on. These tools were more difficult because they had several 3D shut-offs, stepped parting lines and multiple side-actions and made tiny parts. A few exceptionally talented individuals handled these tools outside of our normal production processes."

Steve Kalina, another second-generation owner and Dynamic Group's President, continued, "The mix of work that our customers were awarding us had been very consistent for many years and they were well served by the two value streams we had set up. However, in late 2012, we saw a significant shift in demand from our PIM customers." Steve explained that this shift matched the market research that Dynamic Group was evaluating at the time, which suggested there would be significant growth in both micro-moulding and Powder Injection Moulding over the next five to ten years. The enquiries that Dynamic began receiving followed suit; instead of receiving Request for Quotations (RFQ) for one or two PIM tools at a time, multiple customers began sending Dynamic Requests for Proposals (RFP) to produce PIM tooling packages for 20 to 80 different parts and with unprecedented delivery lead-times. In addition, the part geometries were as small and complex as the company had ever seen; they required tooling that could not run through Dynamic's normal value stream. As fortune would have it, Dynamic was well positioned to address this shift in demand.

"The mix of work that our customers were awarding us had been very consistent for many years and they were well served by the two value streams we had set up. However, in late 2012, we saw a significant shift in demand from our PIM customers"

Brian Kalina explained, "In early 2012, we took on one of the largest tooling projects that the company had ever seen. When the project was over, we had produced nine very large and nearly identical 24-cavity tools, each with its own complex side-action, for a tight tolerance

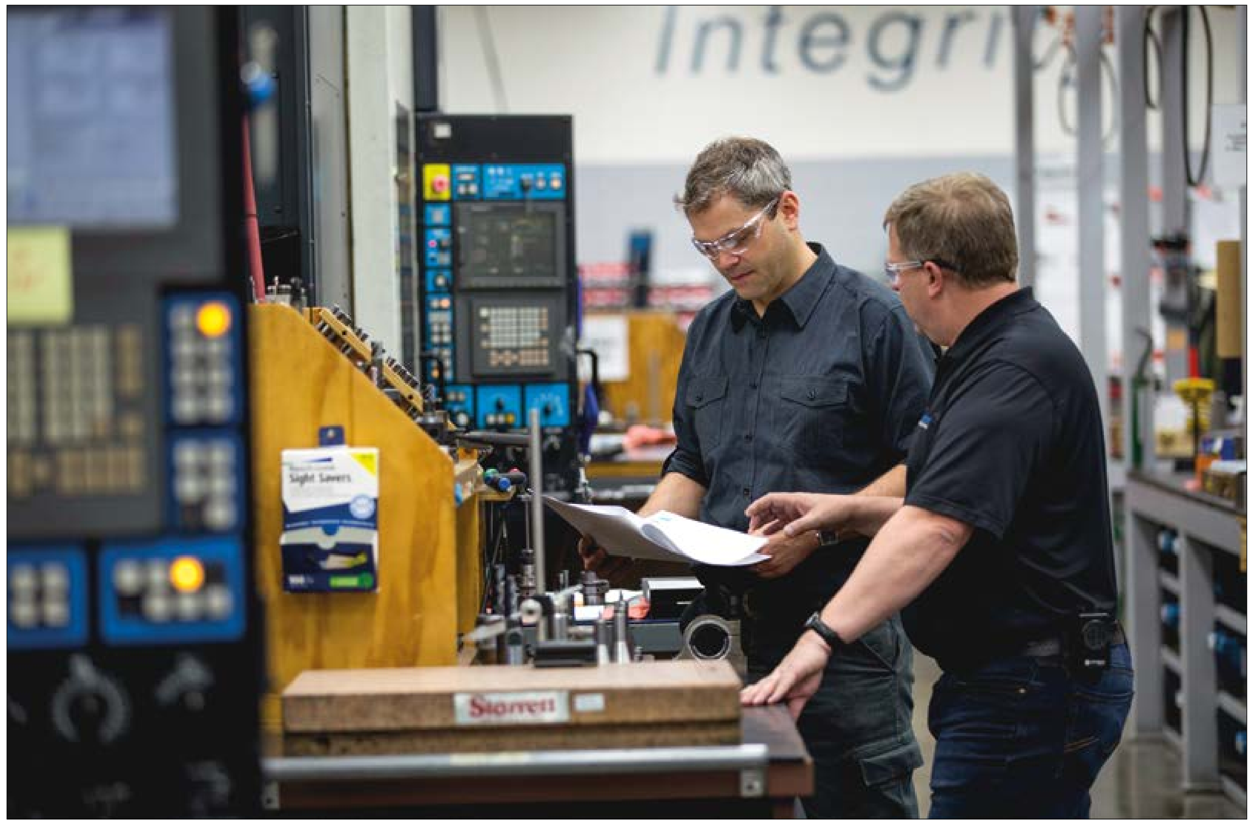

Fig. 3 Brian Kalina discussing tool plans in Dynamic's tool production facility

and highly-cosmetic plastic part. We also had to produce six spare cavity sets for each tool delivered. Our customer wanted to ensure they could maximise their up-time so, during their validation runs, they swapped in spare cavity sets and moved primary cavity sets to random locations in the tool. To perform under these conditions, all thirty cavity sets for each tool needed to be indistinguishable from each other aside from their cavity IDs."

Brian continued, "This program forced us to adopt a totally new mind-set and develop new capabilities. The volume of identical precision components that we needed to produce meant that we had to get into a production-machining mentality and come up with practices that made very efficient use of machine capacity. At the same time, we had to maintain our business of quickly supplying world-class one-off tooling, so our ability to rapidly produce a large number of one-of-a-kind components would not be impaired. Learning how to live in both of these worlds at the same time was not easy. Half of our work needed to be very regimented and the other very flexible. Half of the work needed to be scheduled well in advance and run uninterrupted and the other half needed moment's notice access to the same machines and specialists."

"To be honest, we got off to a pretty rough start. Although our customer was very happy with the first 24-cavity tool we delivered, we missed our mark by a significant margin financially. Thankfully, we learned quickly and brought performance up to expectations. The key was increasing our focus on manufacturing planning. We have got incredibly talented toolmakers and, when we are building one-off tools, they create robust manufacturing plans on-the-fly. But when a large production project comes up and consumes so much of our capacity and has so many people working on it in parallel, planning needed to go to another level," explained Brian.

By the end of the project, Dynamic Group had not only developed machining practices that allowed them to succeed, but an entire system that includes specialised planning, scheduling, purchasing, communication tools, quality controls and more.

Increasing capacity and expertise for high volumes of PIM tooling

"When these huge PIM tooling RFPs started showing up, we had a big decision to make," stated Steve Kalina. "We now knew how to get very large volumes of precision work through our shop and we knew that we had a small group of people who could build the type of tools our customers were asking for. But, these projects would mean we had to take things up a notch. While all the parts in these packages were very similar, almost none of them were the same. That meant we would have a lot more manufacturing planning to do up front. Also, these tools were for

Fig. 4 A 3D inspection system that utilises structured light is used at Dynamic Group

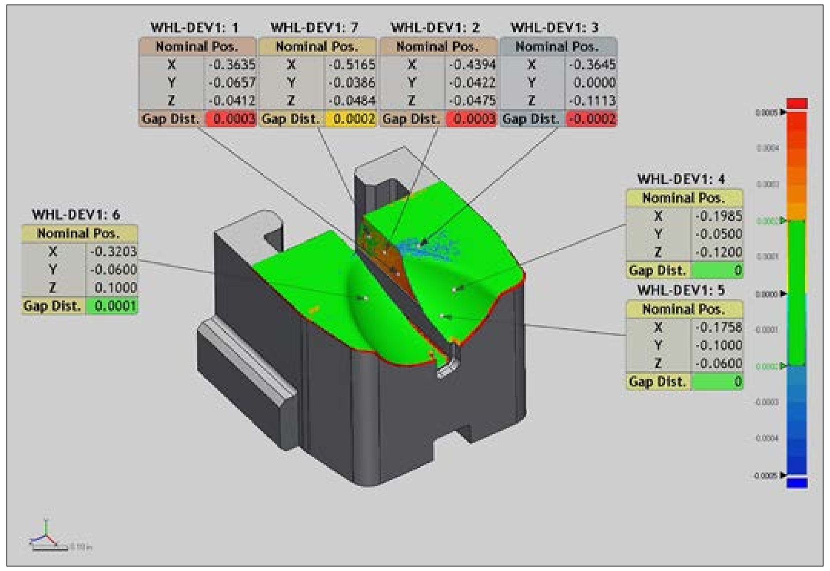

Fig. 5 The inspection system collects hundreds of thousands of data points with 1 micron accuracy in a matter of seconds and 3D metrology software allows the results to be compared to the CAD data

PIM, not plastic, so they would need to be an order of magnitude more precise than the series of tools we had previously made. Lastly, there was no possible way for our small team of experts to get all this work done. The only way we had a chance of succeeding was to train up a large number of our toolmakers and come up with completely new manufacturing methods. It was a very exciting but daunting opportunity."

Again, Dynamic Group was fortunate to be well prepared for the challenge. At the time, the then Vice President of Technology, Joe McGillivray, was finishing an analysis of state-of-the art 3D inspection technologies and was well into research on high-precision 5-axis machining centres. When Brian and Steve presented the new tooling opportunities to Joe, who is the final second generation owner and current CEO of Dynamic Group, he knew there was a good chance that this research could provide the answers they were looking for.

Joe, Steve and Brian quickly pulled together a taskforce of Dynamic's best and brightest minds to take a clean-sheet approach to the RFPs and Dynamic's PIM tool design and production practices. In a matter of days, the team had come up with a concept that relied on lean principles, including just-in-time manufacturing and optimising material flow with Kanban. The plan also relied heavily on the theoretical limits of a high-speed, high-precision 5-axis machining centre. The trio of second-generation owners presented their initial findings to Dave Kalina and Peter McGillivray, Dynamic Group's founding partners, and were given the go-ahead to take a four pronged approach; complete the study of high-speed, high-precision 5-axis machining technology, prepare a capital expenditure proposal and ROI analysis, develop and train the team on the newly proposed lean practices and work with the customer to understand fully the scope of the project and level of commitment each party was willing to make. A full understanding arrived quickly and Dynamic had orders in hand within days and were discussing how they planned to increase capacity to handle the workload promised over the next several quarters.

The speed that the customer was seeking also made it clear that Dynamic needed to validate quickly that the team could achieve the productivity gains that they were hoping high-speed, high-precision 5-axis machining could provide. Over the next few weeks, a list of vendors was narrowed down to two possibilities and a thorough evaluation and selection procedure was developed.

Fig. 6 Various Makino wireless EDM machines at Dynamic Group

By the time the machine manufacturers delivered the sample parts Dynamic Group would use to evaluate their capabilities, significant progress had been made in preparation for the project.

Coping with challenging inspection requirements

Early in the development of new lean processes, Dynamic realised that the inspection requirements of the project were especially challenging and would consume a huge amount of resources. Many of the components that they would produce had several critical-to-quality features that were non-planar or were out of square with their related fixturing surfaces on one or two axes. Both the creation of inspection plans and the act of inspecting components were likely to take longer than the machining cycle. To address this issue, Dynamic Group became one of the first mould shops in the United States to invest in a 3D inspection system that utilises structured light. The system allows Dynamic to collect hundreds of thousands of data points with 1 micron accuracy in a matter of seconds (Figs. 4 and 5).

Joe McGillivray explained, "The point cloud data we collect are brought into 3D metrology software, which allows us to quickly compare them to CAD data. Now, at any stage of production, we can take a scan and obtain a very reliable and complete understanding of our component. At the same time, we have been able to avoid the up-front and on-going costs of purchasing and running a state-of-the-art Coordinate Measuring Machine (CMM). In fact, as more of our toolmakers have learned to use the system, we have seen that we get more reliable and comprehensive results in much less time than it would take using a CMM or by using a touch probe in a machining centre." McGillivray stated that his belief is that high-fidelity, non-contact inspection technology will continue to make great leaps in the next few years and will provide immense productivity gains for machining companies and injection moulders of all sizes.

When Dynamic applied its newly-acquired inspection capabilities to the sample parts provided by the 5-axis machining centre manufacturers vying for their business, they were relieved to find that both machines proved to be capable of the speed, accuracy and precision that they needed. The data gathered from the machine vendors and inspection system were used to produce new capacity estimates and calculate an estimated ROI. Both Dynamic and the customer were very happy with the projected productivity gains.

The 5-axis machining centre's accuracy and ability to cut hardened tool steel promised drastically improved productivity for several key components. Analysis of the most difficult to produce and highest volume part showed that the 5-axis system would reduce an eleven-step process that produced four parts every five work-days to a four-step process that produced up to five parts each working day.

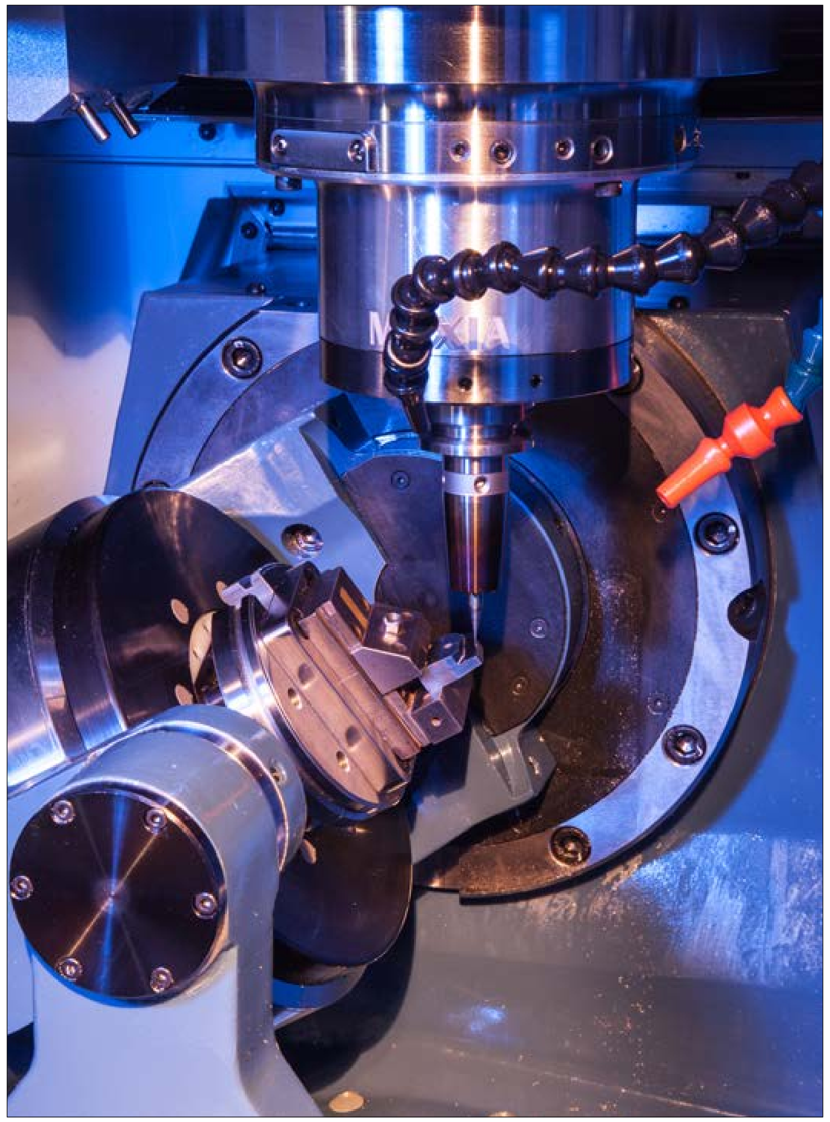

Fig. 7 Detail view of one of the two Matsuura 5-axis high speed high precision milling machines at Dynamic Group (as seen in the background of Fig. 2)

Fig. 8 Detail of a Makino Edge 2 precision sinker EDM machine with horizontal robot

In late 2013, Dynamic took delivery of its first linear-motor driven 5-axis machining centre and this was installed in a newly constructed and precision-climate-controlled micro-machining area. Thanks to the combined efforts of people at many organisations, it was soon apparent to both Dynamic and its customer that the improvements and partnership were an outstanding success. Fifteen months after delivery of the first 5-axis machining centre, Dynamic Group took delivery of a second identical system.

Keys to success

Joe McGillivray credits the company's recent success in the PIM market to the founders' unyielding commitment to building long-lasting and mutually beneficial partnerships with their customers and their core focus "to make things better and make better things".

"Quality PIM tooling for anything other than the most simple of part geometries requires precision that very few organisations are comfortable with or capable of achieving. If Dave and Peter had not built the company with such an expansive and grand vision, as well as invested in building long-term partnerships with their customers from day one, there is little chance that they would have seen the potential that the market held or would have been capable of collecting the state-of-the-art equipment and fostering the talent needed to compete."

He also points out how well PIM technology pairs with Dynamic Group's vision. "Powder Injection Moulding has not only been used to lower production costs and increase the quality of existing parts, but it has also allowed for the creation of revolutionary products that have entirely changed the game in several industries. When applied correctly, PIM truly makes things better and makes better things. It is a technology that enhances the quality of life for this and future generations."

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CASE STUDY: A typical micro-PIM tooling project

Today, well over half of the PIM tools that Dynamic Group produces fits its micro-PIM value stream. The following is a detailed description of a typical part and tool project that flows through that value stream.

The finished parts in this case study are highly complex, precise, micro-sized, medical components that weigh less than 0.1 g after sintering. Typically, the tooling described would produce only two of the 20 to 80 geometries included in an order.

On average, the surfaces of the parts made with these tools are produced by as many as nine precision mould inserts. Each of these inserts creates shut-offs with as many as seven of the other part surface forming inserts.

To ensure tools make flash-free parts the gap between any shut-off surfaces must be <7 microns (<.0003"). This level of precision is achieved by machining dozens of locating features scattered over many components within ±3 microns (±.0001") of target dimensions.

Counting the number and noting the style of shut-off surfaces in a tool is a fairly good gauge of its complexity. The tool selected for this case study is currently in production and fairly typical. It contains six part surface forming inserts and has approximately 85 shut-off surfaces, nearly all of which are non-planar.

Another feature adds a significant amount of complexity to this tool and most others; Dynamic provides interchangeable inserts that enable each tool to produce a family of different parts. This is a very attractive alternative to purchasing additional moulds, but adds considerable complexity for two reasons.

Firstly, a toolmaker can typically make adjustments to both components that form a shut-off, but, when components are interchangeable, a decision has to be made: do they try to make the interchangeable components have identical shut-off surfaces and adjust the non-interchangeable component to fit, or do they leave the non-interchangeable surface as their constant and adjust the shut-off surfaces of the interchangeable components. As previously mentioned, the toolmaker must keep in mind that all shut-off surfaces on all components must have a gap of less than <7 microns (<.0003") as they make their plan.

The second reason why interchangeable components add significant complexity is that moulders want to be able to swap components as quickly as possible; in other words, they want to be able to change out components from the parting line of a tool without removing it from the press. Achieving this requires a significant amount of additional mould design and tooling work as space is created to fit the extra fasteners and components needed to ensure that robust and precision shut-offs are protected and maintained. Designers, toolmakers and project managers also spend additional time creating custom changeover tooling, procedures and documentation and providing training to customers for tools with interchangeable components.

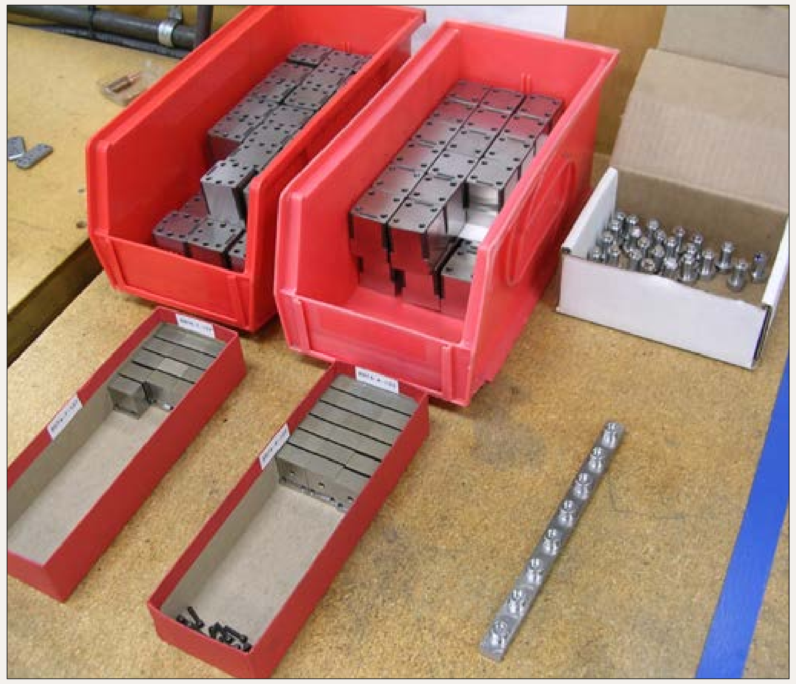

Fig. 9 The components pictured are precision hardened blanks specially designed and manufactured for this large project. They were developed as part of the project-specific lean practices and were part of the Kanban system that Dynamic implemented

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PIM trends from a toolmaker's perspective

- PIM technology's limits are being aggressively expanded
- Parts on both ends of the size spectrum are more common, but, on average, part size has greatly decreased. Finished parts that weigh a few hundredths of a gram are very common
- Complex non-planar shut-offs are very common
- Multiple complex side actions are frequent
- There is high demand for early prototype/bridge sample parts, used to jump start development of de-bind and sinter processes
- Complex in-tool part handling or secondary operations are becoming more common
- Increased demand for PIM tooling designated for ceramics, with a correlated increase in demand for use of extremely wear resistant tool steels
- Increased parallelism of orders: many tools ordered at once instead of in a row, with a related increase in demand for modular moulding systems and interchangeable mould components

Fig. 10 All electrodes are produced on System 3R pallets and manufactured in one of two dedicated and identical Makino machining centers at Dynamic Group

Looking to the future

Joe McGillivray went on to share more about how he believes Dynamic Group and PIM will change in the near future. "I am really excited about how the PIM market is developing. We are seeing somewhat of a fast-motion replay of how plastic injection moulding technologies and the market developed over the last twenty years or so."

"As the PIM market grows and new technologies are developed, we are starting to see space for specialisation. Take our approach to the market as an example. We have maintained our ability to quickly produce world-class one-off tools, but we have also stepped in to fill the market's demand for an organisation specialised in producing a large volume of tools for very small, complex and precise parts."

Joe sees other market niches that have yet to be filled. "In our line of business, the demand to decrease tooling lead-times is never ending, but there is a lot of pressure to take things to another level. Major players in the market have given low-cost, quick-turnaround production of MIM parts a try, but it seems as if they have run into difficulties. Still, I am hearing a lot of demand for someone to fill that space. There seems to be a good amount of opportunity for organisations that can quickly produce high-quality, short-run parts."

Another similar trend is an increased demand for quick-turnaround green parts. "The sooner our customers can get their hands on green parts the better. It lets them get a valuable head start on the development of their debinding and sintering processes."

When asked why Dynamic Group, which does a significant amount of plastic injection moulding and contract manufacturing, has not entered the custom Powder Injection Moulding arena, Joe says that they face many of the same challenges that their PIM tooling customers face. "Our contract manufacturing and moulding team is fantastic, but there is a lot of competition for talent and low unemployment in our local market. That makes it very difficult to find the talent we need to expand our offerings. Then, take into consideration the very small number of candidates that have substantial experience with PIM and the challenge magnifies considerably."

"Another consideration is how our partners would be affected if we added PIM. Would they feel they would benefit from the knowledge we gain as we develop our PIM skillset, or would they view our moulding activities as a conflict of interest? We worked through a very similar situation when we got into plastic injection moulding back in 1994 and it turned out well, but that was a different time in a different market with different partners. Today, I think that the most likely way that we would become involved in making parts would be in partnership with our current customers."

Joe McGillivray went on to point out that he thinks the best opportunities for Dynamic to grow with the PIM industry are through tooling. He points out Dynamic's recent investments in its ability to engineer and manufacture automation systems. "We've been a part of some very exciting developments in both the powder and plastic injection moulding fields that are transforming injection moulds into nearly complete production systems that have quickly saved customers many millions of dollars." McGillivray declined to share any specific examples, citing confidentiality agreements, but stated, "there is a huge and constant flood of new and inexpensive automation, computing and sensing technologies coming to market all the time and these have opened up a huge field of possibilities for those who know how to use them. Today, we develop and test concepts that we would have rejected as too expensive or impossible as little as two years ago. All it took to add this capability was a small investment to enhance our programming and electronics skills."

When asked what current trends he sees as having the largest impact on manufacturing and Dynamic group in the near future, Joe McGillivray stated, "I think a major key to success will be ensuring that we are prepared to keep up with an increasingly rapid pace of innovation. Dynamic is a fairly small company and, despite our size, just a few months ago my full-time job was to track promising innovations in our market. Even with the help of others, I could barely keep up. But, as we have discussed, we are seeing a good return on that investment. I think that the new x-factors in the manufacturing sector are adaptability and restraint. Organisations that want to succeed will have to be aware of the latest innovations, but they will also have to be very purposeful when they select which innovations to adopt. They will need to carefully craft new offerings that are focused on driving business that is very well aligned with their existing core competencies." Joe McGillivray concluded, "We like to think that rapid innovation is making the market increasingly dynamic and that suits us just fine."

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Praxis Technology: Taking the next step in the commercialisation of high performance TiMIM alloys

Praxis Technology has for many years been at the forefront of the development of titanium Metal Injection Moulding for medical and consumer applications. As Praxis' Joe Grohowski and Paul Sheffield explain, the company is now building on the knowledge gained in commercialising Ti-6Al-4V by exploring the potential of higher performance materials such as Ti-6Al-2Sn-4Zr-2Mo, Ti-10V-2Fe-3Al and Ti-5Al-5V-5Cr-3Mo. These materials were selected to address the demand for Ti alloys with improved tensile strength and creep resistance.

Praxis Technology is a specialist manufacturer of titanium components via the powder compaction and Metal Injection Moulding routes based in Queensbury, New York, USA. Over the past ten years the company has continually improved its titanium powder processing methods resulting in multiple patents and several pending patent applications. Praxis' porous and solid titanium parts are today used in the medical and consumer markets worldwide.

In 2014 Praxis commercialised the first TiMIM process that produces components certified to ASTM F2885, a standard for MIM Ti-6Al-4V components for surgical implant applications, which paved the way for adoption of TiMIM for implantable products. The company has since expanded into consumer products and will consume over ten metric tons of titanium powder in 2016.

To support the unique demands of the aerospace and defence markets, Praxis is now using its state-of-the-art TiMIM manufacturing facility to also produce high performance alloys for these specialised markets.

Expanding TiMIM to high performance alloys

The challenges of developing a robust titanium MIM process are numerous, well understood and compounded when the final product is intended for medical implants [1]. However, the rigour required to qualify a process also creates a deep understanding of all of the variables, which in turn produces excellent control over the process and resulting products. The knowledge gathered during the qualification of Praxis' first TiMIM process is readily applicable to the development of subsequent processes. After years of developing and qualifying a titanium MIM process for Ti-6Al-4V, the company's initial explorations of

Fig. 1 Injection moulding of TiMIM parts at Praxis Technology

Fig. 2 Quality inspection of TiMIM components at Praxis Technology

other higher performance materials were also quite successful. This was due primarily to having the benefit of the exhaustive understanding developed during the initial qualification of Praxis' TiMIM process.

A strong Ti-6Al-4V foundation

Praxis' TiMIM process was qualified with the objective of being able to certify the resulting product to ASTM F2885. In addition to certifying the general requirements of a device manufactured in an ISO-13485 environment, the product characteristics measured for this certification are chemical and mechanical properties. Since both of these types of properties require destructive testing, the MIM process must be capable of demonstrating statistical quality control. The approach used to determine the capability of our Grade 5 process has been discussed at length in previous publications [2]. During qualification of the process a target capability of 1.33 was established as the minimum acceptable.

The challenges of controlling interstitial contamination and getting consistent mechanical properties from a TiMIM process are well understood. It is generally accepted that the most difficult to control are oxygen content, carbon content, yield strength and elongation, of which, oxygen content and yield strength are the most difficult. Since its initial process qualification, Praxis has developed long term capability data on its MIM process. Table 1 describes the long term capability data for chemical composition. The oxygen content had a capability of 1.58, exceeding the minimum requirement of 1.33 and approaching 5 sigma capability. It is worth noting that all of the other interstitial contents were capable to Six Sigma or greater.

The importance of high capability with respect to interstitial control cannot be overstated. It not only guarantees consistent part quality, but ensures high yield in the process which can be passed on to the customer in the form of lower part cost.

Table 2 shows long term capability data for mechanical properties. All of the capabilities easily exceed the target capability of 1.33. Yield strength is the closest to this target, with the remaining properties above Six Sigma in capability.

Property	ASTM F2885-11 Requirement	Capability (Cpk)
Nitrogen	<0.05	5.17
Carbon	<0.08	2.38
Hydrogen	<0.015	2.03
Iron	<0.30	2.73
Oxygen	<0.20	1.58
Aluminium	5.5 - 6.75	1.87
Vanadium	3.5 – 4.5	6.25
Yttrium	<0.005	below detection limits
Titanium	Balance	Not required

Table 1 Long Term Capability Data for Chemical Composition of TiMIM Ti-6Al-4V

Markets and materials

TiMIM has many interesting applications within the implantable medical device sector. This sector has historically been limited to using either Ti-6Al-4V or commercially pure (CP) materials. Devices that bear high loads or require higher fatigue strengths such as replacement joints or bone screws specify Ti-6Al-4V. Because of their higher ductility, CP materials are preferred for stamped parts such as cardiac rhythm management or neuro-stimulation packages.

While there has been some academic exploration of other alloys, most often for modulus matching or improved biocompatibility, alloys other than Ti-6Al-4V or CP materials are very rarely used for implantable devices. This is primarily because the cost of demonstrating suitability for long term implants is rarely outweighed by the perceived benefits.

The selection of Ti-6Al-4V as the workhorse for implantable components is mostly due to its ready availability and biocompatibility at the time when the first implantable devices were developed. Now proven and accepted, the motivations for changing alloy specifications for implants are very low.

Historically, there has been tremendous development effort in the area of titanium alloys, mostly fuelled by defence interests in materials with high strength-to-weight ratios. The aerospace and defence markets are likely candidates for the adoption of TiMIM and they have been much more progressive with regards to using newer alloys because the benefits of these newer materials more easily offset the costs of adoption. Consequently, alloys that are welcomed in the implantable market do not necessarily garner as much interest in the aerospace or defence markets.

Based primarily on customer feedback, two performance requirements were used to select which Ti alloys would be explored for the aerospace and defence markets; improved tensile strength and improved creep resistance. Using these requirements Ti-10V-2Fe-3Al and Ti-5Al-5V-5Cr-3Mo were selected to address the customer desire for improved tensile strength and Ti-6Al-2Sn-4Zr-2Mo was selected to address improved creep strength requirements.

Customer input on high strength materials suggested 1240 MPa as a target for ultimate tensile strength. Ti-10V-2Fe-3Al and the Ti-5Al-5V-5Cr-3Mo are capable of achieving this strength. However, these are beta alloys and require heat treatment after MIM processing. Table 3 shows typical or minimum static mechanical properties for these materials and Grade 5 in the heat treated condition.

Property	ASTM F2885 Minimum Requirement	Minimum Result	Ppk Result
UTS (MPa)	896	958	25.29
Yield (MPa)	827	840	1.6
Elongation (%)	10	18	3.2
Reduction in Area (%)	15	30	3.14

Table 2 Long Term Capability Data for Mechanical Properties of TiMIM Ti-6Al-4V

Property	Ti-6Al-4V (Typical)	Ti-10V-2Fe-3Al (AMS 4984F)	Ti-5Al-5V-5Cr-3Mo (BMS 7-360)
Ultimate Tensile (MPa)	1035	1190	1240
Yield (MPa)	895	1100	1170
Elongation (%)	15	4	5

Table 3 Mechanical properties for selected heat treated alloys

Oxygen considerations

Control of oxygen is arguably the most challenging aspect of the titanium MIM process. Titanium oxide is not readily reduced during processing, so the control strategy must be a combination of beginning with low oxygen content materials and preventing oxygen pick-up throughout the process. Many ASTM specifications for titanium alloys have maximum oxygen limits of 1300 ppm or 1500 ppm. While it is possible to robustly process materials in this range, the process will be substantially more costly than material which can use an upper limit of 2000 ppm. The main driver of this is the cost of powder with a low enough oxygen content to accommodate both the process pick up and offset from the upper limit that is required to keep the process statistically robust.

Because of these concerns Praxis is developing and characterising materials using an upper oxygen limit of 2000 ppm. While there will be applications where this will not be acceptable, many applications will be able to use these materials provided they have been well characterised. The approach to characterising these materials is to use existing specifications for mechanical requirements and chemical requirements, except for the oxygen content.

The work presented herein represents Praxis' first efforts with these high performance materials and, while certain properties may not meet the final requirements, the proximity of the current material performance to the desired performance is a reason for high confidence that these materials can be processed by MIM.

While the initial trial of these materials had final oxygen contents over the desired upper limit of 2000 ppm, Praxis is optimising the process for each material with the objective of lowering the oxygen contents to a level that will allow for robust processing of these materials below 2000 ppm. Table 4 shows the oxygen content from our first trial and our target values for the final process.

Alloy	Specification (ppm)	Trial 1 (ppm)	Target (ppm)
Ti-5Al-5V-5Cr-3Mo	1300	2100	1700
Ti-10V-2Fe-3Al	1300	2500	1750
Ti-6Al-2Sn-4Zr-2Mo	1500	2100	1700

Table 4 Maximum oxygen specification, results and targets for MIM processed titanium alloys

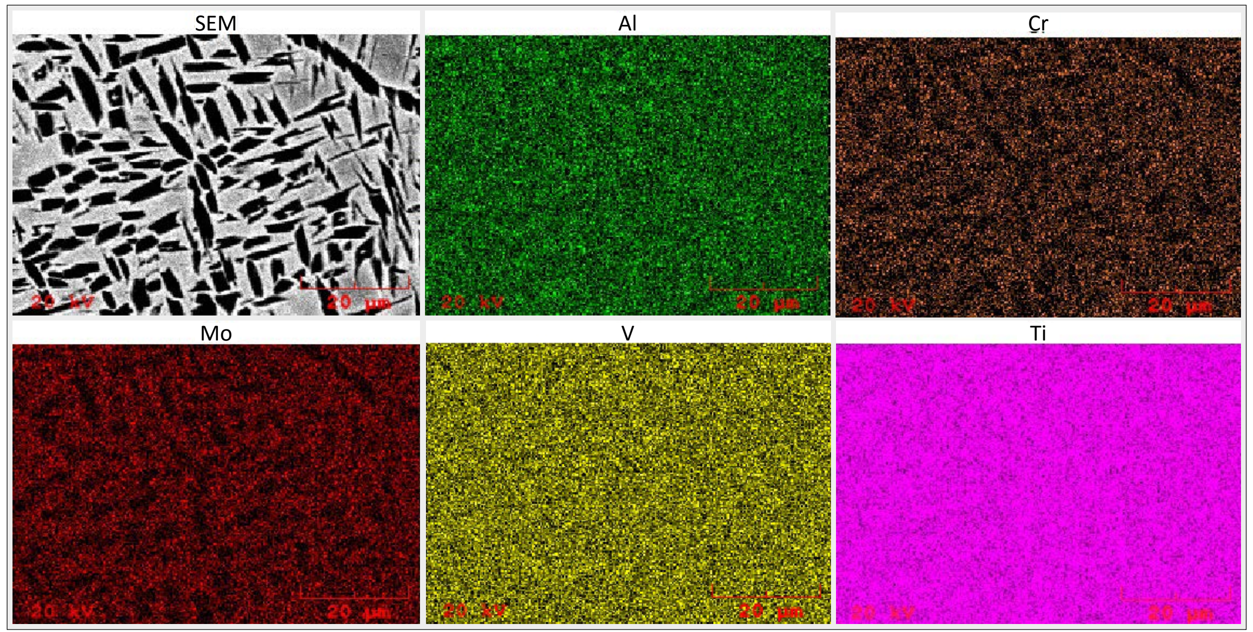

Fig. 3 EDS mapping of MIM processed Ti-5Al-5V-5Cr-3Mo

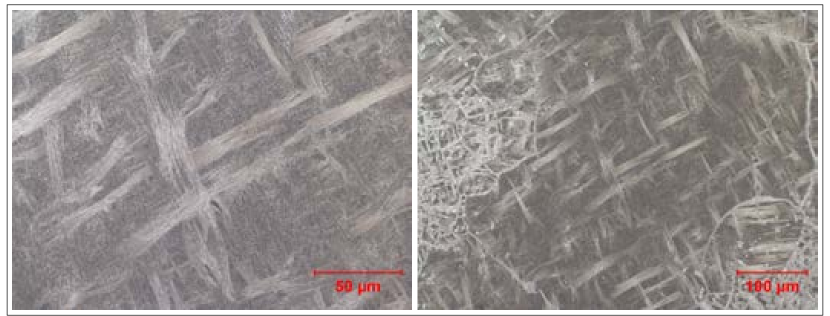

Fig. 4 Ti-5Al-5V-5Cr-3Mo, As HIP'ed

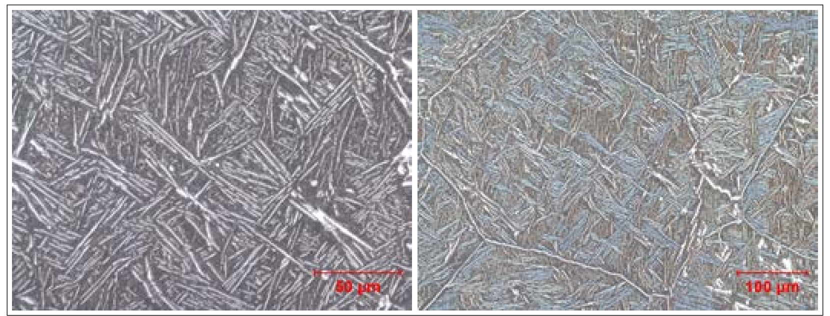

Fig. 5 Ti-5Al-5V-5Cr-3Mo, STA treated using a gas quench (825°C 2h, 595°C 8h)

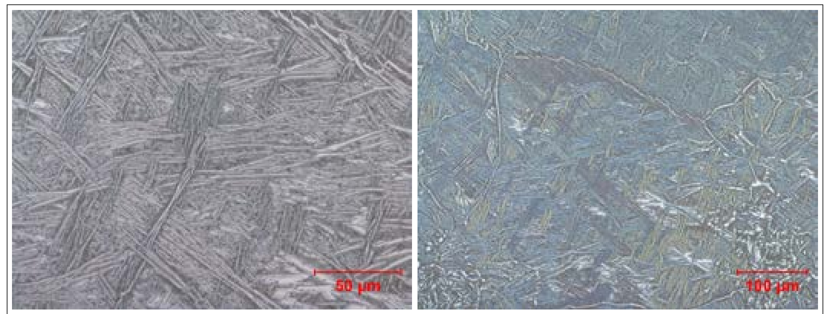

Fig. 6 Ti-5Al-5V-5Cr-3Mo, STA treated using a furnace cool (825°C 2h, 595°C 8h)

MIM processing

Prealloyed, mixed elemental and master alloy powder are all suitable approaches for processing titanium alloys. The selection of which route to use is based upon the product and customer requirements. In order to retain precise control over raw materials and final chemistry, Praxis compounds its feedstock internally. All of the materials discussed were processed using a two stage binder system and were Hot Isostatically Pressed (HIPed) after sintering.

Elemental, microstructural and mechanical evaluation of Ti-5Al-5V-5Cr-3Mo

After HIPing, the elemental distribution in the Ti 5Al-5V-5Cr-3Mo alloy was analysed via EDS mapping and is shown in Fig. 3. Homogeneous distributions of the alloying elements are seen with higher concentrations of the β-stabilising elements in the β-grains.

Microstructures for the HIPed and heat treated conditions were evaluated. Fig. 4 shows the HIPed only specimens with a transformed β microstructure with colonies of coarse acicular α. Fine secondary α is present and there is also grain boundary α surrounding the α colonies. Two heat treatments were examined. Fig. 5 shows the microstructure resulting from a solution treated and aged (STA) cycle using a gas quench. Fig. 6 shows the microstructure resulting from a STA cycle using a furnace cool. Both cycles employed a solution treatment at 825°C for 2 hours followed by aging at 595°C for eight hours. Fig. 5 shows that the specimens that were solution treated, gas quenched and aged show coarsening of the fine secondary α to form a Widmanstatten (basket weave) pattern. Grain boundary α is also more prevalent. Fig. 6 shows that the specimens that were solution treated, furnace cooled, and then aged also show a similar microstructure to the solution treated and aged specimens. There appears to be coarsening of the blocky α colonies.

Mechanical testing results for the heat treated Ti-5Al-5V-5Cr-3Mo specimens are summarised in Table 5. The results show that the solution treated condition via quench and age has the highest strength of the three tested conditions with a yield strength of 1275 MPa and an ultimate tensile strength of 1365 MPa. However, the elongation of the STA-quenched condition falls below 3%. The STA-furnace cooled condition is able to maintain an elongation of around 5%, while having slightly lower tensile strengths.

Property	BMS 7-360 Minimum	ST: 825°C 2hr, Ar Quench Age: 595°C 8hr		ST: 825°C 2hr, Furnace Cool Age: 595°C 8hr	
		Property	St. Dev.	Property	St. Dev.
UTS (MPa)	1240	1365	15.3	1262	2.1
Yield (MPa)	1170	1275	4.8	1172	6.2
Elongation (%)	5	2.2	0.9	4.6	1.1

Table 5 Mechanical properties of MIM Ti-5Al-5V-5Cr-3Mo

While this is a good initial trial of processing this alloy via MIM, it falls short of the elongation requirements in the quenched condition and the yield strengths are too close to the minimum in the furnace cooled condition to be robust with respect to the specification requirements. Prior to commercialisation, substantial work will need to be done with respect to material processing and characterisation. Included in this work is reducing the elongation scatter, improving the elongation, improving the heat treatment and characterising the impact and fracture toughness.

Elemental, microstructural and mechanical evaluation of Ti-10V-2Fe-3Al

After HIPing, the elemental distribution in Ti-10V-2Fe-3Al alloy was analysed via EDS mapping and is shown in Fig. 7. The alloying elements were found to be well distributed throughout the titanium matrix, with higher concentrations of the β-stabilising elements in the β-phases.

Microstructures for the HIPed and heat treated conditions were evaluated. Fig. 8 shows the as-HIPed specimens having a transformed β phase microstructure with acicular α precipitates. Some continuous grain boundary α is present and some blocky α colonies are also present. Fig. 9 shows the specimens that were solution treated, gas

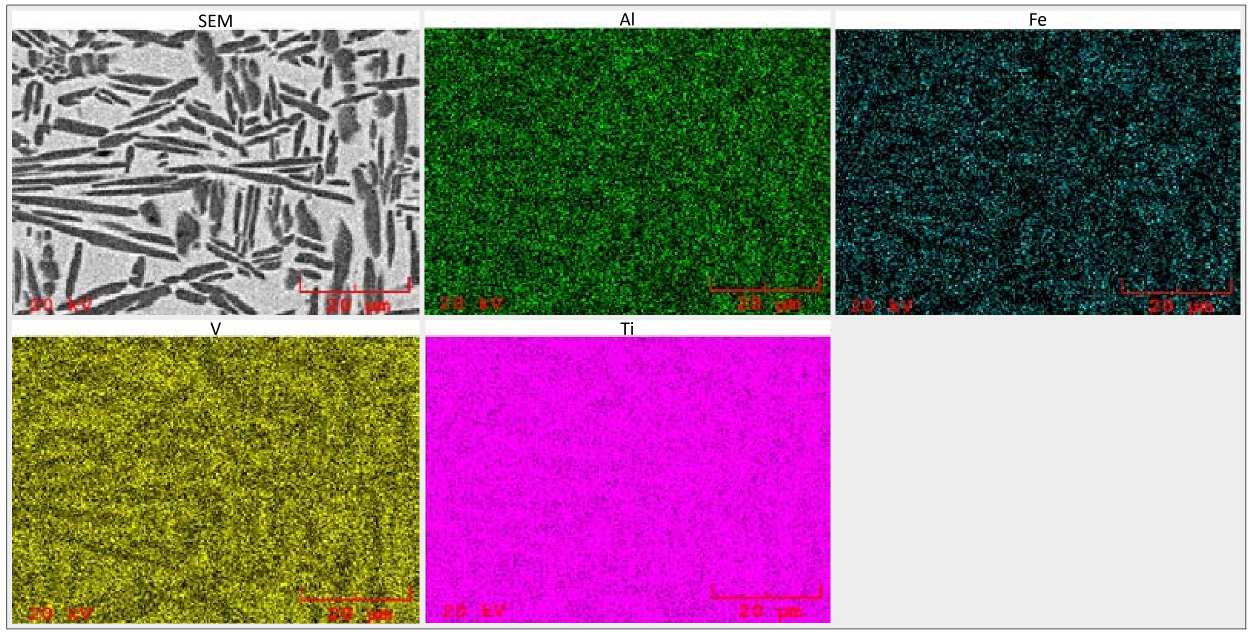

Fig. 7 Elemental distribution of Ti-10V-2Fe-3Al

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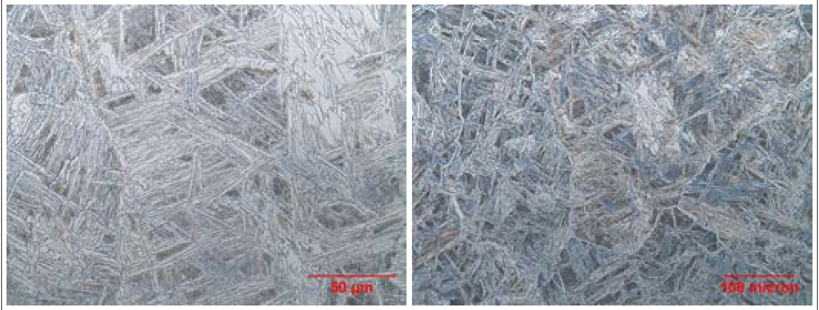

Fig. 8 Ti-10V-2Fe-3Al, as HIP'ed

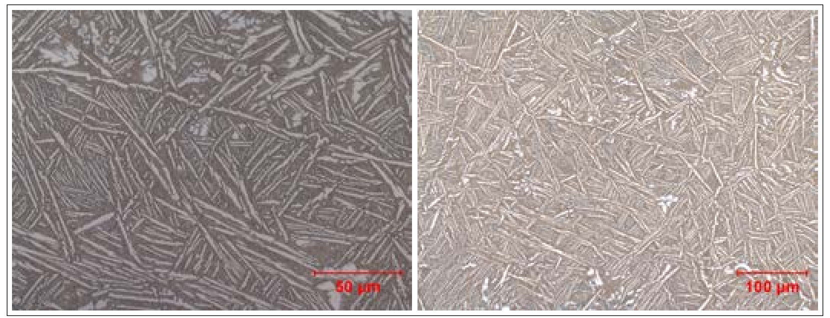

Fig. 9 Ti-10V-2Fe-3Al, STA treated using a gas quench (760°C 1h, 525°C 8h)

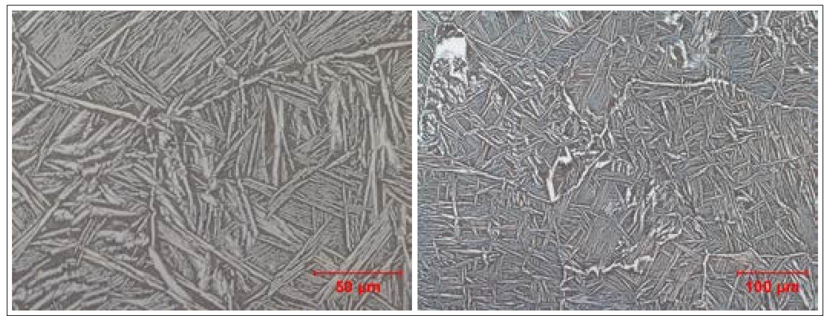

Fig. 10 Ti-10V-2Fe-3Al, STA treated using a furnace cool (760°C 1h, 525°C 8h)

quenched and aged having a similar microstructure to the HIPed only specimens. The α-grains appear to have coarsened slightly. The increase in strength is possibly due to precipitation of secondary α within β grains. However, this is not resolved at this magnification. Fig. 10 shows specimens that were solution treated, furnace cooled and then aged as having a similar microstructure to the as-HIP'ed specimens, although the α grains appear to have coarsened slightly. Additionally, the structure appears to have an increased amount of blocky α.

Mechanical testing results for the heat treated Ti-10V-2Fe-3Al specimens are summarised in Table 6. The tensile data for Ti-10V-2Fe-3Al show that the solution treated condition via quench and age has the highest strength of the three tested conditions with a yield strength of 1131 MPa and an ultimate tensile strength of 1255 MPa. The elongation drops from 16.3% in the HIPed only condition to 10.0% in the STA-quench condition. The reduction in tensile strength between the gas quench conditions and the furnace cool conditions is possibly due to the increase in blocky α in the furnace cooled condition.

The quench condition yields properties that are above minimum requirements and could probably be qualified. Future work on this material will include impact and fracture toughness.

Property	AMS 4984F Minimum Requirement	ST: 760°C 1hr, Ar Quench Age: 525°C 8hr		ST: 760°C 1hr, Furnace Cool Age: 525°C 8hr	
		Property	St. Dev.	Property	St. Dev.
UTS (MPa)	1193	1255	4.1	1124	2.1
Yield (MPa)	1103	1131	2.1	1013	6.9
Elongation (%)	4	10.0	1.4	13.2	1.3

Table 6 Mechanical properties of MIM Ti-10V-2Fe-3Al

Elemental, microstructural and mechanical evaluation of Ti-6Al-2Sn-4Zr-2Mo

After HIPing, the elemental distribution in Ti-6Al-2Sn-4Zr-2Mo alloy was analysed via EDS mapping and is shown in Fig. 11. Note the expected deficiency of aluminium, along with preferential distribution of molybdenum in β-grains (shown as white).

Ti-6Al-2Sn-4Zr-2Mo is an alpha/beta alloy and the annealed microstructure is understood to be preferable with respect to creep resistance. Fig. 12 shows the as-HIPed condition as having transformed β phase microstructure with plate-like α precipitates. These plate-like precipitates should be beneficial for creep properties. There are also intergranular β precipitates present, which is typical for Ti-6Al-2Sn-4Zr-2Mo.

Mechanical testing results for the heat treated Ti-6Al-2Sn-4Zr-2Mo specimens are summarised in Table 7. The material readily met the mechanical requirements of AMS 4975. The materials were also tested for creep resistance using ASTM E139 and test conditions of 510°C and 241 MPa. AMS 4975 requires that the material should demonstrate creep less than or equal to 0.1% after 35 hours. The MIM processed materials readily met this requirement, showing only 0.06% creep after 35 hours. The test was discontinued at 200 hours, at which point the material had exhibited a creep of 0.09%. Future work will focus on reducing scatter and further characterising the material with respect to high temperature tensile strength, impact and fracture toughness.

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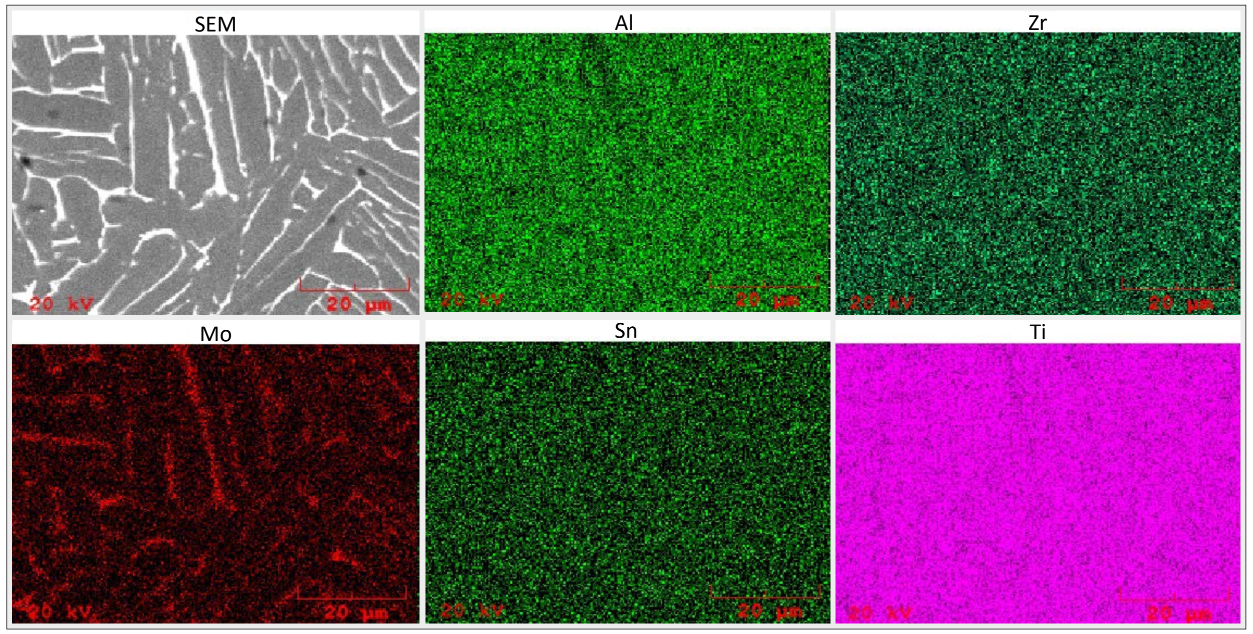

Fig. 11 Elemental distribution of Ti-6Al-2Sn-4Zr-2Mo

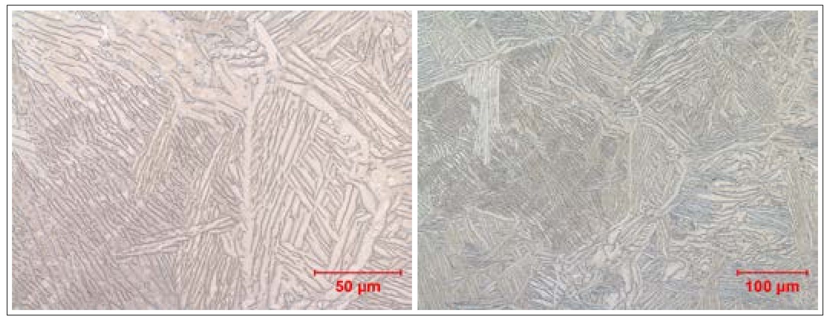

Fig. 12 Microstructure of as-HIP'ed Ti-6Al-2Sn-4Zr-2Mo

Property	AMS 4975 Minimum Requirement	MIM Results	
		Property	St. Dev.
UTS (MPa)	896	1062	3.4
Yield (MPa)	827	951	77.9
Elongation (%)	10	15.4	3.9
Creep (510C, 241MPa, 35hrs)	≤ 0.1%	0.06%	N/A

Table 7 Mechanical properties for MIM Ti-6Al-2Sn-4Zr-2Mo

Summary

High performance titanium alloys are readily processed via Metal Injection Moulding. While some challenges remain with respect to achieving oxygen content of 1500 ppm or lower, oxygen can consistently be controlled and excellent properties can be achieved. Ti-10V-2Fe-3Al can be processed to satisfy the mechanical requirements of AMS 4984F and Ti-6Al-2Sn-4Zr-2Mo can be processed to satisfy the mechanical requirements of AMS 4975.

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Czech ceramics specialist Vibrom adds Metal Injection Moulding to its PIM portfolio

With more than ten years of experience producing Ceramic Injection Moulded parts in the Czech Republic, Vibrom s.r.o., a small family run company, has over the past two years also introduced Metal Injection Moulding production to the country. *PIM International* profiles the challenges the company has faced in introducing both Ceramic Injection Moulding and Metal Injection Moulding and its ambition to become a significant player in the European PIM industry.

Vibrom s.r.o. is a small, family-run company based in Trebechovice pod Orebem, a small town of around six thousand inhabitants near the city of Hradec Kralove in the Czech Republic. The company was originally established in 1993 under the name 'Ing. Ivan Jebavý – Vibrom' to design and produce vibration mills. Two years later, in 1995, the company started the production of ceramic yarn guides for the textile industry using the hot casting process. This involved preparing a ceramic slip comprising a fine powder and binder and hot casting the liquid slip into a complex mould under pressure.

Alžběta Jebavá, one of the daughters of the founder with responsibilty for process engineering and marketing, told *PIM International*, "We used a homemade moulding machine for the process and the technology worked perfectly. However, it was the success of this process that led us to venture into Ceramic Injection Moulding. My father had seen some articles on Ceramic Injection Moulding in magazines and we investigated how we could produce CIM parts, initially using our own homemade equipment to produce prototypes. However, whilst the process worked well we quickly realised that we needed more modern equipment for high quality components and we invested in the necessary injection moulding machines and furnaces."

Fig. 1 Vibrom's production facility in the Czech Republic

Fig. 2 Automatic part removal at Vibrom using Arburg's Multilift H system linked to an Allrounder 370S injection moulding machine

Fig. 3 Ivan Jebavý, left, explaining the MIM process to guests at the opening of Vibrom's Metal Injection Moulding facility

Alongside the investment in modern production equipment, the company also decided to move to larger and more suitable premises. In 2003 the move was made to a renovated old boiler house in Trebechovice pod Orebem (Fig. 1) and the company name was changed to Vibrom s.r.o. The new premises housed the Arburg 270 injection moulding machine purchased in the same year for CIM production. Two more Arburg machines have since been purchased for CIM production and a fourth is used for the plastic overmoulding of sintered CIM parts. Modern debinding and sintering furnaces were also added.

Alžběta told *PIM International* that the biggest challenge in the early days of CIM production was to find the correct ratio of ceramic powder and binder. "We are still producing our own Ceramic Injection Moulding feedstock for white ZrO_2 and Al_2O_3 because we have developed the know-how for these powders and this option is cheaper than bought-in feedstock. However, we do buy in ready-to-use feedstock for black ZrO_2, mainly from BASF." Other significant challenges included injection moulding tools. Alžběta commented, "Every new tool is unique and requires tuning. This needs experience, time and determination. PIM tools are generally made by companies that are more experienced with moulds for plastics. It is really difficult to find good precision tool manufacturers so we rely on suppliers from outside our region. It takes a lot of driving to finish the mould but it's worth it!"

The introduction of MIM

In 2012 Vibrom started to investigate the production of components by Metal Injection Moulding. As with ceramics, Ivan Jebavý had seen reports in the literature about MIM technology and decided to purchase a trial lot of MIM Catamold feedstock from BASF to produce some prototype parts. "At first we used our existing moulding equipment and furnaces and, following a few production trials, we decided to venture into MIM production and to obtain the best feedstock material and equipment available on the market. For us this was a combination of BASF's Catamold feedstock, fully automatic Arburg 370 moulding machines (Fig. 2) and an Elnik Systems debind and sintering furnace. We presently use a range of metal feedstocks including low alloy steels, stainless steels and tungsten. We also have ambitions to produce titanium MIM parts, which are currently being tested," stated Alžběta.

Both thermal and catalytic debinding methods are used depending on the feedstock being processed. "We did not consider preparing our own feedstock because there is such a wide variety of materials already available in the form of ready-to-mould feedstock and we wanted to focus on developing applications," explained Alžběta.

A new Metal Injection Moulding production hall was opened in the summer of 2014 (Fig. 4) and, to supplement the newly installed production equipment, Vibrom also installed a tumbling machine to surface finish MIM parts as necessary. The company has initiated a system of 100% quality control for both its MIM and CIM parts, including a 3D measurement and defectoscopy station for non-destructive testing. Each finished injection moulded part is checked for defects. Some products have their functional surfaces polished and a number of sub-assembly operations are undertaken, such as pressing parts into plastic holders or glue bonding with other components, depending on the customers' requirements. The company is accredited with ISO 9001:2001.

Low volumes, high quality

Alžběta Jebavá explained that Vibrom's key focus is quality rather than quantity. The company is focusing on complex shaped MIM and CIM parts with high dimensional tolerances but with lower than typical production volumes, typically starting at around 5,000 pieces. "As a small company with just twenty employees we can be flexible and react quickly to customers' demands. We are open to all technical components, but we pay particular attention to parts requiring high quality in smaller batches."

Vibrom has a number of customers in the Czech Republic who take around 50% of current production. The balance of production is exported to customers in Denmark, Germany, Slovakia and as far afield as China. Sectors served include the textile industry, firearms, medical instruments and the electro-mechanical goods industry.

Fig. 4 Overmolded Ceramic Injection Moulded parts

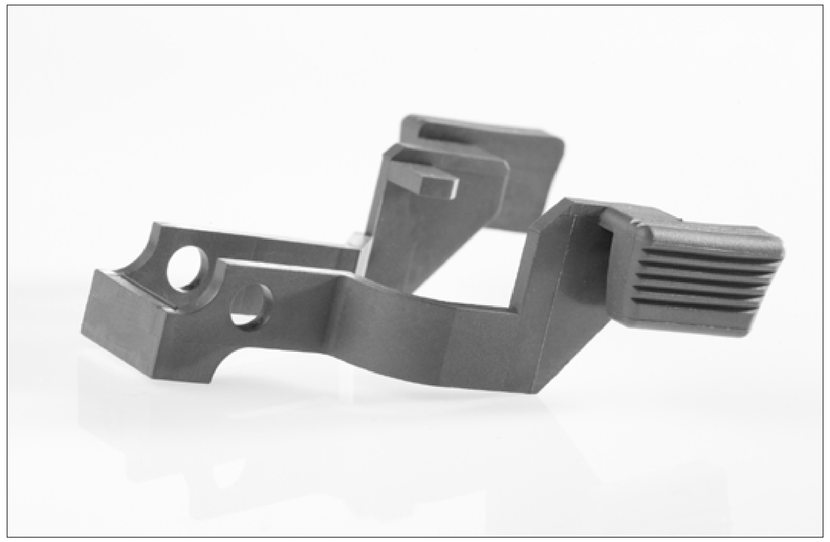

Fig. 5 A Metal Injection Moulded firearms part manufactured by Vibrom

The potential for new MIM and CIM applications

The management team at Vibrom believes that there is still enormous potential for new CIM and MIM applications, not only in the industry sectors it currently serves but also in many other sectors. However, it was stated that awareness of Powder Injection Moulding is extremely poor at many Czech companies and academic establishments and that much more should be done to educate future material and design engineers. "It helps to be able to show design engineers and students real parts in real applications in order to allay their fears about porosity and the performance of MIM parts. We are trying to reach out to new customers by giving them presentations about how MIM and CIM technology works, and we try to convince part designers that metal parts can be designed using plastic moulding concepts and not just machining. It is important to emphasise the point that although the input cost of materials for PIM is higher than conventional metal forming processes and that tool costs can also be high, the price of complex MIM parts with high dimensional tolerances is usually three times lower than an equivalent machined part," stated Alžběta.

"We have ambitions to grow as a company and we plan to promote our technology and expertise at more exhibitions. We are particularly keen to develop new parts for customers using MIM titanium powders, but there is a big variety of MIM materials on the market that we can also offer."

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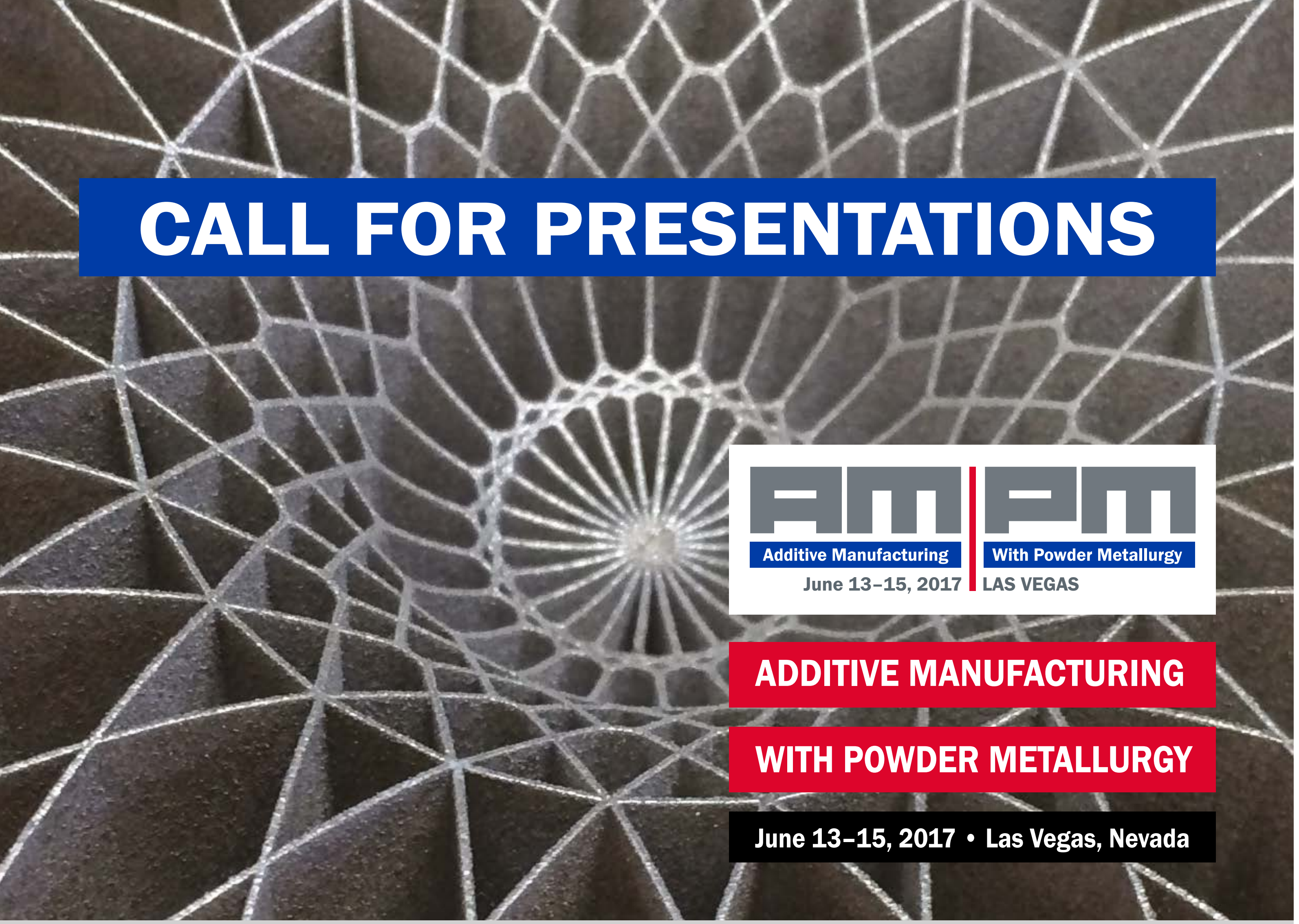

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Hannover Messe 2016: Promoting MIM and CIM technology to a global industrial audience

Powder Injection Moulding may only account for a fraction of the total global demand for industrial components, but the number of MIM and CIM companies exhibiting at the Hannover Messe continues to steadily increase. Dr Georg Schlieper visited the exhibition once again for *Powder Injection Moulding International* and reports on what MIM and CIM producers had on offer.

The Hannover Messe, with 5,200 exhibitors and more than 190,000 visitors, is the world's largest industrial trade exhibition. The event, which took place from April 25 – 29, was for the first time organised with the United States as the Partner Country. US President Barack Obama attended the opening ceremony and toured the exhibition together with German Chancellor Angela Merkel (Fig. 1). This Partner Country status served to illustrate the great importance that the United States attributes to economic relations with Europe.

Powder Injection Moulding companies have promoted the technology at Hannover for many years and this year a large number of international producers used the exhibition as an opportunity to market themselves to a wide industrial audience, as well as meet with established customers. Over the following pages we review a selection of the Metal Injection Moulding and Ceramic Injection Moulding related exhibits at this year's fair.

Advanced Materials Technologies

Advanced Materials Technologies (AMT), based in Singapore, is a major supplier of MIM parts to the Asian market, however the company also has a strong presence in Europe and the United States. All major MIM business segments are supplied by AMT including consumer electronics, firearms, automotive and medical. The importance that AMT attributes to the medical sector is reflected

Fig 1 Barack Obama, President of the United States of America, Dr. Angela Merkel, Chancellor of the Federal Republic of Germany, and Stephan Weil, Prime Minister of Lower Saxony at the opening of the Hannover Messe 2016 (Courtesy Hannover Messe)

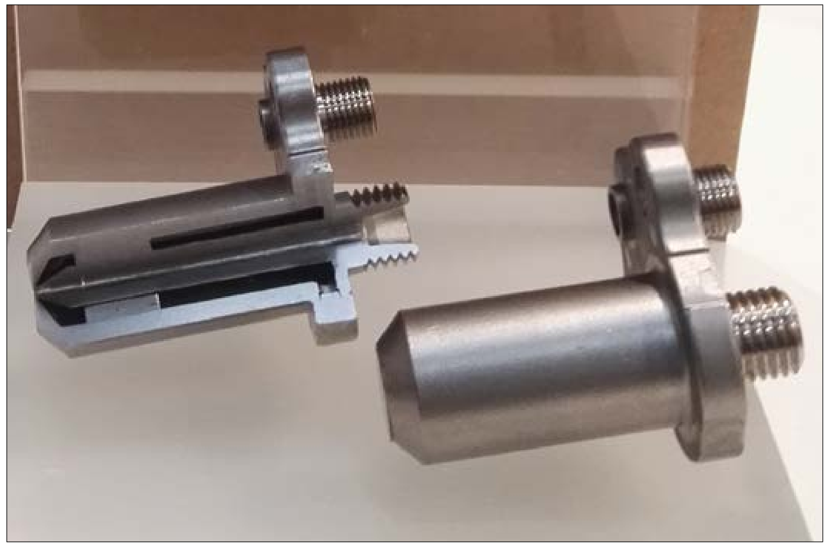

Fig. 2 A nozzle for an automotive application exhibited by AMT

Fig. 3 CIM products of Rauschert GmbH (Courtesy Rauschert)

in the company's installation of a clean room for assembling medical products.

Zulkefli Zainal, Director of Marketing at AMT, stated, "We have also started to produce parts by Selective Laser Melting, an Additive Manufacturing process, to complement our Metal Injection Moulding services. We can now offer customers the chance to create totally new design ideas as well as to test various design options before investing in a MIM tool for mass production. AM also puts us in a position to produce metal parts in small volumes of between one and a thousand parts." Various prototypes can be manufactured by AM and tested in a short space of time and necessary design adjustments are inevitably less costly when tool changes are not required.

One of the exhibits at the AMT stand was a prize winning automotive component, the injector nozzle shown in Fig. 2. This part won a Grand Prize in the 2015 Metal Powder Industries Federation (MPIF) design competition. It is used in commercial vehicle diesel engines and serves to reduce the emissions of climate-threatening NO_x gases by injecting urea and compressed air into the exhaust gas of the engine. This decomposes the nitrous gases into nitrogen and water in a Selective Catalytic Reduction (SCR) system. This technology allows the vehicles to pass the Euro 6 regulation for emission control. The part is made from stainless steel and contains complex internal channels that are formed by a patented method employing a removable plastic core.

Rauschert GmbH

One of the pioneers of Ceramic Injection Moulding is Rauschert GmbH, based in Pressig, Germany. Rauschert's first CIM products were launched as early as the 1970s and the company has a long tradition in the development and production of wear resistant ceramic components for textile machinery. The company has exhibited at Hannover for several decades.

Ulrich Werr, Area Sales Manager at Rauschert, announced that silicon nitride has recently been added to Rauschert's portfolio of CIM materials. The most widely used ceramics such as alumina and zirconia are processed by Rauschert, as well as less common ceramics such as ZTA (zirconia toughened alumina), steatite and magnesia.

More than ten injection moulding machines are in operation at Rauschert producing a wide variety of CIM components (Fig. 3). Besides applications in textile machinery, Rauschert reported a growing demand for electrical applications. Small, complex components that must be electrically isolating and biocompatible are increasingly being designed for CIM medical applications. Electrical engineering also occasionally offers applications for CIM, some of which use materials that are electrically isolating and at the same time have a high thermal conductivity.

Rauschert is flexible with respect to production volumes and sets no minimum order. Where the investment in complex tooling for dry pressing or injection moulding cannot be justified because of the quantities required, other solutions are proposed such as green machining or even Additive Manufacturing.

Sembach Technical Ceramics GmbH

Sembach Technical Ceramics GmbH, based in Lauf, Germany, first established the industrial production of steatite, a magnesium silicate, in the early 20th century. Oxide ceramics soon followed along with a variety of cordierite ceramics. Today a comprehensive range of ceramics is available including aluminium titanate and silicon nitride.

From the earliest days of the Hannover Fair in the 1950s, Sembach has regularly exhibited and Christian Montel, Sales Manager, appreciates the opportunity to present his company and its products. He expressed his satisfaction with the wide diversity of new contacts that have been established over the years. In addition to establishing new customer contacts, Montel stated that Hannover is also a meeting place for existing business. "Nowhere else are there so many manufacturers represented. Visitors can sustain many contacts and renew relationships with a single trip to Hannover."

Sembach supplies ceramic components to manufacturers of household appliances, the automotive industry and the electrical engineering sector, to name just a few. An example of an important automotive application is the lambda probe. The various shaping technologies for technical ceramic parts, such as dry pressing, extrusion and Ceramic Injection Moulding, are all offered by Sembach. Commenting on the trends in these markets, Montel stated, "Our products are becoming smaller, more delicate and more complex and this is where CIM offers technical and economic advantages." The automotive industry accounts for around 60% of Sembach's CIM production.

Montel also believes that CIM should not be restricted to mass production. "Injection moulding tool inserts can often be manufactured in our in-house tool room at moderate cost," he said. In this way CIM can be competitive even for relatively small volumes. If several functions can be integrated in the design of a CIM part, the benefit is even greater. The focus of Sembach's marketing strategy is on technical, preferably high volume, applications as required by the automotive industry.

GKN Sinter Metals GmbH

GKN Sinter Metals is the world's largest PM parts supplier with more than thirty global locations and more than 6,000 employees worldwide. The GKN stand featured conventional Powder Metallurgy, powder forged parts, bearings and filters as well as Metal Injection Moulded parts. The company, which is traditionally closely linked to the automotive market, sees Hannover as a chance to establish contact with non-automotive purchasing agents and consequently diversify into other markets.

"GKN has regularly exhibited at the Hannover Fair over the past five years. The company stated that new projects were developed over a period of two years, sometimes longer, before mass production commenced."

GKN's Metal Injection Moulding plant, GKN Sinter Metals GmbH, Bad Langensalza, Germany, is one of the three leading MIM operations in Europe. One of the objectives at Hannover for GKN was to draw attention to MIM as a relatively unknown manufacturing process and to point out the benefits of this technology. Adler still sees a need to "spread the news" about MIM in market segments outside the automotive industry. "In particular, the higher density and superior mechanical properties of MIM parts over classical PM components is not yet widely recognised," he commented.

GKN has regularly exhibited at the Hannover Fair over the past five years. The company stated that new projects were developed over a period of two years, sometimes longer, before mass production commenced. It was stated that, in Europe at least, this was not unusual for products with a medium to long lifecycle.

Engel Austria GmbH

There was a lot of interest at the booth of Engel Austria GmbH, which presented the Liquidmetal® process. Engel, a manufacturer of injection moulding machinery based in Schwertberg, has developed a modified injection moulding machine for the industrial production of components from Liquidmetal. The amorphous structure of the Liquidmetal alloys makes them extremely hard and at the same time highly elastic. Corrosion resistance is reported to be excellent and surface roughness as well as dimensional accuracy better than MIM (Fig. 4). No extra heat treatment is required to achieve these properties. The data sheet states a strength of 1524 MPa and a hardness of 563 Vickers.

Fig. 4 Demonstration parts manufactured by Liquidmetal showing the as-moulded surface finish (Courtesy Engel)

Fig. 5 A selection of MIM parts in the green and sintered state manufactured by Sintex a/s

The process uses cylindrical ingots which are fed into a melting chamber and melted inductively under high vacuum. The molten metal alloy is injected by a piston into the mould where it solidifies under controlled thermal conditions. Very rapid cooling under vacuum leads to the amorphous structure and the special characteristics. The process is fully automatic and the time required for the moulding cycle is approximately two minutes. Parts are ready for assembly after moulding without any extra processing.

Engel believes that Liquidmetal is a viable alternative for MIM products with complex shapes for certain applications. Engel claims that potential applications can be found in MIM markets such as sports and recreation devices, automotive, medical, aerospace and consumer products.

Pekingstone GmbH

Pekingstone GmbH, Hamburg, Germany, is a service provider for technical products acting as a marketing agent for Chinese and Taiwanese manufacturers and sourcing selected products for their partners in the Far East. Its activities are not restricted to PM, but cover stamping, forging, casting, plastics and rubber. Among many other products, Pekingstone also supplies CIM products to the European textile machinery industry, for example yarn guides made in China.

Taiwan Powder Technologies Co., Ltd.

A global player in MIM is Taiwan Powder Technologies Co., Ltd. (TPT) of Taoyuan, Taiwan. The company presents itself as the leading and largest MIM company in Taiwan. Each year, TPT attends two or three trade shows in Germany. Jenny Chen, Business Development Manager, is convinced that the effort is justified. "Germany is the strongest economy in Europe," she stated. "Here we have the best starting position for new business and it strengthens our global position to have access to the European markets."

"The Asian market for MIM parts is dominated by consumer products such as smartphones and computers, where product lifecycles are short," Chen stated. "In Europe we find applications in industrial machinery, automotive and power tool parts that have a longer lifecycle than IT products. We try to diversify and find new products and we have been quite successful in the past."

Sintex a/s

For Sintex a/s, based in Hobro, Denmark, it is the 16th year in a row at Hannover. Jan Graff, Area Sales Manager, sees it as important to participate in order to meet existing customers and to present new developments. Sintex has a focus on MIM parts made from high alloy steels for pump and valve applications as well as automotive parts (Fig. 5).

A member of Grundfos Group, Sintex specialises in PM products

Fig. 6 Numerous end-user markets for Metal Injection Moulding were present at the Hannover Messe, including the important aerospace sector (Courtesy Hannover Messe)

including press and sinter components, MIM parts, permanent magnets, soft magnetic composites (SMCs) and more. A continuous sintering furnace for Metal Injection Moulding is installed for cost effective high volume production.

"In MIM we now work with simpler, lower cost moulds that allow us to produce prototype samples faster and reduce the time required from the drawing board to mass production," stated Graff. "This also puts us in a position to offer competitive prices even for small to medium volumes."

Indo-US MIM Tec Pvt. Ltd.

As one of the world's largest producers exclusively devoted to MIM technology, Indo-MIM employs around 2,500 workers at two plants in the surroundings of Bangalore, India. A sales office in Stuttgart serves to develop and maintain close relationships with European customers, mainly in the automotive sector. Kiran Kumar, General Manager Marketing, stated, "European MIM markets are very attractive to us with their strong automotive industry and many other highly engineered products."

Indo-MIM is a truly global company and being originally created out of a joint venture with a US firm, Indo-MIM had strong links with the North American MIM market from the start. Soon after the Indian management took control of the company, a sales office was opened in Princeton, New Jersey. Sales offices staffed with company employees have been opened in Taiwan and Shanghai.

USD

USD Formteiltechnik GmbH and USD Powder GmbH of Meinerz-hagen, Germany, exhibited their products and services at a joint booth. USD Formteiltechnik is a service provider and supplier of technical parts made by various manufacturing processes. Specialist engineers with expertise in each technology provide expert knowledge for the selection of the best solution, both technically and economically, to a given application. An increasing demand is found in applications for conventional PM and MIM parts. The company stated that Hannover has, for more than 25 years, been an essential event, enabling it to meet with customers and start new business relationships.

USD Powder is a supplier of unique gas-water atomised high alloy metal powders for MIM and Additive Manufacturing. The most common alloys produced by USD Powder are 17-4PH, 316L and Fe2Ni, but the list of materials is much longer and is continuously being extended. All powder grades are prealloyed. Besides the average particle size D50, tap densities are specified within close limits and most powder grades are available with at least two different tap densities. The reason for this is that polyacetal based MIM binders require higher tap densities than wax based binder systems.

Fig. 7 A selection of MIM and CIM parts manufactured by Maxon Motor GmbH

Ecrimesa

The Ecrimesa Group based in Santander, Spain, is a major manufacturer of complex technical parts made by investment casting and MIM. The MIM division, under the name Mimecrisa, is among Europe's top three MIM producers. All MIM markets including defence, automotive and medical technology are served by Mimecrisa, which was established in 1991. With in-house facilities including tool shop, feed-stock preparation, injection moulding presses and continuous sintering furnaces, Mimecrisa is particularly well equipped for the mass production of automotive parts.

Maxon Motor GmbH

Maxon Motor GmbH of Sexau, Germany, is a specialist manufacturer of DC micro motors and planetary gearboxes that are equipped with high precision ceramic shafts and complex metal and ceramic components. Instead of outsourcing the production of these, Maxon took the decision many years ago to build up the expertise for manufacturing these high precision components by Ceramic Injection Moulding and Metal Injection Moulding. Today, Maxon also manufactures MIM and CIM parts for external customers. Maxon's marketing strategy is particularly directed at microPIM, where the highest dimensional accuracy is required (Fig. 7).

While MIM is competing with other well-established metalworking processes such as investment casting and automatic CNC machining, high-tech engineering ceramics are unique materials with outstanding properties that are extremely difficult to machine. CIM is therefore, in many cases, the best option to produce complex shaped components. To fully exploit the potential of ceramic products, Maxon Motor stated that more engineers must be trained and educated with respect to the requirements of ceramic design and the manufacturing technologies that are available today to achieve the most complex product geometries.

Philips Ceramics bv

Originally a specialist manufacturer of ceramic products for lighting applications, Philips Ceramics, based in Uden, The Netherlands, has diversified its product spectrum towards technical and aesthetic ceramic parts. Translucent alumina is a speciality of Philips that few other manufacturers are able to offer. However, Philips also had zirconia and white alumina products on display in Hannover.

The production facilities at Philips Ceramics were designed specifically for mass production. They are characterised by an exceptionally high degree of automation and process integration. Contamination of the raw materials is consequently prevented by exemplary cleanliness in the entire plant. Multiple cavity tools and hot runner moulds are standard. The number of cavities has been steadily increased from one cavity to over ten cavities per mould and simultaneously the sizes of runners and sprues have been reduced through the optimisation of the hot runner systems. Debinding and sintering processes are continuous and this high level of automation allows the plant to run 24 hours a day, seven days a week, almost without any operating personnel.

Formatec Ceramics bv

Formatec Ceramics bv, Goirle, The Netherlands, has developed special expertise in aesthetic applications for luxury consumer products such as watch cases and luxury mobile phone covers made from black zirconia or white alumina (Fig. 8). Zirconia products are available in a wide range of colours. In recent years, Formatec extended its business strategy towards technical applications and added silicon nitride to its portfolio of materials.

Formatec states that it is capable of producing small to medium production volumes at affordable prices. Machining in the green state is applied where the cost of an injection

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moulding tool is not justified. A high precision five axis CNC milling centre allows the company to produce complex shapes with a high surface quality. The smoothness achieved by CNC milling is, states the company, the same as with injection moulding. It is ideal not only for producing regular parts, but also for prototyping. With this equipment Formatec literally added a new dimension to its options for making ceramic products. Although Formatec's core business is CIM components, the development of prototypes is also an important part of the business.

Fig. 8 A watch case made from black zirconia (Courtesy Formatec Ceramics bv)

Fraunhofer IKTS

The Fraunhofer Institute for Ceramics Technologies and Systems (IKTS), based in Dresden, is a leading research and development centre for innovative ceramics technologies. In the past, IKTS has supported the technical advancement of CIM through research and product development in cooperation with industrial partners. From processes for raw materials preparation through to forming, sintering and finish operations, IKTS today covers the entire CIM process chain. The facilities, which include clean rooms, allow product developments to move from the laboratory to industrial processing.

IKTS sees opportunities in the combining of functional and structural ceramics for innovative multifunctional components. A fundamental understanding of ceramic production processes, a high standard of materials analysis and sophisticated quality control are regarded as key factors for advanced ceramic products. As part of the Fraunhofer Society's research network and spokesperson of the Fraunhofer AdvanCer Alliance, IKTS has access to immense engineering resources.

Conclusion

The organisers of Hannover Messe have made great efforts to reverse a downward trend in visitor numbers, attributed in part to the easy access to information on the internet. In their after-show report, they expressed satisfaction about the high number of visitors from abroad. Attendance from China and the USA in particular soared to record heights. "This Hannover Messe provides impressive confirmation of the event's unique position as a global hot spot for digital manufacturing," stated Dr. Jochen Köckler, member of the Managing Board at Deutsche Messe AG. "This is where the latest technologies and innovations are unveiled to a wide audience. Industry initiatives from Germany, the USA, China, Japan and the EU have come together here in Hannover to embark on a shared journey into the digital future."

Hannover Messe presents itself as a showcase of digital technology. The digitisation of all industrial sectors, as expressed by the wording "Industrie 4.0", is regarded as the fourth Industrial Revolution. It is a trend in all highly-developed countries and Hannover Messe has been supporting it for years. Manufacturers of MIM and CIM products all over the world are part of this revolution. They are continuously faced with new challenges and have to make efforts in order to keep up with the technological change. A visit to Hannover Messe is a way to stay well-informed about the latest innovations.

The next Hannover Messe will take place from April 24 - 28, 2017, with Poland to be featured as the official Partner Country.

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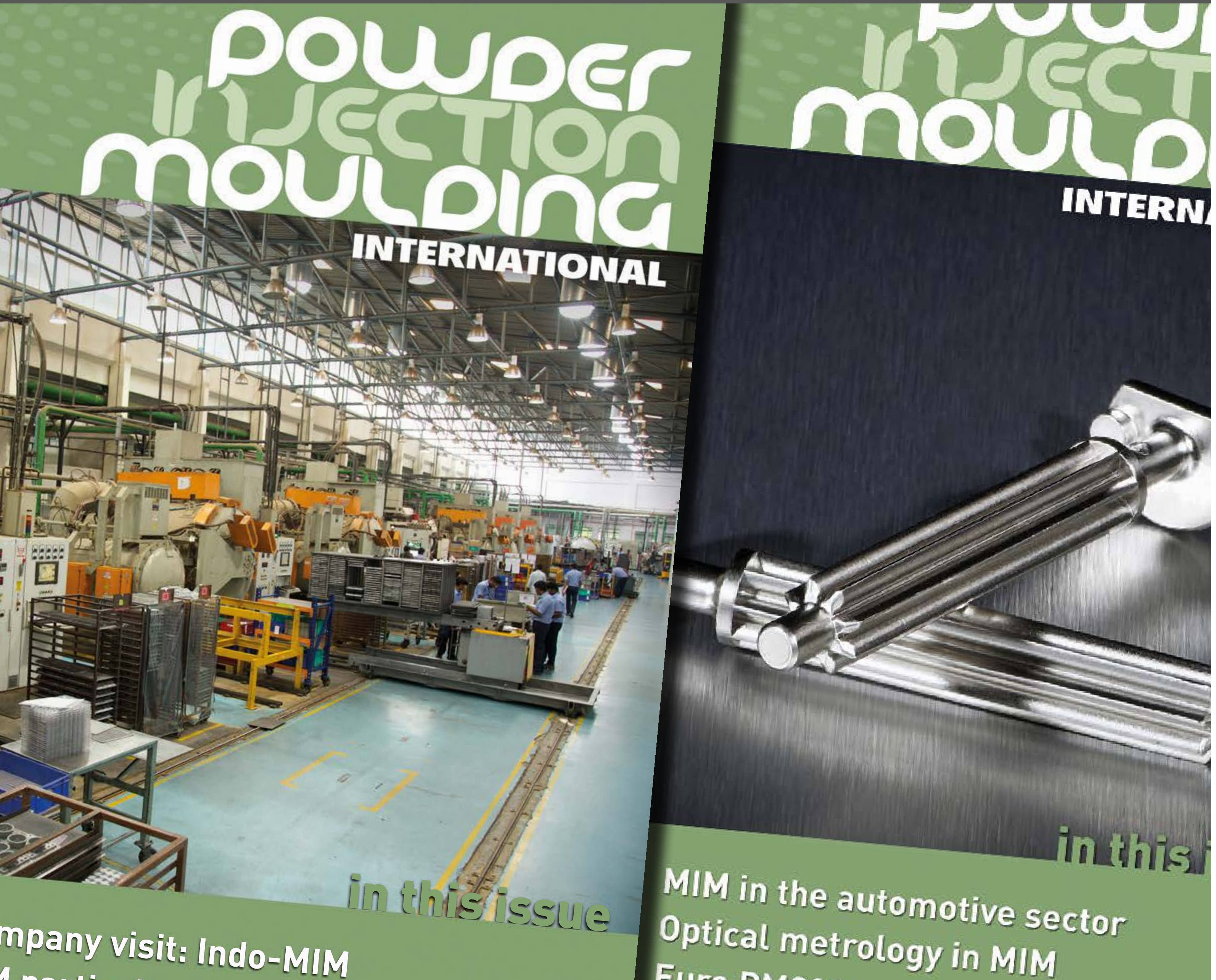

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ampm2016.org

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June 5–8, Boston, USA
powdermet2016.org

ICMME 2016 : 18th International Conference on Metal Materials and Engineering
June 27 - 28, Copenhagen, Denmark
www.waset.org

EPMA PM Summer School 2016
June 27 – July 1, Valencia, Spain
www.epma.com/eventdetail/129/epma-powder-metallurgy-summer-school-2016

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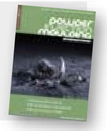

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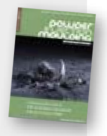

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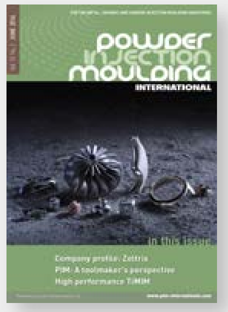

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