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FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

# POWDER INJECTION MOULDING INTERNATIONAL

## in this issue

**Company visit: Maxon Motor**
**Optimising mould design for PIM**
**50 years of PIM at Arburg**

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POWDER INJECTION MOULDING INTERNATIONAL
For the metal, ceramic and carbide injection moulding industries


# A drive towards increased process efficiency

Welcome to the September 2013 issue of *PIM International*. This 96 page issue, the largest that we have published to date, comes on the back of a busy summer for many of those involved in PIM.

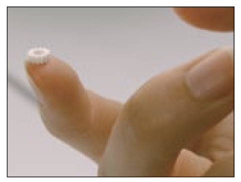
In June 2013 the injection moulding machine manufacturer Arburg organised a conference at its headquarters in Lossburg, Germany, to celebrate 50 years of the company's involvement in developing technology and equipment for PIM. The event attracted more than 200 international participants and covered a diverse range of subjects. A common thread amongst a number of presentations was, however, the efficiency gains that can be made through the use of advanced mould technologies. The feature article on optimising mould design and function for PIM (page 39) looks more closely at this critical area of the process. Our report on highlights from Arburg's summer PIM conference can be seen on page 57.

We also report on a recent visit to Maxon Motor's PIM plant in Germany, where a focus on high precision products has had a distinct influence on the company's unique approach to the process for both CIM and MIM materials (page 47).

In North America, MIM was again well represented at the MPIF's annual PowderMet Conference held in Chicago, June 2013. A substantial number of MIM parts were announced as winners in the MPIF's Design Excellence Awards and the trade exhibition featured a very encouraging number of technology suppliers. A diverse technical programme covered developments in both MIM materials and processing (page 67).

Three new furnace concepts from important industry suppliers are presented in this issue's technical papers. These developments reflect a real diversification in the types of furnaces being offered to part makers, from very small continuous systems for small and micro sized components (page 81) to a new two unit system that offers extremely clean sintering conditions (page 86), plus a new generation of large volume batch vacuum furnaces that can bridge the gap between conventional batch vacuum furnaces and continuous systems (page 91).

Nick Williams
Managing Director and Editor



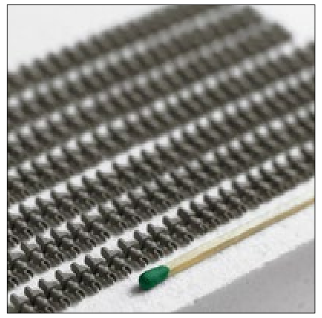
**Cover image**
*Miniature ceramic pinion gear manufactured by Maxon Motor (Photo Maxon Motor GmbH)*

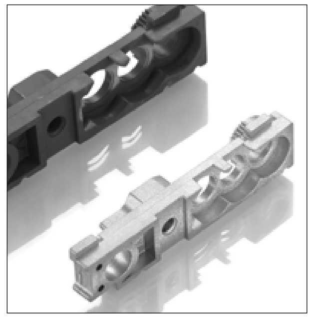
September 2013

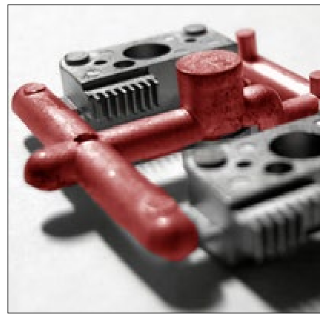
Powder Injection Moulding International


21


34


41


51


65

# In this issue



## Technical papers



## Regular features

# Industry News

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

## Cinven invests in German CIM specialist CeramTec

European private equity firm Cinven announced in June that it has reached an agreement to acquire CeramTec from Rockwood Holdings, Inc. for a total consideration of €1.49 billion.

CeramTec is a leading global manufacturer of high performance ceramics, including those produced by Ceramic Injection Moulding (CIM), for application in medical, automotive, industrial and electronic end-markets. The company's proprietary product portfolio includes hip joint prostheses components, including the Biolox brand, high speed cutting tools and ballistic ceramics for armour. In 2012 the company generated revenues of €425 million. Its main operations are located in Plochingen, Germany, and CeramTec employs more than 3,000 people across 18 facilities worldwide.

Bruno Schick, Partner and Co-Head of Cinven's German team, stated, "Our Fund investment in CeramTec builds upon Cinven's expertise across both the industrial and healthcare sectors, and our previous successful investments in Germany. Consistent with our investment focus, CeramTec enjoys leading competitive positions in markets with strong underlying growth. We are particularly impressed with CeramTec's ability to consistently launch high value, innovative products through economic cycles. We are keen to support the Company's growth outside its core European markets, specifically in North America and Asia, both organically and through acquisitions. Most recently, we have achieved strong growth in the US for our portfolio companies - examples include Phadia, Sebia and CPA Global. In Asia, we have the benefit of our highly experienced Asian portfolio team."

Pontus Pettersson, Principal at Cinven, added, "We are delighted to partner with Dr Zimmermann and his experienced team in CeramTec's transition to an independent company. We support the Company's strategy of ongoing investment that includes the plant expansion in Marktredwitz, and new product initiatives such as LED lighting and semiconductor applications."

Dr Ulf Zimmerman, CEO of CeramTec, stated, "We are glad to be working with the Cinven team. They have an excellent track record of supporting companies to grow globally in both the healthcare and industrial sectors. Cinven's investment will enable us to capitalise on the opportunities in our existing markets as well as further expand the business internationally."

Rockwood Holdings is disposing of CeramTec as part of a broader repositioning of the Group. Completion is expected during the third quarter of 2013 subject to customary regulatory approvals.

www.ceramtec.com

## Indo-MIM announces record turnover and major expansion plans

Indo-US MIM Tec Pvt. Ltd, the world's largest Metal Injection Moulding producer based in Bangalore, Karnataka State, India, reports that it is planning an investment of Rs. 350 crores (approx. US$53 million) in the region over the next three to five years and expects to reach sales in this period of Rs. 1200 crores (approx. US$180 million) while adding 1000 more employees. The company registered a turnover of Rs. 500 crores (approx. US$76 million) in the fiscal year 2013. Indo-MIM, which has offices in the USA, Europe, India and China, has customers in more than 30 countries worldwide across a wide number of industry segments.

Dr Krishna Chivukula, Chairman of Indo-MIM, stated, "We are growing year on year at an approximate rate of 30% and expect to do a turnover of Rs. 1200 crores (approx. US$180 million) in three to five years. During 2014 fiscal year and ensuing five years, Indo-MIM plans to aggressively increase its capacity in Bangalore and in select countries overseas, thereby ensuring its pre-eminence in the MIM industry."

*2013 MPIF award winning MIM automotive sensor components manufactured by Indo-MIM (Courtesy MPIF)*

Established in 1998, Indo-MIM has since expanded its facilities into the largest installed MIM capacity in the world with around 2000 employees in Bangalore. In addition to MIM, the company also offers precision machining and surface treatments for the aerospace sector and has an investment casting facility in Tirupati, Andhra Pradesh, specialising in the production and export of investment castings for the automotive sector.

Indo-MIM received three of the eight Metal Powder Industry Federation (MPIF) PM Design Excellence Awards at the recent PowderMet Conference in Chicago, Illinois, USA. After receiving the awards Dr Shivashankar, Vice President Operations, stated, "It feels great to be globally recognised for the products we manufacture using MIM. These recognitions always motivate us to convert and manufacture lot more complex products via MIM and bring much needed cost savings to our customers".

Krishna Chivukula Jr., CEO, Indo-MIM added, "Winning parts of Indo-MIM in the awards aptly demonstrate that the technology is not resting on its laurels, but these exemplary components fabricated via MIM signal a push into new territories. This recognition by our industry gives us an assurance that our valued customers are satisfied with the technology we provide and at the same time we are carving a niche at every step to achieve our ultimate goals."

www.indo-mim.com ■

## Schunk Group celebrates its 100th Jubilee

The Schunk Group, with its headquarters in Heuchelheim, Germany, celebrated its 100th Jubilee in August with its approximately 8,300 employees at more than 60 locations worldwide joining in the celebrations.

The company was founded by Ludwig Schunk and Karl Ebe as Schunk & Ebe in Fulda in 1913 for the production of carbon brushes for dynamos and engines. After Karl Ebe passed away, Ludwig Schunk led the company successfully until his death in 1947. In his will Ludwig Schunk stipulated that the company be preserved as a Foundation for the employees, and the Ludwig-Schunk-Stiftung e.V. Foundation was established.

"Ludwig Schunk's will still shapes our corporate culture," stated CEO Gerhard Federer. "It obliges us to continually develop and maintain the company's independence. Our business strategy geared towards long-term growth makes Schunk a secure and attractive employer throughout the world. This is also evident in the extraordinarily strong loyalty our employees have to the company."

Schunk sees its large investments in its facilities, which the company makes all over the world, as also being an investment in and for the employees. "With a great deal of commitment and creativity, our employees have continually developed Schunk into what it is today, a successful globally operating technology corporation. The many exciting jubilee events being held this year at all our facilities are first and foremost a way of thanking all our staff," says Federer.

In the hundred years since its establishment, Schunk & Ebe has become a globally operating corporate group with four divisions; Schunk Materials, Schunk Sinter Metals, Weiss Group (environmental simulation and climate technology) and Schunk Sonosystems (ultrasonic joining technology). The original product range covering carbon brushes are today produced in the Group's Materials Division along with technical ceramics, pantograph contact strips, etc.

The Powder Metallurgy products are produced at three main plants in the Schunk Sinter Metals Division, two of which are located in Thale and Giessen, Germany and another in Mexico. Thale specialises in larger PM parts produced on powder presses ranging from 150 to 1500 metric tonnes force and also Metal Injection Moulded parts, whilst the PM plant in Giessen produces smaller PM parts, PM bearings and sintered filters with powder press capacity up to 150 tons. The Schunk Sinter Metals Division contributed around €140 million to Group sales of €930 million in 2012.

The Schunk Group recently reported that Gerhard Federer, CEO of the Schunk Group, will retire from his position with effect from October 31, 2013 due to health reasons. He will be succeeded on November 1, 2013 by Dr Arno Roth, a long-time member of the Management Board who is currently responsible for the Weiss Group and Sonosystems divisions.

www.schunk-group.com

## Call for Presentations issued for MIM 2014 Conference, Long Beach, USA

The program committee for MIM2014, the International Conference on Injection Molding of Metals, Ceramics and Carbides, has issued a Call for Presentations. The focus of the technical program is Materials and Component Integrity.

Sponsored by the Metal Injection Molding Association, a trade association of the Metal Powder Industries Federation, and its affiliate APMI International, the conference will be held in Long Beach, California, February 24–26, 2014, at the Hyatt Regency Long Beach.

Technical program Co-Chairmen Bruce Dionne, Vice President/General Manager, Megamet Solid Metals, Inc., and Uwe Haupt, Key Account Manager, Arburg GmbH + Co KG, request abstracts of 100–150 words, covering any aspect of metal injection moulding, including processing, materials, and applications.

The program committee requests that abstracts be submitted by September 30, 2013, for consideration. Complete details on the conference and on submitting abstracts are available from the Metal Injection Molding Association's website www.mimaweb.org or by contacting Jim Adams at jadams@mpif.org


*The Hyatt Regency Long Beach, venue for the MIM 2014 conference*

## Programme published for 32nd Hagen Symposium

The Fachverband Pulvermetallurgie (FPM) has published the technical programme for the 32nd Hagen Symposium scheduled to take place in Hagen, Germany, November 28-29 2013.

The programme will include presentations on modern methods for quality control in mass production processes such as Powder Metallurgy, including ferrous PM, hardmetals, ceramic and Metal Injection Moulding, plus methods for corrosion testing, surface analysis, and process modelling.

The symposium will include the presentation of the Skaupy Prize 2013 to Josef Seyrkammer of Miba Sinter Austria GmbH in Vorchdorf, Austria. Seyrkammer will present a keynote paper entitled "Road to Success for Powder Metallurgy" in which he will review some of the technology highlights during a career of almost 50 years with Miba Sinter.

www.pulvermetallurgie.com

## New MIM design "app" available for Apple devices

An new app to assist engineers with the design of their complex metal components for the Metal Injection Moulding (MIM) process has just been released. The app has been developed by US MIM producer Kinetics Climax Inc., based in Wilsonville, Oregon.

"Kinetics MIM" is a new smart phone application specifically developed for design engineers who are interested in getting metal alloy selection and design advice for their potential Metal Injection Moulding components. The Material Selector matches material performance criteria to suitable alloys and then provides material property data sheets. The accompanying design guide helps designers get the most from MIM by defining MIM design requirements across a wide range of searchable categories, and includes illustrative figures.

The first MIM app of its kind, Kinetics states that it is designed by engineers for engineers and will help end-users select the right material for their application. "One of the unique powerful tools of this app is the ability to find a material solution based on the property criteria of your application. From the list of material solutions you have the option to add to your favourites or email the material data sheet. Our industry leading Design Guide is now at your fingertips, the paper bound guide that you are accustomed to picking up at industry tradeshows can now be utilised on your smartphone."


The Kinetics MIM app is available free of charge from the the Apple AppStore.

www.kinetics.com

## 2014 PM World Congress set for Orlando, USA

The 2014 World Congress on Powder Metallurgy & Particulate Materials – PM2014 will take place at the Walt Disney World Dolphin Hotel, Orlando, Florida, USA from May 18–22 2014.

Organised and sponsored by the Metal Powder Industries Federation (MPIF) in cooperation with APMI International, PM2014 will be the most important international PM event of the year.

Along with an all topic technical programme a number of special subject areas have been identified for special interest programs, these include:

- NDT/Failure Analysis
- Machinability
- Fatigue
- Technologies for PM Growth.

A major trade exhibition will also feature international suppliers of metal powders, components, equipment and related services.

www.mpif.org

## Olle Grinder and Roger Lawcock recognised at PowderMet 2013

Dr Olle Grinder (left) and Roger Lawcock (right) receive the 2013 APMI Fellow Award

APMI International, the professional society for the PM industry, welcomed Dr Olle Grinder, Consultant, PM Technology AB, and Roger Lawcock, Director, Product & Process Development, Stackpole International, to the 2013 Class of Fellows. They received the award at a special PM Industry Recognition Luncheon held during PowderMet2013, June 24-27, Chicago, USA.

Dr Grinder is a world renowned powder metallurgist who has actively contributed to the advancement of PM technology in Europe, Asia and North America. He is a member of the International Liaison Committee of the International Journal of Powder Metallurgy and has written articles for the Journal's Consultants' Corner. A member of APMI for over 27 years and possessing over 43 years of PM experience, Grinder has published 60 reports in international journals or conference proceedings.

Dr Grinder has made unparalleled contribution in fully dense PM technology, and is one of the leading experts on the subject of Hot Isostatic Pressing (HIP). A recipient of a PhD in metallurgy and material science from the Royal Institute of Technology, Sweden, in 1977, he has made significant contributions in the sintering of high alloys, including tool steels, stainless steels, and cemented carbides. He is author/co-author of four patents, two of which directly related to PM, and has been a lecturer at the Royal Institute of Technology for over 25 years.

Lawcock is one of the pioneers of the roll-densification process for gears, converting numerous gears from wrought to PM. A member of APMI for nearly 20 years, Lawcock has promoted the advancement of PM as a science by disseminating and exchanging information through his many publication efforts. He received the MPIF Howard I Sanderow Outstanding Technical Paper Award as the outstanding technical paper at the 2005 annual conference, as well as the SAE Arch T Colwell Award for significant contribution to literature.

Lawcock received the MPIF Distinguished Service to Powder Metallurgy award in 2013. He received his MSc in metallurgy from the University of Manchester, UK, in 1987. During over 30 years in PM, Lawcock has focused on high volume, high performance automotive applications based on lean alloys, high temperature sintering and improvements to core and surface density. Lawcock has been instrumental during the material and design development phases of several award winning components.

www.mpif.org



## JPMA elects new president

The Japan Powder Metallurgy Association (JPMA) announced at its General Assembly that Mr Tetsuo Ito of Hitachi Chemical Co Ltd will take over as President of the association from Mr Kazuyoshi Tsunoda.

The JPMA also reported a number of changes to its board at the General Assembly held on May 23.

www.jpma.gr.jp


*Mr Tetsuo Ito is the new President of the JPMA*

## University of Trento successfully hosts EPMA's 2013 PM Summer School

The University of Trento hosted the latest EPMA Powder Metallurgy Summer School, which took place 8 - 12 July 2013 in Trento, Italy. The annual summer school, organised by the European Powder Metallurgy Association, provided 52 students from a variety of academic and industrial backgrounds with an introduction to PM by a number of highly regarded academics and lecturers from industry.

Professor José Torralba from the Universidad Carlos III de Madrid, coordinated the event in conjunction with Professor Alberto Molinari and his team from the University of Trento.

Lectures were complemented by the University of Trento's laboratory facilities and as part of the practical side of the event the students visited two companies; Mimest, who produce typical MIM parts, and Eurocoating, a medium sized company working in biomaterials. Participants also received complementary copies of both *PIM International* and *Powder Metallurgy Review*.

Joan Hallward, Summer School Coordinator stated, "This year's Summer School programme has benefited from the University of Trento's superb laboratory facilities and well located hotels. No Summer School would be complete without the now traditional Summer School dinner and song contest held on the last evening of the course at a local restaurant, where everyone sang to their heart's content."

www.epma.com


*Participants at the EPMA 2013 PM Summer School*

## GKN plans new regional headquarters for the Americas

GKN Driveline and GKN Sinter Metals are expanding their automotive operations and moving to a new regional headquarters for the Americas in the Detroit suburb of Auburn Hills early next year.

The new site will also house employees from GKN's Land Systems and North American Services groups. Construction of the 168,000 $ft^2$ facility was scheduled to begin in August on an 11.2 acre site at 2150 N. Opdyke Road, the location of a now-vacant Showcase Cinema complex.

Headquartered in Auburn Hills since 1986, GKN has more than 300 employees at its current 113,000 $ft^2$ facility at 3300 University Drive. Employment is expected to grow by 50 or more full-time employees in the next three years.

GKN Driveline is the world's leading producer of automotive driveline components and systems including constant-velocity-joint, all-wheel-drive, trans-axle and electric-drive systems. GKN Sinter Metals is the world's largest producer of precision powder metal products, including a major MIM production facility in Germany.

GKN's new headquarters complex will provide additional space for state-of-the-art testing and validation equipment along with additional engineering design areas for driveline and sinter metal products. Executive management teams from both GKN Driveline and GKN Sinter Metals will be located in the new headquarters building along with various engineering groups and other corporate activities.

Robert Willig, President of GKN Driveline Americas, noted that the need for additional space and resources has become paramount in view of GKN's substantial growth in recent years and the number of major new program launches planned for the Americas.

"GKN has significantly increased its engineering resources in the past four years and plans to recruit and hire even more engineering personnel to support more than 100 new program launches in the next three years for GKN Driveline and GKN Sinter Metals," Willig said. "Our new headquarters facility underlines our commitment to our customers and to the Americas."

"The increase in demand for our technology-leading driveline systems made it essential for us to find a suitable facility to support projected growth and better serve our customers."

Chris Franks, President, GKN Sinter Metals Americas, added, "The additional space is ideally located in close proximity to many of our global customers and will give us access to the additional resources needed to provide our customers with world-class precision powder-metal products and allow us to deliver on our corporate vision of providing "Engineering That Moves The World."

GKN officials also acknowledged "the tremendous support" provided for the project by Michigan Governor Rick Snyder's office, the Michigan Economic Development Corporation and the City of Auburn Hills.

www.gkn.com



## Stage set in New Zealand for major titanium PM conference

Organisers of the International Titanium Powder Processing, Consolidation and Metallurgy conference in Hamilton, New Zealand, December 2-4 2013, have announced a number of key international guest speakers to be included in this year's technical programme.

The invited speakers come from over ten countries and are leaders in the field of titanium Powder Metallurgy. "The calibre of speakers confirmed from both research and industry arenas is shaping the conference to be a not to miss event for powder specialists," stated Dr Ma Qian, Science Director, RMIT Australia and Conference Committee member. The list of international guest speakers and topics currently includes:

- Development of Large Sized Ti Alloy Compacts for Aerospace Application by Advanced Powder Processing – MIM
*Professor Hideshi Miura, Kyushu University , Japan*
- Titanium Technologies in Powder for Manufacturing
*John Barnes, CSIRO, Australia*
- Low-Cost Processing of Titanium and its Alloys
*Dr Ashraf Imam, Naval Research Laboratory, USA*
- Metal Injection Moulding of beta-titanium alloys
*Dr Thomas Ebel, Geesthacht Centre for Materials and Coastal Research, Germany*
- Porous titanium structures: their fabrication and applications
*Professor Huiping Tang, State Key Laboratory of Porous Metal Materials, China*
- Processing of dense and porous titanium parts by powder injection moulding of titanium hydride
*Professor Efrain Carreno-Mortelli, HES-SO Institute of Systems Engineering, Switzerland*
- Layer manufacturing of porous titanium for biomedical applications
*Dr Seung Eon Kim, Korea Institute of Materials Science (KMS)*
- *Dr Hilda Kundai Chikwanda, CSIR, Materials, Science & Manufacturing, South Africa (Topic TBC).*

Many Australian and New Zealand guest speakers are also presenting, including speakers from the Callaghan Institute, universities across New Zealand and Australia and leading titanium manufacturers.

**The Titanium Industry Development Association**

New Zealand's Titanium Industry Development Association (TiDA) was estbalished in 2010 to develop and promote the country's titanium PM industry. The association is achieving this through research and development, education and training and the provision of a platform for companies to start to use the various titanium powder technologies available.

Dr Wayne Mapp, New Zealand's Minister of Science and Innovation, stated at the opening of the facility, "TiDA is a key piece of infrastructure for the titanium industry. It will significantly boost New Zealand's advantage in the industry, especially in titanium powder technology. The titanium applications industry could be worth $700 million each year to New Zealand by 2020. The opening of this centre is an excellent example of the innovative ecosystem at work. The industry, the Bay of Plenty Polytechnic and the University of Waikato have pooled their resources to make this happen. It is exactly the sort of innovative project that will drive our economic growth."

TiDA has today built a world-class advanced powder metallurgy research centre featuring state-of-the-art testing and prototyping equipment. The facility also provides specialist metallurgy training to provide skills and knowledge for the emerging titanium powder metallurgy and metals testing industries. New Zealand currently has a research programme covering a range of Ti powder areas. The research group includes two universities, two government research organisations and TiDA.

Commenting on the potential for titanium PIM technology in New Zealand, TiDA told *PIM International*, "We believe there is a good opportunity for titanium PIM in New Zealand as the technology reduces processing costs. This makes the use of titanium available to a broader range of applications. Companies designing products can look at the design based on what they want it to achieve and utilise the superior benefits of titanium alloys. The end result can often be a product which is cheaper than using a material that has a lower cost per kg, which is manufactured competitively and which displays the ideal properties of titanium alloys including high corrosion resistance, biocompatibility, excellent weight to strength ratio etc."

TiDA has recently installed a Laser Sintering (3D printing) machine that is able to produce intricate parts in titanium, stainless steel and many other metals. This machine is one of only a few commercial machines of its kind operating in Australasia and it has manufactured items that are widely varied from body implants and complex machinery parts, to high spec sporting equipment and jewellery. Added to this, a newly acquired vacuum sintering furnace which can reach up to 1600°C is used in the Metal Injection Moulding process. This machine is the only one of its kind in New Zealand and available for research or commercial purposes.

www.tida.co.nz

*TiDA's new Laser Sintering machine is able to produce intricate parts in titanium, stainless steel and many other metals*

## Slovakian MIM producer Gevorkyan to expand production

Gevorkyan s. r. o., a MIM and PM parts producer based in the Vlkanová area of Slovakia, has announced that it is to expand production and create 44 new jobs.

The implementation of the €7.57 million investment will be spread over the period 2013 to 2016. The company announced that it will receive investment aid of €1,510,000 in the form of tax relief on income. The increase in production will be achieved through the extension of the company's existing manufacturing plant. Gevorkyan s. r. o. was established in 1996 to manufacture PM parts for a wide variety of industries including automotive, oil, cosmetics, hand tools, locks and security systems, medical devices and air conditioning.

The company's expansion into MIM processing was announced in the September 2012 issue of *PIM International*. The company currently employs more than 100 people.

www.gevorkyan.sk

## Liquidmetal Technologies signs Manufacturers' Representation Agreement with TM&S

Liquidmetal Technologies, Inc. (LTI), a leading developer of amorphous alloys and composites, has signed a Manufacturers' Representation Agreement with TM&S, LLC, also known as Technical Marketing and Sales. TM&S specialises in the sales of Powder Metal and Metal Injection Moulded parts. "TM&S is a trusted advisor for established customers that procure Powder Metal and MIM parts, who often find Liquidmetal provides significant performance or cost advantages," stated Bruce Bromage, EVP of Business Development and Operations at Liquidmetal Technologies

Derek Rasmussen, President of TM&S, stated, "Liquidmetal technology fills a critical gap for design engineers and sourcing professionals that need high precision parts in volume, and especially for those applications that require high quality surface finish or strength. I am pleased to be able to offer this exciting technology to my customers."

From their offices located in Minneapolis, Minnesota, USA, TM&S works directly with design engineers and purchasing agents across the globe.

www.technicalmarketingandsales.com

### Submitting News

To submit news to *Powder Injection Moulding International* contact Nick Williams: nick@inovar-communications.com





## Dion Vaughan appointed Chief Executive of specialist metal powder producer Metalysis

Metalysis, the UK based specialist metals producer, has announced the appointment of Dr Dion Vaughan as Chief Executive. He succeeds Guppy Dhariwal who is retiring, having joined the firm in 2010. Vaughan is a trained metallurgist and has worked across the metals, mining and investment sectors including Hatch Corporate Finance, Sheffield Forge Masters and JP Morgan.

Metalysis has developed an entirely new way of producing high value metal powders that, states the company, reduces the cost and environmental impact of metal production as compared with existing processes. The Metalysis technology is able to transform metal oxides, such as ores directly into metal powders in a single step. It is currently focusing on the high value specialist metals titanium and tantalum.

As a result Metalysis believes that it can play a critical role in two manufacturing revolutions over the coming years. The powders produced by the Metalysis process, states the company, will dramatically change the production of high value titanium components both utilising existing manufacturing techniques and driving forward the adoption of 3D print in specialist metal products.

In addition, this new technology has the potential to significantly reduce the cost of specialty metal powder production. This means previously expensive metals such as titanium can be used in a variety of new applications to satisfy the latent demand for a low cost, light weight, high strength and corrosion resistant metal.

The nature of the Metalysis process means that it can produce alloys that would not be cost effective by traditional processes. It is entirely solid-state; therefore metals with significantly different densities or melting points can be alloyed. These innovative alloys can be tailored to have the desired properties for applications within a variety of industries including automotive, marine, electronics, clean energy and aerospace.

Tony Pedder, Chairman of Metalysis commented, "The company has performed well on its science and technology goals, which has enabled the Board and shareholders to develop a new scale-up plan for the business. This plan, based on simpler and cheaper production cells, is a longer term plan and so it is a natural time for Guppy, who has done a very good job in re-organising the company, to hand over to Dion Vaughan to deliver an exciting future for Metalysis."

Dion Vaughan, Chief Executive of Metalysis added, "Our future emphasis will be on further developing our strength in science and technology, where the company has historically performed, and on partnering with leading metals companies who can help with engineering scale-up and market adoption. The company is already making good progress in exploring such partnering arrangements."

www.metalysis.com

## Nanostructured ceramic powder developments at Innovnano

Innovnano, a manufacturer of high performance ceramic powders, has invested in a high-tech, brand new facility for production of its nano-structured powders, including 3 and 4 mol % yttria stabilised zirconia (YSZ). The new site is based in a dedicated technology park in Coimbra, Portugal, and has been designed to allow high capacity expansion and industrial-scale nanotechnology, enabling the production of up to 1000 tonnes per annum.

With the new facility, Innovnano has the capacity and expertise to rapidly up-scale nanostructured powder production, from small quantities needed in R&D phases, to much larger industrial quantities, as and when commercial progression dictates. As such the company can provide support and supply throughout a project life-cycle, negating the need to source alternative suppliers and eliminating any associated risk of product variation. Importantly, this maximises consistency, dependable end-product performance and user-assurance.

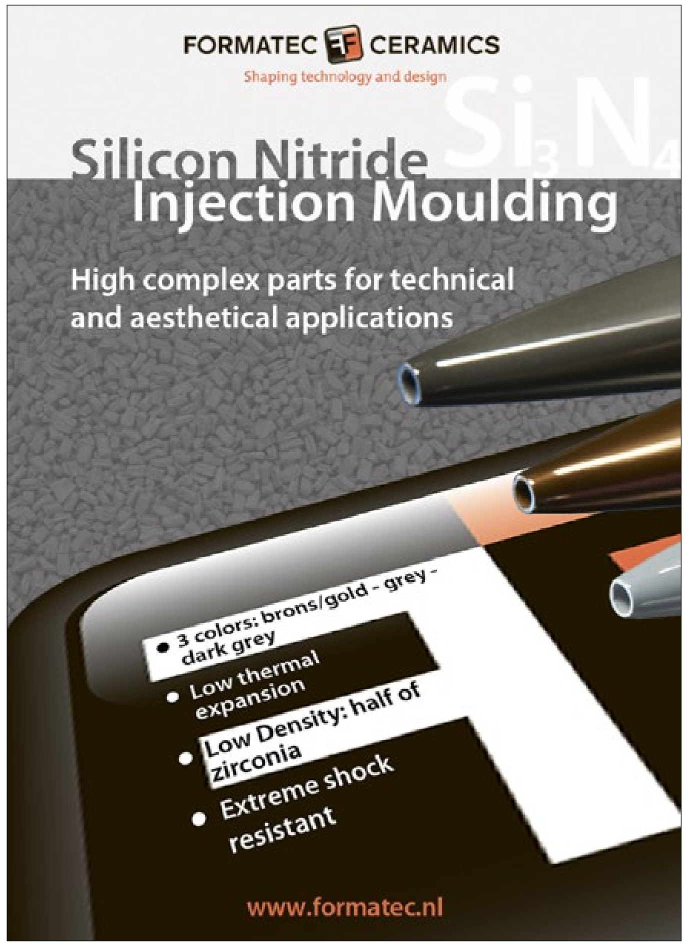
At the new facility, Innovnano's unique Emulsion Detonation Synthesis (EDS) technology has been fully automated, and along with stringent quality control processes, ensures the production of nanostructured powders with extremely high batch-to-batch consistency. This ensures the ceramic powders are developed to exacting specifications with defined properties, for consistent chemical reliability and robust physical performance; characteristics which are then translated to the end-application, for example more efficient thermal barrier coatings or orthopaedic implants with enhanced fracture toughness. Compared with conventional microstructured ceramics, powders with an intrinsic nanostructure translate to finer, denser and often a more chemically homogenous ceramic material, enabling enhanced end properties such as hardness.

QA protocols include comprehensive QC processes for each batch of powder at several steps throughout the production process, from the raw material to the final product. Industry tests are conducted with tight parameters, to verify that the sample meets the expected high-standard at each stage of processing, and properties such as oxide content, phase and chemical purity, particle size, and mechanical performance, along with many others, are measured.

André de Albuquerque, CEO of Innovnano, commented, "Building this new manufacturing facility was a vital move for us, and now guarantees that we can provide long-term support to all our customers, regardless of the quantities of nanostructured ceramic powders they require. Our patented EDS process lends itself perfectly to industrial-scale production and there is no compromise to the quality or performance of the final product."

Working to lead innovation in nanostructured ceramic powders, Innovnano has established a close network of academic, R&D and commercial institutes globally. This allows Innovnano to gain first-hand insight into the capabilities and constraints of existing materials, in turn enabling Innovnano to challenge these limitations and develop powders that are more optimally suited for purpose.

www.innovnano-materials.com





# Chinese MIM producer Shindy creates graduate training partnership with Central South University

Chinese MIM producer Shenzhen Shindy Technology Co., Ltd and the Powder Metallurgy Research Institute of Central South University have entered into a joint venture to establish an "Innovative Engineering and Education Foundation" for the further training of graduate students from the institute employed full time by Shindy.

As part of the venture the institute's senior teaching and research staff will work on site at Shindy with its management to organise a programme on marketing, research and development, and production for trainees on the application and practice of their skills and knowledge in a practical setting.

On 27 June 2013 the inauguration ceremony took place at the Grand Sky Hotel, Shenzhen. The Director of the Economic Development Bureau of the Shenzhen Government, Mr. Zhu Yun, delivered a speech on the occasion. He stated that this joint venture will be a win-win situation for both parties and commented that it demonstrated a landmark success as a result of encouragement from the local government to institutes to work with industry to commercialise their technological developments, as well as creating job opportunities.


*Representatives of Shindy and the Powder Metallurgy Research Institute of Central South University at the ceremony*

*A selection of MIM parts manufactured by Shenzhen Shindy Technology Co., Ltd*

*Prof. Lin Yong of the Institute presenting the joint venture plaque to Mr. Lin Sheng, General Manager of Shindy*

Shenzhen Shindy Technology Co., Ltd was established in July 2009 in Shenzhen, Guangdong Province. The company is a manufacturer specialising in the production of MIM parts for the telecommunication industries, in particular the mobile phone manufacturers in China. Clients include as Foxconn, Oppo and Ginonee. The total turnover of Shindy in 2012 amounted to RMB 38 million and for 2013 it is projected at RMB 80 million.

At the end of 2012 Shindy moved its production facilities to Guland, Shenzhen, Guangdong Province, with an area approximately 6500 $m^2$. The company has around 200 staff, with 20 engineers engaged in R&D for new products. In order to meet its clients' ever increasing demand on quality, Shindy told *PIM International* that it has made new capital investments in the latest models of injection machines from Arburg, Germany, as well as sintering furnaces from Shimadzu, Japan. The company states that it is committed to expanding its capabilities in order to supply the medical, automobile and consumer industries. The development of CIM technology is also reported to be underway.

For more information contact Sam Mok, Business Development Director, email: sam.mok@metamistech.com

www.china-shindy.com

## Submitting News

To submit news to *Powder Injection Moulding International* contact Nick Williams: nick@inovar-communications.com





# Powder Metallurgy Review: Autumn 2013 issue out now

The latest issue of *Powder Metallurgy Review*, the magazine for the Powder Metallurgy industry, has just been published and is available to download free of charge from www.ipmd.net.

The 80 page issue features a specially commissioned report on the evolving relationship between North America's PM parts producers and the region's automotive industry, which has dominated the development of the PM industry for many decades.

Also included is a review covering global R&D trends in hardmetals and the phenomena of cobalt capping, as presented at the recent Plansee Seminar. An additional report covers the Special Interest Program at the PowderMet 2013 Conference, Chicago that looked at technologies for PM growth. To download your free digital edition of *Powder Metallurgy Review*, visit www.ipmd.net/pmreview

## Elino celebrates its 80th anniversary and inaugurates a modernised technical laboratory

Elino Industrie-Ofenbau GmbH, the industrial furnace manufacturer situated in Düren, Germany, recently celebrated its 80th anniversary. The opening of a modernised R&D centre, where customised tests and research can be carried out, was undertaken by the town's mayor, Paul Larue. In his speech Larue praised the stability of the company and underlined the fact that Elino plays an important role in the area's industry. Elino, stated, Larue, has additionally always been exemplary with regards to the training and further education of young people in the town.

Elino is today a global supplier of industrial furnaces, including continuous and batch systems for Metal Injection Moulding. The company stated that it values a reputation that has been built over 80 years for durable, service-oriented furnace plants that today also have a strong additional focus on energy efficiency.

The company celebrated its anniversary together with many long-standing customers and partners. Philippe Blandinières, who integrated Elino into the international PLC Holding group of furnace manufacturers in 2010, praised the commitment of the employees without whom the achievements of the last 80 years would not have been possible. Managing Director Dieter Schäufler additionally praised his team and emphasised that companies with such a long history have a responsible role to assume not only in business but also in society.

www.elino.de

*Fig. 1 Philippe Blandinières, Business proprietor of PLC Holding (left) with Managing Director of Elino Industrie-Ofenbau GmbH Dieter Schäufler*

### Submitting News

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## JPMA reports on 2012 Japanese MIM market

The Japan Powder Metallurgy Association (JPMA) has released its latest detailed annual report on the state of Japan's MIM market. The report, which is based on figures for 2012, shows that Japan's MIM parts produced achieved total sales of 11.2 billion Yen, a 3.4% decrease on the previous year. The association is forecasting that the 2013 results will also reflect a level of stagnation in Japan's MIM markets. The survey's findings are based on the results of a detailed questionnaire that was sent to 23 companies, including JPMA member and non-member companies.

In terms of application areas for MIM in Japan, the strongest growth was seen in the automotive sector, where sales grew to 20.1% of the market, up from 14.9% in the previous year (Fig. 1). Industrial machine parts accounted for 20.4% of sales, up from 19.9% in 2012. Medical appliance parts also saw a growth in market share to 17.4% compared to 14.6% in the previous year. IT parts sales dropped to 9.9% from 17.5% in 2012 because, it is stated, because of order cancellations.

In terms of materials usage, stainless steels rose to account for 63.4% of sales, up 3% on 2012 (Fig. 2). Together stainless steels, magnetic material and Fe-Ni alloys accounted for around 83% of the market. The JPMA also stated that Invar, Kovar and titanium alloys have been decreasing for several years. In the case of titanium, cost was given as a significant factor.

www.jpma.gr.jp

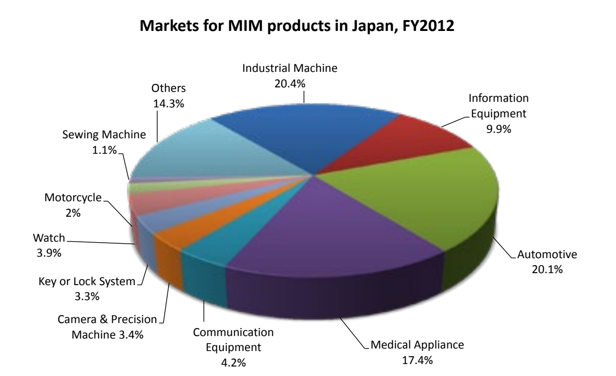


*Fig. 1 Markets for MIM products in Japan, 2012 (Data courtesy Japan Powder Metallurgy Association)*

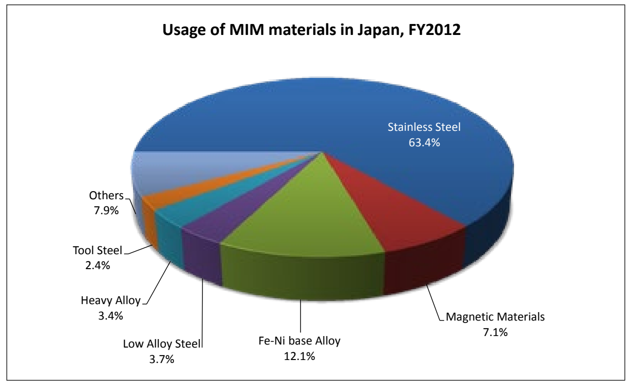


*Fig. 2 MIM materials usage in Japan, 2012 (Data courtesy Japan Powder Metallurgy Association)*



## Dutch group targets the printing of technical ceramics

In December 2012 Dutch CIM specialist Formatec Ceramics introduced a new ceramic printing technology and since this time, states the company, the overwhelming interest in this new technology has encouraged it to continue developments in this field. In order to further develop ceramic printing technology ECN and Innotech Europe joined Formatec's initiative as partners and shortly after this the ADMATEC project was established. The ADMATEC project now develops a wide range of printing solutions for ceramics, with materials, machines and process developments all addressed within the group.

"It is our absolute aim to become the market leader for printing ceramic materials. In order to fulfil this aim efficiently the group decided to invest in a Cerafab 7500 from Lithoz. Adding Lithoz's LCM technology to the project completely underlines our strong commitment to become a leader in this field of expertise," stated Michiel de Bruijcker, Formatec's Managing Director.

Development of printing technologies continues within the group, with the new ADMAFLEX® technology developed in-house. The main focus of the work has been to break down the limitations on precision, building size and building speed. Material research is also cited as a critical development factor, along with reducing costs and broadening the total range of materials. These material developments will not be limited to ceramics, stated de Bruijcker, adding that in the middle to long-term a pre-defined range of metals will also be developed as the process is suitable for all powder materials. Technical information on the process has not been disclosed.

*Fig. 1 A ceramic development study printed on ADMAFLEX® 80*

*Fig. 2 Ceramic sensor housing produced on a Cerafab 7500*

| Specification: ADMAFLEX® | | | |
|---|---|---|---|
| Resolution | µm | 40 | |
| Layer thickness | µm | 12 | 100 |
| Building speed | mm/h | 4-5 | >10 |
| Platform size | mm | 80 x 10 x 150 | |
| Materials | - | Alumina / Zirconia | |
| Density | % | >99% | |

*Table 1 Specifications of the ADMAFLEX® 80 system*

As well as technology development, the ADMATEC group is exploring new market segments with both the Cerafab and the ADMAFLEX® systems. By combining both technologies ADMATEC can supply both small and precise parts as well as larger parts in higher volume.

"The market seems to be discovering this technology sooner than expected, resulting in challenging requirements on a frequent basis. Ahead lies an ambitious development plan with clear milestones and deliverables for commercial and technical challenges. Our current achievements, combined with the Cerafab 7500 capabilities and the outcomes of the development plan, will uniquely position ADMATEC in this new market segment," concluded de Bruijcker. For more information contact Michiel de Bruijcker, Formatec Ceramics, email: m.d.bruijcker@formatec.nl

www.formatec.nl

## GKN continues to make good progress

Group results issued by GKN plc for the first six months trading in 2013 showed that sales increased by 12% to £3,647 million (up 2% on organic basis) compared with the same period in 2012. Reported profit before tax of £134 million (2012: £279 million) was lower, primarily due to foreign exchange rate changes impacting the mark to market value of foreign exchange contracts.

The GKN Powder Metallurgy Division sales grew by 2% to £480 million in the six month period with a trading margin of 10%, including restructuring charges. The PM Division is expected to show good year-on-year sales improvement, although reflecting normal seasonality. Second half profit in the Division will also benefit from the absence of restructuring charges.

"GKN has continued to make good progress against our strategy to grow a market-leading global engineering business. Although some of our end markets remained challenging, we continued to outperform and are reporting good underlying financial results with further benefit from last year's acquisition, GKN Aerospace Engine Systems (formerly Volvo Aero), which is performing well. The first half met our expectations and, with planned restructuring costs now behind us, we expect a stronger second half performance and to deliver good progress in 2013," commented Nigel Stein, Chief Executive of GKN.

www.gkn.com

# MPIF 2013 design excellence award winning parts reflect the continuing growth of MIM technology

Winning parts in the Metal Powder Industry Federation's (MPIF) 2013 Powder Metallurgy Design Excellence Awards competition were announced at the PowderMet 2013 International Conference on Powder Metallurgy and Particulate Materials, Chicago, June 24-27.

The continued growth of the Metal Injection Moulding industry is reflected in the large number of prizes presented to this sector in this year's awards. MIM's growing acceptance in the automotive industry as a trusted manufacturing route is clear, with both a Grand Prize and Award of Distinction being presented for MIM parts in this demanding sector. The MIM process was also the manufacturing method of prize winners in the hand tools/recreation, aerospace/military and medical/dental categories.

## Grand Prize Awards

**Automotive engine**

Indo-US MIM Tec Pvt. Ltd., Bangalore, India, received a grand prize in the automotive engine category for a sensing element, a threaded port and a support ring made for

*Fig. 1 These MIM components are used in a sensor to measure the inlet pressure of the air fuel mixture in each cylinder of a passenger car engine (Courtesy MPIF)*

*Fig. 2 MIM parts for a component used in the M249 squad automatic weapon used by the US Military (Courtesy MPIF)*

Sensata Technologies Holland B.V., Almelo, the Netherlands (Fig. 1).

Made via Metal Injection Moulding these components are used in a sensor kit that measures the inlet pressure of the air fuel mixture in each cylinder of a passenger car engine. The length of the threaded port creates complexity, as do the thin walls and fragile features, and the stringent customer requirements on visual aspects add to the difficulty of manufacture.

Made of MIM-17-4 PH stainless steel, the parts have a heat treated yield strength of 160,000 psi, ultimate tensile strength of 178,000 psi, 7% elongation, 35–40 HRC hardness range, and 7.6 g/cm³ density. The parts are formed close to net shape, with only coining and passivation required on all three, plus CNC thread cutting on the port only.

This new application is estimated to save the customer 50% over the cost of manufacture using alternative technologies.

**Aerospace/military**

Polymer Technologies Inc., Clifton, New Jersey, USA, was presented with the grand prize in the aerospace/military category for two MIM parts, a U-bracket and stop used in a Feedbox Support Improvement Kit (FSIK) for an M249 squad







*Fig. 3 Stainless steel jaw made for a medical grasping device (Courtesy MPIF)*

automatic weapon (SAW) used by the US Military (Fig. 2).

The device is designed to hold various size high volume magazine ammunition packs securely to the gun. It extends the service life of the weapon by enabling the soldier to repair it in the field, thus avoiding the cost of a new weapon.

Drop testing of the firearm with the device attached proved the integrity of the FSIK even while other components were damaged. The innovative I-beam and webbing design allowed the parts to meet the 32–38 HRC hardness range requirement and still maintain the total weight of the kit below 3.5 oz.

Moulded from MIM-17-4 PH stainless steel, the parts have >7.5 g/cm³ density, 130,000 psi ultimate tensile strength, 106,000 psi yield strength, and 6% elongation. The only secondary processing of these near net shaped parts are a coining operation to the bracket in order to achieve the tolerance required for the distance between the notch and the through hole, as well as tapping the hole to provide necessary threading. Both parts are black oxided to remove their reflective properties, a critical consideration for the safety of the soldier.

**Medical/dental**

FloMet LLC/A QMT Company, Deland, Florida, USA, was awarded the grand prize in the medical/dental category for a 17-4 PH stainless steel jaw made for US Endoscopy, Mentor, Ohio, and used in a Raptor™ grasping device (Fig. 3).

Made via MIM, the jaws merge into one design that features both a rat tooth jaw and an alligator jaw, combining the functions of a grasper and a retrieval forces that surgeons use to retrieve foreign objects in the body during minimally invasive procedures.

The component design is enormously complex due to its small size, thin wall requirements 0.25 mm (0.010 in.), and features required to achieve full functionality with the sharp talons and teeth at net shape. The parts have >7.5 g/cm³ density, 130,000 psi ultimate tensile strength, 106,000 psi yield strength, 6% elongation, and 27HRB hardness. Only minimal secondary processing (coining to help maintain the alignment of the jaws) was needed, as other geometries and tight tolerances were achieved in

*Fig. 4 MIM tool holder assembly for a woodworking tool used in fine detail carving (Courtesy MPIF)*

*Fig. 5 Fuel control gear segment of a fuel control device that regulates the entry of fuel into the engine (Courtesy MPIF)*

the as moulded condition. Alternative processing methods could not have achieved the part's intricate geometries at a reasonable cost. MIM is estimated to have saved more than 60% over die casting or machining the parts.

**Hand tools/recreation**

Indo-US MIM Tec Pvt. Ltd., Bangalore, India, also received the grand prize in the hand tools/recreation category for a tool holder assembly made for Scintilla AG, Solothurn, Switzerland. The assembly that incorporates these two MIM parts, a tool holder and a grip spring tensioning part, goes into a woodworking tool for fine detail carving (Fig. 4).

Part complexity made MIM the obvious choice as no other technology could produce the part as an integral unit and deliver it in the needed volumes at the target cost. Made of a low alloy steel, the parts are supplied in the heat treated condition. Properties include 7.5 g/cm³ minimum density, 225,000 psi ultimate tensile strength, and 200,000 psi yield strength. To overcome the possibility of distortion on the unsupported open end, the design provided supporting ribs. The grip support ring was produced per print with the help of one turning operation.





The MIM design contributes to a lean operation for the customer by substantially reducing lead time through the elimination of many processing steps.

## Awards of Distinction

**Automotive engine**

Indo-US MIM Tec Pvt. Ltd., Bangalore, India, additionally won an award of distinction in the automotive engine category for a fuel control gear segment made for Bosch Limited, Bangalore, India (Fig. 5). The part goes into a fuel control device that regulates the entry of fuel into the engine.

Converted from a machined part, the gear segment is fabricated via MIM from a low alloy steel at a saving of 80% over the previous method. Moulded to net shape and requiring no secondary operations, the part has a density of 7.5 g/cm³, 46,000 psi ultimate tensile strength, 19,000 psi yield strength, 25% elongation and 100 HRB max. hardness. Nearly three million pieces are delivered annually to the customer.

**Hand tools/recreation**

An award of distinction in the hand tools/recreation category was earned by Parmatech Corporation, Petaluma, California, USA, for an actuator used in a tool less locking system that enables quick changing of a shotgun stock (Fig. 6).

Made via MIM of a low alloy steel, the complex design part required the use of stepped ejector pins on the sloped surface to allow for smooth ejection with no part damage.

*Fig. 6 This MIM actuator is used in a tool less locking system that enables quick changing of a shotgun stock (Courtesy MPIF)*

It has a 0.05 mm (0.002 in.) straightness requirement on the longer than 25.4 mm (1 in.) shaft and a tight profile requirement of the curved and sloped cosmetic surface. The part is moulded and sintered close to net shape to 7.48 g/cm³ density, and is coined in order to achieve repeatability.

Choosing MIM over casting and machining the part provided a cost savings of 25–35%.

*Fig. 7 MIM stainless steel shuttle used in a stapling device for arthroscopic surgery (Courtesy MPIF)*

**Medical/dental**

Polymer Technologies Inc., Clifton, New Jersey, USA, also received the award of distinction in the medical/dental category for a stainless steel shuttle used in a smart stapling device for both open and minimally invasive arthroscopic surgery (Fig. 7).

It is part of a device that interacts with a disposable staple cartridge in a computer controlled device that provides a high level of precision, consistency, accuracy, agility and compressive force for the surgeon using it.

Manufactured via MIM, the shuttle incorporates two separate components that were previously combined via laser welding. Making this intricate, small, and lightweight 0.175 oz. component presents many challenges, including the extremely thin walls, tight radii, and true position geometries, especially the two leg tips, which need to maintain their required strength and piercing sharpness. Part properties include 7.75 g/cm³ density, 200,000 psi ultimate tensile strength, 160,000 psi yield strength, 11-30% elongation, and 82 HRB hardness.

The shuttle is formed to nearly net shape, requiring only minimal secondary operations of reaming and then tapping the small hole, as well as providing proprietary sintering fixtures to maintain the straightness callout for the parallel walls.

www.mpif.org

## Dates announced for Sintering 2014 conference in Dresden, Germany

Sintering 2014, an international conference focussing on the latest advances in sintering science and technology of powder based materials, will take place in Dresden, Germany, August 24-28 2014.

The conference was last held in Korea in 2011 and next year's event is expected to attract around 300 delegates.

A call for papers will be issued in due course and further information will be available on the event website.

www.sintering2014.com



| contents page | news | events | advertisers' index | email | Industry News

## SciPiVision's market study finds strong growth for the global Powder Injection Moulding industry

A new 160 page market report compiled by Prof Randall M German and Prof Sundar V Atre explores the continued strong growth in the Powder Injection Moulding industry and analyses major growth sectors including healthcare, transportation and electronics.

According to the PIM 2013 Market Study, PIM technology accounted for about $1.45 billion in sales during 2012. The major growth sectors for the technology include healthcare, transportation and electronics with examples of PIM applications ranging from minimally invasive surgical tools and mobile phone components to automotive sensor housings and luxury watches. Nearly 500 production firms support this activity around the world. It is an impressive performance, rising from modest sales of $6 million in 1986 when there were about 30 active operations.

The 160 page report emerges from data collected for nearly 800 organisations associated with the PIM industry and includes Metal Injection Moulding (MIM), Ceramic Injection Moulding (CIM), Cemented Carbide Injection Moulding (CCIM) and composites. With 15 years of history in assembling data on the PIM companies, their products, sales, powder consumption, employment, materials, key customers, and vendors, considerable historical and statistical trend analyses arise beyond the situational report.

The data for the PIM 2013 Market Study was derived from company self-reports, on-line surveys, trade associations, conference reports, magazine articles, subscription business compilations, facility visits, investor reports, interviews, news releases and other reports.

The statistical surveys show an early identification of the unit-manufacturing cell for PIM. Early facilities were typically small, with 10 to 20 people, batch mixing, two to three moulding machines, and two to three batch sintering furnaces. As growth occurred, the number of manufacturing cells grew, but the production ratios remained similar. Today, a typical facility has multiples of the same early production ratios. The estimated unit-manufacturing cell is reported as:

- $2.5 million in sales
- 20 employees per cell
- 1 mixer per cell
- 5 moulders per cell
- 2 furnaces per cell
- 10 million parts per year per cell.

Regional differences make firearm and medical/dental dominant in North America and electronic/computer/cell phone components most significant in Asia. In Europe, consumer and automotive applications were found to predominate.

This report provides an intense focus on PIM and is intended to provide facts for assessment of operations, productivity, financial performance, and relative evaluation for merger-acquisition activity. This report serves by identifying current actors, customers, vendors and suppliers, market trends, materials, and industry concerns. Embedded in the report are details on market segmentation by geography, and emerging concerns.

The PIM 2013 Market Study is organised to show where the technologies came from, the relative market position in terms of production facilities, customers, and materials around the world, and forecasts for the future. Once current statistics are accumulated, prime interest emerges on comparative statistics. To help in the corporate and regional benchmarking, data are included on geographic differences, showing differences in sales, materials, applications, productivity, and financial performance. Specific attention is given to growth opportunities and new markets.

http://pim2013marketstudy.scipivision.com

**Submitting News**

To submit news to *Powder Injection Moulding International* contact Nick Williams: nick@inovar-communications.com

# Optimising mould design and function for Powder Injection Moulding

Powder Injection Moulding (PIM) offers many more creative possibilities than conventional machining processes. Complex components made from metal or ceramic can be created with internal threads, gears or undercuts and produced in high volumes efficiently and cost-effectively. When quality problems arise, it is usually the case that the mould is not optimally designed for the processing of feedstocks. In this article Hartmut Walcher and Marko Maetzig, from Arburg GmbH + Co KG, discuss the specific requirements that a PIM mould must satisfy and outline measures that can enable component quality to be significantly increased.

The most conspicuous advantage of the injection moulding of powder materials is the relatively simple and fast series production of complex metal or ceramic components with minimal finishing requirement, in consistently high quality. That's if you get it right from the start!

At first glance, PIM moulds do not differ significantly from those used in the processing of plastics. All common mould types, such as 2-platen, 3-platen, sliding carriage and split moulds, are also found in powder injection moulding. However, the injection moulding of metal or ceramic feedstocks has its own special rules. In many cases, this factor is not given sufficient consideration in the injection moulding process – and especially where mould design is concerned.

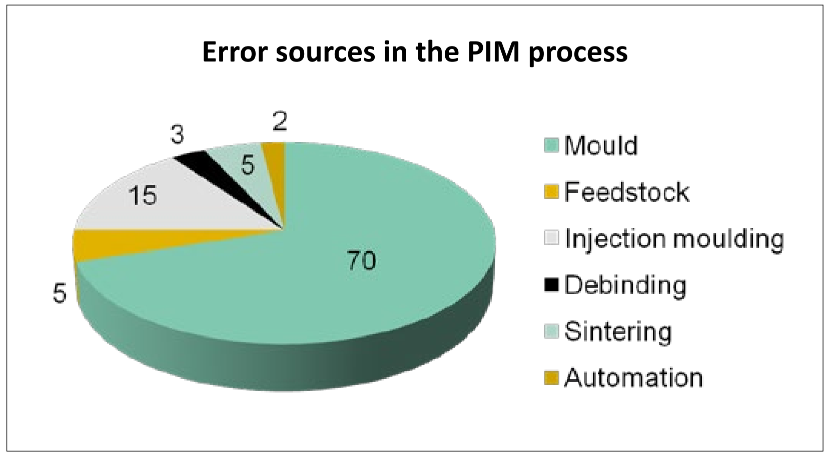


*Fig. 1 Error sources in the PIM process: a non-optimally designed mould is by far the main cause of quality problems with MIM and CIM components (Image courtesy Arburg)*

## The mould as an error source

Around 70% of all defective PIM components are caused by the mould, while about 15% are due to the injection moulding parameters. Much lower down the list of error sources are the feedstock, automation system as well as the sintering and debinding processes (Fig. 1).

In contrast to conventional injection moulding, the cycle time with PIM is not the time-limiting factor that is decisive for production efficiency. Rather, the defining variable is the proportion of good parts after sintering. This, in turn, depends largely on the quality of the mould and can be dramatically increased by using a mould specifically designed for the processing of powder materials.

*Fig. 2 Snapshots clearly illustrate the flow characteristics of a CIM feedstock: jetting occurs as the material flows around a bore (Photo courtesy Arburg)*

In practice, often because of commercial considerations, a supposedly lower-cost mould is employed, instead of using a mould designed for series production. However, if PIM components are to be produced cost-effectively in perfect quality on a daily basis, we first have to observe the following basic principles:

- The prototype mould must be replaced by a series production mould.
- The better the mould is designed for the application and the fewer faults have to be corrected, the simpler the injection moulding machine can be.
- Only machine operators specifically trained in the process can adapt the powder injection moulding process precisely to suit the relevant requirements.

## Feedstocks: significant material properties

The processing of powder materials gained further impetus when BASF introduced feedstocks at the end of the 1980s and Hoechst launched a commercial binder system onto the market. Customised feedstocks can also be developed on this basis. The material properties of injection moulding compounds made with a powder and binder material are significantly different to those of conventional thermoplastics. They are virtually incompressible and exhibit extremely high pressure transmission. The thermal conductivity of the MIM feedstock Catamold 316L, for example, is around 6 W/mK, whereas that of the thermoplastic POM is about five times lower (0.14 W/mK). The value for 316L pure stainless steel, however, is over twice as high (14 W/mK). Because MIM materials therefore cool down much faster than plastics, they have completely different requirements where temperature control of the mould is concerned. Consequently, even if the geometry of components is identical, mould-makers cannot apply the same mould design 1:1.

The greater density (Catamold 316 L: 5 g/cm$^3$, POM: 1.4 g/cm$^3$) also gives rise to a major difference in flow characteristics. Feedstocks glide along the surface, instead of adhering to it like plastic and have a much higher tendency towards undesirable jetting (Fig. 2). The result is the more frequent occurrence of joint lines, air inclusions and cracks. These flaws can be eliminated or reduced by evacuating the mould, for example, or by using the PIM injection compression moulding process.

## PIM-optimised component design

Components that are injection moulded from powder materials must be designed differently from a metal part that is machined from a block, for example. Ideally, the following factors should already be taken into consideration during the design and construction phases of PIM parts:

- Functionally optimised: PIM allows numerous different geometries and additional functions can be incorporated if necessary.
- Optimised for injection moulding: Consistent wall thicknesses and minimal material use reduce component weight and costs.
- Optimised for automation: A robotic system can remove sensitive green compacts gently and set them down on sintering platens.
- Optimised for sintering: Components should have sufficient contact surface with the sintering platen, so that shrinkage is largely isotropic.

## PIM-optimised mould design

Even more important than component design is the correct design of the mould to suit Powder Injection Moulding. Important considerations here are the increased wear due to abrasive ceramic powder and the temperature sensitivity and low degree of thermal expansion of the feedstock. The following measures reduce quality defects to a minimum:

- Producing mould cavities from special materials such as HIP steel, carbide or ceramic.
- Providing all components that come into contact with the feedstock with suitable surface finishes.
- Positioning the mould parting line in a technically unproblematic location instead of on functional surfaces, to prevent problems caused by burr formation.

### Wear-resistant mould inserts

Hot Isostatically Pressed (HIP) PM steel or carbide is predominantly used for the processing of powder materials. The more finely grained the structure, the greater the strength and the lower the wear. When using carbide or ceramic inserts, however, attention must be paid to the thermal expansion of the different materials.

Mould inserts of erodible ceramics are a new development that is ideally suited to Powder Injection Moulding (Fig. 3). This may appear comparatively costly at first glance, but is especially wear resistant. Moulds with ceramic inserts are therefore particularly suitable for components that are produced in large volumes or with stringent tolerance requirements. As this ceramic is conductive, the EDM process can also be used, so that any desired contours can be achieved in the mould.





### Harmonising mould and automation

Gentle removal of sensitive green compacts by a robotic system provides protection against shocks and impacts and increases part quality and process reliability. Furthermore, it enables virtually unmanned series production and the set-down of random samples for quality control (Fig. 4).

The more intelligently the mould is designed for the downstream automation and sintering process, the simpler the associated gripper technology can be. Component orientation and the relationship between the mould cavities should therefore be designed in such a way that the injection moulded green compacts can be set down on debinding or sintering trays as neatly and tightly together as possible, for example with single or double spaced cavities (Fig. 5). This reduces the handling and overall cycle time, the required space and, ultimately, the production costs.

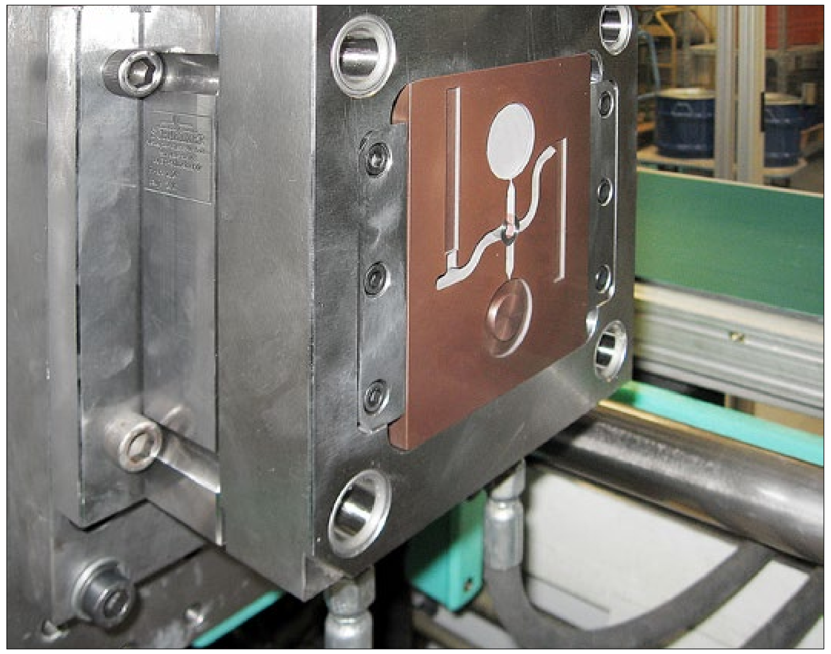

*Fig. 3 Mould inserts of erodible ceramic are wear resistant and especially suitable for high volume series production (Photo courtesy H.C. Starck Ceramics)*

### Moulds with liquid temperature control

As PIM feedstocks are temperature sensitive and can decompose even under the smallest temperature excesses, the mould and, if possible, the hot runner, should have liquid temperature control. This generally offers the following advantages:

- More good parts and fewer flaws such as joint lines, cold displacement and distortion
- No temperature gradient
- Optimum filling of cavities and component
- Short flow paths and short sprues, meaning savings in materials and costs

Liquid temperature control of the mould enables particularly uniform temperature distribution to be achieved. Consequently, hot feedstock compound can be conveyed into the component and optimum filling and flow paths achieved, without the occurrence of unwanted temperature overshoots.

### PIM-optimised sprue design

Due to its high thermal conductivity, a feedstock cools down considerably faster than a thermoplastic. If the direct gating and the sprue channels are too long, the material begins to solidify before the cavity is optimally filled. Moreover, there is more waste or regranulate and higher materials costs than necessary. For this reason, the component should be as large as possible in relation to the sprue and, conversely, the sprue as short as possible (Fig. 6). Resolving this problem becomes more difficult the more cavities have to be filled with one shot and the smaller the component. However, it can be achieved by using hot runners with liquid temperature control.

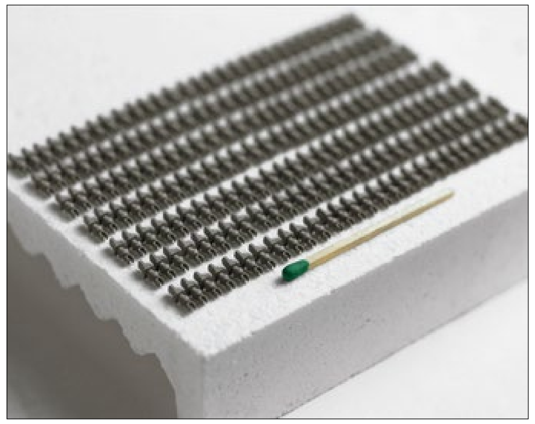

*Fig. 4 Delicate CIM parts such as these insulators for a Märklin model railway require gentle handling (Photo courtesy Arburg)*

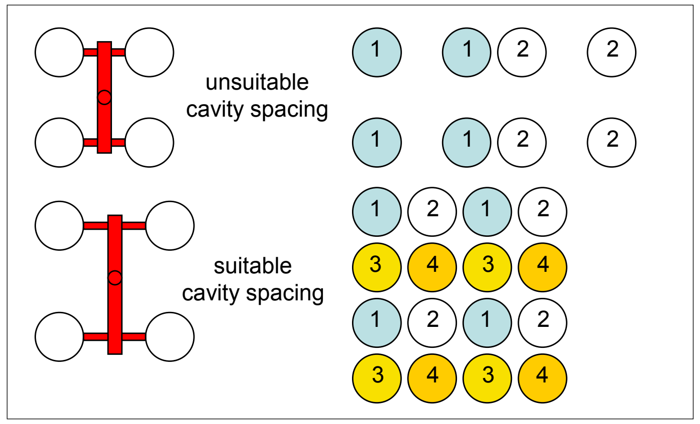


*Fig. 5 The achievement of set-down with optimum, narrow spacing can be ensured even when designing the cavities in the mould (Graphic courtesy Arburg)*

*Fig. 6 A good example of a PIM component with an optimum design is this radius milling cutter with internal thread, which is series produced fully automatically in a cost and material-efficient manner. The mould used is equipped with a hot runner, enabling extremely short sprues to be achieved (Photo courtesy Arburg)*

*Fig. 8 An elongated PIM nozzle penetrates deep into the mould. The sprue can thus be efficiently shortened (Photo courtesy Arburg)*

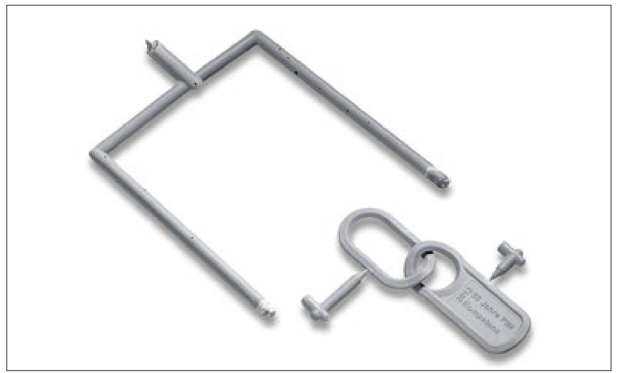

*Fig. 7 Liquid temperature control of the mould and a hot runner in the production of a key fob enabled the overall weight of both sprues to be reduced from 19 to just 2.09 g (Photo courtesy Arburg)*

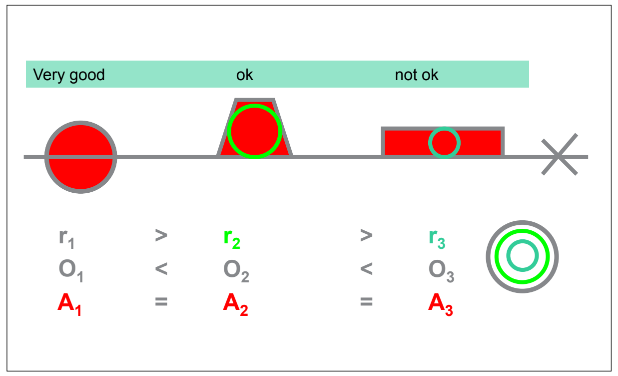


*Fig. 9 Sprues with identical overall surface area (A) but different geometry differ from one another considerably: the larger the radius and the smaller the surface area, the better suited is the sprue for the production of perfect quality components (Graphic courtesy Arburg)*

**Hot runners with liquid temperature control**

Combining a liquid temperature-controlled mould with a hot runner with the same technology, which is now available on the market for moulds with up to 16 cavities, is an ideal solution. This way, the temperature differences in the hot runners can be precisely regulated to within +/- 1°C. An electric hot runner comes nowhere near achieving a narrow temperature range of this kind.

A very clear, practical example of the profitability of hot runners with liquid temperature control can be seen in the CIM key fob, consisting of a disc weighing 4.89 g set in a 2.32 g ceramic ring (Fig. 7). To produce this item, a complex mould with four sliding carriages from Singer Spritzguss Konstruktion is used. The mould technology therefore takes up a lot of space and injection takes place at two points. With cold runner manifolds, the sprue weight would be 19 g – more than twice as much as the component itself. It is thanks to the liquid temperature-controlled hot runner alone that the sprue length could be reduced to a minimum. The weight of the two sprues is now just 2.09 g, corresponding to material savings of almost 90%. It is therefore highly desirable to use a hot runner with liquid temperature control for all MIM and CIM parts.

*'The weight of the two sprues is now just 2.09 g, corresponding to material savings of almost 90%. It is therefore highly desirable to use a hot runner with liquid temperature control'*

**Long nozzle – short sprue**

When a standard nozzle body and nozzle tip is used, the mould has to be equipped with a comparatively large opening to enable its temperature to be controlled by a heater band. This weakens the mould, increasing the risk of overfeed. However, specially elongated PIM nozzles only require a small opening (Fig. 8). Depending on the machine type, they can achieve about twice the entry depth of a standard nozzle. The sprue length can therefore be kept short.

The sprue design also has a significant influence on component quality. Sharp-edged, abrupt deflections lead to separation after the kink. This in turn gives rise to visible streaks on the component – the result of powder-binder separation.

If we compare different sprues with an identical overall surface area (A) but a different geometry, the following is clear (Fig. 9):

- The larger the radius (r), the greater the possibility of influencing component quality
- A small surface area (O) is better than a large one and, ideally, it is round
- A flat, rectangular sprue with a large surface area is unsuitable for Powder Injection Moulding.

**A vented mould prevents component flaws**

Unvented moulds can lead to air inclusions during injection moulding. The result is vacuoles, cracks and incompletely filled cavities. PIM moulds should therefore always be well vented. This is frequently achieved quite simply using ejectors or ventilation ducts. In this case, however, we typically encounter a gradual loss in quality, because the binder migrates out of the feedstock into the ventilation slots and, slowly but surely, contaminates the mould. The consequences are component flaws such as joint lines or pores, which slowly increase over time. It is possible to counteract these problems, for example by using a dummy cavity as an additional overflow at the end of the flow path. This emergency solution does not, however, tackle the actual problem.

In all cases, the optimum solution is to evacuate the mould via the injection moulding machine. Here, evacuation is programmed directly into the control system and integrated in the process. In this way, production can take place at under a defined vacuum and according to specified quality criteria. This increases the reliability of production and lengthens maintenance intervals. With a well evacuated mould, low reject rates are achievable in series production.

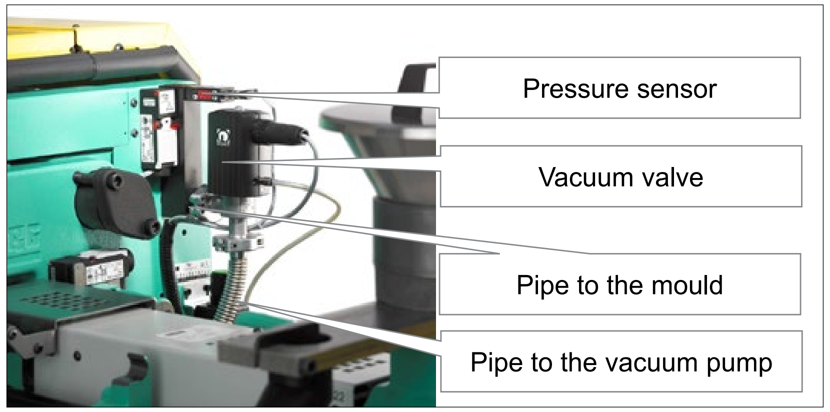


*Fig. 10 With a machine equipped with pressure sensor and vacuum valve, evacuation can be programmed into the process. Production with a defined vacuum level provides additional process reliability (Photo courtesy Arburg)*

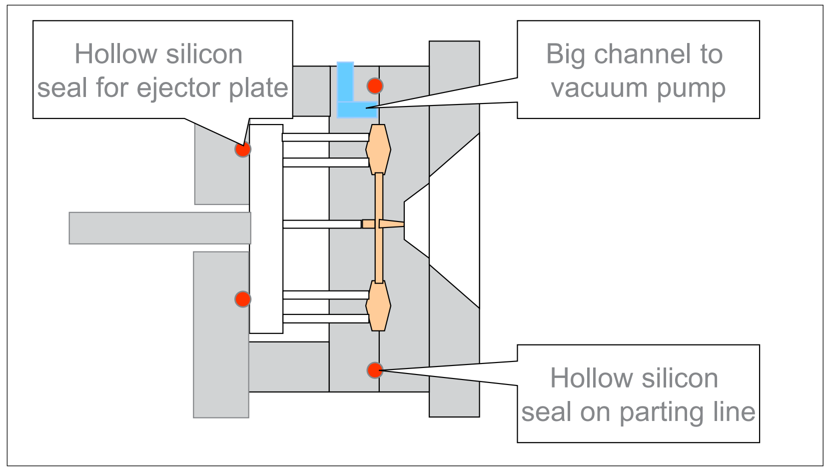


*Fig. 11 A PIM mould can be adapted for evacuation with just a few simple measures. A cover, sealing with hollow silicone seals and a hole to the partition are all that is required (Photo courtesy Arburg)*

The following optional features enable an injection moulding machine to be equipped for mould evacuation (Fig. 10):

- Vacuum devices, comprising a pressure sensor, vacuum valve and pipes to the mould and pump
- Interfaces for vacuum devices
- An "evacuation" functional enhancement integrated in the control system

**Evacuation: A low-cost solution with a major effect**

No complex special solutions or valves are required to prepare a PIM mould for evacuation. Rather, just a few minor and comparatively simple adaptations to the mould are necessary (Fig. 11):

- A cover for the open ejector assembly
- Hollow silicone seal for the ejector plate and parting line
- Large hole to the partition with duct to the vacuum flange

If evacuation is incorporated in the technical planning of the mould design from the outset, it can generally be implemented for less than €1000. This extra investment is amortised very quickly due partly to the significantly improved component quality.

**Injection compression moulding for large and thick-walled components**

In order to produce perfect thick-walled or large-volume PIM components with delicate or complex structures, the PIM injection compression process is the method of choice. It is achieved by advancing the ejector or core pull when the mould is closed. Then, during injection the material pushes the ejector or core pull back to the end position against a programmed counter-pressure in the controlled process sequence. This has the advantage of preventing jetting, joint lines or vacuoles, as the cavity is filled immediately and uniformly.

## PIM-optimised injection moulding machine

The basic equipment for a Powder Injection Moulding machine comprises:

- A highly wear-resistant or carbide MIM or CIM cylinder module
- A non-return valve with carbide inserts, designed to suit the granule size of the powder used
- An elongated PIM nozzle
- A position-regulated screw with special PIM geometry adapted for low compression
- Additional nozzle heater circuit
- Interfaces for vacuum devices.

To achieve really efficient production, it is necessary to take a holistic view of the Powder Injection Moulding process and precisely adapt it to suit a manufacturer's specific needs.

## Summary

Powder Injection Moulding is an extremely complex topic. Component quality is influenced by numerous factors. The mould is an important, if not the most important, item in the production of good parts. Each MIM or CIM mould should be adapted to suit the material properties of the feedstock, work with evacuation and be filled via a liquid temperature-controlled hot runner. Ideally, the geometry of the component and sprues, and the downstream automation and sintering processes, should be taken into consideration during the design and construction phase.

In order to exploit the full potential, development via a turnkey project is ideal, in which a system supplier accompanies the entire PIM process and delivers an individual solution from a single source. An important aspect in this regard is close communication and co-operation between leading manufacturers of moulds, injection moulding machines and feedstocks, and between PIM producers and the end customer.

Arburg's 50 years of PIM expertise has created a great pool of knowledge. Customers receive advice and comprehensive support throughout the value-added chain, from the selection of material and machine technology and peripherals, through to smooth series production. Through close co-operation with leading manufacturers of materials, moulds and furnace technology, they are provided with a customised solution. Complex turnkey solutions are achieved together with our partner Elnik Systems LLC.

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# Maxon Motor GmbH: A Powder Injection Moulding manufacturer driven by precision

The Swiss tradition of manufacturing high precision components and mechanisms is alive and well at the Maxon Motor plant in Sexau, Germany. Here Switzerland's Maxon Motor group has a PIM operation for the production of metal and ceramic components for both in-house use and external customers. Dr Georg Schlieper reports for *PIM International* on a recent visit.

Sexau is a small town situated in the pleasant foothills of the Black Forest in the extreme south-west of Germany, not far from the city of Freiburg and the famous wine-growing district of Kaiserstuhl. Being one of the warmest and sunniest regions of Germany, the area offers a high quality of living and a wealth of leisure activities. In winter, skiing in the resorts of the Black Forest is popular and throughout the rest of the year the beautiful landscape attracts hiking and bicycle tours. This region is the home of Maxon Motor GmbH, a manufacturer of high precision PIM components and a part of the Swiss headquartered Maxon Motor group.

## The story of Maxon Motor

The headquarters of the Maxon Motor group, Maxon Motor AG in Sachseln, Switzerland, was originally established in 1962 as a subsidiary of Braun GmbH in Kronberg, Germany, the manufacturer of high-end household electrical appliances which were renowned for their pioneering product design. The first of Maxon's products were shaving foils for Braun's electric shavers. Later Maxon focused on small and miniature electrical drives, in particular for shavers powered by batteries.

In 1967, Braun AG was acquired by the US based Gillette Company, which itself was taken over in 2005 by Procter & Gamble. Maxon Motor, however, was taken out of this deal and to this day remains in the possession of the Braun family. In addition to the manufacturing facilities in Sachseln and Sexau, the Maxon group has other manufacturing facilities in Veszprém, Hungary, and Sejong, Korea. The plant in Sexau started operations in 1989 and today it employs approximately 400 of the 2200 employees in the whole group. They work in two or three shifts, depending on the level of orders.


*Fig. 1 Maxon Motor factory at Sexau, Germany (Photo Georg Schlieper)*

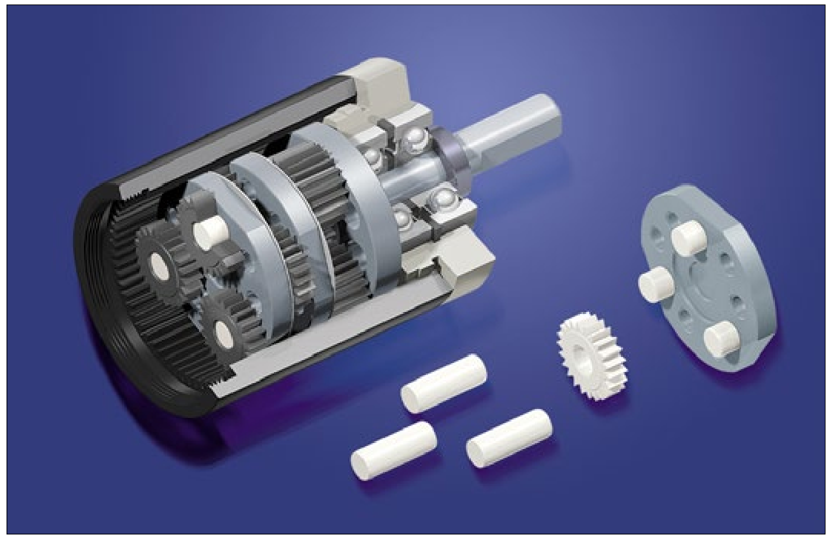

*Fig. 2 Planetary gearbox with CIM shafts and pinion gear (Photo Maxon Motor GmbH)*

*Fig. 3 Examples of ceramic components: shafts, nozzles, pinion gears (Photo Maxon Motor GmbH)*

## Staff and management

Maxon has invested a lot of effort in the appeal of its plant. The company is the biggest employer for miles around and highly favoured by the local population thanks to the good salaries and social benefits offered. Staff turnover is extremely low and seven apprentices are currently being educated in commercial and technical professions. Building up and sustaining a highly qualified workforce, as well as improving the skills of the existing employees, is a continuous task for the Plant Manager. In-service training is therefore an important part of the company strategy.

*Powder Injection Moulding International* was welcomed and shown around at the Sexau factory (Fig. 1) by Thorsten Buurlage, Manager of the PIM Business Unit. Buurlage joined Maxon Motor in 2009 and during his first two years at Sexau was responsible for research and development of drives and gearboxes. This enabled him to become acquainted with the manufacturing technologies applied in the plant, including Metal (MIM) and ceramic (CIM) injection moulding. In 2011 he was appointed Production Manager for the PIM sector at Maxon.

Although the majority of workers are trained in the factory, the Plant Manager is continuously looking to employ specialists in the technologies used. "For certain operations that require a particularly high degree of expertise, such as centreless grinding, we try to attract professionally experienced people. We can then integrate the special know-how that has been built up in other companies," stated Buurlage.

The annual summer and Christmas staff parties that are organised by the company are regularly attended by Karl-Walter Braun, the main shareholder, as well as senior management at the plant. At these parties they dine with their staff and enjoy informal conversations with them, just one way by which the atmosphere in the company is kept informal. The senior management is keen to avoid any distance between themselves and their co-workers, an attitude that strengthens the ties between the staff and management.

## Maxon's route into PIM technology

Swiss engineering is renowned for its high precision and fine mechanisms, with a prime example being watch movements, and Maxon Motor at Sexau perpetuates this tradition. Some 20 years ago the plant began to develop ceramic shafts for their drives and planetary gearboxes (Fig. 2). These were extruded from ceramic feedstock, subjected to a debinding process and finally sintered. The high precision of the shafts was achieved by subsequent centreless grinding. The manufacturing technology for these high precision shafts was developed in-house.

From extrusion technology it was a small additional step to Ceramic Injection Moulding. This technology opened the door for higher geometrical complexity. Major investments were made in CIM production equipment and operating personnel was trained for the new technology.

Miniature gearing requires the highest precision, extreme mechanical strength, low friction and high wear resistance. Steel was often not sufficient for these demanding applications. With the introduction of ceramic shafts and pinion gears in Maxon gearboxes, efficiency was significantly improved and the lifetime was tripled. "Today many manufacturers of medical engineering products stipulate the use of our ceramic shafts because of their high operational safety and reliability", stated Buurlage.





*Fig. 4 A robotic arm removes green parts (Photo Georg Schlieper)*

*Fig. 6 Catalytic debinding ovens (Photo Georg Schlieper)*

*Fig. 5 Green MIM planetary carriers (Photo Georg Schlieper)*

*Fig. 7 Debinding and sintering furnaces for CIM parts (Photo Georg Schlieper)*

## PIM technology at Maxon

Today PIM is an important part of Maxon's portfolio of processing technologies. Maxon's PIM production area covers a floor space of roughly 1200 m². Approximately ten injection moulding machines are in service with clamping forces up to 90 t, with Boy and Fanuc being the prevalent brands in the plant. Full electronic control of the injection moulding process is essential for the high precision requirements of Maxon's products.

Ready-mixed feedstocks from Tosoh in Japan and BASF SE in Germany are used as raw materials in Maxon's PIM production. Screws are wear protected, as is common in the PIM industry. Hot runner moulds are standard, and great attention is given to mould temperature control because this has a direct effect on part quality. Tool service life is generally satisfactory. Process automation is partly installed for components with higher production volumes. Robotic arms are used to remove parts from the mould and place them on carriers for further processing (Fig. 4). A batch of "green" planetary carriers leaving the injection moulding machine is shown in Fig. 5.

Quality control procedures start with regular checks on green parts for surface defects, weight deviation and dimensional accuracy. Flashes and ejection marks are removed in the green state if required. Machining in the green state is frequently applied wherever necessary or beneficial. Buurlage values the expertise within the company for green state machining very highly, particularly for ceramic materials. It is evident of course that secondary machining of ceramics after sintering is much more challenging and costly than in the green state.

MIM parts are packed in cylindrical batches of 340 mm diameter and 800 mm height for debinding and sintering. Both thermal and catalytic debinding processes are applied. MIM parts undergo catalytic debinding for 12 hours (Fig. 6), whilst ceramic parts require 48 hours thermal debinding time. For subsequent sintering of CIM parts another 48 hours is required (Fig. 7). Sintering is performed in batch type furnaces. While ceramic materials are sintered in air, metals are sintered in a reducing atmosphere which is composed of hydrogen and nitrogen. HIPing after sintering is not applied.

*Fig. 8 Selection of Maxon DC motors and drives (Photo Maxon Motor GmbH)*

*Fig. 9 Planetary carriers with integrated output shaft (top) and annular toothing (bottom) (Photo Maxon Motor GmbH)*

Secondary operations are often essential for the high precision of Maxon's products. MIM parts are often sized after sintering in order to improve specific dimensional tolerances. The surface finish is improved as required by barrel finishing or electropolishing.

The production of high precision PIM components is, however, only one aspect of Maxon's manufacturing processes. The assembling of parts into entire modules such as gearboxes is equally important. Assembly is either performed in the Sexau plant or in other Maxon factories worldwide. A new building is currently under construction at Sexau where the gearbox technology will be accommodated. This, it is stated, will release room for further growth of the PIM business unit.

## Tool design and toolmaking expertise

The high precision of Maxon's PIM products can only be achieved thanks to its long experience in tool design and quality toolmaking. The industrial environment in the Sexau area is characterised by a large variety of SMEs with special expertise in cutting edge technologies, including high precision metalworking and toolmaking services. This allows Maxon to out-source the manufacture, repair and maintenance of its injection moulding tools to local enterprises as part of a long standing partnership. In addition, the Maxon group has a Swiss subsidiary specialising in toolmaking whose expertise can be utilised if required. Together with the experienced tool designers in Sexau, Maxon Motor has an outstanding position in tool design.

The price for its high precision requirements is an almost complete lack of multi-cavity tooling at Maxon. Buurlage stated that for most of its products two cavities in a tool are the maximum. In his opinion a higher number of cavities would increase the risk of defective parts and reduce the precision of the products. This reduced productivity in injection moulding is not considered a serious drawback since injection moulding represents only a minor portion of the total costs of manufacturing.

## Products and applications

As previously mentioned, Maxon Motor's traditional product families are miniature drives, shafts, spindles and gearboxes for micro-motors. Motors and gearboxes range from 4 to 52 mm diameter and include gearboxes with up to six planetary trains (sets of planetary gears, Fig. 8). These planetary gearboxes can have step-down gear ratios of more than 1000:1. The motors can run at 30,000 to 60,000 rpm, sometimes even 100,000 rpm. The torque generated by the motor is scaled up according to the reduction of the rotational speed by the planetary gearbox, resulting in remarkably high torques although the drive motors themselves have only relatively low torques.

Numerous applications are found for these miniature drives. For example, robots for the automatic placement of electronic components on circuit boards are often equipped with these drives. Besides their small size, the enormous dynamic response of these motors is the main reason why they are used in this application.

Another field of application for micro motors are pumps for medications such as insulin. The small size and weight allows the patient to carry the pump on the body and the extremely high reduction of the motor speed serves to dispense medicine in small quantities under exactly controlled conditions. The outstanding reliability and light weight of Maxon's DC motors has also lead to aerospace applications such as in the unmanned space vehicle Mars Rover.

Examples of the high standard of Maxon's PIM technology are the planetary carriers shown in Fig. 9. The upper part has an integrated output shaft and the bottom one, shown in the green and sintered state, has annular toothing for the next set of pinion gears.

The miniaturisation of planetary gearboxes has imposed ever increasing requirements with regards to strength, wear resistance, precision and on the reduction of friction. The MIM steel parts, although offering a very high performance levels, were replaced step by step with ceramic shafts, pinion gears and planetary carriers. Fig. 10 shows a miniaturised pinion gear and a planetary carrier for the 4 mm diameter gearbox.

A comprehensive overview of Maxon's MIM parts for electric motors is shown in Fig. 11. In addition to planetary carriers there are pinion gears, gears with double sets of teeth, bushings and housings with or without annular toothing.

Some larger MIM parts are shown in Fig. 12. On the left side is the housing of an automatic guitar tuner. This includes six planetary gear drives which serve to automatically tune the six strings of a guitar independently. The part on the right is an assembly component for Maxon DC motors.

The ceramic products range also includes some impressive components. Fig. 13 shows a collection of ceramic drills and scalpels. Ceramic tweezers are also made by Maxon.

Ceramic spindles with a proprietary surface treatment for extremely low friction have been developed for precision linear drive systems. The same spindle made from steel has a service life of 140,000 cycles and a conventional ceramic spindle has a service life of 300,000 to 400,000 cycles. The special surface treatment, however, increases the service life to millions of cycles without any sign of wear under the same dynamic loading conditions. A whole range of spindles is now being developed and Maxon expects this product family to substantially extend their ceramics business. Sizes will range from 2 mm, perhaps even as small as 1.6 mm, to 12 mm in diameter.

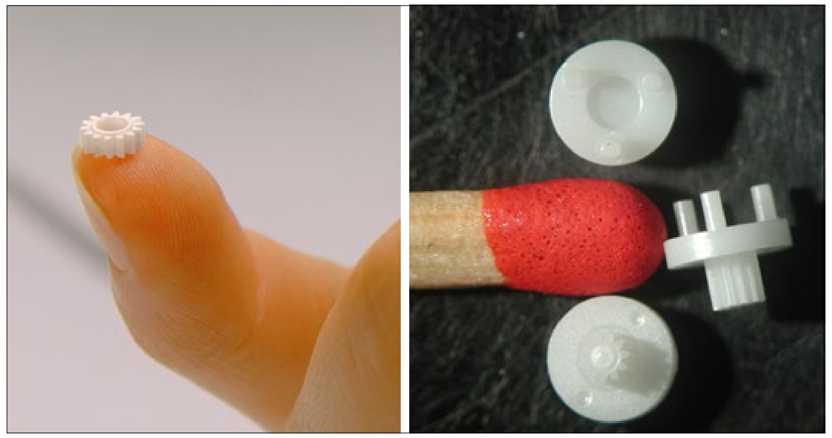

*Fig. 10 Miniature ceramic pinion gear (left) and planetary carrier (right) (Photo Maxon Motor GmbH)*

*Fig. 11 Overview of MIM components produced at Maxon (Photo Maxon Motor GmbH)*

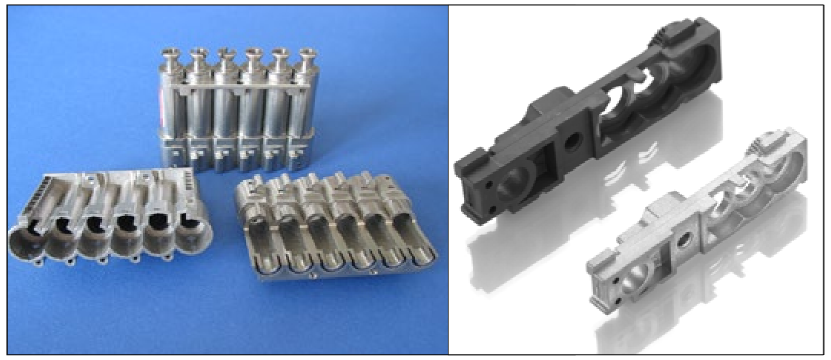

*Fig. 12 MIM guitar tuner housing (left) and DC motor assembly part (right) (Photo Maxon Motor GmbH)*

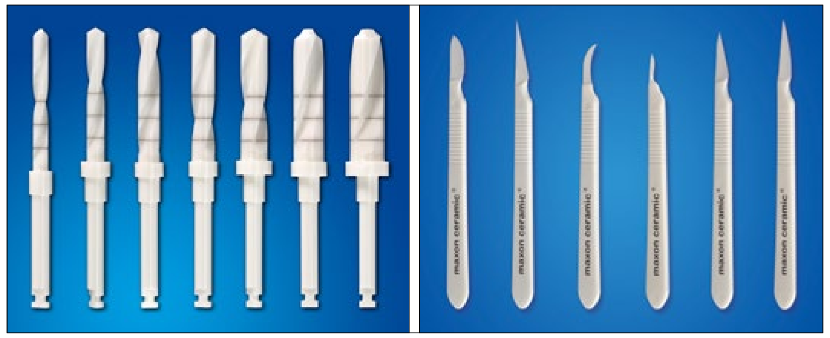

*Fig. 13 Ceramic drills (left) and scalpels (right) (Photo Maxon Motor GmbH)*

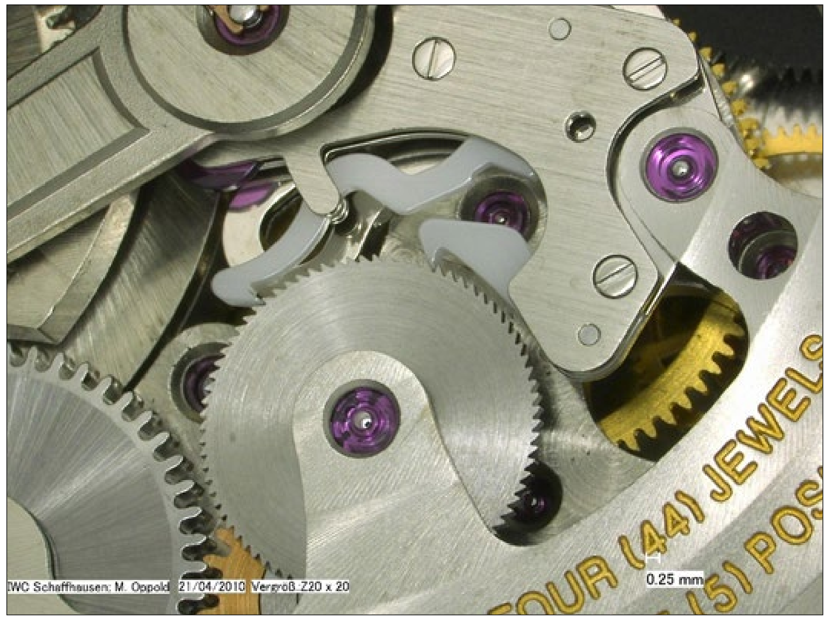


*Fig. 14 Miniature ceramic watch parts (white) (Photo Maxon Motor GmbH)*

*Fig. 15 Selection of ceramic dental implants developed by Maxon (Photo Maxon Motor GmbH)*

Maxon's range of PIM products has continuously been extended and improved over the years. One driving force for the development of high precision micro components was the Swiss watch making industry, where a close relationship already existed. Fig. 14 shows the interior of a watch with two miniature levers manufactured by Maxon from zirconia using CIM technology.

During the last year Maxon has invested great efforts in the development of a new product family, namely dental implants made from translucent zirconia (Fig. 15). The company states that the biocompatibility of the material is excellent, all technical problems have been solved, the competitiveness of production scale manufacturing costs has been proven and the capacities to produce large quantities is now being built up. At the same time negotiations with a reseller with a strong position in the dental implant business are in progress.

These products are screwed into the jaw bone and support a tooth replacement. They have been designed so that tensile stress on the ceramic is avoided. Dental implants, which are today predominantly made from titanium, will be offered in white zirconia ceramics with a light, translucent colour matching perfectly with the colour of the tooth. These products have better aesthetic properties than titanium implants which may give the tooth a dark appearance.

## PIM materials

A variety of ceramic materials and metal alloys are processed by CIM and MIM at Maxon. The ceramic materials are zirconia and alumina (Table 1). High-tech engineering ceramics are characterised by their high hardness and wear resistance, temperature stability, electrical isolation and corrosion resistance.

Zirconia is the best choice for low friction applications and can be produced with an extremely smooth surface. It has a relatively high toughness, is insensitive to thermal shock and its modulus of elasticity and thermal expansion coefficient are similar to steel which makes it suitable for combinations with steel components. Due to its excellent biocompatibility, zirconia is preferred for medical implants. Alumina has a significantly higher hardness than zirconia, lower toughness and lower density.

The low alloy steel MIM parts produced by Maxon (Table 2) include the high performance steel 42CrMo4 for quench and temper (Q&T) heat treatment. This is used for components requiring high strength and ductility. The case hardening steel FN02 is used for parts where a high surface hardness is required. FN08 can be case hardened or subjected to quench and temper. The high nickel content provides it with a high strength and ductility even after heat treatment.

For applications requiring high corrosion resistance Maxon offers three stainless steel grades (Table 3). PANACEA is a nickel-free steel, mainly used where nickel allergy is an issue, for parts that are in contact with human tissue and for medical and dental applications. The austenitic 316L stainless steel is the standard grade for corrosion resistant structural parts. It has excellent corrosion resistance, high toughness and medium strength. For higher strength requirements the hardenable steel, 17-4PH is recommended.

Finally, there is a soft magnetic alloy in Maxon's materials portfolio, namely FeSi3. This alloy containing 3% silicon, balance iron, has medium strength and ductility properties. Soft magnetic materials are usually used as cores of electromagnetic coils.

| Designation | Unit | Zirconia ($ZrO_2$) | Alumina ($Al_2O_3$) |
|---|---|---|---|
| Theoretical density | g/cm³ | 6.08 | 3.98 |
| Hardness | HV | ~ 1200 | ~ 2000 |
| Bending strength (4-point) | MPa | 800 – 1000 | 350 – 450 |
| Modulus of elasticity | GPa | approx. 200 | approx. 350 |
| Max. operating temperature | °C | <1000 depending on humidity | 1400 |
| Thermal expansion coefficient | $10^{-6}$/K | approx. 10 | approx. 5-7 |
| Specific heat @ 20°C | J/kgK | 550 | 900 |
| Thermal conductivity @ 100°C | W/mK | approx. 1.5 | approx. 25 |
| Electrical resistivity @ 20°C | Ohm cm | 1010 | 1015 |
| Colour | | white | white |
| Remarks | | very rigid, highly wear resistant | for high temperature applications |

*Table 1 Properties of ceramic materials processed at Maxon Motor*

| Designation | 42CrMo4 | FN02 | FN08 |
|---|---|---|---|
| Composition | 1% Cr-0,25% Mo-0,42% C-bal. Fe | Fe carbonyl – 2% Ni | Fe carbonyl – 8% Ni |
| DIN standard | 1.7225 | - | - |
| Heat treatment | quench & temper | case hardening | Q&T, case hardening |
| Applications | toothed parts | structural parts | structural parts |
| Yield strength [MPa] | >400 | >170 | >210 |
| Tensile strength [MPa] | >650 | >380 | >380 |
| Elongation [%] | >3 | >3 | >15 |

*Table 2 Properties of typical MIM low alloy steels processed at Maxon Motor*

| Designation | PANACEA | 316L | 17-4PH |
|---|---|---|---|
| Composition | X15CrMnMoN17.11.3 | X2CrNiMo17.13.2 | X5CrNiCuNb17.4 |
| DIN standard | - | 1.4404 | 1.4542 |
| Remarks | non-magnetic nickel-free | non-magnetic easily polished | hardenable ferromagnetic |
| Applications | medical & dental | corrosion resistant high toughness | corrosion resistant high strength |
| Yield strength [MPa] | >690 | >180 | >660 |
| Tensile strength [MPa] | >1090 | >510 | >950 |
| Elongation [%] | >35 | >50 | >6 |

*Table 3 Properties of typical MIM stainless steels processed at Maxon Motor*

## Commercial success

Maxon's PIM business is growing fast. The last year has already seen a 38% increase of external sales for ceramic products and further double-digit growth of this sector is expected in the years to come. The production area has been doubled and the injection moulding, debinding and sintering operations have now been arranged in separate areas. Thanks to improved automated manufacturing processes the expected strong growth will be achieved with current staff levels, so substantial additions to the workforce are not envisaged.

High raw material costs account for a significant share of the total manufacturing costs, at least for the larger components, and can have a negative impact on the competitiveness. For small parts, however, if a large number of secondary processing is required the raw material cost is often negligible. This is one of the reasons why PIM parts are usually very small.

## Business strategy

After Powder Injection Moulding technology had been developed for in-house production, the decision was taken in 2006 to enter the open market with PIM products. This strategy is being further extended. "The focus of our PIM technology is clearly directed towards high precision parts and low to medium quantities of up to several hundred thousand parts per year. We have a great deal of experience in manufacturing planetary carriers, pinion gears and stepped gears by PIM, but our internal structure is not suited for high volume production with millions of parts. This area is better served by manufacturers with continuous sintering equipment," Buurlage stated.

Consequently Maxon Motor follows a strategy of focussing on carefully selected market segments. These target markets have been defined and investments are specifically directed at serving these markets.

One sector where Maxon certainly has an advantage over competitors is microPIM. This is not only applied for drives and gearboxes, but also in medical technology. Examples of micro drives with a significant commercial potential are lightweight insulin pumps that the patient can carry with them and automatic pipettes. Ceramic shafts, spindles and bearings with unparalleled low friction are Maxon's speciality. Dental technology is another sector where rapid growth is foreseen since the market for dental implants is growing fast.

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 which require sintering and are difficult to machine. Therefore CIM is the only option to produce many complex shaped components. To fully exploit the potential of ceramic products, engineers must be trained and educated with respect to the requirements of ceramic design and the manufacturing technologies that are available today enabling the most complex product geometries. Buurlage's opinion is that design engineers are primarily thinking in terms of metals and plastics today and do not realise that ceramics can offer a better solution to their problem. He is convinced that the future economic potential of high-tech ceramics is still enormous.

## Product development

Customers coming with clear ideas of the function of a new component find expert support at Maxon for the optimisation of their product design and the planning of the best manufacturing technology to deliver the most economical and technically feasible solution. In addition, Maxon develops products for its in-house requirements and, thirdly, a range of finished products are developed by Maxon and marketed as standard modules via a catalogue.

Five engineers work on the development of new products, two design engineers develop the injection moulding technology and tooling and three process engineers work for the continuous improvement of the manufacturing processes. All developments are carried out and entirely financed by Maxon's own resources without recourse to external funding.

## Sales and marketing

Roughly half of the PIM production at Maxon is for internal use and requires no marketing activities. Marketing of the company's services for external customers, includes the regular attendance of trade exhibitions such as Hannover Messe and various medical engineering shows. Where appropriate, the PIM technology is presented on exhibition stands of the wider Maxon group. The company believes that there is still a huge potential for improvement of the awareness of this technology in many industries. The only exception, states Maxon, is the automotive industry where, particularly in Europe, MIM parts are well known and the capabilities of the technology are widely recognised. In medical engineering the potential of MIM and CIM components are just being discovered and Maxon is working hard to develop these markets.

Maxon's customers are typically located in Germany, Switzerland, Austria and other European Union countries. "Close cooperation, ease of communication and short distances are essential for the successful implementation of our products," commented Buurlage. "Therefore our business relationships are concentrated primarily in the German-speaking countries and central Europe."

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# Arburg celebrates 50 years of PIM expertise with a major international conference

Injection moulding machine manufacturer Arburg GmbH + Co KG recently celebrated 50 years of involvement with Powder Injection Moulding (PIM) by organising a major international conference for customers and partners at its headquarters in Lossburg, Germany. The event attracted more than 200 delegates from Europe, North America, Asia and Africa and formed the centrepiece of what has been a year of celebrations for the company. *PIM International* attended the event and Nick Williams reports on highlights.

Arburg, a pioneer in the supply of injection moulding technology to the Ceramic (CIM) and Metal Injection Moulding (MIM) industries, invited industry experts to its headquarters in Lossburg, Germany, from June 5 - 6 to celebrate 50 years of the company's involvement in PIM.

The focal point of the two-day event was an international conference attended by more than 200 invited guests from 25 countries. Sixteen presentations were made by PIM experts from Europe, Asia and North America, with backgrounds covering all areas of the PIM industry, from research to industrial production and professional associations.

A broad range of topics was covered at the conference, with presentations focussing on applications, production technologies, market developments and the prospects for the future of the industry.

The PIM industries in Europe, Asia and North America were reviewed, as were research and development activities. Key areas in which PIM products are used were also covered in detail, including the automotive, jewellery and watch-making industries, as well as the IT and dental sectors. Presentations also covered all aspects of the value-added chain, with topics ranging from the effect of feedstock preparation on component quality and the complex production of micro PIM parts, to cost-effective component integration and production using complete turnkey systems.

The central venue for the anniversary event was the Arburg Customer Center, which offered a stylish setting for a varied programme that provided a unique insight into the PIM business worldwide.

In between the presentations, guests had the opportunity to experience Powder Injection Moulding at first hand on seven different injection

*Fig. 1 On stage at the Arburg PIM conference (from left to right): Prof. Dr. Frank Petzoldt, Fraunhofer IFAM; Ingo Cremer, Cremer Thermoprozessanlagen GmbH and former EPMA President; Prof. Dr. Kuen-Shyan Hwang, National Taiwan University; Bruce Dionne, Vice President and General Manager of Megamet Solid Metals, Inc. and MIMA President, along with Stephan Doehler, Arburg's Director Sales Europe who chaired the event (Photo Arburg)*

*Fig. 2 Delegates at the Arburg PIM Conference , June 2013 (Photo Arburg)*

*Fig. 4 International participants network during a refreshment break (Photo Arburg)*

*Fig. 3 Live demonstrations of MIM and CIM part production took place throughout the conference (Photo Arburg)*

*Fig. 5 The event attracted leaders from both industry and academia (Photo Arburg)*

moulding machines operating in the conference area. Parts being moulded included special stainless steel buccal tubes for permanent orthodontic braces, zirconium oxide drill bits for the dental sector, intermediate levers for the automotive industry, precision hard-metal milling cutters with interior threads, intricate moulded wheels for the Märklin "Krokodil" millennium model railway locomotive, triangular ceramic cups and a key chain with two integrated parts.

With these live demonstrations visitors could view the past developments of MIM and CIM as well as the latest innovations. While the mould for the buccal tubes was more than 30 years old, the mould for the key chain featured a hot-runner system and was a perfect example showcasing the PIM industry's latest capabilities.

Guided tours of Arburg's production facility were provided in German, English, French, Spanish and Chinese, offering international visitors an insight into how Arburg machines are produced.

**Celebrating 50 years of PIM**

The central purpose of the conference was to bring together leading industry professionals to celebrate 50 years of PIM development at Arburg. The story of PIM processing began at Arburg in 1963 with the first ever ceramic part produced on an Allrounder 200 S by Feldmühle. This was a geometrically complex pigtail thread guide for the textile industry. In their welcoming speeches, Helmut Heinson, Managing Director Sales, and Stephan Doehler, Arburg's Director Sales Europe, who chaired the entire event, recounted a history of the successful development of the part. During the evening programme, Hans Jud, a former member of the Executive Board at Ceramtec (formerly Feldmühle), also reflected on this formative period (Fig. 6).

Throughout the conference a number of speakers and guests took the opportunity to congratulate the Arburg PIM team not only for the company's 50 years of contribution to the development of PIM technology, but also for the successful hosting of what was surely the largest international conference yet organised that focused exclusively on PIM technology. *PIM International* also would like to congratulate the Arburg PIM team, comprising of Hartmut Walcher (Application Technology Consulting), Marko Maetzig (Process Development), Uwe Haupt (Sales/Key Accounts), Gunther Ziegler (Marketing) and Stephan Doehler, Director Sales Europe, on the successful organisation of such a major event.

## A global material supplier's perspective: BASF restates its commitment to PIM

Martin Bloemacher, Senior Technical Manager at Germany's BASF SE, in his presentation "The Global orientation of a PIM feedstock supplier" took the opportunity to review the strategic development of the company's Catamold feedstock system. Bloemacher started by presenting an overview of BASF with the purpose of allowing the company's strategy for PIM to be seen in the context of the aims of the wider business.

He commented that the Catamold strategy may be hard for those outside of BASF to understand, but stated that it is important to recognise that the Catamold business unit, which includes carbonyl iron powders, is just a small part within a giant company. On the broader aims of BASF, he explained that when one talks about strategy at BASF, it has to fit within the company's strategic principles of seeking sustainable solutions that add value for customers.

Commenting on how the BASF slogan "We create chemistry for a sustainable future" could be understood in relation to Catamold, he stated that BASF innovates to make its

*Fig. 6 Hans Jud, a former member of the Executive Board at Ceramtec (formerly Feldmühle), reflected on the production of the first CIM part in 1963. The part was produced on a Allrounder 200 S, similar to the machine shown in the foreground (Photo Arburg)*

## 1000 Allrounders for the PIM industry

In addition to celebrating 50 years of PIM at Arburg, the conference coincided with the delivery of the 1,000th Allrounder injection moulding machine for the PIM sector.

The machine was purchased by Comadur, a Swiss company that produces high-quality components for the watch industry. Herbert Kraibühler, Arburg's Managing Director Technology & Engineering, explained how Comadur had ventured into the Powder Injection Moulding industry over 20 years ago with the support of Arburg in order to produce chain links for watch straps.

Initial teething problems, it was stated, were ironed out by Arburg, laying the foundations for successful cooperation and joint development. Over the years, stated Kraibühler, Arburg not only acted as a machine supplier, but also as an application technology adviser. Comadur was also one of the first customers to use hardmetal screws in order to achieve a longer service life. Together, the companies further optimised the screws, helping to bring them to production maturity.

The company exclusively uses Allrounder injection moulding machines for the manufacture of its black and white ceramic parts for watch casings and watch straps and the anniversary machine will bring Comadur's fleet of machines to 21. With the new Allrounder 270 A, the company will be using an electric machine for the first time.

To mark the 1000th PIM Allrounder, Herbert Kraibühler officially presented Patrice Jaggy, Director of Purchasing at Comadur, with a certificate as well as a hard-metal version of a plasticising unit.

*Fig. 7 Taking delivery of the 1000th PIM Allrounder: Comadur's Director of Purchasing Patrice Jaggy (2nd from left) and Arburg's Managing Director Technology & Engineering Herbert Kraibühler (3rd from left) with Arburg Partners Juliane Hehl, Michael Hehl, Renate Keinath (from right to left) and Eugen Hehl (left)*

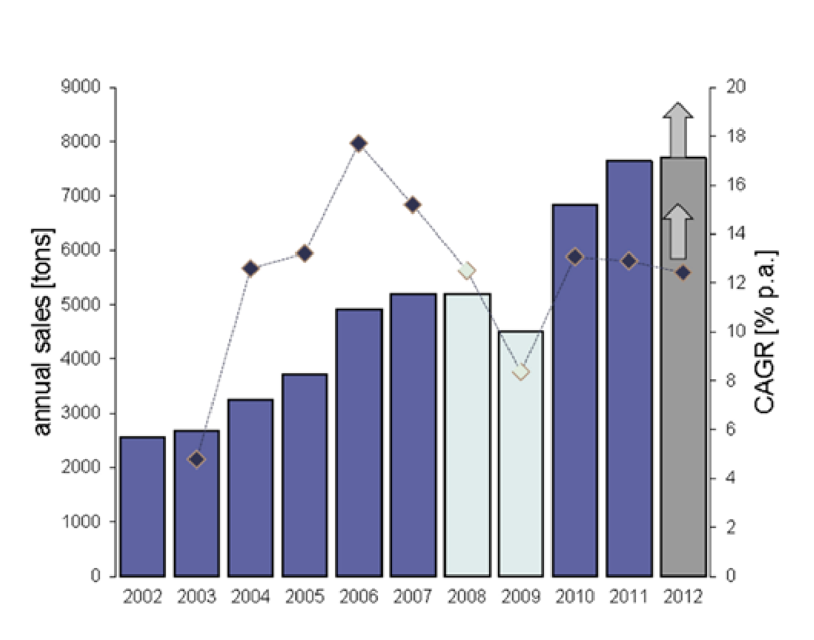


*Fig. 8 The growth of PIM 2002-2012, showing estimated annual sales (in tons) and the Compounded Annual Growth Rate (CAGR)*

customers more successful and that its innovations have to be sustainable. "Sustainability is for us a starting point for new business opportunities. All we do has to comply with these purposes, including Catamold."

Bloemacher explained that the company's structure has been shaped to allow an integrated approach to manufacturing, research and an overall management philosophy. This philosophy, together with the maximum integration of infrastructure, processes, energy and waste management, is known as Verbund, a German word meaning "linked" or "integrated". As an example, by-products from one plant or process can, with the help of deep integration, find usage as the primary raw material for another product or application in another division. The Catamold project itself, stated Bloemacher, was started more than 25 years ago with a view to developing applications for its carbonyl iron powder.

The Catamold and carbonyl iron powder business unit is just one of around 80 strategic business units, all of which fit into five segments; Oil and Gas, Agricultural Solutions, Functional Materials and Solutions, Performance Products, and Chemicals. Together these segments generated worldwide sales in 2012 of around €72 billion. Bloemacher stated that whilst 58% of sales are generated in Europe, in the last five or six years the Asia Pacific region has started to play a far more important role. The Chemicals division, to which Catamold belongs, is the largest division of BASF, with 2012 sales of €18 billion. It is based in Ludwigshafen, Germany, where BASF operates the world's largest chemical/industrial site with more than 35,000 employees.

*Fig. 9 Delegates in the Arburg PIM laboratory (Photo Arburg)*

**The on-going development of Catamold**

Bloemacher stated that the simple aim of the Catamold team was to help the PIM market grow. He explained that today the core markets for Catamold's customers are 3C, automotive, mechanical, and consumer, noting that aerospace was also becoming an increasingly important market for a number of customers.

Looking back over the last ten years, Bloemacher stated that from 2002-2012 PIM had a strong Compounded Annual Growth Rate (CAGR) in the range of 10 to 12%, in some years even more (Fig. 8). He added, "We believe that this growth rate will go on. The 2012 column is probably much higher than indicated here, we are just not too sure right now about how much higher."

In terms of regional trends, Bloemacher explained that today approximately 59% of the MIM market is in Asia, with North America and Europe each now accounting for 20-21%. "When we started 25 years ago we were all looking to America. At that time the initial technology was made in America. They had the key people in the industry and that's where the market was. Today it is completely different."

Bloemacher explained that whilst tremendous growth has taken place in the general engineering, automotive, and 3C sectors the market remains very fragmented. He stated, "In Asia the growth is achieved by a few giant companies and hundreds of small ones and 3C market is characterised by very short reaction times. We therefore recognised that as a raw materials supplier it is a must for us to be there because of the short cycle times and the short production life cycles."

Recognising this was the driving force behind the company's decision, announced in December 2012, to set up a new Catamold production facility at its Kuanyin site in Taiwan. The plant will have a production capacity of 5000 tonnes per year.

Bloemacher stated, "When we consider previously stated estimations of the total MIM market being 9000+ tonnes, just this one plant in Taiwan could cover more than 50% of the global market today. I think that this is a strategic move."

When considering current trends in MIM, Bloemacher suggested that 2011 is perhaps the most helpful year to look at, stating that 2012 was in many people's eyes an extreme year thanks to some widely publicised new 3C applications. It was stated that in 2011 more tonnage went to the automotive sector than to any other and although this sector was weaker than in 2010, it still remains very large. "The newcomer in our eyes in 2011 was Aerospace," added Bloemacher. "It looks to me like aerospace is a new and very interesting playground for the MIM community and I see many companies going in the aerospace direction."

In terms of materials, it was stated that stainless steel today dominates the MIM industry. This, commented Bloemacher, is a surprise if we look back over the last 25 years, where historically the use of low alloyed steels based on carbonyl iron powder, the workhorse of feedstocks for so long, dominated the industry.

**Working with producers to grow MIM**

Considering the future opportunities for MIM, Bloemacher asked "Where is the competition? I see this in investment casting. Yesterday we heard about additive manufacturing and liquid metals, but I personally think that this is for the future. We have to deal with the competition today, and today the competition is not amorphous metals or additive manufacturing, our competition is investment casting."

"What can investment casting do that MIM can't? If we look at a part in the range of 40 mm or 40 g I am sure that MIM can compete better on cost and quality. MIM can do so much more than investment casting. In my opinion this is where the future of MIM lies, we just have to take simple parts away from investment casting, add function to these and thereby bring added value to the customer. MIM is simply better."

*Fig. 10 Speakers from Europe, Asia and North America presented at the Arburg PIM conference (Photo Arburg)*

The Catamold team, it was stated, wants to help the MIM industry target the investment casting market. "We want to do this through competitive raw materials prices. This is the reason why we recently introduced two new Catamold product lines that should enable customers to compete against other technologies. These grades we have named K. The Catamold portfolio will further be expanded to push the technology to industrialisation. This is a simple statement, but there will be more new grades to come to extend our competitive price strategy, with these being available on a real industrial scale."

Concluding, Bloemacher stated, "Catamold wants to stay as the leading supplier of feedstock in the PIM world. We will further invest in Catamold. We have invested in a new service laboratory in Shanghai with new staff and new equipment. We are right now at the start of an investment offensive at BASF and we will invest further in the Ludwigshafen site where we have new sintering systems installed, as well as a new Arburg injection moulding machine. BASF is committed to the industry and we are committed to the market. We are ready to produce as much feedstock as needed. Our focus will be on industrial scale production and processes and we will help our customers to be more competitive through the development of new grades and systems."

## The MIM industry in Europe

In his presentation reviewing the status of MIM in Europe Ingo Cremer, Managing Director of Cremer Thermoprozessanlagen GmbH and outgoing President of the European Powder Metallurgy Association (EPMA), told delegates that more than 50 companies, from component manufacturers to raw materials and equipment suppliers, were active in Europe's MIM industry.

"Today in Europe MIM is a well-established industrial sector with a wide variety of different applications and markets. Unlike other regions, we cannot break the markets down to a dominating sector, like 3C in Asia. Even in the recession in 2009 we had continuous growth, so we could say that the industry is crisis-resistant," stated Cremer.

Although Europe accounts for one fifth of global MIM production in tonnes per year, Cremer stated that in terms of raw materials and production equipment for MIM, Europe enjoys a world leading position.

**MIM applications in Europe**

Cremer explained that the market for MIM products was not static but rather evolving, with new sectors turning to MIM as the technology continues to advance. Comparing the 2010 and 2011 estimations of MIM markets in Europe, the most striking changes were the growth of the aerospace and medical sectors (Fig. 11). Aerospace,

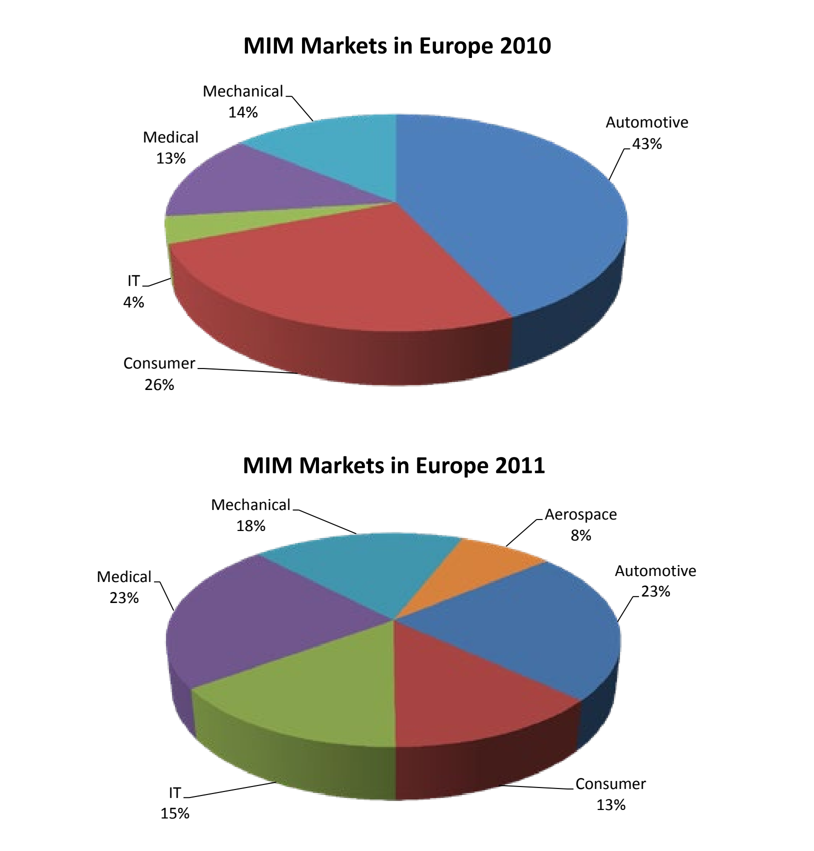


*Fig. 11 The evolution of Europe's MIM markets, 2010-2011 (data EPMA)*

Cremer stated, had in 2011 grown to an estimated 8% of the total European MIM market, whereas in 2010 it did not even warrant its own listing, being included with the mechanical sector that covers, amongst other markets, firearm components. Medical applications grew from 13% of the market in 2010 to 23% of the market in 2011.

Cremer cautioned, however, about negatively interpreting the automotive industry's falling share within Europe's MIM markets, stating that in 2011 it only appears to be weaker than in 2010 because of strong growth in other sectors. He stated that MIM still has the potential to grow within the automotive sector thanks to the opportunities that MIM technology can offer designers. These were identified as cost efficiency, the ability to lower a component's weight thereby reducing energy consumption, the ability to combine various functions into a complex net-shape component and the ability to deliver products with a high quality appearance. Sensor components and housings were identified as application areas for MIM with growth potential, including numerous engine, chassis and safety devices, as well as major opportunities in the next generation of green vehicles.

"So the car industry will be a stable business partner for MIM, maybe not with the highest margins, but stable," concluded Cremer.

**Technology trends**

Cremer stated that 2-colour MIM presented opportunities for the industry as no other manufacturing process could produce material combinations as effectively as MIM. Examples of 2-colour combinations were given as magnetic/non-magnetic, ceramic/metal, hard/tough, and dense/porous.

MicroMIM (μ-MIM) was also highlighted by Cremer as an important niche in MIM. "Naturally the tonnage is low, but it has the highest value added figure. The technology requires special tools, injection machines and furnace equipment. It is often used in high-tech areas and for very valuable parts such as heat sinks, micro gears, surgical instrument applications, implants and blenders. To enter this market you must understand its special demands - these are totally different to conventional 3C parts or automotive applications."

Cremer also identified the simulation of the MIM process as a key technology trend, "As in other industry sectors simulation is becoming more and more important. It can help for faster development, feasibility studies and will help towards cost savings. We can say that simulation software is today mature. For sure it's not without hiccups, but it is a must have for PIM part development."

| MIM-MASTER MACHINES INSTALLED 1992-2013 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **MIM-Master** | **4** | **6** | **8** | **6XL** | **8XL** | **8XXL** | **8XL-Twin** | **Total machines** |
| **Capacity in tons/year of feedstock** | 73.33 | 110 | 146.67 | 157.83 | 210.43 | 255.07 | 420.87 | |
| **Europe** | 1 | 1 | 7 | 0 | 5 | 0 | 0 | 14 |
| **America** | 0 | 3 | 3 | 0 | 1 | 0 | 0 | 7 |
| **Asia** | 5 | 2 | 4 | 2 | 3 | 1 | 1 | 18 |
| | 6 | 6 | 14 | 2 | 9 | 1 | 1 | **39** |
| **MIM-Master** | **4** | **6** | **8** | **6XL** | **8XL** | **8XXL** | **8XL-Twin** | **Annual capacity/ tons** |
| **Europe** | 73 | 110 | 1,027 | 0 | 1,052 | 0 | 0 | 2,262 |
| **America** | 0 | 330 | 440 | 0 | 210 | 0 | 0 | 980 |
| **Asia** | 367 | 220 | 587 | 316 | 631 | 255 | 421 | 2,796 |
| | 440 | 660 | 2,053 | 316 | 1,894 | 255 | 421 | **6,039** |

*Table 1 The total capacity of MIM-Master furnaces worldwide, based on a MIM 316L or 17-4 PH cycle, processing a 25 g part for 300 days, 24 hours a day over three shifts*





**Global MIM furnace capacity installed by Cremer**

In his presentation Cremer also shared with delegates some data on MIM continuous sintering furnace capacity as installed by Cremer Thermoprozessanlagen GmbH, the leading global supplier of continuous MIM sintering furnaces, between 1992 and 2013. This data was given with a view to helping the industry gain a better understanding of global production capacity. Table 1 shows that the total capacity of MIM-Master furnaces worldwide stands at just over 6000 tons of feedstock per year, with Asia being the largest market. The annual capacity of each type of Cremer's MIM-Master system is based on a MIM 316L or 17-4 PH cycle, processing a 25 g part for 300 days, 24 hours a day over three shifts.

## The past, present and future of the North American MIM industry

Bruce G Dionne, Vice President and General Manager at Megamet Solid Metals, USA, and President of the Metal Injection Molding Association (MIMA), brought a North American perspective to the conference with his presentation "The past, present and future of the North American MIM industry."

Whilst the focus of the conference's celebrations was 50 years of PIM, linking to the production of the first CIM part by Feldmühle in 1963, Dionne started his presentation by outlining the development of MIM technology

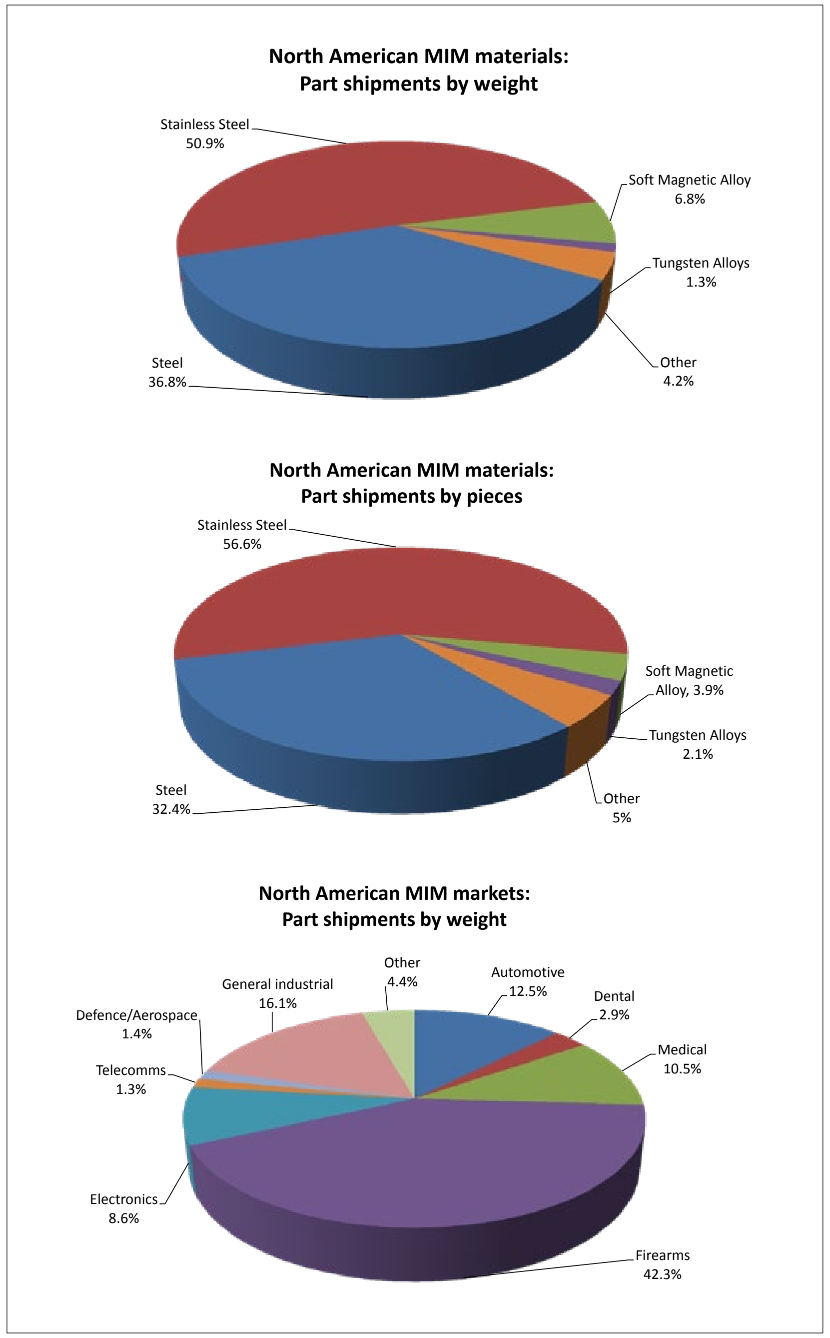


*Fig. 12 North American MIM parts shipments. Top, materials by weight; middle, materials by pieces; bottom, MIM markets, part shipments by weight (Based on data obtained in a MIMA survey)*

in California in the early 1970s. The developments by Ray Wiech, Ray Millett, Karl Zueger and Peter Roth at Parmatech, founded in 1973 to commercialise the process, led to the earliest MIM parts finding applications in the US aerospace and defence industries. One application example, a rocket engine thrust chamber injector, from 80Cb-10W-10Ta, was in 1979 the first MIM part to win an MPIF Design Competition Award and led to a surge in interest in this revolutionary new technology.

In 1980 the patent for the MIM process was awarded to Wiech, who then left Parmatech to form Witech. Parmatech and Witech then proceeded to license the technology and, stated Dionne, MIM was spread around the globe faster than ever could have been realised without a licensing strategy. Many successful new applications followed, with early examples including components for typewriters, dot matrix printers, disc drives and firearms.

In 1985 fewer than ten companies were known to be supplying parts to customers in North America, however within a decade the number had tripled to more than thirty companies.

**The North American MIM landscape today**

There are currently around fifty companies supplying parts to customers or in captive production in North America. Dionne explained that of the current MIM parts fabricators in North America most are located in the US, with a few in Canada and Mexico. The total North American market is estimated to be worth US$300-350 million with the sizes of operations ranging from fewer than 20 employees to more than 300. Current growth estimates recently reported by members of the Metal Injection Molding Association were in the region of 15-20% per year.

It was also stated that there are strong indicators that MIM parts makers in North America are increasing both capital spending and the sizes of their workforce, however Dionne added that as in other world regions it is hard to find talented and well educated employees to help meet the growing demand for MIM products.

In terms of business approaches and technological innovation, Dionne stated that ISO/TS certifications are common place, lean manufacturing principles have been widely adopted, Six Sigma principles are commonly applied and large scale production capacity is growing, reflecting a strong business focussed approach. The use of simulation packages is also common, as are state of the art moulding practices such as hot manifolds, unscrewing cores and automated part handling.

**Looking to the future**

Automotive applications are increasing in North America, suggested Dionne, with several companies having the capacity to support the large production runs that are required to serve auto makers. The widely reported surge in demand for firearms has driven MIM sales higher in recent years but Dionne cautioned that the bubble will eventually burst, "The unfettered growth of the industry is not sustainable over time - the demand spike is based upon politics and fear and eventually politics change."

It was anticipated that as the industry continues to mature there will be a continued development of MIM materials for new applications, a focus on higher efficiency production as part of a drive towards higher profits, and strong growth opportunities for implantable MIM alloys.

Looking to the sources of competition for the industry Dionne stated that these were not only from conventional investment casting and machining industries, but from super high performance thermoplastic materials such as PEEK and Kevlar filled nylon, as well as new technologies such as Additive Manufacturing and the liquid metal injection moulding of amorphous alloys.

| | Small Part | Large Part |
|---|---|---|
| No. of cavities | 16 | 2 |
| Part weight | 0.064 g | 117 g |
| Runner + sprue weight | 58.3 g | 9.7 g |
| Material use/cycle, % | 1.7% | 96% |

*Table 2 Data on the two parts used for a study of material usage and recycling methods*

| METHOD 1: Feedstock recycled 100% w/o replenishing | | |
|---|---|---|
| | Small Part | Large Part |
| Material use/cycle, % | 1.7% | 96% |
| Utilisation rate after 3 cycles or 8,546 parts | | 100% |
| Utilisation rate after 9 cycles or 2.27 million parts | 14.5% | |
| Utilisation rate after 15 cycles or 3.59 million parts | 23.0% | |

*Table 3 Materials utilisation for feedstock that is continuously recycled without the addition of new material*

| METHOD 2: Feedstock replenished with 50% new materials after every 4 cycles | | | |
|---|---|---|---|
| | Small Part | | Large Part |
| | Method 1 | Method 2 | Method 1 |
| Material use/cycle | 1.7% | **1.7%** | 96% |
| Utilisation rate after 4 cycles | 6.7% | **6.7%** | |
| Utilisation rate after 8 cycles | 13.0% | **10.0%** | |
| Utilisation rate after 12 cycles | 18.9% | **13.2%** | |

*Table 4 Materials utilisation for feedstock that is recycled with the addition of 50% new material after every 4 cycles*

## An Asian perspective: Understanding MIM for IT applications

In his presentation "MIM for IT Applications" Prof Kuen-Shyang Hwang, from the Department of Materials Science and Engineering at the National Taiwan University, Taiwan, reviewed the historic development of the use of MIM parts in 3C applications, identified current trends and challenges, and discussed issues surrounding the efficient use of feedstock in the production of extremely high volume miniature components.

Prof Hwang explained that despite the current explosion in the growth of MIM parts for cell phone applications, the use of the technology by this industry is not new. A number of older application examples were given, including the Nokia 8800 that dates back to 2005 and the original iPhone from 2007 in which the Apple logo on the reverse was a polished MIM part. Prof Hwang explained that whilst cell phone applications have hit the headlines in recent months, IT applications including parts as diverse as hinges, fibre optic connectors and computer security systems have all contributed to the huge success of the Asian MIM industry in supplying the 3C sector.

Trends in MIM in Taiwan were highlighted based on data gathered for Prof Hwang's presentation at the PM2012 World Congress, Yokohama, 14-18 October 2012. It was stated that as of August 2012 the Taiwanese MIM industry consisted of 32 MIM parts producers operating 747 moulding machines, 145 vacuum furnaces, and 14 continuous furnaces, consuming an estimated 1500 tons of powders in 2012, 55% of which were stainless steels. A full review of the survey results was published in the December 2012 issue of *PIM International* (Vol. 6 No. 4, p. 45-50).

**Issues unique to IT and 3C MIM parts**

When considering issues that are unique to the production of MIM parts to the 3C sector Prof Hwang stated that location and delivery were of high importance. It was for this reason, he suggested, that the largest four Taiwanese owned MIM producers all have plants in China. The primary benefits, he explained, were down to being closer to the manufacturing centres, thereby reducing delivery times, and having subcontractors located close by. Quicker communications relating to design and engineering developments, inspection methods and inspection gauges were also identified as factors. Product development discussions, he added, were also far more effective face to face, especially considering the typically high number of revisions associated with the development of cell phone parts.

The volumes of parts required for many applications in the 3C sector also posed challenges as quantities can be extremely high. Not only do strategic investments need to be made in MIM production facilities, but also in the extensive facilities required for finishing, polishing and final inspection. To give an insight into the recent levels of investment in MIM by Taiwanese owned companies, Prof Hwang stated that 182 new moulding machines were installed between August 2011 and July 2012.

It was stated, however, that the risks to new investors were high. Not only is there a continuous threat from competing technologies, but a new operation needs to be able to secure a good source of technical staff and labour. There is also the constant challenge of the short lifetime of cell phone parts. As examples, Prof Hwang stated that there have been seven versions of the iPhone in six years, and in only two years ten versions of the Nokia Lumia and sixteen variants of HTC phones. Each phone, he stated, typically comes with new or redesigned parts and it can be very difficult to predict the commercial success of each model.

"With such short part lifetimes, projects that die before production, order cancellations or reductions, and big differences between customer forecasts and actual shipments - this sector is full of challenges for MIM parts producers,"stated Prof Hwang.

**Materials utilisation and recycling**

When reviewing the production of small parts for the 3C sector particular attention was paid to the challenge of efficient material usage and recycling considerations. The component in Fig. 13 was presented as an example of just how much excess material (highlighted in red) can be generated in the production of small MIM products.

Prof Hwang explained the two recycling methods used in the MIM industry. In the first method 100% of all scrap is recycled without the addition of unused feedstock. The disadvantage of this method, it was stated, is that the rheometry of each feedstock deteriorates as recycling progresses.

The second recycling method involves mixing 30-50% waste material with new unused feedstock. It was suggested that the drawback of this method is that some feedstocks may eventually contain materials that have been recycled more than ten times.

Following investigations into the production of the two parts, one small part (0.064 g) and one large part (117 g), Prof Hwang compared the materials utilisation data for both feedstock recycling methods. Calculations were based on one ton of feedstock. Table 2 shows basic part and production data, whilst Tables 3 and 4 show the final materials utilisation for both recycling methods.

It was suggested that much could still be done to improve materials utilisation in small components through the use of more sophisticated tooling designs with shorter runners, the optimisation of cavities, and moulds incorporating hot runner systems.

Concluding, Prof Hwang stated that the 3C industry is important for the MIM industry and vice versa. The challenges for the future lie in how to develop products and a process for mass production in an ever more timely and cost-effective way. Continued expansion for the industry also requires large investments in capacity for what may be high risk short lifetime parts. Finally, it was stressed, the industry needs to ensure a future supply of highly skilled and hardworking engineers.

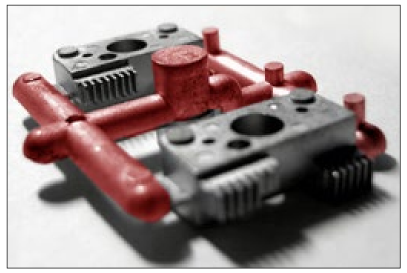

*Fig. 13 An example of typical low material usage in a small MIM part*

## An Asian perspective: Meeting the demand for ultra high volume small MIM parts

Taiwan Powder Technologies Co. Ltd. (TPT), represented by the company's President Jonathan Tsou and its General Manager and founder Dr Y C Lu, offered further insight into MIM production for Asia's 3C sector with the presentation "Unique solutions for small MIM Parts."

Founded by PhD students from the National Taiwan University in 2001, TPT has grown under Dr Lu's guidance into one of Taiwan's largest MIM producers. Additional production facilities were opened in mainland China in 2012 and today the company operates 99 injection moulding machines, 21 vacuum furnaces and two Cremer MIM-Master continuous furnaces, the first of which was installed in 2007. In 2011 the company celebrated the milestone of shipping more than 200 million parts.

Tsou told delegates that the very high volume production of small parts for the 3C sector pushed MIM technology to the extreme, but there was a growing requirement for such parts to serve the demand for components for ever smaller, lighter and more complex electronic devices with increased functionality.

The 3C sector's primary characteristics include extremely high volumes, which can be in the tens of millions of parts in a week at peak, fast design






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and prototyping cycles, high-precision and low variability finished parts for efficient automated assembly, as well as fast production ramp-up times, short product life cycles, and high uncertainty as to future demand.

Tsou stated that MIM parts for 3C applications typically fall into three categories; mechanical components (fasteners, hinge, pivot level, fixtures and holders etc.), cosmetic parts (logos, bracelets, covers etc.) and electromagnetic parts (connectors, latches, hooks, shields etc.). Such parts typically weigh 0.3 to 1 g and are between 2 and 10 mm in length.

The primary benefits of using MIM for such high volume parts were given as design flexibility for complex forms and significantly superior mechanical properties compared to plastics – with the differences in mechanical properties being particularly apparent in small scale products. Tsou stated that MIM was the most effective route for the high volume production of such components and that the process was significantly more economical than machining, with excellent versatility for surface finishing and good corrosion and abrasion resistance.

| Cavity Number | Cycle Time (sec) | Capacity (pcs/day) |
|---|---|---|
| 4 | 40 | 7.2K |
| 8 | 40 | 14.4K |
| 16 | 40 | 28.8K |
| 32 | 40 | 57.6K |

*Table 5 Using multi-cavity moulds enables the rapid production of components for the 3C sector, but there are drawbacks in terms of tooling and production costs*

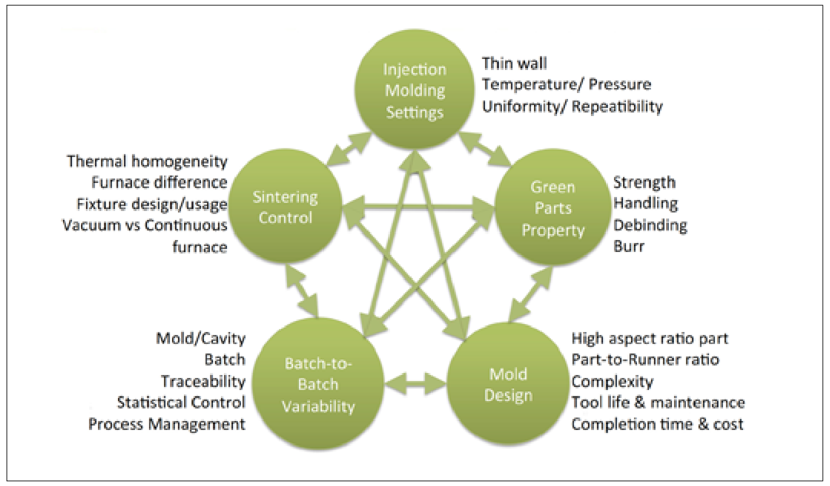


*Fig. 14 Balancing conflicting objectives in the extremely high volume production of small MIM parts*

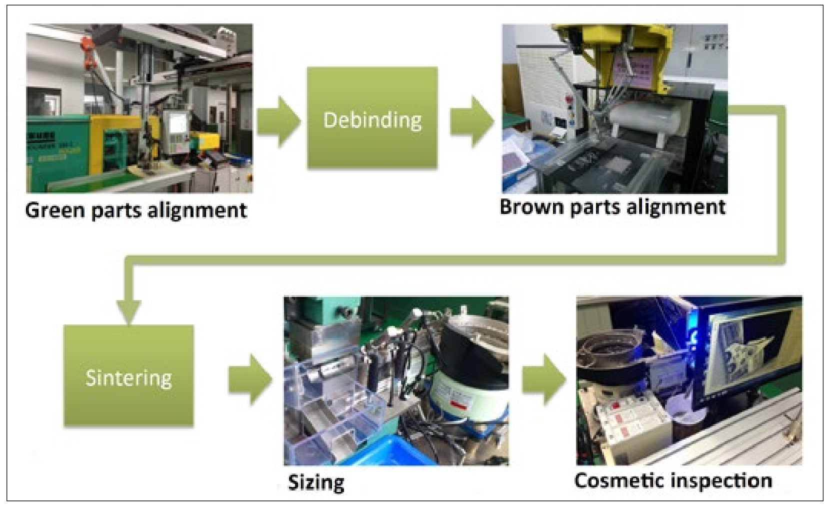


*Fig. 15 Moving towards full process automation at Taiwan Powder Technologies*

In terms of determining what applications succeed in being produced by MIM, Tsou stated that the key factors were speed of part development, speed of production, production volumes and cost. Technically, the future challenges for producing such high volume small, thin walled and complex shape parts will require ever better binder formulations and mould designs. High volume production also required high cavity moulds (Table 5), however whilst such moulds reduce the number of injection machines, there is a significant increase in the complexity and cost of moulds and production.

Elaborating on the challenges in producing small MIM parts for the 3C sector, Tsou stated that an automated, flexible production facility was essential to be able to cope with orders that can change from a trough to a peak in a very short period. Quality control and process monitoring of all aspects of the process, from feedstock production to injection moulding and sintering, was also essential in order to achieve the necessary high uniformity and low batch-to-batch variation demanded by end-users.

Echoing the presentation by Prof Hwang, Tsou stated that reducing runner-to-part ratio through better mould design and binder systems was also important.

**Areas of future development**

Looking to the future, Tsou explained that a further move towards fully automated production was a key goal. An advanced automated production cell for extremely small parts was shown (Fig. 15). In terms of alternative processing technologies, the company is also developing what it calls High Performance Powder Metallurgy (HPM) which uses powder grades similar to those found in MIM, combined with a powder pre-treatment and then a pressing step in a PM powder press to create small green compacts that can then be sintered using a similar process cycle to MIM. The company also sees value in expanding from solely an OEM (Original Equipment Manufacturer) to an ODM (Original Design Manufacturer).







# Developments in PIM materials and processing at PowderMet 2013 Chicago

Although the increasing popularity of MPIF's spring Metal Injection Moulding conference has, to some extent, diminished the coverage of the technology at its international all-subject summer conference, there remained more than enough content at PowderMet 2013, held in Chicago, June 24-27, 2013, to capture the attention of MIM devotees. Dr David Whittaker reports for *PIM International*.

## Close-coupled gas atomisation of fine powders

**CFD study on flow characterisations in the upstream of gas atomisation process**

In an update on work reported by the same authors at PowderMet 2012 and covered in the September 2012 issue of *Powder Injection Moulding International*, Guanghui Yu and Gregory Del Corso (Carpenter Technology Corporation) presented the latest results in their modelling of the close-coupled atomisation process.

Gas atomisation is a sophisticated bi-fluid process. Highly pressurised gas is released very tightly around the coherent melt stream. Both streams, with extremely high speed and temperature, result in unparalleled challenges in accurately measuring and fully understanding the process.

Flow behaviours upstream are more difficult to investigate due to the nature of the harsh environment and limited space. However upstream flows play important roles in the atomisation process in terms of efficiency, consistency and reliability.

In the reported work, computational fluid dynamics (CFD) models have been used to study these upstream effects. Models have been built based upon an industrial-scale unit (a 300 lb experimental facility at the company's R&D Department). Free expansion flow field and pressure distribution at different injection conditions were reported. Melt stream has also been studied using the volume of fluid (VOF) method.

Three different types of nozzle setup were included in the modelling research. Modelling results have shown that a Type I nozzle, in aspiration pressure style, shows a very typical stagnation area several nozzle diameters away from the tip. It also shows a small scale pressure wave and a so called pressure punch on the central axis and close to the tip (Fig. 1). High pressure in the gas punch can squeeze the melt to the side and form the typical melt film curtain and hollow centre in a close-coupled process (Fig. 2).

The type II nozzle had a smaller tip and extension, and was in back pressure style. The modelling (Fig. 3 and 4) showed that back pressure fully occupied the nozzle tip area. Nozzle tip pressure went from negative to positive and crossed the neutral zero region. This was also observed in experimental testing. Although the positive back pressure can effectively overcome the metal head, hold the stream and stop

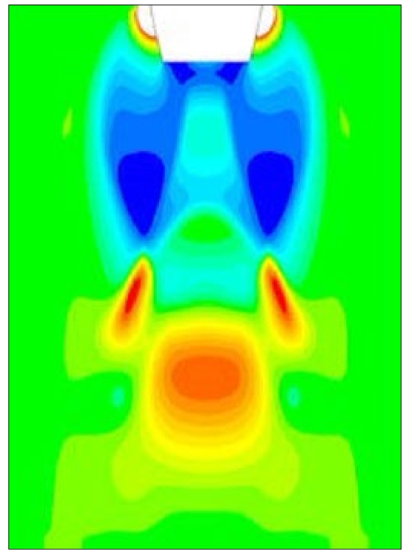

*Fig. 1 CFD modelling of near field pressure distribution. A pressure punch plays an important role in the primary break-up phase. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*

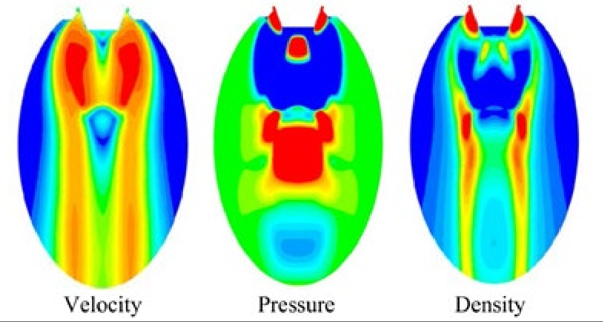


*Fig. 2 Modelling results of the Type I nozzle in the high pressure condition. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*

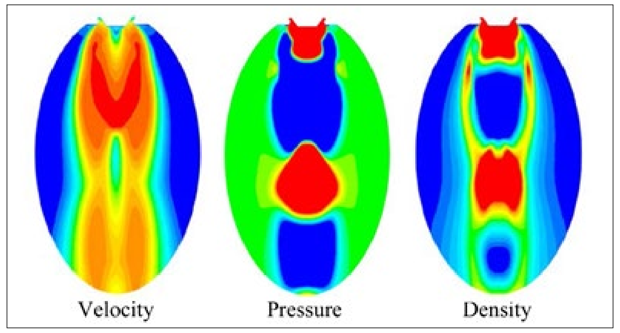


*Fig. 4 Modelling results of Type II nozzle at the high pressure condition. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*

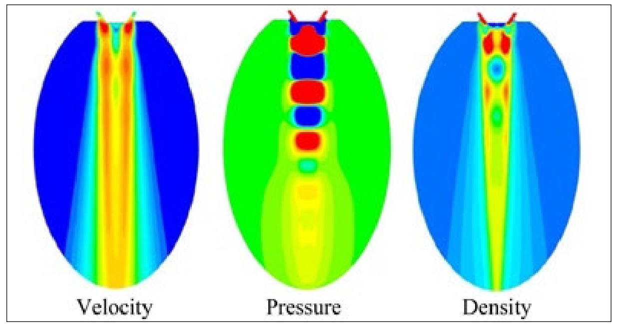


*Fig. 3 Modelling results of Type II nozzle at the low pressure condition. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*

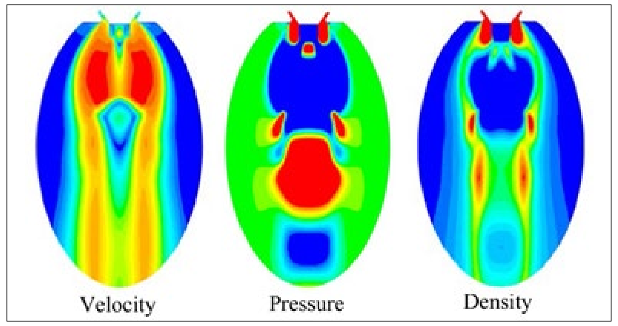


*Fig. 5 Modelling results of the Type III nozzle at high pressure condition. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*

the flow, it was observed that a back pressure nozzle can work continuously without trouble. It has been proposed that the melt film curtain around the nozzle rim plays an important role in sustaining the continuous process.

The type III nozzle was introduced to simulate this metal film. It turned out to show very similar effects to an aspiration style nozzle (Fig. 5).

To some extent, it was confirmed that a small segment of metal film will significantly change the working mechanism of certain nozzle setups and play a critical role in sustaining the continuous process.

Two types of tapping setup were also studied. The tundish, inducing pipe and the ceramic orifice remain unchanged in the two variants, but tapping location and tapping angle both varied from Type A to Type B. Both tapping spot and angle were more moderate in Type B.

Non-optimised tapping positions can detrimentally cause stream interruption or wiggling (Fig. 6) due to large air bubbles scrolling down through the orifice. On the other hand, a good tapping position (Type B) can eliminate the worst scenario. Melt stream is more steady and consistent (Fig. 7).

Further potential modelling research was discussed and this will include the areas of atomisation by elevated temperature gas, the effect of supplementary gas in powder production and anti-recirculation and optimised tundish design in reducing tapping disturbance of the melt steam.

**Evaluation of titanium aluminide close-coupled atomisation and multi-stage passivation**

In a second paper in this session, Andrew Heidloff, Joel Rieken, Iver Anderson and David Byrd (Ames Laboratory) reported on an evaluation

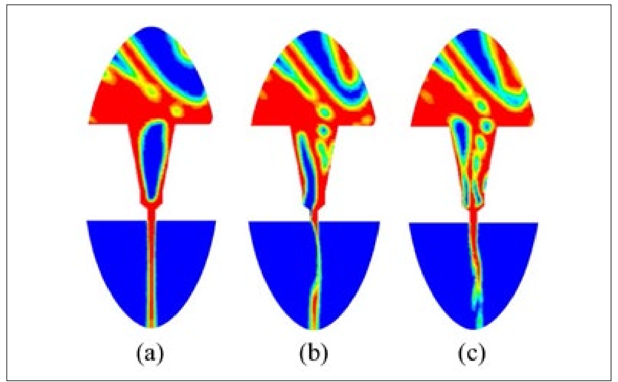


*Fig. 6 Two-phase modelling results of the tapping process with the Type A set-up. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*

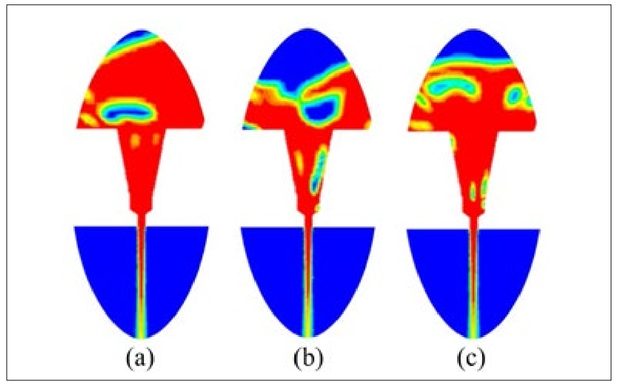


*Fig. 7 Two-phase modelling results of the tapping process with the Type B set-up. From presentation by G Yu et al. at PowderMet 2013 (Courtesy MPIF)*





*Fig. 8 Image of the "skull" remaining after atomisation, indicating complete emptying of the pouring nozzle. From presentation by A J Heidloff et al. at PowderMet 2013 (Courtesy MPIF)*

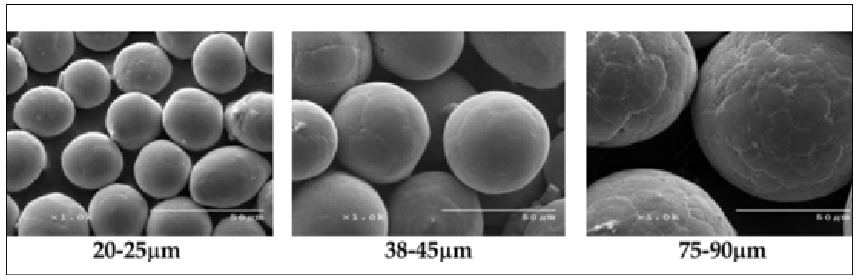


*Fig. 9 SEM images of as-atomised powders in various size ranges, showing their spherical nature and satellite-free surfaces. From presentation by A J Heidloff et al. at PowderMet 2013 (Courtesy MPIF)*

of close-coupled atomisation and downstream controlled multi-stage passivation of titanium aluminide.

Fine powder production of titanium aluminides was made possible by a prototype close-coupled gas atomiser, specifically designed for titanium, and provided powder with sufficient surface area to enable downstream controlled passivation.

The halogen species, fluorine, was introduced into the passivation reaction gas to provide a reservoir (once the powder was consolidated) for improved oxidation resistance of consolidated parts.

A methodology for halogen (e.g. fluorine) introduction into titanium aluminides for improved oxidation resistance was described. Fine, high surface area powders are ideal for low temperature reactions with a halogen species for process control.

Volatility of fluoride species motivated the use of a more stable oxy-fluoride species in reaction with titanium aluminide powders. For a multi-species reaction layer, a multi-stage passivation process was integrated into the atomiser system.

Two multi-stage reaction halos were implemented downstream of the atomisation using $O_2$ and $NF_3$ reaction species.

Ti-48Al-2Cr-2Nb (at%) was atomized using the prototype CC-GA. Complete emptying of the superheating pouring nozzle was observed during atomisation and in the final remnant skull (Fig. 8). As-atomised powders were very spherical in nature and were consistent with previous prototype atomisation runs (Fig. 9).

Multi-stage passivation target temperatures were 400-600°C and 300-400°C for the oxidation and fluorination reactions, respectively.

Chemical granular analysis, XPS (X-ray Photoelectron Spectroscopy) and AES (Atomic Emission Spectroscopy) were used to characterise the resulting powders. Chemical granular method of analysis indicated an oxygen-rich layer thickness of 4.5 nm and fluoride-rich layer of 2 nm.

XPS analysis was conducted on

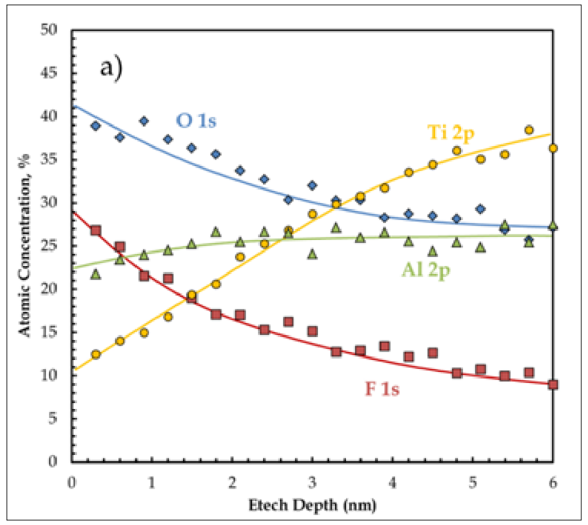


*Fig. 10 Semi-quantitative chemistry from XPS depth profile data showing change of oxygen and fluorine with increased depth. From presentation by A J Heidloff et al. at PowderMet 2013 (Courtesy MPIF)*

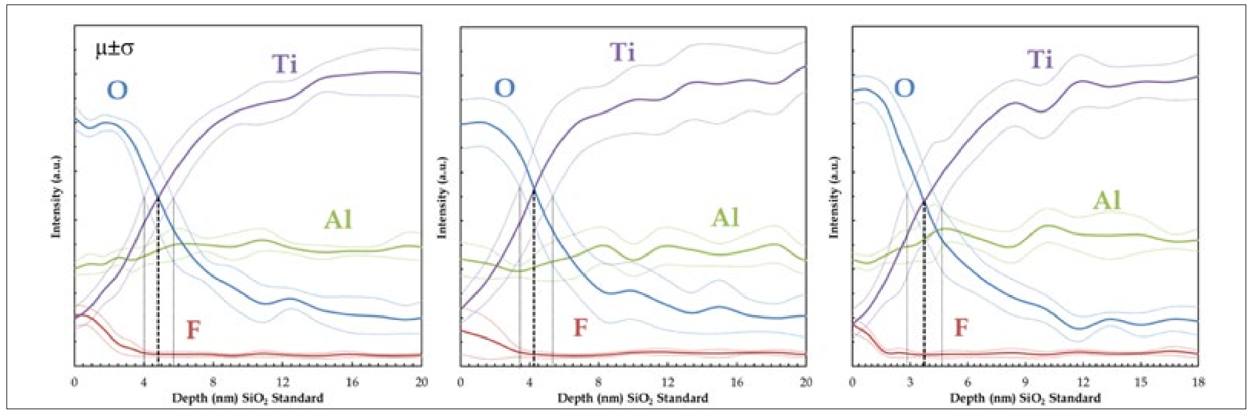


*Fig. 11 AES depth profiles of three sets of five particles to assess multi-layer thicknesses. From presentation by A J Heidloff et al. at PowderMet 2013 (Courtesy MPIF)*

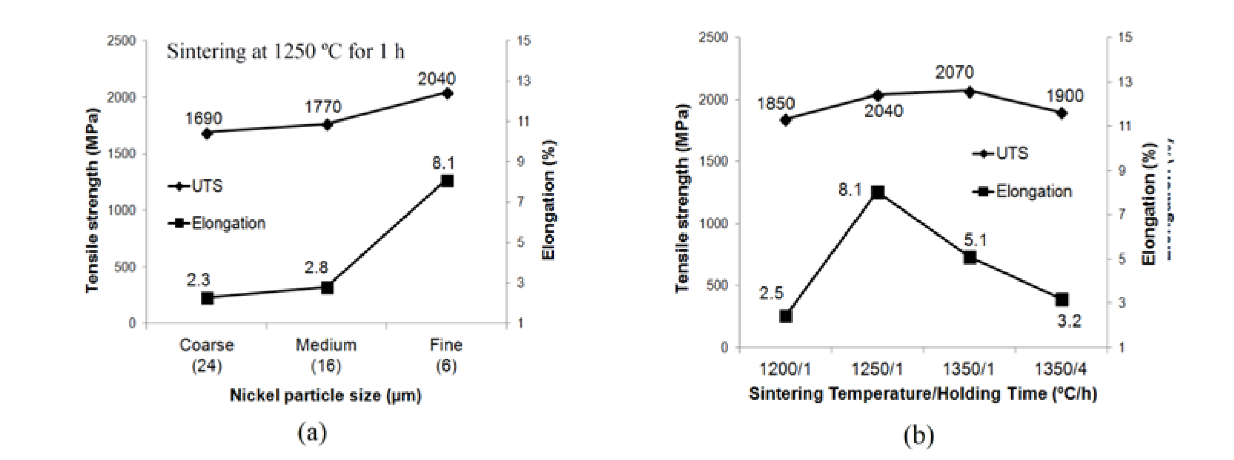


*Fig. 12 Effect of (a) Ni particle size and (b) sintering conditions on UTS and elongation of quenched and tempered Fe-6Ni-0.4C compacts. From presentation by W S W Harun et al. at PowderMet 2013 (Courtesy MPIF)*

unexposed and exposed powders. Surface chemistry was consistent across the characterised powder size range. Exposure resulted in slight oxygen enrichment at the surface, but was maintained after long term exposure.

Surface layer thickness from XPS was determined at 3.5 nm and 1.5 nm for the oxygen- and fluorine-rich layers, respectively (Fig. 10). Surface layer aluminium compounds with oxygen and fluorine were produced in the consolidated alloy based on XPS Al2p binding energy shifts.

AES depth profiles confirmed the presence of distinct surface films of oxygen- and fluorine-rich components. Layer thicknesses from AES were determined to be 4 nm and 2 nm for the oxygen- and fluorine-rich layers respectively (Fig. 11).

These various characterisation techniques were therefore seen to produce remarkably self-consistent results. It was concluded that, if provided with the proper temperature profiles, a novel multi-layer passivation coating can be created in-situ during atomisation.

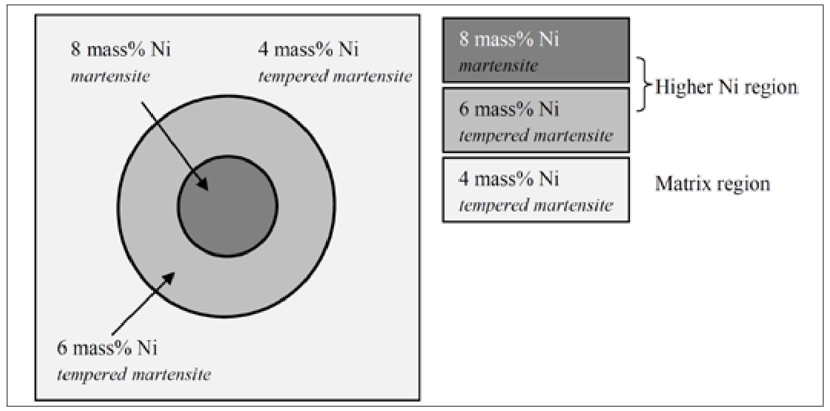


*Fig. 13 Schematic diagram of multi-regional Ni concentration within Fe-6Ni-0.4C compacts using fine (6μm) nickel powder. From presentation by W S W Harun et al. at PowderMet 2013 (Courtesy MPIF)*

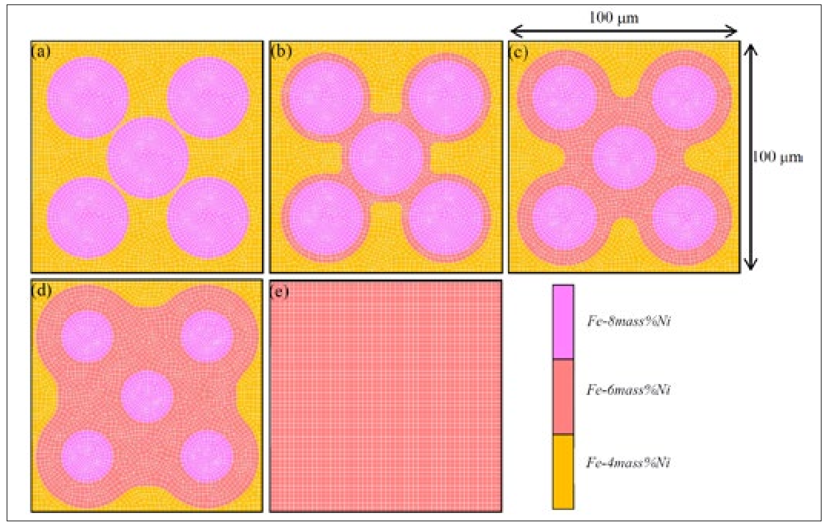


*Fig. 14 FEA models used in the study. The models were identified as (a) hetero-100, (b) hetero-80, (c) hetero-60, (d) hetero-40 and (e) hetero-0 (homogeneous). From presentation by W S W Harun et al. at PowderMet 2013 (Courtesy MPIF)*

## Structure-property relationships in MIM Fe-Ni alloy steels

**Fine heterogeneous microstructure and mechanical properties of MIM Fe-Ni alloy steels**

Wan Sharuzi Wan Harun, Toshiko Osada, Yang Xu, Fujio Tsumori and Hideshi Miura (Kyushu University) reported on a study of the heterogeneous microstructure created in MIM processing of Fe-Ni alloys, based on elemental mixes of carbonyl iron and water atomised Ni, and the resultant mechanical properties.

The composition Fe-6wt%Ni-0.4wt%C was studied and this material was oil quenched and tempered following MIM processing.

EPMA analysis of the Ni distributions confirmed that the microstructures of the compacts were consistently heterogeneous, even after sintering at high temperatures and long times, as was the case in previous studies reported by these authors.

In this particular study, the microstructural aspects of the compacts were changed by altering the characteristics of the Ni powder used, such as particle size, shape and distribution. The most impressive properties were attained in quenched and tempered compacts containing 6 wt% fine Ni powder (mean particle size of 6 μm). This material generated a "ultrahigh" tensile strength of 2040 MPa coupled with an elongation of 8.1 % (Fig. 12).

The state of the Ni dispersion throughout the matrix was deemed to be the key factor in determining these mechanical properties.

In order to understand how the microstructure results in these high mechanical properties, the authors developed a 2D finite element model based on the spatial distribution obtained experimentally.

The existence of a higher Ni region surrounded by the matrix region in the Fe-6Ni-0.4C compact using fine Ni powder was observed experimentally. To implement this structure into the numerical model, the experimentally observed heterogeneous microstructure had to be simplified. From detailed Ni element topographies derived from image analysis software, average Ni peak in the higher Ni region was about 8 wt%. The concentration gradually decreased from the centre of the Ni rich area to the matrix region. The concentration reduced to around 4 wt% Ni in the surrounding matrix region. Fig. 13 shows the schematic diagram of a single Ni rich area and the surrounding matrix region for the Fe-6Ni-0.4C compact using fine Ni powder after heat treatment.

Four heterogeneous models and one homogeneous model were constructed, as defined in Fig. 14. The full characteristics of these models are summarised in Table 1.

The simulated results from the model were compared with experimentally observed behaviour, and showed good agreement,

Modelling, in fact, has predicted that the best mechanical properties, of 2272 MPa UTS and 7.7% elongation, could be attained at a heterogeneity level of 40% (Fig. 15).

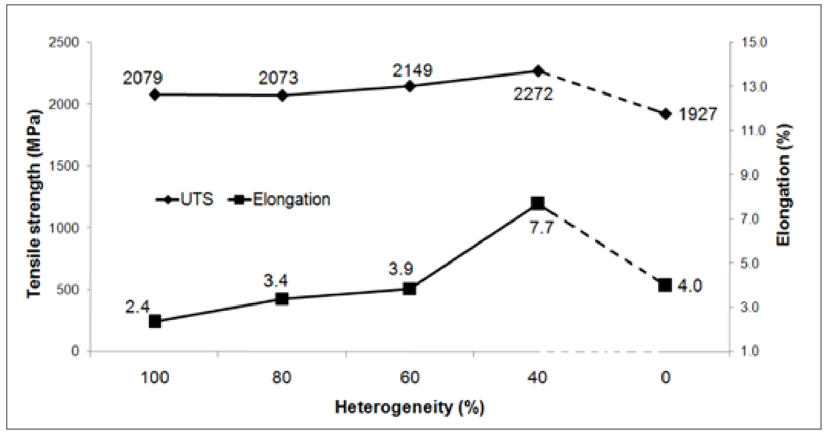


*Fig. 15 Results of uniaxial deformation simulated by the FEA models. From presentation by W S W Harun et al. at PowderMet 2013 (Courtesy MPIF)*

## HIP densification of MIM parts

MIM processing techniques have evolved to the point where parts makers consistently produce a high quality PM part having three dimensional complexity with as-sintered density levels that are 96% - 98% of the theoretical density for a given alloy.

In cases where all porosity must be eliminated, Hot Isostatic Pressing (HIP) is used as a post-sinter treatment.

Commercial HIP operations often have a collection of proven processing conditions for the various alloys handled by MIM parts makers. However these standard HIP conditions were typically developed for the processing of large metal castings or large PM products.

**The relationship between MIM process variables and HIP densification**

The paper, presented by Stephen Mashl (Michigan Technological University), Alan Sago (Net Shape Technologies) and Robert Conaway (IFI Global Services) provided an analysis of the combined MIM plus HIP processes using metallurgical principles.

From this analysis, it would appear that a practice of pursuing maximum sintered density followed by HIP is, possibly, not optimal for full densification. This paper examined the relationship between MIM process variables and HIP densification, identifying several key areas where current practices, both in MIM and HIP, might be modified to yield improved response to post-sinter HIP.

While metallurgical theory indicates that grain growth could have a negative effect on HIP densification, other factors, such as the concentration of inclusions within a MIM material may tend to mitigate grain growth.

It should be noted that an increasing population of non-metallic inclusions negatively affects the same properties that a part maker hopes to improve by eliminating porosity via HIP.

If a parts maker desires to make a pore-free MIM part having optimal mechanical properties it is necessary to both minimise and preferably elimi-

| Model | Nickel Concentration Region | | | Hetero-geneity (%) |
|---|---|---|---|---|
| | 8 mass% | 6 mass% | 4 mass% | |
| Hetero-100 | 50 vol% | 0 vol% | 50 vol% 1 | 00 |
| Hetero-80 | 40 vol% | 20 vol% | 40 vol% | 80 |
| Hetero-60 | 30 vol% | 40 vol% | 30 vol% | 60 |
| Hetero-40 | 20 vol% | 60 vol% | 20 vol% | 40 |
| Hetero-0 (homogeneous) | 0 vol% | 100 vol% | 0 vol% | 0 |

*Table 1 Summary of modelling conditions for Fe-6Ni-0.4C compacts based on the degree of heterogeneity. From presentation by W S W Harun et al at PowderMet 2013 (Courtesy MPIF)*

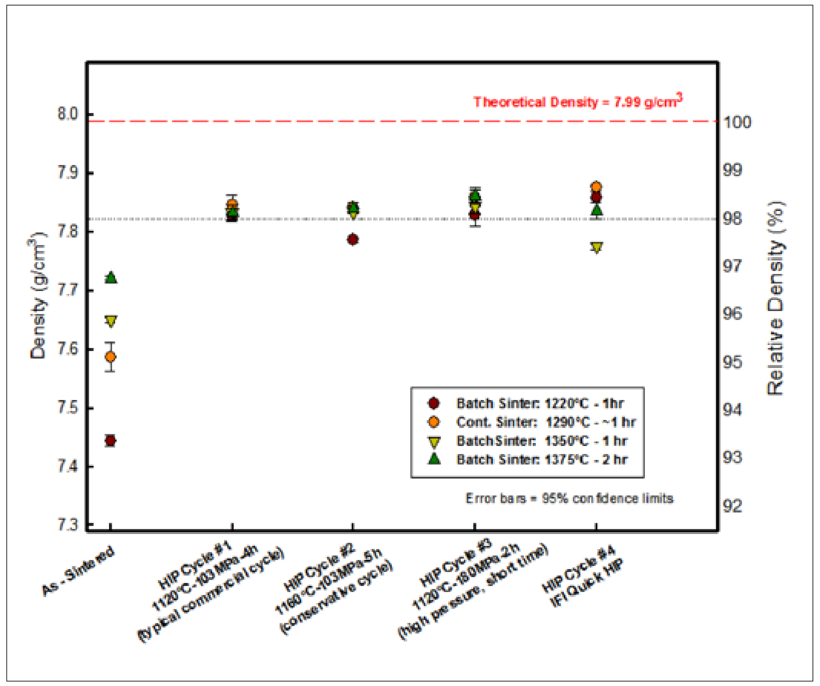


*Fig. 16 A plot of achieved density as a function of process route. All samples, regardless of sintered density, HIPed to a nominal 98% density level. From presentation by S J Mashl et al. at PowderMet 2013 (Courtesy MPIF)*

| Label | Description | As-Sintered Density |
|---|---|---|
| S2 | Batch Furnace 1220°C, 1 hour | Density = 7.44 – 93.2% |
| S3 | Pusher Furnace 1290°C,~1 hour | Density = 7.59 – 95.0% |
| S4 | Batch Furnace 1350°C, 1 hour | Density = 7.65 – 95.8% |
| S5 | Batch Furnace 1375°C, 2 hours | Density = 7.72 – 96.6% |

*Table 2 Sinter cycle designations. From presentation by S J Mashl et al. at PowderMet 2013 (Courtesy MPIF)*

| Label | Description | Conditions |
|---|---|---|
| H0 | no HIP | (As-sintered) |
| H1 | Typical Commercial SS HIP cycle | (1120°C / 15 ksi / 4 hour) |
| H2 | Conservative (long/hot) HIP Cycle | (1160°C / 15 ksi / 5 hour) |
| H3 | Rapid High Pressure HIP Cycle | (1120°C / 26 ksi / 2 hour) |
| H4 | Quick HIP like cycle | (High pressure, very short dwell) |

*Table 3 HIP cycle designations. From presentation by S J Mashl et al. at PowderMet 2013 (Courtesy MPIF)*

nate porosity while also minimising non-metallic inclusions within the alloy of interest.

In this work, MIM 316 stainless steel tensile specimens, sintered to varying density levels (Table 2) and HIPed using four significantly different HIP cycles (Table 3), yielded similar as-HIPed density level (Fig. 16).

A low temperature HIP cycle yielded similar density levels to a higher temperature, longer time cycle. This result raises the question of whether temperature or dwell time could be further shortened, potentially providing a lower cost route to the high level mechanical properties associated with a pore-free PM material.

The density data from the "Quick-HIP" like cycle (see Fig. 16), with a high pressure and very short dwell, indicate that this is quite possible. Follow-up mechanical testing will confirm or refute this suggestion.

## The production of micro- and precision PIM parts

### Examinations on the production of micro and precision PIM parts

An important challenge in developing further the capabilities of PIM and MicroPIM is to improve dimensional tolerance control capability. A paper from Volker Piotter, Elvira Honza, Alexander Klein, Tobias Mueller and Klaus Plewa (Karlshuhe Institute of Technology) addressed this issue.

Dimensional tolerance control of +/- 0.2% to +/- 0.5% has been quoted in the literature, with claims that, in certain cases, +/- 0.1% can be achieved. The study reported in this paper set the objective of achieving tolerance control below +/- 0.1%.

To aid these accuracy investigations, a new tool was used, which was equipped with two pistons at each end of the cavity. The position and forces of the pistons could be controlled autonomously, thus allowing the gate position to be varied between die side, middle and ejector side.

For these basic trials, a simple cylinder geometry was chosen (Fig. 17). The feedstock used was a formulation of 67Vol% 17-4PH steel powder (mean diameter approximately 4 µm) and a typical MicroPIM binder system consisting of paraffin wax, PE and certain additives.

Initial trials revealed that the best accuracies could be reached if the piston pressure was chosen to be relatively low, i.e. the injected feedstock pushes back the piston in a quasi-balanced force state thus avoiding jetting effects.

Furthermore, an optimised tool temperature was determined as being 60°C and a middle gate position was found to be the best position to achieve high accuracies.

Having set these parameters, diameters of the green and sintered cylinders were measured at five different positions (Fig. 18).

It transpired that the absolute diameters differed according to the measuring position. In series precision production, it was considered that this effect might be compensated by an adequate tool modification.

In relation to the main aim of the study, standard deviation of the diameter was lowest at the middle position, i.e. nearest to the gate (Fig. 19). A relatively long time packing pressure is effective in this position and





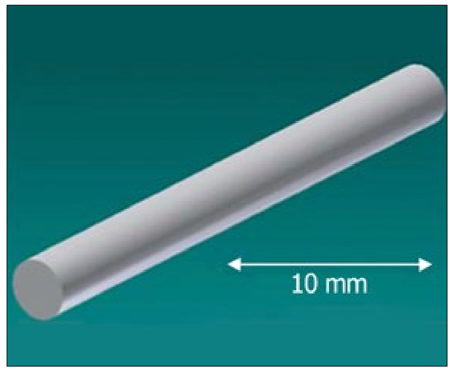


*Fig. 17 Schematic drawing of the test part, a simple cylinder geometry with a length of 20 mm and a diameter of 2.015 mm in the green state. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

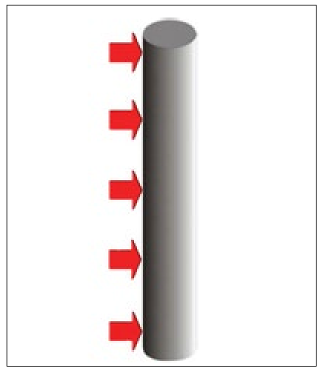

*Fig. 18 The five positions for diameter measurements indicated by arrows. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

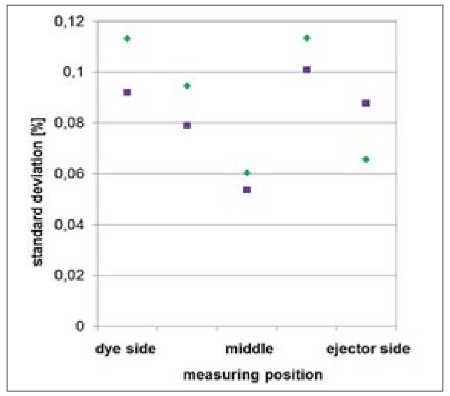


*Fig. 19 Standard deviations of diameter measurements for both green and sintered parts. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

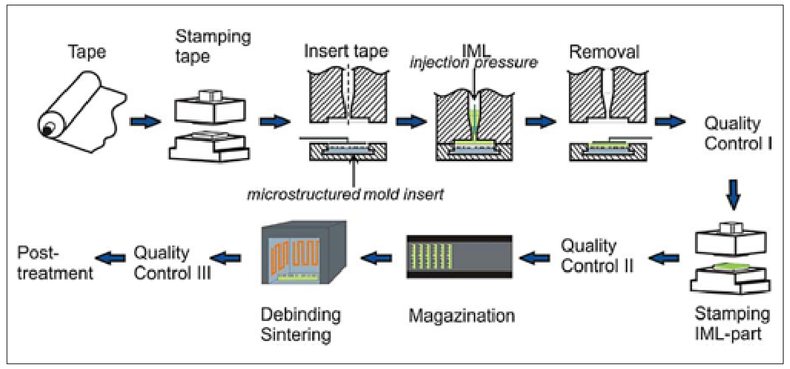


*Fig. 20 A schematic of the IML-MicroPIM process. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

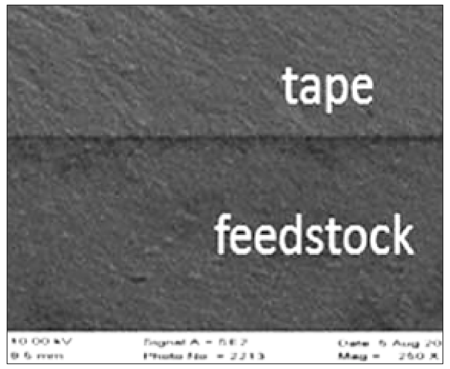


*Fig. 21 Boundary between tape and PIM feedstock. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

this can be regarded as an explanation for this result.

The second part of the paper focussed on the authors' developments in combining inmould-labelling and micro powder injection moulding (IML-MicroPIM).

Applying the most common means of performing multi-component-PIM, (at least) two feedstocks filled with different powders are injected into a tool more or less simultaneously to produce a compound green compact.

However, this "classical" variant of 2C-PIM is not the only way to produce multi-component devices. A supplementary option is to use a procedure quite similar to the inmould-labelling process, which is well-known in plastic packaging. A pre-fabricated insert in the form of a foil or film is positioned in a tool and, subsequently, covered by a backwards injection-moulded layer (Fig. 20).

Foils filled with metal or ceramic powders might be manufactured by, for example, slip casting, foil casting, or rolling processes. Before inserting them into the injection moulding tool, they can be printed, punched, embossed or subjected to other preliminary treatments. In this way, it is possible to generate colour patterns or lateral structures on the surface of the PIM body.

Further benefit can be derived from the opportunity that submicron or even nano-powders can be merged into the foils without the tremendous increase in viscosity that usually arises.

The process has already been investigated for macroscopic applications and trials for adaptation to micro systems technology have been carried out within the former EU Large Integrated Project "Multilayer". The main outcome from this project was the combination of different $ZrO_2$ powder fractions in one part. A tight connection between the former tape and the feedstock was obtained (Fig. 21).

## MIM of complex tungsten devices

Nuclear fusion is one of the great hopes of the nuclear power generation community as, unlike nuclear fission, it does not give rise to any long-lived radioactive products.

Nuclear fusion involves the collision of nuclei of the isotopes of hydrogen, deuterium and tritium, causing them to fuse together to form helium nuclei and release energy in the form of neutrons.

The temperatures involved in nuclear fusion are very high (100 million°C). The most promising means of achieving these conditions is "magnetic confinement" of the hot gas, as a plasma, in a ring-shaped magnetic chamber known as a "tokamak".

The world's current largest tokamak, the Joint European Torus (JET) at Culham, UK, has produced 16 megawatts of fusion power and proved its technical feasibility using deuterium and tritium.


*Fig. 22 Various test specimens and divertor components produced by WPIM. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

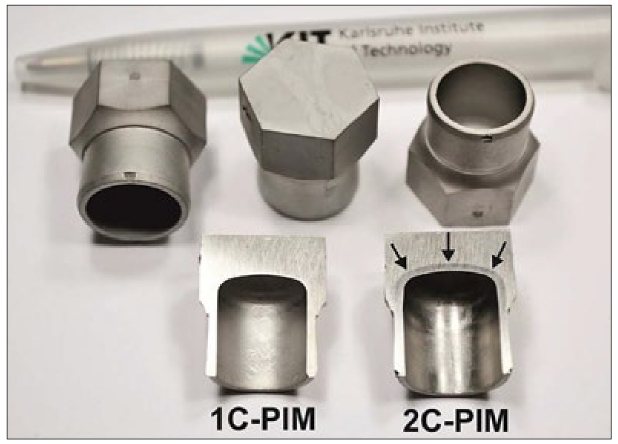


*Fig. 23 Comparisons of "thimble-tile" combinations. The first sample (left) was produced by one-component PIM and the second sample (right) by two-component PIM. From presentation by V Piotter et al. at PowderMet 2013 (Courtesy MPIF)*

| Material composition | Density [% T.D.] | Grain size [µm] | Vickers-Hardness [HV0.1] |
|---|---|---|---|
| W | 98.6 - 99.0 | 5 - 7 | 457 |
| $W\text{-}2La_2O_3$ | 96.5 - 97.2 | >3 | 586 |
| $W\text{-}2Y_2O_3$ | 96.3 - 97.1 | <3 | 617 |

*Table 4 Values of density, grain size and hardness of the final densified materials*

The challenge now is to prove fusion can work on a power plant scale. International fusion research is following a roadmap to achieve power generation within 30 years. The next stage in this programme is ITER (the International Tokamak Experimental Reactor), a multinational project that is being built at Cadarache in the south of France. ITER will be a 500 megawatt tokamak (equivalent to a small power plant).

Although it will be some decades before commercial deployment of nuclear fusion could be contemplated, there is a significant demand in large development projects, ITER and possibly beyond, for solutions to the many significant material performance and engineering challenges that exist.

**PIM of complex tungsten devices**

A significant challenge, in this context, relates to the so-called "plasma-facing components". Tungsten-based materials have emerged as a prime choice for this type of application and the paper by Volker Piotter, Steffen Anlusch and Klaus Plewa (Karlsruhe Institute of Technology) reported on MIM material and process developments aimed at this opportunity.

For this purpose a special process based on combined compaction by pre-sintering and Hot Isostatic Pressing was developed at KIT. The new manufacturing sequence had been named Tungsten Powder Injection Moulding (WPIM).

Combinations of pure tungsten plus tungsten alloys have been realised showing almost defect-free boundaries. Examples for fusion reactor components consisting of pure tungsten and tungsten alloys ($W\text{-}La_2O_3$, $W\text{-}Y_2O_3$), including examination of the interfaces, were presented in this paper.

With reference to suitable materials, tungsten and tungsten alloys are presently considered as the most promising candidates primarily due to their high temperature strength and low erosion rate in withstanding the extreme conditions. However, manufacturing of such parts by machining processes, such as milling and turning, is extremely costly and time consuming because tungsten is very hard and brittle. A net-shape process such as Powder Injection Moulding is therefore an attractive alternative.

"manufacturing of such parts by machining processes, such as milling and turning, is extremely costly and time consuming because tungsten is very hard and brittle. A net-shape process such as PIM is therefore an attractive alternative"

Typical properties of successfully manufactured divertor parts, consisting of pure tungsten alone, were density >98 % T.D., hardness of 457 HV0.1, a grain size of approximately 5 µm and a microstructure without cracks or porosity. Examples of such parts are shown in Fig. 22.

These fusion energy generation applications and many others, however, do not require parts made from tungsten alone. Rather, combinations of W with W-alloys are required in order to reduce the risk of brittle fracture and to achieve satisfactory joining with the adjacent sections of the reactor blanket. Therefore, a fabrication method, which inherently combines a shaping and an assembly step, namely 2-Component-WPIM (2C-WPIM), had to be developed.

To pursue 2C-WPIM, a new two-component PIM tool had to be developed to allow the fully automatic replication and joining without brazing of fusion relevant components in one step and the creation of composite materials.

Prior assessments had shown that a binary tungsten powder particle system is advantageous with respect to sintering activity and achievable density. For the reported trials, therefore, two types of pure tungsten powders were used, with an average grain size distribution of 0.7 µm (W1) or 1.7 µm (W2) Fisher Sub-Sieve Size (FSSS), respectively. Mixing ratio was set at W1 : W2 = 50% : 50%.

The binary tungsten powder particle systems were doped with 2wt.-% $La_2O_3$ ($W\text{-}2La_2O_3$) or with 2wt.-% $Y_2O_3$ powder ($W\text{-}2Y_2O_3$), respectively.

To perform the injection moulding trials, the new 2C-tool was used. The most important feature of this tool was that it allowed for the production of two divertor components, namely the tungsten tile and the tungsten alloy thimble, in one cycle, without additional assembly steps.

Metallographic investigations showed that the material connection of the 2C-WPIM combinations (W + $W\text{-}2La_2O_3$ and W + $W\text{-}2Y_2O_3$) could be performed without visible defects: No cracks or pores could be detected in the seam of the joining zone between the W tile and the W-alloy thimble so a solid and relatively strong bond between the two materials can be assumed (Fig. 23).

A compilation of the measurement results is given in Table 4 and these suggest that, for both doped material, the embedded particles act as grain growth inhibitors leading to a smaller grain size compared to pure PIM tungsten.

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# LÖMI: New developments in solvent and water debinding systems for MIM and CIM

Germany's LÖMI GmbH is widely recognised as a market leader in the production of explosion-proof solvent debinding furnaces for PIM and the company has for many years worked in close cooperation with feedstock and part manufacturers to continuously improve its technology. As water debinding becomes more important for PIM producers, the company reports on the latest innovations in its range of debinding systems for the industry.

Located close to Frankfurt, in the centre of Germany, LÖMI GmbH was established in 1991 as a manufacturer of solvent recovery systems. From the start the company has had a strong research and development focus and many of its systems were developed through research initiatives with project partners such as Fraunhofer-Gesellschaft and a number of renowned German universities.

In 2001 the company added solvent debinding furnaces to its manufacturing portfolio and over a period of just a few years established itself as a market leader in this area. Now, with over twenty years of experience in explosion-proof technology for handling flammable solvents, LÖMI offers a range of debinding furnaces for the PIM industry. Customers include some of the leading MIM/CIM manufacturers worldwide, including those that supply the automotive, aerospace and medical sectors.

Today the company offers three different types of debinding furnaces; one for organic solvent soluble binder systems, one for water soluble binder systems and one unique furnace type which is capable of debinding with both organic solvents and water in one single system.

Fig. 1 Solvent debinding furnace EBA-300 with a solvent recovery system MDA-100

## Solvent debinding systems

Commenting on the advantages that the organic solvent debinding process has over other processes, Christian Ferreira Marques, Managing Partner at LÖMI, told *Powder Injection Moulding International*, "The first advantage is that MIM/CIM part producers are free in their choice of feedstock, as numerous kinds of feedstock systems can be processed via the solvent debinding process. This makes it easy for part producers to test new feedstocks, or to add another feedstock producer as a supplier, without having to invest in a new debinding furnace. In addition, solvent debinding furnaces offer a very long lifetime as the solvent debinding process causes very little wear and tear."





LÖMI's debinding furnaces can use various organic solvents, including acetone, ethanol, hexane, heptane and trichloroethylene (TCE). "The solvent debinding furnaces always come with a solvent recovery system which provides a fresh debinding medium at all times. The solvent recovery rate of the system is up to 99%, making our debinding furnaces very economical and environmentally beneficial," added Marques. The solvent is operated within a closed loop and, together with the debinding furnace being explosion-proof, this ensures a safe work environment.

The company's solvent debinding furnaces are available with capacities from 50 litres to 2,500 litres. "For small numbers of injection moulded parts, our EDA series of furnaces combine debinding, vacuum drying and solvent recovery in one single unit. For medium and large numbers of MIM/CIM parts, our systems consist of two units, an EBA series debinding furnace with a capacity of up to 2,500 litres and a parallel solvent recovery system matched to the customer's process. Should a part producer later wish to expand its production capacities, all LÖMI systems can be extended on a modular basis," stated Marques.

Fig. 2 Three solvent debinding furnaces EBA-900 with a parallel solvent recovery system MDA-3000 shortly before commissioning at a major Indian customer

## Water debinding systems

Water debinding has to-date primarily been used by CIM part producers. LÖMI's José M Dias Fonseca stated, "In the past some producers used large open water baths to immerse their green parts. After the debinding process, the watery brown parts had to be removed from these baths and transported and loaded into a drying oven. This often caused damage to the brown parts, in addition to the increased time span and costs for the extra handling step. We addressed these problems two years ago by developing our EBA-W series water debinding furnace. These furnaces are designed as ergonomic front-end loaders, making it very easy to load and unload MIM and CIM parts."

In addition, these systems feature the integrated drying of parts so that the brown parts can remain within the furnace after the debinding process. Programmable logic control (PLC) ensures an automatic process once the parts are loaded.

Fig. 3 Water debinding furnace EBA-50W: a front-end loader with automatic process and integrated drying of parts

Fig. 4 Rental system EDA-50LW for debinding with organic solvents or water in one single furnace for testing new feedstocks or optimising processes

## The latest research and development in water debinding

"In recent years a number of MIM and CIM part producers have tried to optimise their water debinding processes only to find that this technique places much higher demands on the performance and quality of water debinding equipment than many anticipated. To address these issues and further improve our water debinding furnaces, we have undertaken extensive research and development in recent months, in close cooperation with some renowned MIM/CIM part producers," continued Dias Fonseca.

"To debind green parts containing a water soluble binder system, part producers often use acidic demineralised water. This type of water, along with certain additives and inhibitors which the feedstock producers require the part producers to add to the debinding water, has been shown to be capable of corroding even stainless steel. As a result, this demands

*Fig. 5 Mobile loading aids allow easy transportation and preparation of the next batch of parts while the current batch is still in the furnace*

*Fig. 6 Easy single handed and time saving loading and unloading of debinding furnaces using a loading aid with wear-free rollers*

increased requirements for the materials and components of a water debinding furnace. This holds true for the material of the process chamber, which no longer can be an ordinary stainless steel, as well as for the materials used in the pumps, hoses, sensors and actuators. All welded seams also needed to be reviewed and the welding process modified where applicable. All the surfaces with direct contact to water vapour have to be reappraised and, where needed, their materials replaced. In addition, when water is used to debind metal parts from a MIM process, this often leads to corrosion of the parts themselves. This has to be prevented with suitable measures."

As a result of its research, LÖMI undertook a complete review of its water debinding furnaces and the company's engineers are currently implementing solutions to the challenges identified. In addition, with regards to the drying process, it became evident that vacuum drying alone was not sufficient. Water bubbles could form on the loading trays and these made the green parts move, sometimes even making them stick together. As a solution, the company has developed and installed a specific new drying technology.

"For manufacturers of medical devices and luxury goods, a major problem was the fact that superfine particles accumulated on the surfaces of brown parts during the water debinding process. Sometimes smear marks due to additives in the debinding water could be found on the brown parts after the debinding process. We have solved these problems by developing and implementing a specifically modified debinding process," stated Dias Fonseca.

To facilitate the water debinding process for its customers, LÖMI has embedded sensors into its equipment that monitor various parameters of the utilised water and show them on a display in real time. For a higher-quality process (debinding and drying), a temperature control was installed that can reach up to ten target values over a certain time period. This feature is particularly important for water debinding processes but can also be installed in solvent debinding furnaces.

## Solvent and water debinding in one system – for testing and diversifying

"In recent years many producers who operate conventional manufacturing processes for metal or ceramic parts have learned about PIM technology. Some of these producers are still reluctant to enter into PIM production and wish to test it first. Likewise, producers that already use PIM technology are looking to diversify their processes or test new feedstocks," stated Ralf Wegemann, LÖMI's Marketing Director.

To meet this demand, the company has developed a furnace capable of debinding with both organic solvents and water in one system, the first of its kind in the industry. The system, EDA-50LW, is available as a rental system so that prospective PIM producers can test their processes in their own company. "Experienced PIM producers can try out new kinds of feedstock and/or binder systems or optimise their existing processes, using both organic solvents and water to debind their green parts. Should a PIM parts producer later decide to purchase a new debinding furnace, LÖMI will customise the furnace to the producer's process, based on the test results," continued Wegemann.

## Common characteristics of all LÖMI debinding solutions

The engineers at LÖMI conduct their research and development in close cooperation with feedstock producers and MIM/CIM part manufacturers and as a result the company has gained a comprehensive understanding of the entire PIM technology process chain. This has led to the near continuous enhancement of the company's debinding furnaces, improving both reliability and efficiency. The furnaces employ well proven technology and are fully customisable by means of a programmable logic control system. Even complex processes can be operated with a LÖMI debinding furnace, as the company develops tailor-made systems specific to customer requirements.

LÖMI is an accredited company according to the EU Water Framework Directive and its furnaces meet European directives for occupational health and safety, as well as environmental protection. An in-house accredited safety engineer will give prospective customers advice where needed.

The company's furnaces feature a high-quality stainless steel design and an integrated drying of parts, which saves production time and costs, as no additional handling of the brown parts is required between debinding and drying. LÖMI's debinding furnaces are ergonomically designed as front-end loaders with an optimal loading and operating height. To facilitate the operation of a system, remote diagnostics and maintenance are available, as well as a telephone service hotline.

"Our furnaces are cost-saving through their compact and energy-saving design, their low investment and a short lead time. Generally, one of our furnaces pays for itself within one or two years after commissioning. Rental systems are also available for prospective customers to test their debinding processes in-house in their own companies. The costs for the rental system can be credited to a purchase of a new debinding furnace," stated Wegemann.

## New features and new auxiliary equipment

Many of the most recent improvements to the company's debinding furnaces and their auxiliary equipment have been directed at making their operation more ergonomic and efficient, thus saving time and costs during the production of PIM parts. Wegemann stated, "As an example of some of these improvements, to facilitate the monitoring of the debinding, drying and solvent recovery processes for the operator, the current states of the various process parameters are now shown on the display in real time. Additionally, we have entirely revised the locking mechanism of the front-end sealing cover. A ratchet tensioner now enables the operator to increase the tightness of the equipment even during its operation, at the same time preventing him from accidentally opening the cover."

"Also, the auxiliary equipment has been considerably improved and standardised. A large variety of trays and mobile loading aids are now available in order to save time and costs during the production process. While one batch is still inside the debinding furnace, the operator can prepare the next batch by placing the green parts on trays of different LÖMI-standardised sizes and heights, then stacking these trays onto a mobile loading aid. When the batch inside the debinding furnace has undergone the drying process, the operator can move an empty loading aid right in front of the opened front-end cover of the debinding furnace and slide the racks of trays with the brown parts easily out of the furnace onto the mobile loading aid. Prepared racks of trays with the new batch can then be slid into the furnace. This unloading and loading procedure now takes only a few moments, making switching batches between processes much more efficient and cost-saving."

Until a few months ago, the loading mechanism used stationary mounted metal rails within the debinding chamber, and the metal racks with the green parts were slid onto these rails. This used to cause abrasive wear and small metal particles therefore ended up within the debinding chamber. As they impaired the quality of the surfaces of the brown parts, the company has completely revised the loading mechanism, which now utilises wear-free rollers. In addition, the components of the loading mechanism within the debinding chamber are now completely removable. This makes the cleaning of the debinding chamber significantly easier and the operator only needs one hand to remove the loading mechanism from a small furnace.

*Fig. 7 The new large display in control cabinet shows current states of various process parameters in real time for debinding, drying and solvent recovery*

## Contact

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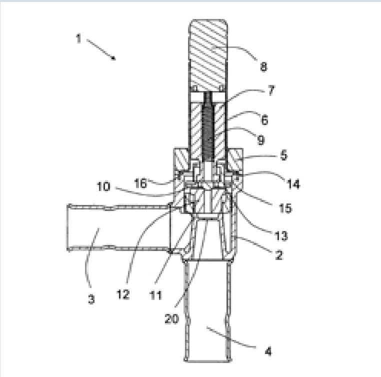
# Global PIM Patents

The following abstracts of PIM-related patents have been derived from the European Patent Organisation databases of patents from throughout the world.

**WO2011018087 (A1)**
**MANUFACTURING METHOD OF A VALVE**
**Publication date: 2011-02-17**
**Inventor(s): Hoeyer Jesper Hoejland et al., Danfoss AS, Denmark**

A method of manufacturing a valve using Metal Injection Moulding is disclosed in this patent. The valve housing comprises a welding cap for welding the upper part of the valve to the valve housing. The welding cap is placed so the upper part can be welded to the housing without damaging the inner cavity of the housing. There is a gap between the welding cap and the inner liner so the heat from the welding does not damage the inner liner, allowing the inner parts of the valve to move freely.



**CN101643355 (A)**
**INJECTION MOULDING TECHNIQUE FOR TRANSLUCENT ALUMINA CERAMIC BULBS**
**Publication date: 2010-02-10**
**Inventor(s): Xueguo Zhao et al, Changsha Jingtai Plastic Machinery Technology Development Co., Ltd, China**

The invention discloses an injection moulding technique for translucent alumina ceramic bulbs. The process for integral ceramic bulbs comprises the following steps: proportioning, mixing materials, granulating, pressing a fusible core, inserting the fusible core, injection moulding, debinding, biscuit firing, co-firing and high-temperature sintering.

The injection moulding technique for split-type ceramic bulbs comprises the following steps: proportioning, mixing materials, granulating, injection moulding, degreasing, biscuit firing, co-firing and high-temperature sintering.

The technique utilises the injection moulding process for preparing translucent alumina ceramic bulbs for the first time and explores suitable grain boundary doping components evenly spread in alumina ceramics so as to prepare the high-performance translucent alumina ceramics for metal halide lamps.

**WO2011149401 (A1)**
**METHOD FOR PRODUCING CEMENTED CARBIDE PRODUCTS**
**Publication date: 2011-12-01**
**Inventor(s): Jonsson Per et al., Seco Tools AB, Sweden**

The patent relates to a method for the production of cemented carbide based hard metal parts comprising hard constituents in a binder phase by using Powder Injection Moulding or extrusion. The method comprises of: mixing powders of hard constituents and binder phase to form a mixture; heating said mixture of hard constituents and binder phase to a temperature; when the temperature of the mixture of hard constituents and binder phase is above the melting point of the organic binders, adding the organic binders in melted form, making sure that the temperature does not fall below the melting point of the organic binders; forming the parts by powder injection moulding or extrusion; removing the organic binders from the obtained parts by a debinding step; and sintering the parts.

**WO2011120066 (A1)**
**METHOD FOR PRODUCING SHAPED BODIES FROM ALUMINIUM ALLOYS**
**Publication date: 2011-10-06**
**Inventor(s): Danninger Herbert et al., Univ Wien Tec, Austria**

The invention relates to a method for producing shaped bodies based on aluminium alloys by metal powder injection moulding. The process comprises the following steps: a) preparing a feedstock by blending the metals contained in the desired alloy in the form of metal powders and/or one or more metal alloy powders with a binder; b) preparing a green compact by injection moulding the feedstock; c) preparing a brown compact by at least partially removing the binder from the green compact by catalytic and/or or solvent and/or thermal debinding; d) sintering the at least partially de-bindered brown compact to obtain the desired shaped body. The invention is characterised in that in step c) the binder is removed completely, wherein, optionally after carrying out one or more preceding de-binding stages, a thermal debinding in order to remove the (residual) binder is effected and is carried out in an atmosphere containing at least 0.5% by volume of oxygen, after which the resulting completely de-bindered brown compact is sintered.





# The development of an innovative continuous belt furnace for the high temperature sintering of MIM and CIM products

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Centorr Vacuum Industries, based in Nashua, New Hampshire, USA, has specialised in the development, engineering, design and manufacture of vacuum and controlled atmosphere furnaces since 1954. In the following paper the company introduces a unique low mass, fast throughput belt furnace design that operates in ultra clean environments of inert or process hydrogen gas that can be used over a wide temperature range from 1000°C up to 2800°C. While this continuous furnace design is not suitable for all applications, if considered for the right process, it can provide the combined benefits of fast cycle times in an oxygen free atmosphere.

Processing metals and ceramics can require very special sintering conditions and operating environments in order to achieve optimal physical properties. While conventional vacuum, atmosphere batch, and continuous belt or pusher furnace designs work well for a majority of these applications, there are some unique materials (or processes) that could benefit from an ultra clean, oxygen free environment and a fast ramping speed with minimal soaking times.

Although vacuum and atmosphere batch furnaces are commonly used in industry, cycle times can be long and there can be variances present throughout the load, especially when processing a large quantity of small parts in a large furnace chamber. This is especially the case where fixturing and setter furniture like hearth plates can cause thermal scattering of the heat or act as a heat sink for the small components.

Conventional belt furnaces utilise Inconel mesh belts, have refractory ceramic (brick or fibre) insulation, and can process loads of many kilogrammes per $m^2$ of belt area. They are typically rated for maximum continuous use at temperatures to 1150°C or up to 1288°C for units with ceramic belts. While large belt and pusher furnaces are ideally suited for high throughput applications such as those found in the Powder Metallurgy industry, they are not as economical for lower volume, shorter furnace runs of small parts under 6-12 mm in size that need to be run in ultra clean environments. These conventional belt furnaces require expensive nickel alloy or ceramic muffles inside the hot zone to help control, protect and direct the reducing gas away from the insulation and heating elements, and maintain the desired furnace atmosphere. These muffles can have a short lifespan if cycled frequently and for this reason, once the units are heated up, they are seldom turned off and instead idled over weekends or periods of low production rather than turned off completely. Large belt furnaces are typically shut down only one to two times over several years of use, and not every application can justify these production capacity requirements. They must also be cycled with dummy loads during periods of non use to prevent overheating of the main chamber. For improved cleanliness, some designs also include a "humpback" feature which lifts the belt and load into a higher area of the hot zone where cleaner, lower dewpoint hydrogen gas is present.

To address the above concerns and accommodate these niche small volume and fast throughput applications a new style of furnace design was conceived which was born of the benefits of vacuum batch furnaces, with the processing speed and process uniformity found in continuous designs. This novel high temperature continuous belt furnace is shown in Fig. 2.

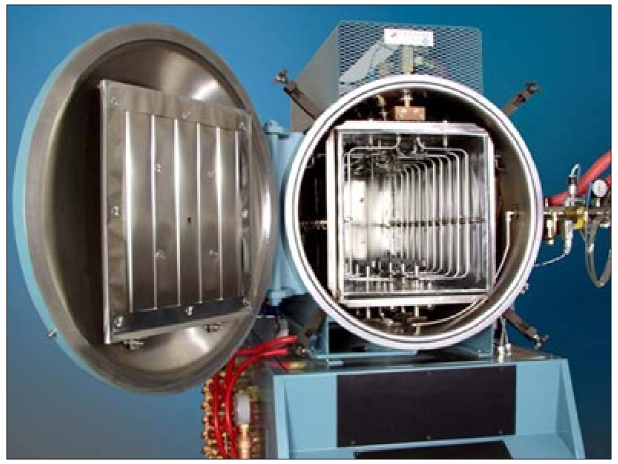

*Fig. 1 Conventional vacuum furnace hot zone*

*Fig. 2 2000°C rated belt furnace for sintering refractory metals in hydrogen gas*

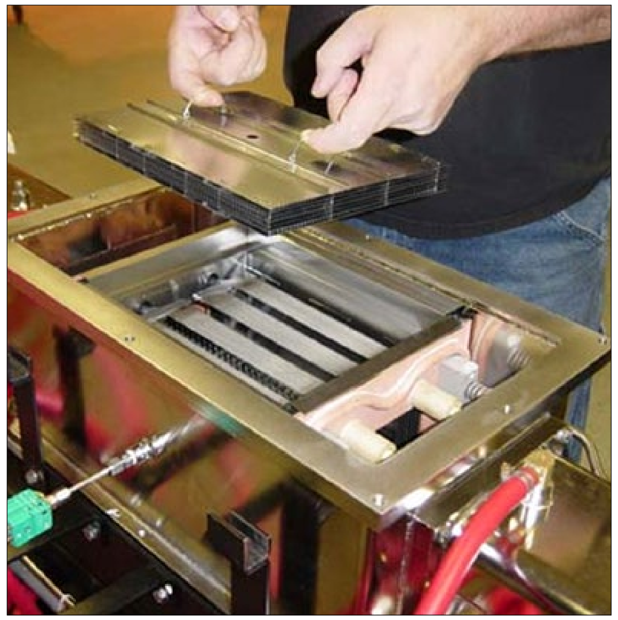

*Fig. 3 Refractory metal belt furnace hot zones*

*Fig. 4 Refractory metal belt furnace hot zones*

While this unique belt furnace design was originally introduced in the early 1990s its popularity has recently begun to rise in the past five years as a number of new applications have opened up for its use. The furnace is built similar to vacuum furnace construction with a water cooled stainless steel chamber and an interior hot zone designed using refractory metals for the heating elements and shielding (such as molybdenum or tungsten), or rigid graphite insulation and graphite elements for ceramics applications. These unique continuous furnaces are rated for maximum temperatures of 2000°C in either inert or process hydrogen gas with a refractory metal hot zone, or up to 2800°C in inert gas when using graphite hot zones. To provide fast heat up and cool downs, double wall water jacketed entrance and cooling tunnels are located on the ends of the chamber. For material transport, the furnace is fitted with a range of belt materials depending on use temperature and load weights. This includes a proprietary patented molybdenum or tungsten mesh belt design rated to 1550°C or 2000°C. For higher load applications, silicon carbide link belts are used to 1800°C, and for temperatures over 2200°C flexible graphite cloth is the belt material of choice. The furnaces are available in a range of sizes and throughputs, with a nominal belt width of between 50 - 200 mm, a height of 25 - 100 mm, and a length dependent on the desired throughput, but typically 200 - 1525 mm. They are configured in either one, two, three, four or five zones of control and achieve excellent temperature uniformities of +/- 3 to 5°C across the belt in inert or hydrogen process gas.

The throughput and process repeatability have made this furnace a successful tool for dependable production in applications such as Metal Injection Moulding, the high temperatures sintering of refractory metals and ceramics, precision brazing, metallization and the ceramic to metal joining of components. Recent installations to date have centred around applications in Micro-MIM parts, silicon nitride components, high temperature sintering and hydrogen brazing. Four application case histories are presented below.

## Metal Injection Moulding

A MIM parts producer was looking to manufacture large quantities of a relatively small part with the flexibility to start and stop runs several times per week. These parts were made of stainless grades including 17-4PH or 316L and applications included orthodontic braces and brackets, cell phone cam hinge pieces and miscellaneous small parts weighing under 5 g each.

Unlike the previous applications, this one added the complexity of removing up to 1-3 wt% of a difficult polymer based binder system commonly used in Metal Injection Moulded parts during a low temperature binder burnout step. In this case the belt furnace's hydrogen flowthrough gas provided an excellent vehicle to breakdown the binder's hydrocarbon chains so that offgassing could be safely removed from the parts, and reduced to gaseous form with little solid binder residue left in the entrance tunnel. In certain applications a gas moisturising system can be added for processes requiring higher hydrogen gas dewpoints (typically from -20°C to over + 20°C), such as used in metallising applications, or instances where moisture assists in the binder removal phase.

The small cross section and fast throughput of the belt furnace was advantageous in providing a thorough and uniform debinding environment which is considered a bottleneck in batch sintering applications where larger loads must be debound slowly with several holds at intermittent temperatures. By keeping the load weights light and the furnace cross section small the parts are intimately and quickly debound before entering the sintering section. By using a specially designed gas labrynth curtain at the entrance and exit zones, the customer is able to maintain the clean





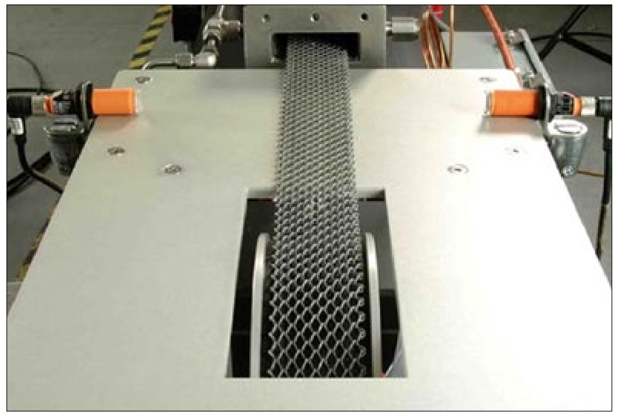

*Fig. 4 Proximity sensors at the exit tunnels signal to operators when a work tray is ready for unloading*

*Fig. 6 Centorr Vacuum Industries belt furnace for the processing of advanced metals and ceramics*

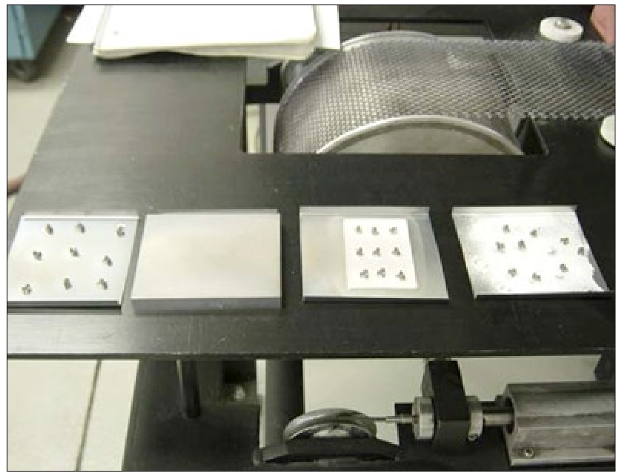

*Fig. 7 Trays of small hinges on varied ceramic setter materials including sapphire, ceramic paper and alumina powder*

*Fig. 8 Photograph of stainless steel component*


*Fig. 9 Microstructure of part with 97% theoretical density*

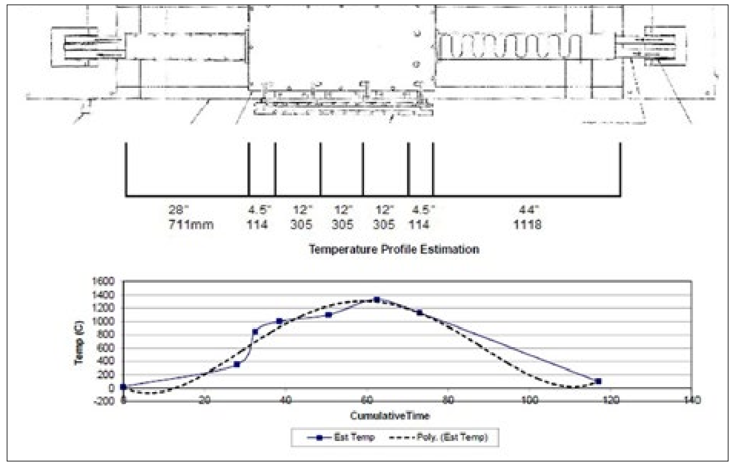


*Fig. 10 Belt furnace time/temperature modelling curve for a MIM process run at 25 mm/min, yielding fully sintered parts in 120 minute cycle time*

environment inside the furnace even at the tunnel ends, and ensure that the hydrogen process gas is directed up the burnoff chimneys located at both ends.

Final sintering of the parts takes place in the main furnace chamber and the three zones of control are individually adjusted to get the desired heatup, soak time, and cool down profile, which results in theoretical densities of 97% for the 316L components in cycle times of 120 minutes. Various trays and setting material were also evaluated to minimise sticking of the parts to the metal trays.

Future work in the MIM field is being performed to determine the effect of cycle times on carbon control and investigating blended gas atmospheres in an effort to reduce operating costs. Future development work will additionally include adding debinding capabilities in order to provide a two stage debind and sinter design for MIM parts.

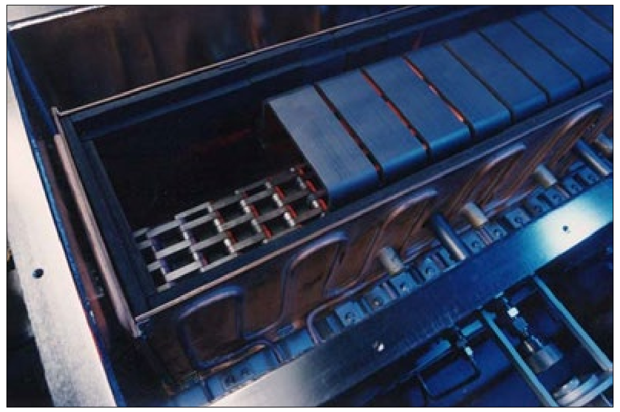

*Fig. 11 Graphite hot zone and SiC belt in ceramic belt furnace*

## Ceramic processing

In 1993, Centorr Vacuum Industries cooperated in a study by Prof. Dale Wittmer, Southern Illinois University (SIU), USA, to develop a cost effective means of sintering selected $Si_3N_4$ compositions in large volumes required by the automotive industry. While these parts could be reliably produced in a batch process, the major barrier to extensive use of $Si_3N_4$ components was cost. The primary areas of research had to do with evaluating low cost raw material powders and the sintering process. Previously, Wittmer and Miller showed that it was feasible to sinter large $Si_3N_4$ disks of 100 - 150 g to full density in a continuous belt furnace in flowing nitrogen gas. A comparison was made between continuous sintering in a commercial belt furnace and sintering in a batch furnace for similar times and temperatures [1]. For the $Si_3N_4$ sintered in the belt furnace, the average four point flexural strength was found to be 35% higher with a fracture toughness over 22% greater. Remarkably, the overall cycle times for the continuous process were in the range of 3.5 - 4.5 hours compared with 18 - 24 hours cycles in batch sintering furnaces, and this translated to a reduction in time at sintering temperature of 30-60 minutes for continuous compared with more than three hours in the batch process. It was determined that this reduced time in the presence of flowing nitrogen gas, was one of the main reasons the continuous furnace provided enhanced material physical properties. Another explanation why the continuous furnace made parts with improved properties when compared with pressureless sintered furnaces, or even overpressure furnaces is that the belt furnace provides very fast uniform heating and cooling (as the effective hot zone is essentially a 100 mm x 100 mm square), which positively affects the structure of the material.

Depending on formulation, the parts could be processed in graphite, BN, or ALN workboxes with or without the use of packing powders. Early work was done in a tungsten hot zone but the SiO vapour attack that dissociated off the load was degrading to the refractory metal. Later designs at SIU used an all graphite hot zone with rigid graphite board insulation and graphite resistance heating elements.

And while SiC formation was a concern with the graphite hot zone, the new belt furnace hot zone lasts significantly longer than what is achieved in graphite batch furnaces or tungsten refractory metal designs. Fears about a graphite hot zone contributing to a carbon reaction layer have also been alleviated as there was no difference in the material properties produced in tungsten versus Graphite hot zones.

In recent years, this work has transferred over to other ceramic formulations traditionally processed in batch sintering furnaces and has led to more work in oxide sintering with sapphire formulations for applications in wafer annealing and LED processing, and polycrystalline alumina for metal halide lighting. Benefits of improved densification, minimised weight loss due to dissociation, and preferred crystallinity are possible with this unique belt furnace design.

## High temperature sintering

When faced with high temperatures and low dewpoint hydrogen gas requirements for the sintering of refractory metal components used in consumer electronic applications, a customer had a choice of using either high temperature ceramic lined pusher furnaces, or expensive refractory metal batch furnaces. However, because the customer's parts were small and the volumes were not large in terms of mass, large pusher or batch furnaces were not an economical solution.

Due to the fact that refractory metals are very sensitive to oxygen contamination, which is very damaging at high temperatures, the cleanliness of the furnace interior is of paramount importance. The small belt furnace design utilises refractory metal insulation shielding and heating elements which generate no significant offgassing inside the furnace as can be found with traditional porous refractory brick or fibre insulation materials. In fact no 'conditioning' (running the furnace for one to three days upon initial startup to drive off moisture from the insulation brickwork), is necessary with this belt furnace design, and it is simply purged with inert gas for 30 - 45 minutes at the start of the cycle to ensure an oxygen content of under 10 ppm, as interlocked by an integrally mounted oxygen monitor. These belt furnace designs routinely achieve the same dewpoint of hydrogen gas inside the hot zone during operation as is measured at the gas bottle inlet (typically in the range of -50 to -60°C).

The customer in question ended up with multiple belt furnaces with 5 cm and 10 cm wide tungsten mesh belt and 20 - 30 cm long hot zones rated for operation at 2000°C. The units are set up in small independent manufacturing cells where a pick and place robot automatically loads the parts onto small trays that are continuously queued up in front of the belt furnace entrance. Proximity switch sensors located at the exit of the belt furnace signal when a boat is ready for unloading, and can be interlocked to put the belt furnace drive motor into hold, if a tray is not removed from the unloading area.

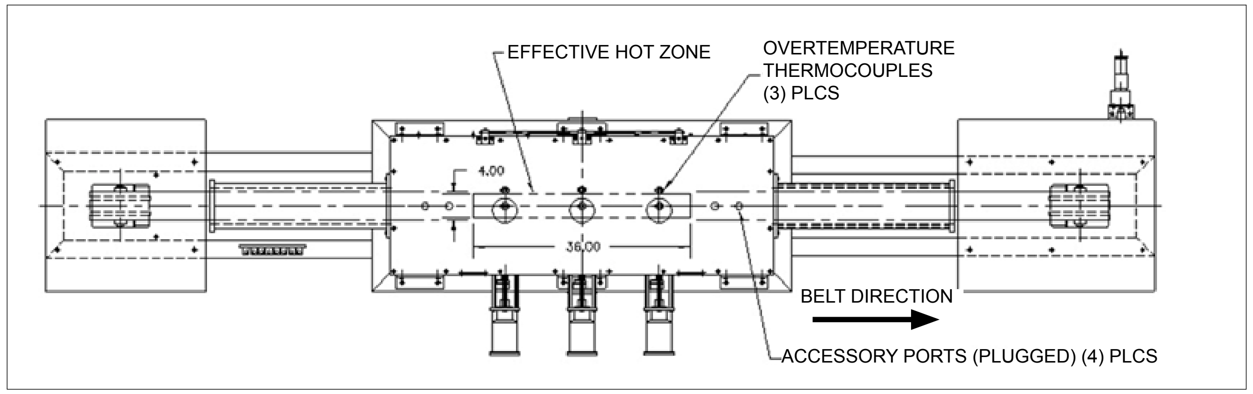


*Fig. 12 Hot Zone layout of three zone Ceramic belt furnace*

Because the small belt furnaces can be heated up to temperature from a cold start and operational in under 90 minutes, the belt furnaces are run either weekly (Monday through Friday), or can be run daily similar to a batch furnace and cycled on an 8:00 am to 5:00 pm schedule depending on production volumes and holiday schedules. There is no longer the requirement to run the units at lower idling temperatures over the weekend if production demands don't require the throughput, which allows for significant savings in energy costs, as well as process and inert gas costs. At the end of each process campaign the belt furnace is powered down and purged with inert gas for approximately 30 - 60 minutes before it reaches room temperature. Compare this to conventional brick lined units that take two to five days to cool down depending on maximum operating temperatures, and the operating cost savings at this customer were further multiplied. Another benefit is that problems such as tunnel blockages, stuck trays, or minor hot zone or belt repairs can be readily accessed and corrected in under a day including time for cool down and reheating due to the novel hot zone design. The overall length foot print of this customer's small belt furnace fits in a 2.8 m long space, which was less than half the length of a conventional brick lined continuous furnace.

It is important to note that these high temperature continuous furnaces are generally limited to applications with light part weights up to 1.3 kg/linear 300 mm of belt length for molybdenum and tungsten mesh belts, and up to 4 kg/linear 300 mm of belt width for SiC link belts, so thought needs to go into the choice of fixturing for these furnace designs. Operators should consider the use of low mass plates or trays, made of thin molybdenum or tungsten sheet material, with lightweight ceramic separator plates if required by the process. Dense ceramic plates cannot be used in most instances, as the fast cooling that occurs in the cooling tunnel results in thermal shock and cracking of the ceramics.

## Brazing

Conventional brazing encompasses a wide variety of techniques and materials, and can be performed in a variety of furnace equipment; however, for some specialised braze materials either vacuum batch processing or hydrogen belt or pusher furnaces are used. One such niche process would be for the precision brazing of very small, lightweight parts such as those found in the medical industry. The secret to excellent brazing in this case is summarised by the mantra of "get to temperature quickly, stay there a short period of time, and get down in temperature quickly". The primary reason for this sentiment is the desire to minimise high temperature reactions between the braze filler metal and base metal which can occur if the two materials are in contact at temperatures above the liquidus point for long periods of time. A second corollary reason is that the shorter the overall cycle time, the less time there is available for contamination of the base metal to occur which can result in brazing defects such as poor adhesion between base metal and filler metal, and insufficient bonding properties.

In order to achieve this goal a very clean "vacuum like" atmosphere is desired to ensure little to no oxidation of the base metal. This means conventional belt or pusher furnaces could not be used because these designs cannot offer the fast cycle times and level of cleanliness and low dew point required for some braze processes, such as those involving active metal or Ti-Cu-Ag/Ti-Cu-Ni formulations.

A customer had a difficult brazing request for a small medical part that used a tiny amount of braze at temperatures under 1100°C. After testing in various vacuum batch furnaces and batch hydrogen units it was decided to try the parts in the belt furnace using hydrogen process gas to maintain a clean, oxygen free environment. While the parts processed in the batch cycles were acceptable, there were braze blush variances throughout the load due to the different thermal conditions each part was subjected to, and each cycle took on the order of three to four hours, whether the unit had a full load or not.

After completing two days of test runs at varying belt speeds and zone temperatures, the customer achieved parts that exited the 15.25 cm wide by 91.5 cm long hydrogen belt with excellent surface finish, a bright shiny exterior, and excellent braze joints. Furnace speeds of 75 mm/min were used during development, which provided a door to door time of just under 40 minutes. For budget reasons and total capacity requirements, this customer opted for a 10 cm wide belt furnace with an 20 cm long hot zone. While a belt speed of approximately 13 mm/min would have been appropriate to provide a similar time at temp inside the furnace hot zone, compared with the lab testing in the 91.5 cm long unit, this customer made their initial runs at the same 75 mm/min speeds and found that the parts came out every bit as shiny and clean as the lab testing done in the longer belt furnace design. While not true for all applications, because the mass of these parts were so small this customer found that their parts would almost instantaneously heat up inside the hot zone, being bathed by the low dewpoint $H_2$ gas, and due to the small amount of braze material present, result in contamination free joining in a matter of seconds. This application in a way simulated the speeds of batch induction brazing, except for the ability to continuously and safely maintain the clean hydrogen gas environment.

The only operational issues onsite have been related to environmental conditions on the shop floor. Due to the small size of the furnace openings, if the entrance or exit tunnels are close to a loading dock or large window, the gas curtains and process gas chimneys can have their flow patterns disturbed resulting in frequent flow adjustments to the gas panel. It was also learned that the furnace preferred to be run with a full load of workboats to get consistent gas flow dynamics, or else the process gas that is introduced into the main chamber and entrance/exit tunnels will preferentially exit out the furnace end with the smallest blockage. Happily, the customer has noticed that the water cooled shell of the furnace results in almost no heat radiation to the surrounding plant environment (as opposed to the significant heat generated from conventional brick lined furnaces), and the furnace operation has not impacted facility heating or air conditioning utilities

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| contents page | news | events | advertisers' index | email | Technical Paper

# New two-unit one step batch debinding and clean sintering system for improved efficiency and carbon control in the MIM process

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Elino Industrie-Ofenbau GmbH, Düren, Germany, has developed a new batch furnace system specifically for the Powder Injection Moulding (PIM) process. Consisting of two units, the first unit has been developed for the complete debinding of MIM parts, from initial catalytic debinding to thermal residual debinding and pre-sintering up to 950°C, with changeable atmosphere during the process. The second unit is designed for very clean sintering that is free from carbon contamination and can be operated under different process gases and vacuum up to maximum sintering temperature of 1450°C on the standard system, or 1600°C on an upgraded system. The main advantages of the new system are fast production, the avoidance of carbon pick up especially in Mo, W, and Fe alloys, longer life time of hot zone and heating elements, and improved cost efficiency. This two furnace system has been tested with 316 L and 17-4 PH materials and the technology was able to deliver sintered densities of 7.70 g/cm$^3$ and 7.65 g/cm$^3$ respectively without any distortion in the MIM parts.

The Metal Injection Moulding (MIM) process is an efficient method for the high volume production of complex shaped components from powders for high performance applications. The MIM process consists of mixing a small amount of organic material with the desired inorganic powder (metals or alloys) to create a feedstock that can flow like plastic under temperature and pressure. Following standard polymer processing techniques, this feedstock can be injection moulded into a 'green' shape that is an oversized replica of the final part. Generally, the organic binder is removed during a step known as debinding, usually carried out in at least two stages. After debinding, the part is consolidated to high densities by sintering at appropriate temperature. In this way the MIM process provides designers and engineers with a powerful material shaping technique that can form metals and alloys into extremely complex shapes.

Usually the major binder component is removed in a first stage debinding process, for example through solvent extraction or by catalytic decomposition, resulting in the 'brown' part. This brown part still contains binder, but only a small amount of organic phase binder, the so called backbone component that grants the stability of the brown part necessary for handling. Thermal debinding is then the most common method for the final removal of this residual polymer from a MIM compact prior to sintering.

Current batch furnace technology does not provide a one step complete MIM debinding system. Usually current processing systems remove the first part of the binder by solvent extraction or a catalytic method in one furnace and then the backbone binder is removed thermally followed by a sintering process in another separate furnace. In these cases secondary thermal debinding and sintering process are done in the same furnace, resulting in some drawbacks.

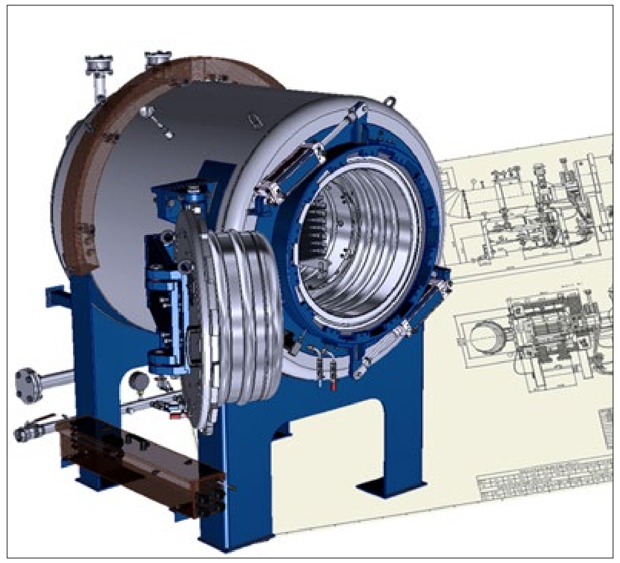

*Fig. 1 Furnace TYPE CT MIM-ECO*





These drawbacks can include difficulties in the control of carbon levels, especially in low carbon stainless steels or other alloys which have high affinity to carbon pick up, resulting in the deterioration of mechanical properties of final products.

In a technical development designed to address these challenges Elino Industrie-Ofenbau GmbH developed the MIM-ECO CT one step complete debinding furnace (Fig. 1) along with MIM-ECO VR sintering furnace. The one step debinding unit includes catalytic debinding, thermal debinding and pre-sintering up to 950°C and is designed with a convection system to allow for temperature homogeneity of less than ±5°C. The special off gas burner system is installed to convert process gases into environmental acceptable exhaust gases.

Different atmospheres (Ar, $H_2$, $N_2$, air, $N_2$-$H_2$) can be used during the thermal debinding process depending on selection of the materials, including under air for Ceramic Injection Moulded (CIM) products. Users can switch to different protective atmospheres during the process prior to the pre-sintering step to enable good metal-metal bonding.

Water/solvent debound parts can be dried between 80-90°C and individual temperature-time profiles can be defined for different debinding steps with different atmosphere. Production can be increased up to three cycles in a day with the air cooling system. In the thermal debinding step the complete removal of residual binder is beneficial, so when transferring the parts into the sintering furnace they free from hydrocarbons.

The speed of the sintering cycle in the MIM-ECO VR can be increased by using a fast heating ramp and can increase production up to three complete cycles in a day (24 hours). Some key results of the new sintering furnace are; no condensation, no contamination, no blockages in the vacuum pump and long lasting life time of the muffle, which is completely made of molybdenum. The charge carrier fits exactly the same way in sintering furnace as in the debinding furnace, so handling of the charge carrier will be easier.

The main benefit of splitting debinding and sintering operations is the avoidance of carbon pick up during sintering, particularly in case of Fe, W and Mo alloys. Materials that are reactive with atmosphere such as Ta and Ti alloy can be sintered with fewer impurities under vacuum level from $10^{-2}$ to $10^{-5}$ and with a temperature accuracy of less than ±10K at sintering temperature.

## Furnace design challenges

PIM parts are made of different metal powders ranging from iron - nickel to stainless steel, and from titanium alloys to superalloys. Each of these materials may require the use of different types of binders, which are often removed by catalytic debinding process from the products under atmospheric pressure or partial pressure. The atmosphere of this process is nitrogen as well as chemical acid additives, such as $HNO_3$ at a concentration of 98-100%.

In the debinding furnace the heating elements are outside a hermetically sealed hot zone, whilst in the sintering furnace the heating elements are inside a hermetically sealed hot zone. Both types of devices are characterised by different properties from the point of view of physics and thermodynamics of the process. The first difference is the temperature distribution in the hot zone. A device with a cold wall can reach ± 10K of temperature distribution while for comparison a furnace with the hot wall can reach ± 5K. For the selection of these individual designs, previous experience had been taken into account that showed the need for high temperature accuracy during the debinding process combined with a sufficiently high flow of process gas. For the sintering phase under atmosphere the temperature homogeneity is even better than ± 10K but for sintering processes under vacuum it showed that at the applied high temperatures the radiation in between the parts assures more than sufficient homogeneity.

Another important element for debinding and sintering is the thermodynamic potential of a chemical reaction. This depends on the characteristics of the process as well as on the use of a device with a cold or hot wall. This consequently leads to the requirement of a proper gas flow which is necessary for the processes under consideration.

The thermodynamic potential drop is a measure of chemical affinity of reacting bodies, which shows the tendency of substrate to combine into a particular chemical compound. The thermodynamic potential can be compared to the potential energy of the mechanical system. Therefore, while the reaction takes place, the ΔG must have a negative value and be less than the equilibrium state. The chemical reaction proceeds more easily as the negative value of ΔG increases. This is general approach for catalytic , thermal and sintering processes.

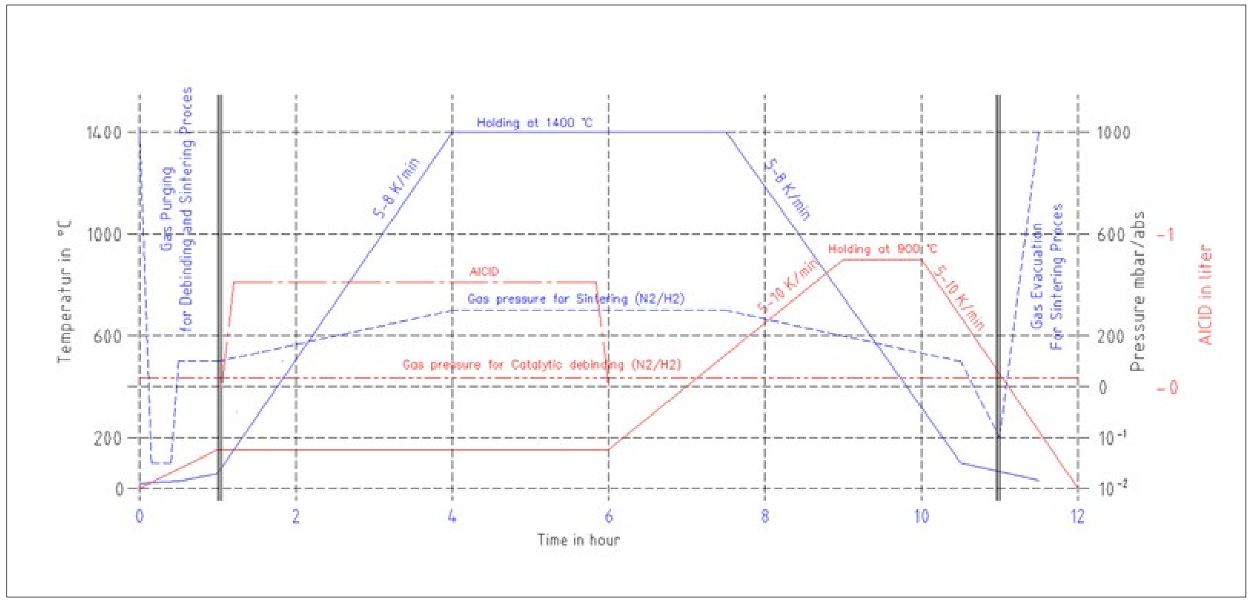


*Fig. 2 The technological process parameters of complete debinding and sintering of a MIM part*

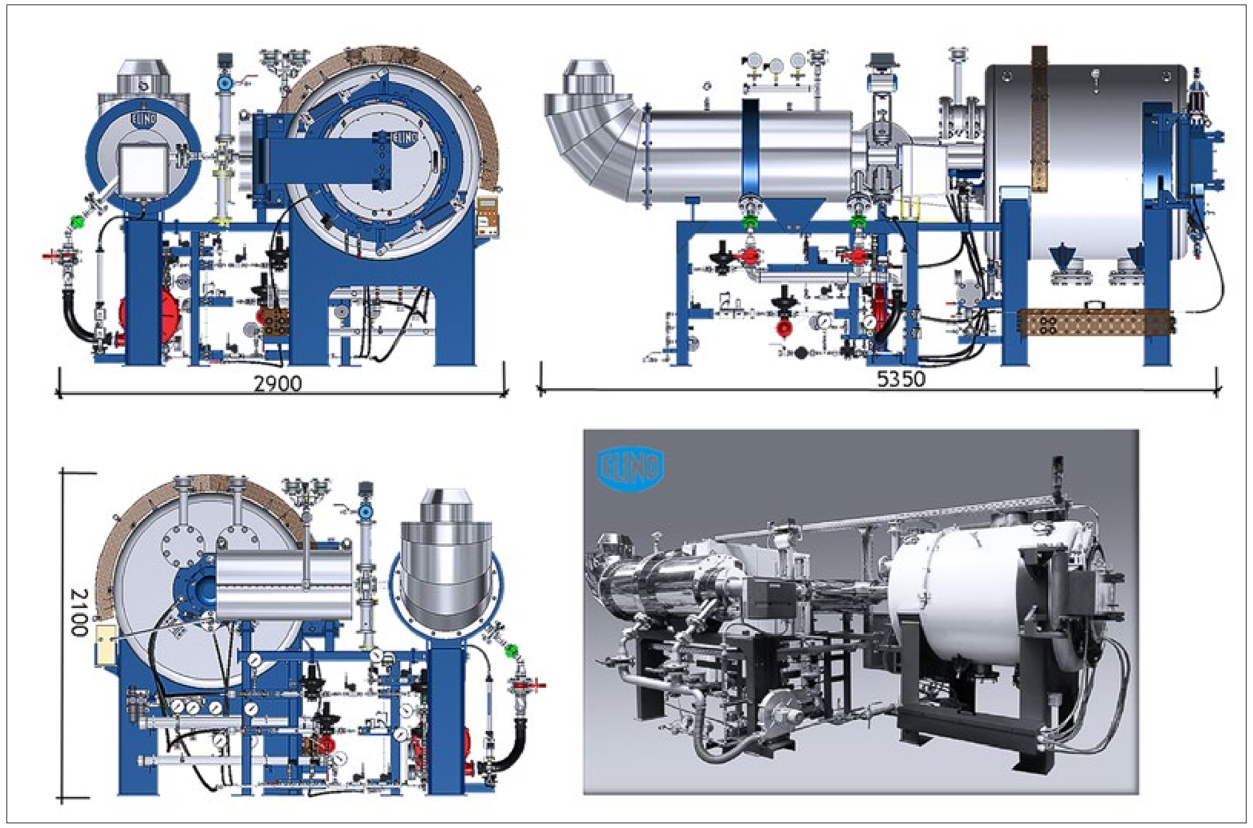


*Fig. 3 Batch debinding ECO -MIM unit CT050-085*

Typical processes of catalytic, thermal debinding and sintering may be carried out in gas pressures from atmospheric 1010 mbar to a vacuum of 0.10 mbar. In exceptional cases the vacuum can be much lower, around $10^{-5}$ mbar.

Regardless of the chemical reaction of gases and acids, at high temperature a phenomenon of selective sublimation takes place in components of the processed materials or a binder. Importantly, the vapour pressure over a specific material at a given temperature can be determined by considering the balance between the number of evaporating and condensing particles. It is necessary to have the knowledge of pressures and temperatures of sublimation in the selection of construction materials of the furnace and in the selection of the vacuum for a given technology.

A major challenge is therefore to prevent this phenomenon, which in the devices with a cold wall undoubtedly has an adverse influence both on the properties of the thermal insulation, the electrical connections of the heating elements, the heating elements themselves and especially on the operation of the vacuum pumps. In practice we are dealing with turbulent, laminar and molecular gas flows.

It should be noted, however, that a very important element for the proper debinding process is a laminar flow and for sintering a molecular flow of the gases used. The proper way to prepare the furnace in order to achieve these flows undoubtedly depends on the engineering practice and a thorough understanding of aspects of the technological processes.

Another challenge, though not the last one, to be faced by an engineer is the atmosphere for the catalytic, the thermal debinding processes and the sintering process, as well as ensuring the accuracy of the individual processes.

Catalytic debinding requires the use of acids ($HNO_3$) at a concentration of 98-100% and a temperature of up to 150ºC. Working with an acid and hydrogen at high temperatures up to 950°C forced the engineers to find the most sophisticated sealing solutions. This is critical as it is no longer only the process itself that needs to be considered, but also the safety of workers. It is best to use polytetrafluoroethylene $-[-CF_2-CF_2-]_n$ for the acids, but it cannot be used in flanged joints exposed to temperatures higher than 200ºC. However these are exactly the joints used in devices for catalytic debinding, for example for supplying acid into the interior of the hot zone. What can be used here are inert gases and gas curtains determined with CFD methods. But one should keep in mind that the type and volume of the flowing gas has an impact on the final result of the machined work piece as well as on building-up of binder on the colder parts of the device. This eventually causes downtime and the need for service. In Fig. 2 the complete debinding and sintering process can be seen for 316 LA and 16-4 PH MIM parts indicating the use of the MIMECO CT and MIM-ECO VR models. The sintered densities were measured by the Archimedes method and obtained excellent results.

## One-step debind and pre-sinter unit ECO-MIM-CT

The debinding unit ECO-MIM-CT is supplied in five sizes. These values are chosen on the basis of many years of practice and in accordance with market standards and customer requirements. Table 1 shows the basic specifications of the device.

The unit is a typical hot wall unit with the heating elements located outside the gas-tight and acid-tight metal muffle. Inside the muffle are all necessary connections for supplying and for draining process gases, for supplying acid as well as for the connection of atmosphere sensors and the necessary support elements to place the work pieces inside. The muffle is a floating design, which means that it has the property of thermal expansion in the horizontal direction.

In addition, the design of the metal muffle allows for the appropriate orientation of process gas circulation controlled by a fan located in the rear of the device. Due to the acids and high temperatures, plus hydrogen, the electric motor and its connection to the rotor feature a specially constructed solution to thoroughly ensure basic heat treatment parameters while ensuring safety at work. A very important factor in this part of the unit is the configuration of steel materials, which allows for long-term work in a harmful environment. This is the result of many hours of calculations and optimisation with the use of the software for CFD and FEM calculations.

Protection is also achieved by a three-stage gas curtain. This prevents both the corrosion by the acid and the contamination of the cooler parts of the device with binder. The gas flow from these curtains is fully synchronised with the process parameters.

In addition to the gas system controlled by the MFC valves, a system of complete combustion of process pollutants is located on the outside of the device. This system operates with a fan which is also used for the cooling of the device during the final phase. On average, the standard device reaches a heating rate of 15 K/min and cooling rate to 5 K/min. The system control allows adopting these values dependent on the technological process. The entire structure is CE-marked and meets the ATEX requirements.

| Type MIM Eco Unit | CT 025-095 | CT 050-095 | CT 100-095 | CT 150-095 | CT 300-095 |
|---|---|---|---|---|---|
| Effective volume (approx. litres) | 25 | 50 | 100 | 150 | 300 |
| Loading width (mm) | 280 | 280 | 420 | 420 | 560 |
| Loading height (mm) | 300 | 300 | 400 | 400 | 500 |
| Loading depth (mm) | 310 | 620 | 620 | 930 | 1240 |
| Max. batch weight (kg) | 30 | 60 | 120 | 180 | 360 |
| Max. temperature (°C) | 950 | | | | |
| Installed load at 3 x 400 V (kW) | 30 | 60 | 90 | 120 | 210 |
| Nitrogen (Nm³/h) | 5 | 10 | 10 | 12 | 15 |
| Hydrogen (Nm³/h) | 2 | 5 | 10 | 12 | 15 |

*Table 1 The standard unit sizes for one step debinding process*

| Type MIM Eco Unit | VR 025-145 | VR 050-145 | VR 100-145 | VR 150-145 | VR 300-145 |
|---|---|---|---|---|---|
| Effective volume (approx. litres) | 25 | 50 | 100 | 150 | 300 |
| Loading width (mm) | 280 | 280 | 420 | 420 | 560 |
| Loading height (mm) | 300 | 300 | 400 | 400 | 500 |
| Loading depth (mm) | 310 | 620 | 620 | 930 | 1240 |
| Max. batch weight (kg) | 30 | 60 | 120 | 180 | 360 |
| Max. temp. in °C (option) | 1450 (1600) | 1450 (1600) | 1450 (1600) | 1450 (1600) | 1450 (1600) |
| Installed load at 3 x 400 V (kW) | 165 | 165 | 195 | 250 | 400 |
| Nitrogen (Nm³/h) | 2 | 3 | 4 | 4 | 4 |
| Hydrogen (Nm³/h) | 2 | 3 | 4 | 4 | 4 |

*Table 2 The standard specifications of ECO-MIM devices for sintering process*

## Sintering unit ECO-MIM-VR

The sintering furnace is also supplied in five basic sizes. Table 2 shows the basic specifications of the device. It is a typical cold wall system with heating elements placed inside a metal muffle - the hot zone (Fig. 4).

The muffle itself is made of molybdenum screens or, for an application of higher temperatures, a combination of molybdenum and tungsten screens. The metal muffle is placed in a vacuum-tight housing with a double-wall. The double-wall designs provides for the space between the inner and outer jacket in which water is circulating to cool the entire device. The process gases supplied through special collectors are fully monitored by a set of sensors

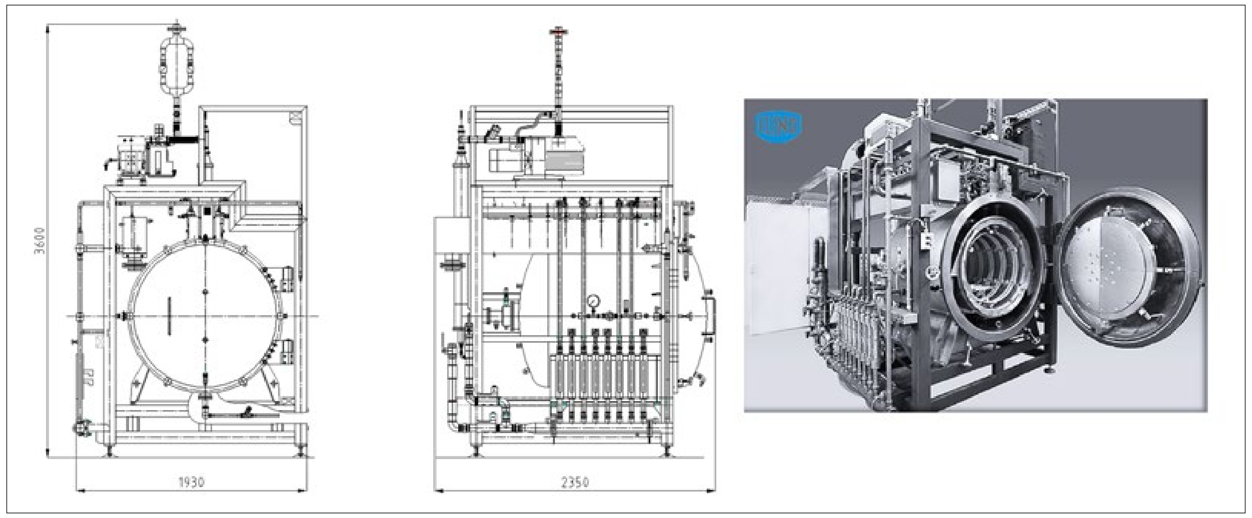


*Fig. 4 Batch sintering ECO -MIM furnace type VR 050-145*

*Fig. 5 A Continuous MIM furnace developed by Elino*

and also the flow is controlled by MFC valves. The device has a vacuum pump installed in order to obtain vacuum of approximately $10^{-2}$ mbar. All components in contact with explosive gases have ATEX certifications. The device has a fully safe hydrogen combustion system, which is designed to prevent misuse by an operator.

## Conclusions

A brief analysis preceded by many months of engineering research shows that in the case of catalytic and thermal debinding there are no appropriate solutions currently available to combine the two processes into a single device with a straightforward and economically viable approach to commercial production. There are a few manufacturers around the world who today are trying to connect all the processes into a single device, but to-date the solutions are a compromise. It should be noted that the cost of purchasing a universal device is not much lower than the cost of purchasing two devices dedicated strictly to the given types of processes. Further development work is ongoing to further increase cost-efficiency in terms of total operational cost, reduction in consumption cost of industrial gases and increase in number of cycles per day.

The MIM-ECO CT and MIM-ECO VR batch furnaces supplement an existing and well-proven product range of Elino continuous furnaces for MIM which have been manufactured since 2005. These continuous MIM furnaces consist of continuous catalytic debinding systems and continuous thermal debinding and sintering systems. The continuous catalytic debinding furnace is designed as complete gas tight system and operates at temperatures up to 160°C. It has a verified throughput rate as high as 50 kg/h at 4 h effective debinding time. The design is based on a patented system, provides for a special cross convection system and has shown to use 50% less in acid and nitrogen consumption in production compared to conventional systems. The continuous catalytic debinding furnace can be linked to the succeeding continuous thermal debinding and sintering furnace.

It is the basic concept for our continuous furnaces to allow for a strict separation of each individual process step and to assure absolute clean and complete exchange of atmospheric conditions before the next process step is initiated. The experiences from the operation of this continuous furnace product range led to the new concept for the above described batch furnace designs.

The continuous thermal debinding and sintering furnaces are separated by a gas-tight double-door lock chamber with purging system. The thermal debinding furnace is operated with high-velocity gas flow. The sintering furnace has a fully muffled high temperature sintering zone. Both, the thermal debinding and the sintering furnace can be designed in form of a L-, Z- or U-shape configuration, giving highest flexibility to fit in restricted production areas. Due to the strict atmosphere separation and the therewith linked atmosphere control schematic, the gas consumption shows to be less than 5 $m^3/h$ with excellent temperature homogeneity. The pusher system is designed such that no vibration during the movement of the plates occurs and has shown to be able to transport multi-layer stacks with very small parts without any damage to the parts.

The continuous furnaces have a proven record of achieving exceptional corrosion resistance and the highest quality parts. Different sensitive products are produced in such furnaces, including MIM stainless steels, foam materials, sintered aluminium parts, ultra-fine brazing products and even for standard sintered parts a high-level quality can be achieved using much cheaper alloys due to the sintering temperature above 1250ºC.

## Acknowledgments

The complete engineering work was done at Elino Industrie–Ofenbau GmbH in Duren, Germany. Elino is the part of the PLC holding group which includes the companies Wistra (Germany/China), Elmetherm (France/Germany), Wisconsin Oven (USA) and Mecarom (Romania).





# MIM industry expansion: What does it mean for vacuum furnace technology?

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With the MIM industry on the rise and expanding across an increasing number of sectors, requirements have been set to ensure that the quality of MIM parts is consistently high and MIM processing equipment is accurate and efficient. Debinding and sintering furnace performance needs to advance concurrently in order to accommodate these requirements without sacrificing cost-effective operation. Ipsen Inc. outlines how it has incorporated new technologies to address MIM part quality and economical operation concerns. This paper specifically illustrates how its furnaces' temperature uniformity, hot zone design, process gas management and binder removal systems can combat many of the common problems part manufacturers face when looking to fulfil increasing capacity requirements while also reducing manufacturing cost per part. Such technical advantages are crucial in staying ahead in the booming MIM industry.

As the MIM industry continues to grow and attract more interest from a widening range of industries, the advantages of MIM technology have contributed to the increased demand for high-quality MIM parts with tighter geometrical tolerances and ever improving material properties. With the desirable benefits of state-of-the-art MIM technology (e.g., capability of designing complex parts, cost-effective assembly, high-quality parts and enhanced production capacity) increasing in popularity, industry requirements have been outlined to ensure the increase in demand does not lead to lackluster, rushed results.

Higher power densities in modern car engines, power trains and other mechanical machinery requires the miniaturisation and compaction of mechanical systems that offer greater potential for innovative and cost-efficient production technologies. Furthermore, the enhanced functionality of intricate MIM parts can also lead to reduced assembly costs when mass producing products such as premium notebooks or mobile phones. However, to meet the increasing technical requirements and specifications of the industry, the potential to further improve the accuracy and efficiency of the MIM process equipment has to be exploited. Current limitations in terms of mechanical and chemical properties, as well as optical appearance, of the parts are determined, amongst others, by:

1. Inhomogeneous shrinkage (i.e., geometrical distortion) caused by:
   a) Non-uniform powder and feedstock mixing
   b) Density fluctuations introduced during moulding and/or the first debinding step
   c) Inaccurate temperature uniformity in the sintering furnace
2. Chemical decomposition and discolouration by:
   a) Inaccurate process gas management
   b) Binder re-deposition during the second debinding step
   c) Residual sintering furnace contamination

In addition to those technical limitations, highly competitive market conditions put intense cost pressure on part manufacturers. Thus, in order to drive the MIM industry forward, the need for more cost-efficient and technically improved production equipment and material is crucial.

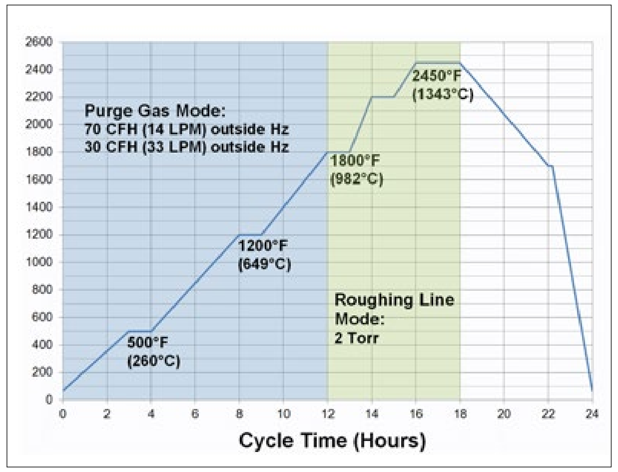


*Fig. 1 A typical MIM process, highlighting the different process modes used at different temperature levels*

*Fig. 2 An Ipsen TITAN DS MIM vacuum furnace*

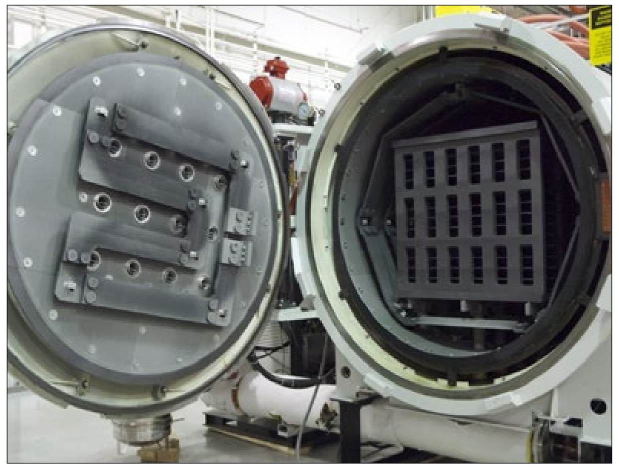

*Fig. 3 The interior and hot zone of a TITAN DS vacuum furnace*

Beside high purchasing prices for raw materials (e.g. fine-grained metal powders, polymer binder systems and ready-to-mold feedstock), high utility consumptions are among the major cost drivers of the MIM process. Low investment and operating costs of debinding and sintering furnaces are therefore key to the competitiveness of MIM part producers. Moreover, depending on the specific production situation of the individual manufacturer, the choice of the most suitable furnace technology is a prerequisite to becoming a successful player in the MIM industry.

## The typical MIM process and MIM industry requirements

A typical MIM process in a batch furnace uses the Purge Gas Mode during debinding temperature, followed by a Roughing Line Mode used up into sintering temperatures. With the larger furnace production lines, high quality is always a key requirement. Therefore, accurate process control is critical throughout the cycle, as well as cleanliness of parts, and scrap rate must be reduced and kept to a minimum.

An important factor for cost-efficient MIM vacuum furnace operation is the economical consumption of process gas and electrical power. Depending on the gas type, these two large cost elements of the sintering process can account for more than 50% of the total cost. The adjustability of a Partial Pressure Mode with the lowest possible gas flow, while still enabling a contamination-free debinding and sintering operation, must be implemented. Low heat losses in a well-designed hot zone with an efficient set-up of optimised heat elements will help to reduce electrical power consumption. To keep design and development costs reasonable, powerful CFD simulation tools were used to find optimised gas and heat flow patterns in modern and resource-saving vacuum MIM furnaces.

For fast-growing MIM companies looking for flexible production capacity and the ability to react quickly to changing market demands, long delivery times for production equipment can slow down growth. Usually, furnace manufacturers start producing equipment only after receiving an order, not keeping key components and long lead time materials in stock. The resulting delivery times of nine to twelve months for new furnaces regularly lead to bottlenecks in MIM production lines when additional part orders have to be scheduled at short notice. Only recently have lean manufacturing and standardised production concepts been introduced by leading vacuum furnace manufacturers to meet this rapid demand.

## Furnace technology

Apart from tailor-made, highly specialised systems, most of the MIM sintering furnaces on the market can be subdivided into vacuum batch or continuous atmospheric furnaces. Both technologies offer the possibility of integrating the thermal removal of residual polymer still contained in the brown parts after moulding and catalytic or solvent debinding.

For high volume MIM producers with correspondingly large lot sizes of identical or geometrically similar parts, the operation of a continuous atmospheric furnace may be appropriate if fully utilised. In this case, comparably low cycle time with high sintering capacities can result in a favourable cost-benefit ratio. However, with minimum annual production volumes in the range of 150 to 200 metric tons, high investment costs and large footprints, continuous furnaces are not economical in small or medium lot production lines. Furthermore, they are still prone to longer downtimes for maintenance, causing reduced manufacturing agility.

On the other hand, vacuum batch sintering furnaces, as offered by a number of commercial suppliers, allow for excellent control of the debinding and sintering process. The aforementioned limitations, in terms of geometrical distortion and chemical composition of the finished MIM parts, can be contained by for example sophisticated gas management systems providing laminar flow of unloaded gas to flush away outgassing binder material. Furthermore, by means of the smaller hot zone volume, temperature uniformity in vacuum furnaces can be extremely accurate and reach values as low as +/- 1K. In general, the superior cleanliness of the gas atmosphere, the enhanced adjustability of the process parameters, as well as the reduced vibration on the parts means that vacuum batch furnaces are the technology of choice when producing high-quality components for, as an example, medical applications. The lower investment and higher cycle flexibility offer further advantages when companies are facing volatile order situations and need to run parts with different geometries and materials. Operating an array of vacuum furnaces not only provides a flexible and robust production line, but also offers the possibility to run largely deviating operating programs at the same time.

**A MIM furnace's key components**

About 60% of commercial MIM part production uses stainless steels. The most popular alloys are 17-4 PH and austenitic stainless steels 304L and 316L. Prices for commercially available, ready-to-mould feedstock can be high and after moulding and debinding, the monetary value of the raw parts loaded into the furnace can exceed thousands of US dollars. Thus, the reliability and performance of a MIM furnace's key components is essential.





Hot zones

A hot zone must have excellent temperature uniformity of no more than +/-7 °F. This can be achieved by having multiple heat zones and by utilising front and rear elements. Process gas management is essential when it comes to protecting the hot zone from any binder wax contamination. Smart process control can be integrated within the furnace's program to efficiently transport the gaseous material out of the hot zone, while minimising the consumption of the process gas being used.

Binder removal can be achieved through the use of the high pumping capacity of a booster and mechanical screw pump. Efficient pumping out of the hot zone area is realised through a powerful pumping unit, which in this case consists of a vacuum booster (lobe pump) supported by a mechanical screw pump.

Comparing hot zones

As mentioned above, one of the critical requirements in the MIM industry is the reduced cost of the initial investment and the power consumption of the furnace.

However, some of the specialised MIM vacuum furnaces combining the previously mentioned technical advantages are limited to rather small usable volumes. Due to their disadvantageous invest-to-capacity ratio and lower energy efficiency, sintering costs per part might consume potential savings realised in other MIM process steps.

## Ipsen's MIM Technology

The TITAN DS debinding and sintering furnace incorporates a number of cutting-edge technologies that allow MIM manufacturers to compete in such a high-growth industry.

**Temperature uniformity**

The temperature uniformity required by the industry is particularly important for large volume furnaces. The TITAN DS work zone of 36" x 36" x 48" (910 mm x 910 mm x 1220 mm) and hearth gross load weight capacity of 4000 pounds (1800 kg) have a maximum operating temperature of 2550°F (1399°C) and a burnout temperature of 2600°F (1427°C). Even with the large size of the furnace, the temperature uniformity is within the required +/- 7°F through the use of Ipsen's patented DigiTrim® software technology which allows the user to control the power output of the furnace's three heat zones at four different temperature ranges, giving a flexibility to adjust uniformity at critical temperatures. Front and rear elements are also utilized in order to achieve greater uniformity.

**Hot zone design**

The hot zone is designed with two inches of graphite felt and backed with a carbon steel plenum as a structure. The design also integrates a durable CFC hot face designed to take any undesired force such as impact of parts during loading and unloading. Although not required for the MIM process, the CFC lining is capable of taking up to 12 bar range of quenching pressure, protecting the layers of the high-performance graphite felt. Robust, thick graphite elements can also take some of the unavoidable force.

Three heat trim zones are used with a total of six complete loops which are evenly distributed to provide optimum heating to the work load.

**Process gas management**

The TITAN DS can reach an ultimate vacuum level of less than <10 microns due to the booster and mechanical pump capability. Using nitrogen, hydrogen and argon, the furnace is equipped with a partial pressure of up to 10 Torr. For quenching, it is equipped with a 30 HP motor capable of cooling up to 2 bar with the option to select between nitrogen or argon gas.

The intuitive VacuProf® control software also allows the user to choose a Purge Gas Mode and Roughing Modulating Line Mode.

The main purpose of the Purge Gas Mode is to eliminate binder contamination inside the furnace. During this mode, we introduce the process gas at two different locations: one outside the hot zone, which always has the higher pressure, and the other inside the hot zone. Outside the hot zone, the process gas is introduced to prevent binder contamination on the furnace wall. Since we are pumping from inside the hot zone, the gas will flow inwards and out of the pumping port inside the hot zone. The process gas inside the hot zone continuously moves the evaporated binder, avoiding re-deposition of the wax on the parts and the stacking system used to support the parts.

The Roughing Modulating Valve Mode is used during a specific part of the high temperature sintering stages. At this time, it is assumed that all of the binder wax has been evaporated and purged out of the hot zone. Therefore, operators pump straight through the roughing line bypassing the Binder Trap System. The purpose of this valve is to control the partial pressure set point during the sintering stages where there is minimal outgassing occurring in the furnace, slowing the pumping down to maintain a set point at a constant flow rate of gas minimising the total consumption throughout the remaining stages of the cycle.

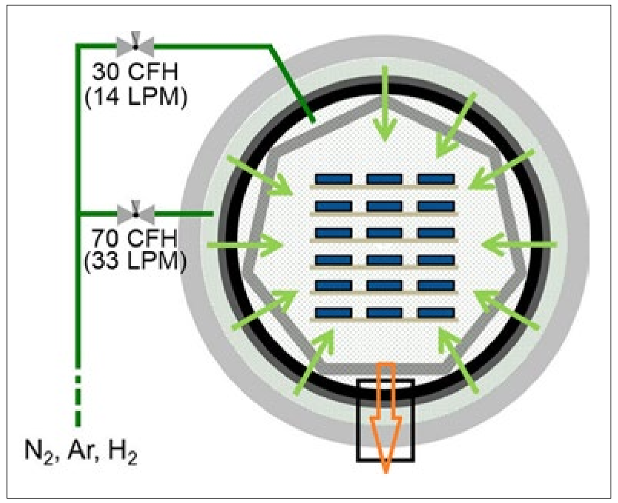


*Fig. 4 Partial pressure gas diagram. During the debinding cycle, gas is evacuated from the hot zone to the binder trap before going through the pumping system. Wax is removed from the hot zone and collected in the binder trap*

| Graphite |
|---|
| Less expensive to replace than molybdenum |
| Easier to maintain |
| More energy efficient (50% lower heat loss) |
| Longer lifespans |
| **Molybdenum** |
| Better leak rate |
| Minimises water absorption |
| Suitable for titanium materials |
| Higher temperature applications – less risk of eutectic melting |

*Table 1 Hot zone benefit comparison*

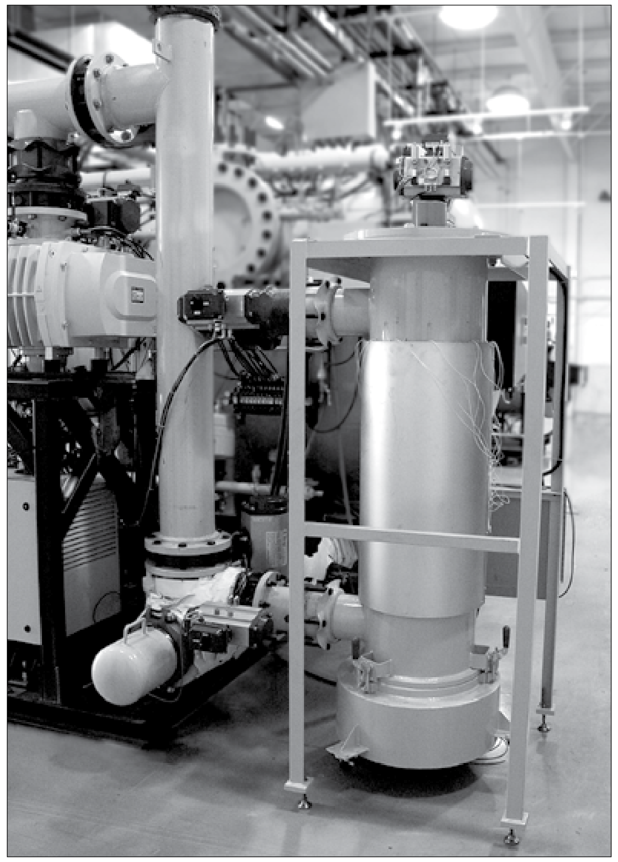

*Fig. 5 Ipsen's versatile binder traps are equipped with heating elements and quickly interchangeable collection bucket*

**Binder removal system**

After meticulous removal of the polymeric binder residues from the hot zone, continued efficient handling and filtration of the charged process gas is critical to avoid unwanted binder material buildup in pipes, valves or pumps. For an uninterrupted and low-maintenance operation, it is therefore essential to protect critical furnace components by means of an efficient binder trap system. With a pumping rate of 3000 cubic feet per minute (5097 cubic meters per hour), very little process gas is used during the debinding period of the cycle. To protect the pumps, an efficient binder trap system must be installed prior to the pumps to avoid binder contamination.

This features a four-stage effluent trapping system. The first stage knocks down heavy particles and condenses volatile solids and liquids on large surface areas. Stages two and three contain wire mesh screen elements strategically located to filter the binder gradually. The last stage is designed to trap any vapour molecules that might have passed the previous stages. The modular system is designed with heaters to dissolve trapped binder which is then collected in a collection bucket that can be easily removed and changed for cleaning.

Even though the risk of contaminating the vacuum pumps is now reduced to a minimum, long-term buildup of binder deposits, for example on the lobes or casings, still can occur when continuously running the furnace in 24/7 operation. In order to maintain maximum pumping performance, fast-rotating parts assembled with minimal clearances need to be kept clean. An innovative cleaning concept based on software-controlled pump flushing procedures was recently tested in a new vacuum MIM furnace from Ipsen. Liquid solvent, capable of dissolving hardened polymeric binder, is injected in the suction line of the vacuum booster and the connected screw pump. Rotational speed of the lobes or screws can be adjusted by means of a variable frequency drive to control liquid flow velocity and to ensure efficient washing out of the polymeric precipitations.

## Conclusion

Modern vacuum furnaces featuring innovative technologies will improve the efficiency and competitiveness of the industrial MIM process. For its economic success, capital and operational costs of such specialised MIM furnaces must be kept within reasonable limits. With the demands on the MIM industry on the rise, technologies such as those introduced in the TITAN DS furnace combat problems that may arise as customers look to meet increasing requirements and stay competitive, while also reducing the manufacturing cost per part in larger vacuum MIM furnaces.

# Events Guide

## 2013

**APMA 2013 International PM Conference and Exhibition**
November 3-6
Xiamen, China
www.apma2013.com

**Hagen Symposium (32nd)**
November 28-29, 2013.
Hagen, Germany
www.pulvermetallurgie.com

**2013 International Titanium Powder Processing, Consolidation and Metallurgy Conference**
December 2-4
Waikato, New Zealand
www.tida.co.nz

## 2014

**PM14 - International Conference on Powder Metallurgy and Particulate Materials & Exhibition**
January 23-25, Chennai, India
www.pmai.in/pm14

**MIM 2014**
February 24-26
Long Beach, California, USA
www.mpif.org

**10th International Conference on the Science of Hard Materials (ICSHM10)**
March 10 - 14
Cancun, Mexico
www.icshm10.org

**PM China 2014 - International Power Metallurgy Exhibition & Conference**
April 27-29,
Shanghai, China
www.cn-pmexpo.com

**PM2014 World Congress**
May 18–22
Orlando, Florida, USA
www.mpif.org

**HIP 2014, 11th International HIP Conference**
June 9 -13, 2014
Stockholm, Sweden
www.hip14.se

**Sintering 2014**
August 24-28 Dresden, Germany
www.sintering2014.com

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