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FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

POWDER INJECTION MOULDING INTERNATIONAL

in this issue

MIM in Taiwan

Company profiles: FloMet, LÖMI

MIM2011 conference review

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

MIM2011 highlights the evolution of Asia's MIM industry

The MPIF's annual MIM conference was for many years a predominantly domestic event, however in recent times the event has succeeded in attracting a much more diverse international audience. As a result, it now offers a valuable insight into global PIM industry developments.

What was clear from this year's event is that Asia's PIM industry is currently experiencing the most significant changes. In particular, China is now making its presence felt as both a supplier of raw materials and as a producer of PIM parts.

Chinese powder suppliers have worked hard to improve quality and consistency in recent years and it now appears that, thanks in part to global shortages of fine powders for MIM, some suppliers are achieving success in the international marketplace. For example, in this issue's news section alone we highlight two important deals for Chinese powder producers with well established European and North American distributors.

Chinese PIM part producers are also seeing business grow at a dramatic rate, with sales being generated both domestically and internationally. There are also reports of major increases in capacity planned in the near future.

Within the rest of Asia, the impact of the growth of Chinese PIM has been, in many cases, to focus efforts on developing niche local markets whilst leveraging the ability to process more sophisticated parts and materials. Read our full report on MIM2011 from page 42.

In this issue we also look at the current status of MIM technology and production in Taiwan (page 29), as well as reporting on MIM production at one of North America's most well known MIM producers, FloMet (page 35). We additionally highlight the success of German debinding equipment producer LÖMI, which is doubling production capacity to meet demand from the PIM industry (page 48).

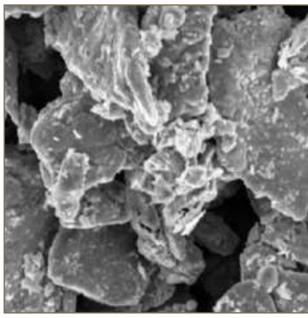
Nick Williams
Managing Director and Editor

Cover image
Surgical tool featuring Stryker MIM parts
Courtesy Stryker Corporation

Powder Injection Moulding International







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

Yuelong Superfine Metal Powders appoints US Metal Powders as distributor for the Americas

Yuelong Superfine Metal Powders (YSM), a leading Chinese producer of carbonyl iron (CIP) and stainless steel powders, has appointed United States Metal Powders, Inc. (USMP) as its distributor for the Americas.

YSM was founded in 2001 initially as a producer of carbonyl iron powders (CIP) and during the past eight years has become one of the major global producers of CIP. At the same time, YSM has expanded its product range to include a series of atomised stainless steel and high alloy metal powders for use in both MIM and conventional PM applications.

USMP was founded in 1918 and was formerly United States Bronze Powders, Inc. In 2010 USMP sold its copper based powder business to focus on the growing global demand for specialised aluminium powders and those specialised metal powders provided by YSM. These powders take advantage of the rapidly increasing demand for technically superior particulates for industries such as the MIM and renewable energy processes.

YSM, it was stated, were greatly influenced by USMP's success in marketing and providing technical support for more than 15 years for a Japanese producer of similar powders.

www.ylcip.com ■

MIM producer ITB appoints Vervoort as Technology Manager

Peter Vervoort, formerly Group R&D Manager at Elino GmbH, has been appointed as Technology Manager at Dutch MIM producer ITB Precisietechniek.

René van Ommeren, COO and Chairman of the Board, of ITB Group told *PIM International* that Vervoort would, as of July 1, be responsible for the global ITB MIM business world-wide, including new business, projects and technology/operations. ITB specialises in MIM and plastic injection moulding, stamping and assembly, as well as product and tool design.

www.itb.nl ■

Höganäs AB includes MIM in key industry segments for growth and development

Swedish metal powder producer Höganäs AB has identified six segments where it sees especially high potential to create cost efficiency and environmental benefits using powder technology. The segments were outlined in the company's 2010 Annual Report, published earlier this month.

The company states that it has appointed specialist "Global Development Teams" to cover each segment, with the assignment of developing an understanding of needs for application ideas and customer collaborations.

The areas identified are Powder Metallurgy, specifically the development of automotive gears, Surface Coatings, Brazing, Electromagnetic Applications, Filters and Metal Injection Moulding (MIM).

Höganäs stated that MIM was a "technology that offers the same benefits as pressed components, simultaneous with greater design flexibility. In the future, many forged or cast components should be suitable for injection moulding with powder."

The full 2010 Annual Report is available for download from the Höganäs AB website.

www.hoganas.com ■

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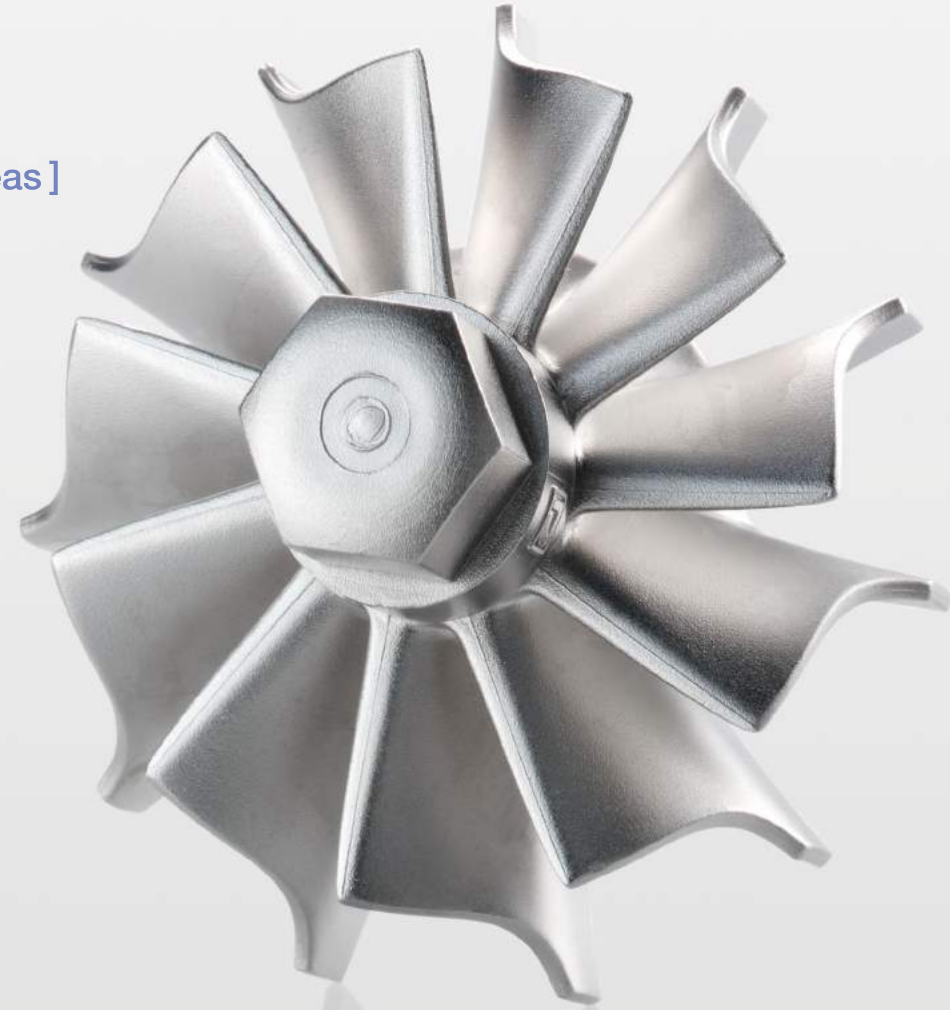

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BASF
The Chemical Company

BMV to distribute AT&M's atomised powders in Europe

AT&M has announced it will partner with Burkard Metallpulver Vertrieb GmbH (BMV) for the sales & marketing of atomised powders used in Metal Injection Moulding (MIM), thermal spraying and rapid tooling processes. BMV will be the representative of AT&M in Europe, the cooperation became effective April 20, 2011.

Based in Beijing, China, AT&M was established by the Central Iron & Steel Research Institute (CISRI), and underwent a successful IPO on the Shenzhen Stock Exchange in 2000. AT&M has been engaged in the production of atomised powders for more than 40 years and provides the full range of powder manufacturing technology from open air gas, vacuum gas, and conventional water atomisation through to high pressure water atomisation, which is particularly suitable for extra fine powders. The scope of powders covers Fe-, Ni- and Co-base alloys.

A projected expansion of the current capacity will enable AT&M to support the strong growth rates of the MIM industry on a long term-basis.

Jing Chenghai, General Manager of AT&M's PM division stated, "AT&M is pleased to have reached this agreement with BMV. It enables us to ensure stringent and successful marketing of our powder products especially for use in MIM, and to learn about the particular market requirements in Europe."

"With his longstanding experience in sales & marketing of powder products and his excellent market reputation, Harald Burkard is the ideal partner and contact for our target customers. He shall help to increase AT&M market presence and achieve our ambitious goals," continued Jing Chenghai.

BMV, based in Düsseldorf, Germany, was established in 2006. More than 25 years of experience in global marketing of powder materials form the backbone of successful consultancy and business support. The company considers itself as a service point between the manufacturer and the consumer, supporting either side for both, sales and marketing as well as sourcing and supply.

BMV is already a representative for the fine MIM-powders of Eurotungstene, France (W, W/Cu, Ni, FeNi), AP&C (Raymor), Canada (Ti), Hilderbrand CH (Ag, Au, Pd) and H.C. Starck for refractory metal components and Wall Colmonoy UK for Colferoloy® (Fe-base thermal spray powders).

Harald Burkard, owner and Managing Director of BMV commented, "The completion of the portfolio with fine stainless and low alloyed steels as well as super alloys is a perfect match with our existing product range and contributes to the company's long-term strategy. I am pleased that with AT&M we have found such a high level potential partner with advanced expertise, modern manufacturing technology and sufficient capacities to support our ambitious growth strategy."

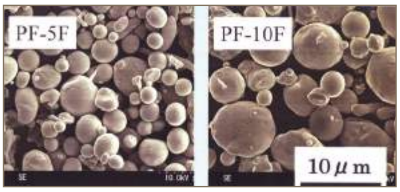
www.atmcn.com

www.bmv-burkard.com

Business resumes at tsunami damaged Epson-Atmix Corporation

Epson-Atmix Corporation has issued a series of statements regarding its metal powder and MIM parts operations since the earthquake and tsunami of March 11th. The Northern Japanese city of Hachinohe, in which the company's metal powder and MIM operations are based, suffered major damage after being struck by the tsunami.

In its statements, the company confirmed that thankfully there were no injuries amongst their employees, however the facilities had been seriously affected by water damage.



Epson Atmix is an important supplier of fine water atomised powders for the global MIM industry

Despite the impact of the tsunami, the company confirmed that its metal powder production operations had partly resumed operations at the end of April. Epson Atmix is a leading international supplier of water atomised metal powders for the MIM industry.

Limited electricity supplies immediately after the disaster were believed to be a major factor in delaying initial efforts to survey the extent of the damage and commence repairs.

The company also stated that its MIM parts business, which was not as badly damaged as the powder production area, restarted production on April 4th. The company is the largest producer of MIM parts in Japan.

www.atmix.co.jp

Elnik Systems launches new website

Elnik Systems, a market leading supplier of debinding and sintering furnaces for metal injection moulding, has launched an fully revised and updated website, www.elnik.com.

The site includes a new "Virtual Tour" of an Elnik MIM 3000 furnace, improved quote request process for easier and faster response times, and updated brochures of equipment Elnik offers.

Links to DSH Technologies, a leader in MIM consultation and project enhancement is included, along with other selected equipment and material supply partners.

www.elnik.com

MIM stainless hinge makes sunglasses unbreakable

The Sutro Fisk range of sunglasses, designed by Jeff Sands, incorporates metal injection moulded 17-4PH stainless steel ratchet hinges in the sunglass frame which, Fisk states, makes the frame 'virtually unbreakable'.

The MIM hinge is integrated into the face frame in the front and screwed directly into the temple at the rear

The MIM hinge in the Sutro Fisk range of sunglasses

Eramet Group turnover up 23% in 1st Quarter 2011

Eramet, the French-based producer of alloying metals, particularly Mn and Ni used to improve the properties of high performance special steels, reports increases in all divisions in the first quarter of 2011.

The company's consolidated turnover rose 23% to €973 million, of which €237 million was contributed by the Alloys Division – an increase of 30% compared with the same quarter in 2010.

The Alloys Division includes the production of the ASP range of PM alloys produced by gas atomisation and HIPing used in tooling, aerospace and specialty steel. Eramet employs around 14,000 people in 20 countries.

www.eramet.fr

H.C. Starck continues positive performance

H.C. Starck, one of the leading manufacturers of refractory metals and advanced ceramics, has reported continued growth in all of its business units through the first quarter of 2011.

In the 2010 fiscal year, H.C. Starck increased its revenues by 59% to €689 million. In doing so, the company exceeded its expectations in all of its business units and gained significant market shares, particularly with regard to its tantalum and tungsten activities.

One important factor that contributed to this performance was the resurgent demand seen across all markets. "The rapid and systematic restructuring of our company also played a significant role in the positive development of our business. We made our organisational structure more efficient and more tailored to the needs of the market, and also focused our product range on our core business area," commented Dr. Andreas Meier, CEO of H.C. Starck. "In addition, the cost-cutting measures we implemented made a noticeable contribution to our excellent annual result."

In the first quarter of 2011, business was also strong, thanks to the ongoing economic recovery and the resulting continued increase in market demand. "In addition, we have completed one of our most important strategic tasks," added Dr. Meier. "Thanks to longer term supply agreements with established mines and the EICC certification for our tantalum procurement process, we have been able to secure our supply of ethically produced raw materials. As a result, we are in an excellent position to achieve our above-average growth targets for 2011."

www.hcstarck.com

Submitting News

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

AT&M Highmag expands MIM production in Shenzhen

Shenzhen AT&M Highmag Metal Ltd, located in the Pearl River delta zone of Shenzhen in the Guangdong Province in China, is an established manufacturer of bonded NdFeB magnets with monthly production put at over 26 million pieces.

In the second half of 2008, AT&M Highmag established a new advanced, high volume MIM manufacturing facility on the site and the company reports that it has just completed the expansion of a fourth MIM production line, taking monthly production to over 2 million pieces and annual MIM capacity to over 100 tonnes.

Annual sales are reported to be in the region of CNY 60,000,000 ($9.2 million). The expanded MIM facility is now said to be operating 24 injection moulding machines and 22 debinding/sintering furnaces, and is said to be using BASF feedstock and catalytic debinding for MIM part production.

www.hmg-mim.cn

New Chief Executive for engineering giant GKN

GKN plc, a global leader in the production of MIM components and the world's largest manufacturer of powder metallurgy components, has announced that, as of 1 January 2012, Nigel Stein will succeed Sir Kevin Smith as Chief Executive of the group.

In a statement issued by the company, Sir Kevin Smith has informed the Board that he wishes to retire from GKN at the end of 2011 after nine years as Chief Executive. Smith joined the Board of GKN in 1999 as head of its Aerospace division and became Chief Executive in January 2003.

Nigel Stein has been a member of the Board since 2001 and is currently Chief Executive of GKN's automotive division, a position he has held since June 2007. Prior to that he was Group Finance Director.

Smith said, "GKN is a great company with a fantastic team of people. I am proud to have led them through a period during which we have transformed the Group into a premier global engineering company. After nine years as Chief Executive, I feel that the time is right for me to step down, with the Company now entering a new phase and well positioned to deliver sustainable growth."

Roy Brown, GKN's Chairman, added, "The Board recognises the very significant contribution that Kevin has made to GKN during his 12 years with the Company, and particularly during his nine years as Chief Executive. This has been one of the most challenging periods in the long history of GKN. Kevin has led the team through that period and laid the strongest foundations for growth now and into the future."

www.gkn.com

GKN's Bad Langensalza MIM plant is one of the largest in Europe

Xiamen Tungsten and China Minmetals to expand tungsten production capacity

Xiamen Tungsten will cooperate with China Minmetals Non-Ferrous Metals (CMNM), a Xiamen-based tungsten company, and the Jiujiang government in Jiangxi province, to explore and develop tungsten resources in Jiujiang.

The total investment amount is expected to reach four billion yuan. According to the agreement, Xiamen Tungsten and CMNM will jointly invest two billion yuan to set up a new company.

The company will be in charge of a project which will produce around 6,000 tons of tungsten powder and 4,000 tons of kentanium.

The first phase of the project will be put into operation by the end of the first half of 2011.

www.xiamentungsten.com

EuroPM 2011 Barcelona: Conference Programme now available

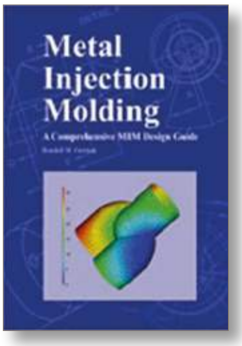
The conference programme for this year's EuroPM 2011 conference is now available to download from the EPMA's website.

The event includes over 250 technical papers, presented in oral and poster sessions, as well as three in-depth "Special Interest Seminars". There will also be customised programmes for the 'Hard Materials', 'Metal Injection Moulding' and 'Hot Isostatic Pressing' sectors, in addition to mainstream 'Ferrous Parts' presentations.

An extensive social programme will give delegates additional opportunities to network, and includes an Exhibition and Poster Reception sponsored by leading PM industry news service *ipmd.net* as well as a Gala Dinner at the Casa Llotja de Mar in the heart of Barcelona.

www.epma.com

MPIF publishes new MIM book



The Metal Powder Industries Federation (MPIF) in Princeton, NJ, has published a new 208 page book entitled 'Metal Injection Molding' written by Professor Randall M. German, San Diego State University, USA, which is available in soft cover and as a CD-ROM.

The book's nine chapters include: Introduction, Process Options, Design Principles, Manufacturing Considerations, Materials Properties, Costs, Applications, Market Considerations and Supplemental Data. ISBN No. 978-0-9819496-6-6, 2011. The list price is $100, however discounts are available for APMI and MPIF members.

www.mpif.org

H.C. Starck and Jiangxi Rare Metals Tungsten Holding Group Co. Ltd. to cooperate on advanced tungsten products business in China

H.C. Starck and Jiangxi Rare Metals Tungsten Holding Group Co. Ltd. (JXTC) have signed two agreements to form a joint venture to produce advanced tungsten chemicals, metal and carbide powders.

For H.C. Starck the joint venture is a crucial element of the company's strategy to expand its presence in China. Based on the agreements, the joint investment sum will be 800 million RMB (€85 million) to establish two companies based in the Chinese city of Guanzhou. With an installed capacity of 30,000 tons, by 2012 both companies will be producing approximately 10,000 tons of advanced tungsten products for the market annually.

Each partner holds the majority share in one of the two companies: JXTC in the manufacturer of ammonium paratungstate and tungsten oxide; H.C. Starck in the manufacturer of tungsten metal powder and tungsten carbide. The establishment and development of these two joint ventures will support the high-tech development of the tungsten industry in Jiangxi as well as in China. It will also provide additional economic and social benefits to Jiangxi Province.

"Both JXTC and H.C. Starck are key players in the refractory metals industry, and have a unique expertise and a long-standing company history. This joint venture will definitely have a very positive impact on China's, as well as on the world's, refractory metal industry development. It will be a role model for Sino-German refractory metal strategic cooperation," said Zhong Xiaoyun, President and CEO of JXTC.

"This Joint Venture is our largest project in China to date and is a core part of our growth strategy in Asia. With this step, we aim to significantly accelerate our capabilities to better serve the fast growing Chinese market," said Andreas Meier, CEO of H.C. Starck. "Our outstanding long-term relationship with JXTC, the intense efforts shown by both parties during the negotiations, and the support of government agencies in China all helped to ensure a smooth process in the founding of these joint ventures. We believe that the Joint Venture will provide a win-win situation for both partners."

Advanced tungsten products are used as high performance materials in a variety of different growth industries, including speciality cutting tool manufacturing, wear parts for mining, tunnel and street construction, as an alloy metal, and for components in the aerospace and medical engineering industry.

www.hcstarck.com www.jxtc.com.cn

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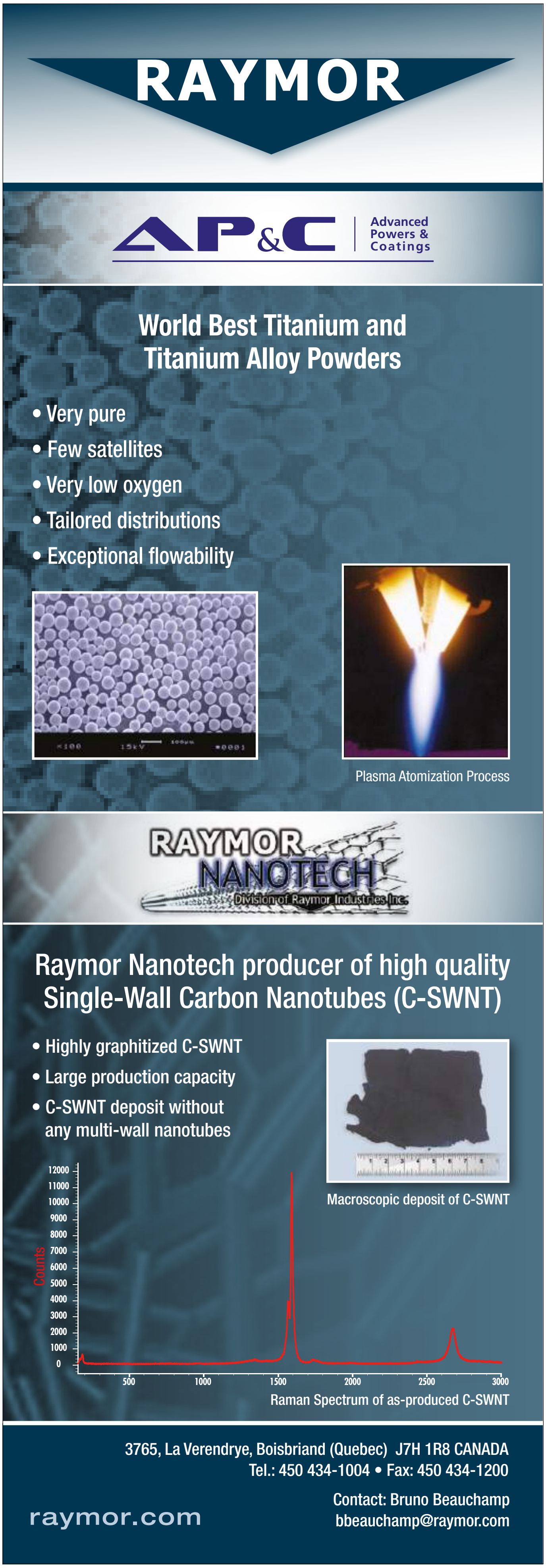

Single-Wall Carbon Nanotube product line launched by Raymor Nanotech

Raymor Nanotech, a sister division of AP&C and part of Raymor Industries group, has recently introduced a new high tech product line consisting of Single-Wall Carbon Nanotubes (C-SWNT). Carbon nanotubes, when used as reinforcement fibres, can greatly enhance the characteristics and properties of metals, ceramics and polymers.

Single-Wall Carbon Nanotube materials when combined with Al, Cu, Mg, Ni, Ti, and Sn have clearly demonstrated improved tensile strength, hardness and elastic modulus properties. Aluminium and C-SWNT composites have shown to have improved tensile strength in the order of 129% compared with pure aluminium.

Recent research has demonstrated that titanium/carbon nanotube composite materials produced by PM can significantly increase tensile stress, hardness and yield stress, as well as increasing hardness properties of the metal by as much as 450% combined with an improved elastic modulus of 65% when compared to pure Titanium

Nanotech C-SWNT are 100 times stronger than steel for a fifth of the weight, conduct heat just as well as diamonds and can support a very large current density ($>10^9$ A/cm^2). A material with such outstanding properties is ideally suited to applications that include:

- Reinforcing polymers, metals, metal alloys and ceramics
- Electrical and thermal conductivity products
- Electromagnetic shielding applications
- Catalyst support.

Single-Wall Carbon Nanotubes can also be integrated into sensors in order to detect gas and biological compounds. As membrane foam the product can also provide exceptional filtering properties. Raymor states that C-SWNT can also be used as a field emission device and for battery electrodes as well as promote biocompatibility to human tissue.

There are a number of challenges with regards to developing Metal/Carbon Nanotube composite materials. These include dispersion and preservation of the Nanotube structure. Raymor states that C-SWNT could be the key for the future development of advanced metal properties in countless every day applications, adding that the company is committed to developing the best C-SWNT and within the near future, metal/carbon nanotube composite materials.

Raymor Nanotech's main production facility is located in Boisbriand, Canada and can now claim to be amongst the largest producers of C-SWNT in the world. Contrary to most processes, the Raymor Nanotech plasma torch based technology is continuous. This innovative process is licensed by the National Research Council of Canada and the University of Sherbrooke.

The product is highly graphitised and is available defect free and without multi-wall carbon nanotubes.

For more information regarding Raymor Nanotech products contact Bruno Beauchamp at bbeauchamp@raymor.com

www.raymor.com ■

PM2012 Powder Metallurgy World Congress organisers issue Call for Papers

The organisers of the PM2012 Powder Metallurgy World Congress and Exhibition, October 14-18 2012, Yokohama, Japan, are inviting the PM community to submit presentations for inclusion in the technical programme. Interested parties are asked to submit an abstract no later than November 20, 2011.

The event is organised by the Japan Powder Metallurgy Association (JPMA) and the Japan Society of Powder and Powder Metallurgy (JSPM), with the support of the European Powder Metallurgy Association (EPMA), Metal Powder Industries Federation (MPIF) and Asian Powder Metallurgy Association (APMA).

The event carries the theme "Challenge for the next generation" and it is stated that advanced technology and information for the "Environment" and "Energy Saving" will be introduced.

Special session topics include:

- Thermoelectric materials and devices for green energy harvesting
- Nano-structured and/or nano reinforced metal/ceramic composite
- Synthesis and processing of materials by Spark Plasma Sintering

Main oral and poster topics are set to include:

- Powder Manufacturing & Processing
- Powder Pressing
- Sintering
- Full Density & Alternative Consolidation
- Powder Injection Moulding
- Miniaturisation & Nanotechnology in PM
- Secondary & Finishing Operations
- Tools for Improving PM
- Irons & Steels
- Nonferrous & Special Materials
- Lightweight & Porous Materials
- Biomaterials
- Hard Materials
- Magnetic & Electric Materials
- Functional Materials
- PM for Current & Future Applications

All submitted papers will be reviewed and allocated to Oral or Poster Sessions by the Technical Program Committee, based on authors' choices and acceptance notification will be e-mailed to the authors by the end of February 2012.

In a statement on the event website, the organising committee is seeking to reassure potential participants about the safety of attending the event. Yokohama is situated just south of Tokyo, more than 250 km from the areas hit by the March 11 earthquake, tsunami and the Fukushima nuclear plant.

www.pm2012.jp

Arburg celebrates 50 years of its Allrounder with 5,200 "Open Day" guests

At Arburg's Customer Centre some 30 Allrounder machines were on display

"The injection moulding sector is booming again," stated Arburg as its 2011 Technology Days got underway on March 23rd, running until March 26th. A record 5200 visitors attended the event from 54 countries, which took place at the company's headquarters in Lossburg, Germany. Some 40% of visitors, stated Arburg, came from outside Germany.

Michael Hehl, Managing Partner and spokesperson for the Arburg Management Team, was highly satisfied with the event, stating, "No other event world-wide combines detailed insights into the current Arburg technology so well with the opportunity to engage in exhaustive technical discussions with our specialists. Moreover, the unique atmosphere at the Customer Centre and throughout the company never fails to impress our visitors."

Electric Allrounder Edrive machines

A permanent fixture at the Technology Days is the presentation of product and application innovations. This year, the new electric Allrounder Edrive machine series, which enables high-end entry into the world of Arburg electric machines, celebrated its global premiere. In terms of performance characteristics, the Allrounder Edrive machines represent an alternative to basic hydraulic machines. They cover a broad range of applications, particularly with regard to the technical injection moulding segment. All four sizes of the Edrive machine series were presented, covering a clamping force range from 600 to 2,000 kN.

"50 years of Allrounder"

In 2011 Arburg celebrates 50 years of its Allrounder injection moulding machine range. "More than 40 hydraulic, hybrid and electric machines, as well as a comprehensive range of applications, provided impressive evidence that the modular Allrounder range always provides optimal customer-specific solutions," stated Arburg.

The applications presented included the production of packaging and medical technology products, clean-room technology, multi-component injection moulding, micro-injection moulding, the production of technical parts and the processing of different materials, from liquid silicone (LSR) and thermosets through to metal and ceramic powders.

Foreign delegations who visited the Technology Days in the company of the Arburg subsidiaries and trading partners were offered guided tours of the production areas in their own national language. In addition, around 2,000 visitors took part in the approximately 250 German language tours.

www.arburg.com

Global economic expansion powers growth at OM Group

The OM Group (OMG) based in Cleveland, Ohio, reports an increase of 9% in net sales in Q1 2011 to $331.3 million compared with the same period in 2010, with net income for the first quarter at $30.7 million. The increase was said to be driven by sustained growth across all three of the company's operating segments, including Battery Technologies, Advanced Materials (cobalt powder), and Specialty Chemicals.

The company reported that global economic expansion is powering growth in many sectors which it serves, including semiconductors, memory disks and printed circuit board and materials used in rechargeable batteries, hardmetal cutting tools for automotive and industrial production, and speciality batteries for defence and aerospace applications.

"We are pleased to report that we are picking up in 2011 where we left off in 2010, as demand remains strong across most of our global end markets," said Joseph Scaminace, Chairman and Chief Executive Officer. "Equally important is the fact that we continue to translate our strong top-line results into profitable bottom-line growth and positive cash flow from operations. This financial strength gives us the flexibility to continue to fund our growth for both the near and longer term."

OM Group's Powder Metallurgy team recorded another record quarter in Q1 due to a combination of gains in market share and very strong global tooling demand. Cobalt sales volumes were up 22% sequentially and up 19% compared with the same period in 2010.

www.omgi.com

New compound opens way to Electric Vehicle magnets without rare earths

Existing magnets for EV motors use neodymium, a rare-earth metal mostly produced in China, as well as iron and boron. As prices of neodymium rise, the industry has actively been seeking alternative materials. As reported on the *Nikkei* website, a team of researchers, mainly from Toda Kogyo Corp. and Tohoku University, have announced that they have succeeded in making a magnetic material without rare-earth metals.

The material is an ultrafine powder made from iron and nitrogen, measuring tens to hundreds of nanometers in diameter, which can be used in electric-vehicle motor magnets, the researchers say. A magnet made of this compound will be "60% more powerful than existing magnets," says Professor Migaku Takahashi of Tohoku University.

This opens a new frontier in the development of smaller magnets, making it possible to reduce the size of EV motors by 40% without compromising power. The team was able to make several tens of grams of the compound while ensuring consistent quality. But for commercial applications, the material must be moulded into a magnet by using heat and pressure. Toyota Motor Corp. and Honda R&D Co. plan to commercialise the new compound powder by 2023.

www.nikkei.com

Microwave furnace produces superior sintered zirconia dental restorations, states Spheric Technologies

Superior zirconia-based dental restorations can be produced with a microwave sintering furnace, according to Spheric Technologies, based in Phoenix, Arizona, USA.

The company states that it has developed a batch-type microwave sintering furnace specially designed for dental laboratories.

Microwave sintering of ceramics, state Spheric, offers significant advantages over conventional sintering methods. Research conducted at Arizona State University shows that microwave-sintered zirconia samples had increased flexure strength compared to those sintered in a conventional furnace. This was attributed to a reduced grain size and rapid densification in the zirconia samples due to microwave-driven enhanced sintering kinetics. Microwave sintering also produces a more natural and translucent appearance in dental restorations.

Samples tested in a steam environment at 125°C and 200 kPa pressure for 75 hours showed a reduction of flexure strength by 43% for conventionally sintered samples and only 14% for microwave-sintered samples. It was estimated that this corresponded to ten years of simulated testing in the mouth, after which microwave-sintered zirconia does not deteriorate significantly and is nearly 50% stronger than conventionally sintered zirconia.

Advanced microwave sintering furnaces specially designed for dental labs are now available. The ADS (private labeled as the MicroSinterWave A1614) microwave batch furnace is air-cooled; offers an effective uniform heating volume of approximately 100 x 100 x 60 mm; has a maximum microwave power output of 1.1 kW; and features computerised temperature programming and control in the range 250-1650°C. The system includes factory preset programs for automatic mode operation that complete zirconia sintering runs in as little as 90 minutes. Various operator-defined temperature ramp-up rates, temperature hold stages (up to about 1550°C) and hold times may also be programmed.

For labs with higher throughput requirements, the Spheric AMPS continuous microwave furnace is available.

Spheric Technologies develops, licenses, acquires and commercialises critical microwave technologies to support the production of advanced industrial materials and products. The company markets patented SPHERIC high-temperature microwave systems for applications that include the sintering of powdered metals, advanced ceramics and high-temperature chemical synthesis. The company has also patented technologies for the production of high-purity, small particle metal oxides.

www.SphericTech.com

Seong Jin Park named Namgo Young Chaired Professor

Dr. Seong Jin Park, Associate Professor at POSTECH (Pohang University of Science and Technology, Korea) has been named Namgo Young Chaired Professor.

Dr. Seong Jin Park

He has held a number of posts at various international organisations including LG Electronics, Pennsylvania State University, Mississippi State University, and CetaTech, Inc. He is the author of 72 peer-reviewed journal papers, over 180 conference presentations, and eight books and book chapters, holds five patents, and created four commercialised software programs.

His area of specialisation and interest is polymer-assisted powder processing with physical modelling and numerical simulation, including mixing, powder injection moulding, die compaction, debinding, sintering and HIPing.

www.postech.ac.kr

Molycorp and Ames Laboratory look to further developments of rare earth magnets

Molycorp, Inc., the Western hemisphere's only producer of rare earth oxides, recently announced that it has entered into a cooperative research and development agreement with the U.S. Department of Energy's Ames Laboratory. The Molycorp-Ames partnership will focus on developing new methods to create commercial-grade rare earth permanent magnets.

The collaboration combines Ames Laboratory's 60+ years of experience in the critical materials science field with Molycorp's 58+ years of experience in developing and commercialising innovative rare earth processing technologies.

"We are looking forward to a highly successful partnership between Molycorp and the Ames Laboratory that will incorporate new techniques, processes, and materials into U.S. supply chains," stated Debra Covey, Ames Laboratory associate laboratory director for Sponsored Research Administration.

"This is a significant first step towards a long and mutually beneficial relationship between these two committed entities," said Karl Gschneidner Jr., who will lead the research efforts at Ames Laboratory. "The Ames-Molycorp partnership will serve to re-energise applied rare earth research in the U.S., and will begin to ameliorate the current void in intellectual infrastructure in rare earths by training undergraduates, graduate, and post-doctoral students and providing them with research opportunities."

Ames Laboratory scientists will investigate several compositions of rare earth materials and processing techniques with the goal of making permanent rare earth magnets with properties comparable to currently available neodymium-iron-boron magnets. The material combinations studied will correspond with the relative concentrations of rare earth elements in Molycorp's Mountain Pass mine, using techniques that are more cost effective and leave a smaller environmental footprint than current methods.

Dr. John L. Burba, Executive Vice President and Chief Technology Officer of Molycorp, Inc. commented, "It is my hope that this cooperative agreement will lead to breakthroughs in rare earth material manufacture that can advance the state of the art in rare earth magnet design and manufacture, as well as strengthen our nation's productive capacity of these and other critical rare earth materials."

Based in Colorado, USA, Molycorp, Inc. currently produces around 3,000 metric tons of commercial rare earth materials per year. Molycorp expects an annual production capacity by the end of 2013 of approximately 40,000 metric tons of REO equivalent per year, following its current modernisation and expansion programme. Molycorp intends to provide a range of rare earth products, including high-purity oxides, metals, alloys, and permanent magnets.

www.ameslab.gov
www.molycorp.com

Malvern's new telephoto lens pushes the limits of real-time particle size measurement

The introduction of a new telephoto lens for Insitec laser diffraction process systems from Malvern Instruments enables the on-line measurement of larger particles, extending their application in the minerals, metal powder and food industries, amongst others.

By combining two different focal length lenses, the innovative telephoto design concentrates an expanded measurement range, with a new upper limit of 2500 µm, into a physically shorter lens, just 160 mm in length. Compatible with all current Malvern Process products, the new lens can replace those 300 mm or 450 mm models currently in use in the field.

By increasing the upper sizing limit of Insitec technology from 1000 µm to 2500 µm, Malvern's new telephoto lens broadens access to reliable continuous laser diffraction particle size measurement, enabling customers to tackle new applications and increase the efficiency of current systems. Additional benefits include improved stability and ease of alignment, better vibration tolerance, robustness to temperature, and reduced space requirement without compromising measurement quality at lower size limits.

The system is ISO13320 compliant and suitable for the measurement of atomised metal powders, among other products.

www.malvern.com/telephotoweb

The new Telephoto lens from Malvern Instruments

Uddeholm to invest over 11 million Euro at Hagfors facility

Uddeholms AB has announced it will invest over €11 million (100 million SEK) in the company's production facility at Hagfors in Sweden.

In order to increase the capacity, and to be able to grow within the market segment of highly sophisticated steel grades, the company plans to invest in a new ESR furnace. This will be the ninth ESR furnace that Uddeholm has acquired.

The second part of the investment will enable Uddeholm to move from oil and gas to liquid natural gas (LNG), an alternative energy source which will provide better financial and environmental benefits.

"By converting to natural gas we will reduce our CO_2 emission as well as having a positive effect on the upcoming demand for NO_X, which is necessary considering the growth plan for the next years to come," stated the company.

www.uddeholm.com

CM Furnaces celebrates 65th anniversary

CM Furnaces, based in Bloomfield, New Jersey, USA, is celebrating its 65th anniversary this year. The company provides furnaces for PM, MIM, refractory metals, lighting, nuclear fuel, wire, ceramics, fibre optics, universities and R&D.

CM Furnaces Model 368-72-3Z

The company's primary products are high temperature electric furnaces that can process parts in air, hydrogen and inert gasses. Furnaces can be built in both batch and continuous pusher furnace configurations and, to date, the company has produced over 4,500 furnaces. CM also offers a complete range of debinding ovens specifically designed to process MIM components produced with BASF Catamold™ feedstock.

Founded in 1946 by Seth Combs and James Murphy, the company's initial focus was the production of refractory metal coils (molybdenum and tungsten) used in the lighting and the electronics industry. CM began manufacturing furnaces in order to produce the coils and over time the manufacture of high temperature laboratory and production furnaces became CM's primary business.

www.cmfurnaces.com

Wittmann Battenfeld's first MicroPower up and running at UK Polymer Centre

The RKT Centre for Polymer, Micro and Nano Technology at Bradford, UK has just commissioned the first new Battenfeld MicroPower injection moulding machine. Ordered from the Wittmann Group stand at the world's leading plastics exhibition in Dusseldorf last year, the new moulding machine is currently being equipped with various ancillary pieces of equipment related to the centre's leading edge work in micro and nano moulding technologies.

Ben Whiteside, Centre Manager stated that, "the centre has used three generations of Battenfeld micromoulding hardware and we were therefore delighted to be able to discuss our micromoulding interests with the Wittmann Group and get our hands on the first of the new machines out of the factory at Kottingbrunn. Delivery and installation have gone well and we shall shortly be conducting a new batch of micromoulding experiments on the machine and hiring our facilities out to clients. The new MicroPower has quickly become our primary research machine and the queue of projects and experiments is lengthening."

Whiteside added that, "micromoulding actually shows us how little we know about the real conditions as regards to heat flow during moulding, which are dependent on actual mould surface temperature, pressure effects and the structure of the mould surface. To date, the convention – for lack of data or empirical research – has assumed a constant thermal contact resistance in these matters. This is clearly not the case. Recently awarded EPSRC grant funding ensures that we, at the centre, are actively looking forward to researching and communicating from the frontiers of these issues with our new MicroPower."

The centre will also be investing time and energy in connecting the new MicroPower both to computing power and to the Internet. "Everything that we do with our new machine will be more easily captured using ethernet-based state of the art data acquisition and measurement systems," said Whiteside. "These exacting data records will provide a substantial key to determining and predicting in-mould behaviour for many materials; including nanocomposites."

Such data will also be made available to users over the internet, allowing full traceability of the entire process from raw materials storage, drying conditions, moulding parameters to final product quality inspection.

"It's perhaps an exaggeration to suggest that our micromoulding research could be hooked into a cloud computing model," said Whiteside, "but we won't be far off it. Our principal user markets are in medical and healthcare and our international clients in these areas value the real time access to the results of their micromoulding research work via the Internet."

Based at Bradford University, the centre has been winning repeat business throughout the world as the leading player in its field. An investment to date of some £5 million in state of the art equipment and a complement of twenty expert staff has helped Bradford to pioneer many micromoulding advances.

The centre's mission is to consolidate its micro manufacturing leadership position within the next three years, both for blue sky micromoulding research and also in terms of the number and scale of industrial and commercial projects coming through its doors. The intent is to keep developing UK innovations and industrial projects and also broaden the scope for a fully European outreach. The newly launched Battenfeld MicroPower moulding machine will play a key part in the work ahead.

Daniel Williams, Wittmann Battenfeld UK, with the machine at its new home in Bradford, UK

Together with micro-optics, automotive applications and certain other research areas, medical and healthcare markets are driving the bulk of the centre's work for the foreseeable future.

www.polymer-mnt.brad.ac.uk
www.battenfeld-imt.com

AT Wall Company celebrates 125th anniversary

A.T. Wall Company, of Warwick, RI, USA, a global supplier of precision tubing and fabricated metal components, recently celebrated its 125th anniversary in business. From its founding in 1886 as a jewellery manufacturer, the company has grown and expanded to become a global supplier of seamless cold drawn speciality tubing, high-quality waveguide tubing, and metal stampings that include drawn and coined products, to the medical, aerospace, telecommunications, electronics, and automotive industries.

"As the 5th generation of my family to work at A.T. Wall, I am proud of the company's long history in the metal fabrication industry and committed to diversifying to take advantage of our strengths while avoiding the pitfalls of over-reliance on one technology," said Peter C. Frost, President and CEO of ATW Companies, the parent company of A. T. Wall Company, Judson A. Smith Company (Boyertown, PA), Parmatech Corporation (Petaluma, CA), and Proform (East Providence, RI). He added, "We are especially focused on bringing additional manufacturing jobs and opportunities to Rhode Island, our long-established headquarters and base of operations."

ATW recently opened Parmatech-Proform Corp. 25,000 ft^2 manufacturing facility in East Providence, Rhode Island, which focuses on metal injection moulding (MIM) for the medical, telecommunications, firearms, hand tools, semiconductor, and electronic packaging markets.

www.atwall.com

The ultimate in nail clippers

Klhip of Ketchum, Idaho, USA, has been US granted a design patent for what it calls the 'Ultimate Nail Clipper' made by metal injection moulding. The sturdy, high quality design uses injection moulded 17-4PH stainless steel which allows Klhip to offer a life time guarantee on the clipper.

The MIM clipper is said to cost $70, or $95 if it comes in a leather case. Setting itself apart from traditional nail trimmers, The Ultimate Clipper's proprietary reversed-engineered design is said to give the user more control, and the falling-rate cam requires far less pressure than traditional clippers. Its modern design and single-blade cutting creates smooth nail edges, eliminating the need for filing afterward and, clippings tend to stay on board.

www.khip.com

MIM 17-4PH nail clippers by Klhip, USA

Novel injection mould cavities system for precision high volume applications

Polyshot Corp., a manufacturer of hot-runner systems based in West Henrietta, New York, USA, reports that it has reached an exclusive distribution agreement with Plasel Mold of Lavon, Israel, to sell Plasel's novel injection moulded mould cavities for high-cavitation injection moulded applications in North America.

Plasel has developed the unique injection moulding process using powdered metal technology to produce the precision mould cavities. "This is game-changing technology for the mouldmaking industry and we're excited about our partnership with Plasel," said Doug Hepler, President of Polyshot Corp.

The company states that for high-cavitation moulds, typically 32 cavities and larger, the technology developed by Plasel delivers higher repeatability and greater precision than today's conventional metal working processes. The process allows PMT duplication from a master mould, guaranteeing all cavities are precisely the same, regardless of volume or date of manufacture. Due to the extremely precise cavity replication, tolerances of up to 15 microns are achievable, depending on cavity size and configuration.

PMT mould cavities are injection moulded from H-13 tool steel and shipped hardened to standard Rockwell hardness with surface finishes of up to Rmax2. High-cavity definition, including fine detail and sharp corners are easily produced. PMT mould cavities permit unique shapes that would be difficult or impossible to produce with other metal working processes, says Hepler.

PMT cavities can be machined (EDM, grinding, etc.) like conventional mould cavities, allowing for design and engineering changes at a later date. Maximum PMT cavity size is 25 mm by 30 mm by 70 mm.

www.polyshsot.com

New Micromeritics accelerated surface area and porosimetry system

Micromeritics reports that its new Accelerated Surface Area and Porosimetry Analyzer, ASAP® 2020, is being successfully used to characterise the active and support surfaces of catalysts, to determine the high surface areas of adsorbents, and to determine the microporosity and hydrogen storage capacity of various nano materials. Materials with low surface areas including powdered metals can also be analysed. Options include the micropore option, the high-vac option, and the chemisorption option, which uses the static volumetric technique to determine the percent metal dispersion, active metal surface area, size of active particles, and surface acidity of catalyst materials.

www.micromeritics.com

New range of rotary tube furnaces from Linn

Linn High Therm, based in Eschenfelden, Germany, has introduced a new range of rotary tube furnaces, suitable for the heat treatment of powders and granules.

The electrically heated rotary tube furnaces are available with either 1200°C or 1600°C maximum heating elements and offer rotation speeds between 0.5 and 5 rpm. An incline of up to 10° is possible.

Linn High Therm specialise in the production of industrial and lab furnaces/kilns, microwave furnaces, sample preparation units for spectroscopy, induction heating systems, precision fine casting systems and customer-specific systems. The company employs around 100 at its production site in Germany.

www.linn.de

FDHK-3-100/750/1100 Rotary tube furnace from Linn High Therm

Apple looks to advanced metal-ceramics for lighter and stronger casings

Apple Inc. has been granted a US Patent (No. 7,911,711, March 22, 2011) which will allow the electronics giant to explore a range of advanced metal-ceramic composites for use as light-weight structural casings and housings for personal electronic devices.

The patent given to Apple cites several different types of metal-ceramic composites, including ceramic fibre reinforced metals such as aluminium and titanium in order to provide the light weight and high stiffness. However, it does not specify any particular manufacturing route. PIM is thought to be an option as it is already being used by some manufacturers to produce complex shapes from Al-SiC metal-ceramic materials.

Another material option for Apple, cited in the patent, is a ceramic matrix composite reinforced with discon-tinuous metal fibres.

Apple recently signed an agree-ment with California-based company Liquidmetal Technologies to acquire the exclusive right to use essentially all of its intellectual property in the consumer electronics field relating to 'Liquidmetal alloys' while Liquidmetal retains usage rights in other fields.

Liquidmetal alloys are said to deliver stronger and harder device casings while also offering thinner designs. The relatively low melting temperature of the amorphous alloys lend themselves to be injection moulded like plastics into a variety of forms while retaining their excellent strength and durability.

The Swatch Group in Switzerland has also acquired a license from Liquidmetal Technologies to use the technology for its entire line of timepieces.

www.apple.com

Apple is already reported to be a major user of MIM components and the next generations of its highly successful mobile devices could use metal-ceramic composites (Photo courtesy Apple Inc.)

Leading UK nano organisations lend support for NANO Live UK 2011

The Institute of Nanotechnology and NanoKTN have announced that they are lending their support to NANO Live UK 2011. NANO Live will be co-located with MM Live UK and MEMS Live UK, which focus on Micro Manufacturing and Micro Electro Mechanical Systems respectively. The events take place at the NEC, Birmingham, September 27-29 2011. The three shows, state the organisers, are a natural fit alongside each other and will offer the prospective visitor a one-stop shop for small and ultra precision part technology.

Exhibits will cover the full spectrum of technologies from the NANO manufacturing sectors, including fabrication techniques, inspection and measurement equipment and materials alongside research groups, contract manu-facturers, consultants, trade organisations and training services. Duncan Wood, Managing Director of the Events Group at RNCG stated, "We are delighted to welcome these organisations as Industry Partners on this event. We are pleased that they see the event as significant for the UK nano landscape and we value the input, support and involvement very highly. We look forward to working with them both to make this years event a success."

NANO Live UK will be co-located with MM Live UK, MEMS Live UK, TCT Live, Interplas, The PPMA Show and Sensor Technology and the seven shows will form the largest manufacturing gathering in the UK in 2011, comprising over 500 exhibitors and an expected attendance of in excess of 10,000 visitors.

www.nanoliveuk.com

New PIM company established in Seibersdorf

A new powder injection moulding company called Pimtec GmbH has been established as a spin-off of the PIM department at the Austrian Institute of Technology / Research Centre Seibersdorf, Austria. The company will have have access to the PIM process know-how, existing manufacturing capacities, and the vast technologically based knowledge at Seibersdorf, and will have the objective to transfer the existing production processes into marketable and commercially successful products.

The company is initially concentrating on highly complex components and parts in small production quantities up to 150,000 pieces. The plan is to build up a production line for semi-finished PIM products for manufacturing of medical implants. As a future step, the company will try to expand the value creation chain by developing the semi finished PIM parts into a final end-user product.

An additional product will be bedding layers, or setters, used in the sintering. To resist the high thermal impact in the sintering furnace, bedding layers must be made of ceramic materials. However, due to the limited volumes of these specially shaped layers, production figures tend to be low. This leads to a very high production costs for these individually geometric shaped parts. Pimtec's advantage will be its ability to produce small numbers of these highly complex parts by PIM at a very attractive price.

The management team comprises three partners, Thomas Wilfinger, Dr Thomas Habenreich, and Dr Harald Klimesch. All have a long-term record of interdisciplinary experience and complementary capacity in their field of working

www.pim-technologies.com

Pimtec GmbH's management team, from left to right, DI Thomas Wilfinger, Dr. Thomas Habenreich and Dr. Harald Klimesch

New ASTM Standard for MIM Ti-6Al-4V alloy for surgical implants

The Technical Committee for Medical and Surgical Materials and Devices of ASTM International has issued a new ASTM Standard F2885-11 'Standard Specification for Metal injection moulded titanium-6 aluminium-4 vanadium components for surgical implant applications'.

The specification covers the chemical, mechanical and metallurgical requirements for two types of MIM Ti alloy components, Type 1 being MIM components covered by the specification which may have been densified beyond their as-sintered density by post-sinter processing.

www.astm.org

Korean company exploits PIM titanium technology

Material Technical Innovation Group (MTIG) was established in Gangnam-gu, Seoul, in September 2006 by Mr Young-Seok Park as the first Korean company to exploit new patented technology for the production of complex components from pure titanium powder using conventional PM and powder injection moulding (PIM) manufacturing techniques. The technology developed by MTIG is said to negate the need for specialised equipment normally needed to produce titanium components, thereby drastically cutting manufacturing costs. The company reports that it has already developed a number of applications for PIM titanium over the past five years including mobile phone parts such as side keys, hinges, keyboard buttons, MP3 and GPS cases, earphone cases, and titanium electrodes for ionising water purifiers.

MTIG completed construction of its Hwaseong factory in June 2009 where PM and PIM production is undertaken. The company is also exploiting its unique titanium powder process for the thermal spraying of coatings in air as opposed to having to use a vacuum. Coatings ranging in thickness from 51 to 300 microns can be produced. Some key applications include the Ti powder coating of wind turbine parts, solar panels, and corrosion resistant coatings for the marine sector. MTIG titanium raw materials are also finding applications in allergy-free 3D jewellery and in coloured titanium buttons produced by atomic and molecular vacuum sputtering and anodic oxidation technologies.

The heart of MTIG technology is a method for preparing a titanium hydrogen compound powder which can be used to produce PM and PIM components having low levels of impurities. According to the patent application*, the titanium hydrogen compound powder can be prepared using various methods. For example, pure sponge titanium can be heated in a hydrogen atmosphere to form TiH_2, and the TiH_2 is then dehydrogenated to form the TiH_x powder compound used in the PIM feedstock. This TiH_x powder can range in particle size from 225 mesh to less than 625 mesh.

In PIM the titanium hydrogen compound powder is mixed with a binder, for example low density or high density polyethylene, polyethylene glycol (PEG), and paraffin wax, with powder loading ranging from 40 to 60 vol%. The resulting feedstock can be injection moulded in the normal way. During the debinding or sintering process the titanium hydrogen compound is decomposed into titanium and hydrogen, and the hydrogen reacts with the oxygen, carbon and nitrogen to minimise impurities in the sintered product. MTIG has also developed PM titanium nuts, bolts, and washers for marine applications as well as titanium rivets and screws for aerospace and communication equipment ■

**WIPO Patent Application WO/2010/010993*

MTIG Hwaseong factory in Koera

Freeman Technology appoints distributors in Asia for FT4 Powder Rheometer

Powder characterisation company Freeman Technology is significantly expanding its activities in Asia with the appointment of distribution partners in the region who will sell and support the company's FT4 Powder Rheometer.

DKSH, an established organisation which operates in 35 countries and has a particular focus on Asia, will be Freeman Technology's distribution partner in Singapore, Malaysia, Thailand and Taiwan. In India Freeman Technology will partner with Aimil Ltd., a highly respected distributor of analytical instrumentation, which serves the Indian market via 10 offices around the country and some 50 channel partners.

According to Freeman Technology's Director of Operations, Tim Freeman, the growing demand for the company's universal powder tester in these dynamic markets means that additional local support is now needed.

"Freeman Technology has been working in powder characterisation for the past 10 years and today the FT4 Powder Rheometer is used all around the world," said Tim Freeman. "For some years we have had a direct presence in Europe and the US and a distribution partner in Japan. While a dedicated team at our headquarters in the UK provides excellent sales and technical support to customers everywhere, there is now so much interest in Asia that the time is right for us to extend the local services we offer. I am delighted to be working with such long established and well respected companies as DKSH and Aimil."

The FT4 Powder Rheometer is a universal powder tester that uses patented dynamic methodology, fully automated shear cells and several bulk property tests, including density, compressibility and permeability to quantify powder properties in terms of flow and processability. Correlating this data with processing performance enables users to optimise powder processes.

The FT4 Powder Rheometer (with Aeration Unit) from Freeman Technology

www.freemantech.co.uk
www.dksh.com www.aimil.com

Ceramic turbine cores made by CIM

ENGIMICS based in Novazzone, Ticino, Switzerland, is using powder injection moulding to produce highly complex silicon oxide ceramic cores which are then used in the production of high temperature turbine blades for gas turbines in power generation as well as aircraft jet engines.

A key process step in the production of the turbine blades is the inclusion of cooling channels inside the blades, and this is where the CIM cores manufactured by ENGIMICS come into play. ENGIMICS was founded in Ticino in 2005 and uses an Arburg ALLROUNDER 630C with a clamping force of 2,500 kN to injection mould the silicon oxide cores in a single cavity mould.

The ceramic cores can be up to 700 mm long and 2,000 g in weight. The injection unit cylinder is made from high chromium PM steel to aid wear resistance, and the screw is made from a PM hardened steel

Submitting News

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

Cranfield publishes timely review of MicroPIM technology

With the accelerating interest in micro powder injection moulding for high volume production of metal and ceramic components, the comprehensive review of μPIM technology just published in the *Journal of Micromechanical and Microengineering* (Vol.21, No.4, 2011) puts trends and future challenges in this area into perspective. The authors of the review, Usama M Attia and Jeffrey R. Alcock at Cranfield University, UK, state that according to definitions in the literature, μPIM can be divided into the following three classes:

- Micro-parts: parts with a maximum size below 10 mm and features in the micron range.
- Microstructured parts: parts with dimensions between several millimetres and several centimetres with 3D microstructures located on one or more surface area.
- Micro-precision parts: parts of unlimited size, but with tolerances in the micron range or smaller.

In their review the authors have covered the design of μPIM components including mouldable shapes and geometries, and the influence of dimensional changes – particularly during the sintering process. They state that, "The changes in dimensions during the μPIM process chain affects the overall volume of the produced part," and that "very little is available in the literature about achievable dimensional tolerances by μPIM." However, typical reported tolerances are said to be between ±0.2% and ±0.5% of nominal dimensions. They also cite a recent study which suggested that with thorough process optimisation, accuracies of ±0.1% of the nominal dimension of some ceramic components could be reached in certain directions of the final part.

The authors state that with regard to mouldable shapes and geometries very little is available in the literature about the relation between component geometry and filling quality in μPIM. Similarly, very little information is available in databases or standards for materials suitable for μPIM, especially for relevant properties such as particle size, impurity, and agglomeration. They state that ceramic powders are reported to be easier to handle in μPIM compared to metallic materials, as the latter are often pyrophoric in the nanopowder size range. In addition, because of their relatively lower thermal conductivity, ceramic-based feedstocks tend to less prematurely freeze during injection moulding due to lower cooling rate. Optimum powder loadings, binder systems and feedstock characterisation are covered by the review, with recommendations for future developments in these areas.

The various approaches and challenges to micro injection moulding of PIM feedstock are also included in the review as are debinding, sintering and the resulting dimensional accuracies and surface roughness of μPIM components. Finally, given the small size of the micro components or micro features, the authors state that assessing the quality of the produced μPIM parts depends on the ability to measure relevant properties, such as dimensions, weights, roughness values or mechanical properties. Different techniques and instruments are said to have been implemented to inspect micro-structures produced by μPIM, but the need for specialised equipment for micro-components is still said to persist.

The authors have addressed the challenges and research gaps throughout the μPIM process. They also state that variant processes, already showing success in μIM, are likely to expand the range of μPIM capabilities. Two-component moulding, micro-overmoulding, lost-core technology and similar variants are examples of potential research areas that would enable combining structural complexity with the high-volume capabilities of μPIM. The review includes 145 references.

u.attia@cranfield.ac.uk

Metal Injection Moulding in Taiwan: Electronics sector continues to support rapid industry growth

In the following exclusive report for *PIM International*, Prof. Kuen-Shyang Hwang, from the Department of Materials Science and Engineering at National Taiwan University, reviews the development and current status of MIM technology in Taiwan. In addition to commenting on markets, suppliers to the Taiwanese MIM industry, R&D and technology promotion, Prof. Hwang also profiles three leading part producers.

The MIM industry in Taiwan dates back to 1988, when it was started by Witec Taiwan, a licensee of Witec Japan. In that same year, local research on MIM also started at the National Taiwan University (NTU) and the Industrial Technology Research Institute (ITRI).

'The estimated annual revenue from MIM parts in Taiwan is about $100 million, up from $50 million in 2007'

Both institutes later transferred the technology to several private companies, including those who had contracted the research. By 1995, there were five MIM companies. That number continued to increase, climbing to 14 by 2005. Today, Taiwan boasts 35 MIM companies (Fig. 1), 25 of which are in commercial high volume production and ten of which are in pilot production. Of the 25 companies in commercial production, five have manufacturing plants in China.

The size distribution of the companies in the PIM industry in Taiwan is similar to the particle size distribution of atomised powders - a few large companies with more than 100 employees, and a few small companies with fewer than 10 employees. Among the 35 MIM companies, about 80% are defined by the government as small or medium enterprises (SME's), those with either capital of less than US$ 2.7 million or fewer than 200 employees. Five years ago, almost all of the MIM companies belonged to this category.

However, a trend of developing in-house MIM production lines started in 2006, when some local information technology (IT) industries realised that by outsourcing the production of all the small components of cellular phones and notebook computers, they could not meet demand or the requirements for delivery, quality, and cost. The Taiwanese electronics giant Foxconn International (part of the Hon Hai group), the largest assembler of cellular phones and notebook computers in the world, then decided to establish MIM production lines in Guangdong, China. This manufacturing model was soon followed by Catcher, which also supplies IT and notebook subassembly products, and Shin Zu Shing (SZS), which is currently the largest manufacturer of hinges worldwide. The in-house MIM lines, along with die casting, plastic injection moulding, plating, stamping, forging,

Fig. 1 Locations of MIM companies in Taiwan

Fig. 2 Examples of IT components produced by TPT

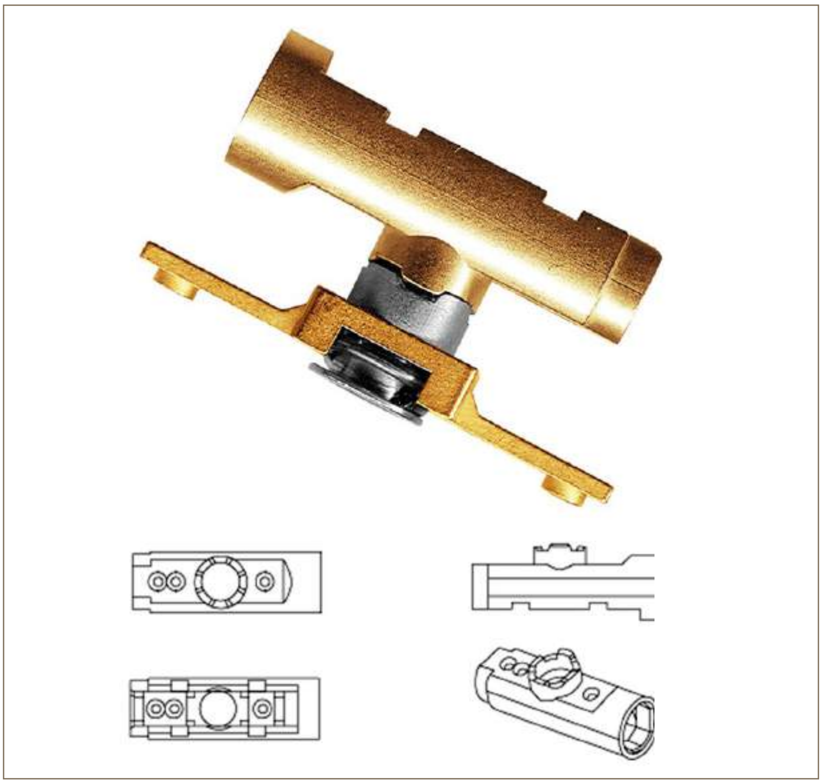

Fig. 3 An example of assembled hinge parts containing housings and rotating cams manufactured by SZS for cameras

and other manufacturing processes, provide their customers with a total solution for the finished products. There are now six in-house MIM facilities in production.

Markets

Since the Far East, in particular Taiwan and China, is the largest base in the world for assembling cellular phones and notebook computers, it is not surprising that millions of small parts with complicated shapes are produced using MIM every day in this region. These IT and notebook components (Fig. 2) account for more than 60% of the MIM market in Taiwan, with industrial applications such as tools and locks in second place.

Although the automotive market is extremely small at the moment, it is still viewed with optimism among parts producers, who see the automotive industry as a strong growth area due to the huge automotive market in China. The challenge now is to communicate the importance of this relatively new manufacturing process to more designers and engineers so that they will design parts with MIM in mind.

The estimated annual revenue from MIM parts in Taiwan is about $100 million, up from $50 million in 2007, not counting those generated in Chinese plants by Taiwanese companies. The average annual growth rate between 2000 and 2010 was 15-20%.

Process and materials

Almost every MIM company in Taiwan uses wax-based feedstocks prepared in-house. With wax-based binder systems, a solvent + thermal debinding process is used. Since IT is the dominant market, stainless steels, 316L and 17-4PH, account for about 50% of the MIM materials used. Fe-Ni steels comprise about another 45%, most of which is heat-treated for use in hand, electric and pneumatic tools, in locks, and in wear-resistant cams and housings in hinges (Fig. 3). The remaining portion is made up of tool steels for cams in hinges, and copper for thermal management devices.

Equipment suppliers

MIM companies in Taiwan use a combination of domestic and imported equipment. There are several vacuum furnace makers in Taiwan. With the advantages of lower cost and quicker local service, most MIM companies use local furnaces, with the total number in service now exceeding 40. However, there are three Elnik, three Vacuum Industries, and more than fifteen Shimadzu vacuum furnaces in the field. In addition, to the author's knowledge, four continuous walking beam or pusher furnaces from Cremer and CM are used in production. With multi-national suppliers for furnaces, it is somewhat surprising that the moulding machine market is dominated by Arburg, thanks in large part to the high quality and strong service team from Germany and the efforts of the local agent. Even though there are more than ten large moulding machine makers in Taiwan supplying huge numbers of plastic injection moulding machines annually, more than 70% of the 300 plus moulding machines used in MIM are supplied by Arburg.

MIM parts producers

The following is a brief introduction of three MIM parts makers of IT components, hinge parts, and thermal management devices.

Taiwan Powder Technologies (TPT)
Taiwan Powder Technologies (www.tpttw.com.tw) was established in 2001 in Ping-Ching with an initial investment of $1.8 million. In 2005, TPT made a further investment of $1 million and moved to Dasi as part of an expansion. The current plant covers a manufacturing area of 5,000 m^2 and employs a staff of 160, along with varying numbers of contractors. TPT is optimistic about the steady growth of MIM and is currently planning a new manufacturing site.

TPT currently has 49 moulding machines, from 25 to 100 tons, mostly equipped with automated handling systems (Fig. 4). After moulding with wax-based feedstocks, parts are solvent debound using local equipment, and then thermally debound and sintered using an international mix (USA, Germany, Japan, Taiwan) of furnaces, 11 batch vacuum furnaces (Fig. 5), and two continuous furnaces.

Among the 150 million plus parts produced in 2010, 80% were for cellular phones and notebook computers (Fig. 6). In addition to the abovementioned industrial applications, an interesting development program of TPT's R&D team involves working with artists and using MIM technology to produce decorative parts (Fig. 7). At the moment, only stainless steel parts are produced, but preparations are being made for sterling silver parts.

TPT's R&D facilities include SEM, N/O analyser, XRF, surface roughness tester, 3D profilometer, hardness tester, and a tensile test machine.

Fig. 4 A view of the moulding area at TPT

Fig. 5 A view of the sintering area at TPT

Fig. 6 Examples of components in cellular phones produced by TPT. (left) Hanger produced using an ultra-high strength (>1500MPa) patented sinter-hardened material, and (right) audio jack ring, 0.30mm thick for the ring wall and 0.40mm thick for other sections (Designed by HTC)

Fig. 7 A selection of decorative parts produced using MIM by TPT. A 10cm tall Lion Guardian (left), 3cm tall kitty (centre), and 3cm tall chihuahua (right)

Shin Zu Shing (SZS)

SZS (www.szs.com.tw) was established in 1968 to make spring-related products. It soon moved into the hinge business and is now the largest manufacturer of hinge parts in the world for consumer products such as cellular phones, digital cameras, and notebook computers.

Although SZS had in-house production facilities for plastic injection moulding, CNC turning, die-casting, stamping, and wire forming, they used to purchase MIM parts from external suppliers. Due to the advantages of MIM parts, more and more replacements for welded, brazed, or riveted subassemblies in the hinges were designed (Fig. 3). In 2007, due to the increasing demand for large quantities of MIM parts, SZS decided to invest in MIM lines.

'Today, SZS has about 6,000 employees, and the MIM section has a staff of 280. It has the largest moulding capacity, 52 moulding machines of both horizontal and vertical types'

Today, SZS has about 6,000 employees, and the MIM section has a staff of 280. It has the largest moulding capacity, 52 moulding machines of both horizontal and vertical types, in Taiwan (Fig. 8). To match these moulding machines, 12 domestic vacuum furnaces are used for sintering (Fig. 9).

Amulaire

Amulaire (www.amulaire.com) is a MIM company headquartered in the United States with its manufacturing plant in Taipei. It is a MIM manufacturer of Cu-based parts for thermal management devices and is currently a leader in pin-engineered cold plates for hybrid electric and electric vehicles (Fig. 10). In addition to MIM production, Amulaire also provides design, prototyping, and system integration for customers. Established in 2005, the company has more than 10 injection moulding machines and over 100 employees. Due to the large size of the copper cold plates, large tonnage moulding machines are used, from 80 to 400 tons.

To sinter these large copper parts, four belt furnaces are used. These copper parts require high thermal conductivity, and thus the selection of copper powders and the process must be well-controlled to avoid possible metallic contaminations, which deteriorate the performance of the thermal management devices.

Promotional activities

Taiwan is small, only 140 kilometers wide and 394 kilometers long (Fig. 1), and populated with 23 million people. Thus, the exchange of information is quite fast in Taiwan. Nonetheless, awareness of the MIM processes from the end-user side is still very limited.

The promotion of MIM is still a major focus of the PM society in Taiwan (PMAROC), as it has been for Powder Metallurgy societies worldwide. Short courses and symposiums are offered at varying intervals to promote the technology by informing design engineers

Fig. 8 A view of the injection moulding area at SZS

Fig. 9 A view of the sintering area at SZS

and buyers in various OEM companies, and the end user, of the MIM process.

The purpose of the PIM Symposium, which started in 1996, is to improve the proficiency and knowledge of the MIM houses in order for MIM to remain competitive with other processes, such as die casting, investment casting, brazing, and even conventional PM. The most recent PIM IX Symposium, held on April 15, 2011, was organised by NTU, Arburg Agency in Taiwan, and the PMAROC. It attracted 160 attendees, both MIM specialists already in the MIM business and parties interested in this relatively new manufacturing technology (Figs. 11 & 12).

Fig. 10 Large cold plates (165mm x 152mm) with cooling pins produced by Amulaire

R&D activities in academia

Most PIM companies in Taiwan have limited resources for research, development, and training. To encourage the MIM companies, large or small, to spend time and effort on R&D, the National Science Council (NSC) has been providing collaboration programs to join MIM companies and universities.

This NSC program began in 2002 by matching two to three times the funds provided by the private industry. The Industry Bureau of the Ministry of Economic Affairs also provides similar programs. It supports private companies also by providing matching funds, on an even larger scale.

Universities that have MIM R&D programs include NTU, National Taiwan University of Science and Technology (NTUSC), Tungnan University, and Far East University. In the MIM programs at NTU, for example, research areas include:

- Predictions of the sintering window of supersolidus liquid phase sintered tool steels
- Ultra-high strength (tensile strength >2,000MPa + elongation>5%) MIM steels
- Dimensional stability and the causes and solutions of defects;
- Process development of Ti-Fe-TiC, TiNi, and Kovar materials;
- Binder design to improve surface quality and green strength;
- Solvent and thermal debinding mechanisms;
- Swelling of various binder systems, and
- Hardening of austenitic stainless steels.

Half of these programs at the NTU PM/MIM Laboratory are funded by the

'There is no doubt that reservations about the IT market exist among parts producers. IT products require fast turnaround; four weeks for mould making and another week for sample submission'

Fig. 11 A view of the PIM IX symposium held on April 15, 2011

NSC, and the other half are supported by private industry.

Looking ahead

Although MIM parts producers in Taiwan have enjoyed strong growth since 1988, based mostly on the strong growth of cellular phones and notebook computers, the market is too heavily concentrated in these devices. There is no doubt that reservations about the IT market exist among the parts producers. These IT products usually require fast turnaround; four weeks for mould making and another week for sample submission would be typical. Design changes can go up to more than ten rounds, which requires intensive communications between users and the MIM houses. However, the life of these IT products is usually less than two years, and for some, even less than six months. Thus, several MIM parts producers are considering diversification into other areas.

Despite the 35 companies in Taiwan today, it is believed that new members will be joining the MIM community every year. Such growth may increase the competition and reduce the profit margin across the market, for this industry is getting more and more mature technologically.

One major question is how many MIM companies is too many for Taiwan, which already averages one MIM company for every 1,000 square kilometers. But the big question is whether all of the MIM companies can survive through creating new markets and lowering manufacturing costs. For example, some rotating cams in hinges with simple shapes can be produced by either press-and-sinter or MIM processes. Just a few years ago, such a competition was clearly one-sided, but today, MIM is becoming more and more competitive. With strong manufacturing and cost control management, all MIM parts producers may stay healthy, like the current PM industry in Taiwan, of which more than 90% of the 50 plus PM companies in business have been continuously growing since they were established years ago.

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FloMet: A North American MIM pioneer continues to expand the possibilities of MIM technology

FloMet has for more than twenty years been a leading member of North America's MIM community. Its bright and spacious production facility in DeLand, Florida, has evolved over time into a state-of-the-art centre for MIM manufacturing. The company has continued to push the capabilities of the process and today manufactures a diverse range of innovative and complex MIM components. Nick Williams, Editor of *Powder Injection Moulding International*, reports on a recent visit.

The history of FloMet

The story of metal injection moulding (MIM) at FloMet can be traced back to the earliest days of the technology in the United States. In 1980, Raymond Wiech began licensing the MIM process through the company Witec California, and it was in 1982 that Brunswick Technetics, a business division of the Brunswick Corporation, purchased the rights to Witec and relocated operations to DeLand, Florida.

The Brunswick Corp. was primarily a manufacturer of recreational and sporting goods, but by the 1970's it had diversified into sectors that included medical and marine products as well as niche high-tech manufacturing. By 1977 the corporation's sales had passed $1 billion for the first time.

Following the relocation to DeLand, Brunswick Corporation invested significant resources understanding and improving the MIM process technology that it had acquired from Witec. Over a period of eight years the initial process was refined into a reliable and predictable manufacturing process and much work was put into the development of the feedstock system, as well as enhancements to the binder removal and sintering steps.

During the late 1980's, however, Brunswick went through a period of significant restructuring that saw it refocus on its core business of recreational goods and marine manufacturing. In 1990 it sold all of its technical businesses. Out of this sale FloMet Inc. was established as a division of US powder metallurgy parts producer Metal Powder Products Inc. (MPP), headquartered in Indianapolis, Indiana.

'The manufacturing facilities were expanded in 2000, making a total of 42,000ft² of floor space on a 15 acre site'

In 1997 a new 20,000ft² manufacturing facility was built in DeLand and the company obtained ISO9001/1994 certification. A year later, in 1998, MPP spun off FloMet and it became a privately held company.

The manufacturing facilities were further expanded in 2000, making a total of 42,000ft² of floor space available on a 15 acre site (Fig. 1). The open

Fig. 1 FloMet's 42,000 ft² MIM facility in DeLand, Florida

Fig. 2 A view of FloMet's injection moulding facility

Fig. 3 Components awaiting debinding and sintering

Fig. 4 Sintering furnaces at FloMet

plan facility was purpose designed for flexibility and ease of expansion, and in 2005 production capacity was doubled to 19 injection moulding machines. In the same year FloMet achieved ISO9001-2000 certification.

Today FloMet employs 120 people, including part and flexitime workers, and is one of the leading MIM organisations in terms of sales in North America.

Injection moulding and tooling

FloMet operates injection moulding machines with clamping forces ranging from 50 to 165 ton, 17 of which are Milacron all-electric machines (Fig. 2). Dan Tasseff, FloMet's Director of Sales and Marketing and former Manufacturing Manager stated that the all-electric machines offered a higher degree of precision than was possible with the more commonly used hydraulic machines.

The company designs all tooling in-house however the actual tools are built by outside tool shops. Flomet LLC has a tool room that is able to perform maintenance operations as well as develop prototype tools. "We place a lot of importance on the quality of tooling, working with a small number of trusted external tooling suppliers and only specifying class A tooling. The benefit of FloMet's rigorous approach to tool design and manufacture, combined with a stringent maintenance schedule, results in very low downtime because of tooling related issues," stated Tasseff.

'The benefit of FloMet's rigorous approach to tool design and manufacture, combined with a stringent maintenance schedule, results in very low downtime'

Keeping MIM moulds at FloMet in perfect condition is also helped by the use of an advanced machine vision system to monitor moulding operations. The system can detect if a green part, or a broken off section of a part, has been left in a cavity, thereby preventing severe damage to the mould during the next cycle when the mould closes.

The system, initially installed to monitor the production of tiny orthodontic parts, not only saves on potentially expensive mould repairs, but also ensures that production and delivery goals are not compromised. The system, by Avalon Vision Solutions (AVS), checks every cavity for each mould after every single cycle, something that operators are just not able to do in reasonable time.

Eight high speed USB cameras with 50 mm lenses are used to capture images on both sides of the

Fig. 5 Orthodontic brackets, slide and hook produced by FloMet, and winner of a 2007 MPIF award. (Photo courtesy Metal Powder Industries Federation)

mould, which are then compared with reference images. If images pass the inspection criteria, the moulding machine continues production, and in the case of a failure to pass the inspection criteria, production is automatically stopped, an alarm tower is activated and an image of the failed cavities is highlighted on a display screen.

In contrast to many other high volume MIM producers, hot runner systems are extensively used at FloMet with the claimed benefit of reducing overall moulding complexity.

Having a component that is suitably designed for MIM goes a long way to ensuring successful commercial production. FloMet's Engineering Development Team works with customers to maximise the potential of MIM. "Our Engineering Development Team can assist a company to design their product so that MIM can be an option for production. We have state of the art software applications such as Pro/ENGINEER, CADKEY, Solidworks and AutoCAD to help us meet our customers' requirements," stated Tasseff.

Almost all machines are fitted with robotic handling systems that make efficient work of the removal of components from the tooling and placement on trays prior to quality checking and sintering. The injection moulding operation is currently run on two shifts a day, five days a week.

FloMet's feedstock

To this day there is an air of confidentiality at FloMet regarding its MIM process. The many years of process development whilst under Brunswick ownership led to innovations that are still closely protected for fear of losing a competitive advantage. At the heart of FloMet's process is its feedstock.

Thanks in a large part to its proprietary system, FloMet prides itself on an ability to manufacture parts that, it claims, other MIM part makers are simply unable to process. "We have the ability to do complex multi-cavity tooling that is not even considered by others," stated Tasseff.

The company manufactures all of its feedstock in-house, bringing with it the significant advantage of being able to customise the feedstock, for example in terms of solids loading, to the dimensional requirements of a component, often avoiding expensive tooling modifications.

Debinding and sintering

Debinding and sintering are key to successful MIM production, and another unique aspect of MIM at FloMet is the company's proprietary debinding and sintering process.

Following thermal debinding in forced air to remove the lower molecular weight components of the company's binder system, parts are sintered in "Batch Hydrogen Reactors" to remove the backbone polymers and sinter the part to near full density (Fig. 4).

These relatively compact batch sintering furnaces were specifically designed by FloMet. Unusually, they are vertical "can" shaped units. Once loaded, the main body of the furnace drops down to cover the parts and is sealed using an 'O' ring system. The furnaces are then purged with argon before hydrogen is introduced.

Whilst sintering cycle times are no match for the fastest commercially available vacuum furnaces, it is claimed that the company's custom furnaces have two major advantages.

CASE STUDY 1:

Thin walled hearing aid component

In 2008 FloMet and its customer, Starkey Laboratories, Inc., Eden Prairie, MN, USA, won an MPIF award for this hearing aid receiver can.

The thin-walled part is made from a nickel–iron–molybdenum alloy material that provides the magnetic shunt effect required in the hearing aid to separate the internal receiver signal from the telecoil signal.

The parts are a conversion from a deep drawing and annealing process, a process that encountered problems with distortion and shielding properties. In addition, latch features had to be added in a secondary operation. The parts wall thickness 0.254 mm was recognised as a potential problem prior to taking the job, stated FloMet, however internal flow paths were added to the inside to assure proper filling of the cavities.

Ejecting a part with such thin walls also proved to be a challenge. The unique ejection system used by FloMet also creates the internal undercuts used to latch the part in place. The internal and external shapes have a profile tolerance of 0.0508 mm from the open end up to 0.76mm, then 0.127mm over the rest of the part. A coining step was therefore required.

Choosing the MIM manufacturing process provided a 50% cost saving over deep drawing as well as improved performance. The parts were injected on an all electric Milacron 55 ton machine (Roboshot SiB 55) using a two cavity mould. Total development time, including the new 80% Ni alloy, was reported to be less than four months. Tool design and build, alloy development and coining fixture design were done simultaneously in order to meet this very short time line.

FloMet produces more than 25,000 of these parts per month.

Photo courtesy Metal Powder Industries Federation

CASE STUDY 2:

Stainless steel compressed air nozzle

In 2009 FloMet received an MPIF award for this large 316L stainless steel compressed air nozzle made for Silvent AB, Borås, Sweden.

The part was produced on an all electric Milacron 55 ton injection moulding machine (Roboshot SiB 55) using a two cavity mould, using feedstock produced in-house by FloMet. After sintering, the seams where the two sections join together are laser welded for a leak-free seal.

A unique process was also developed for the processing of the threads used to mount the part, ensuring that the part conformed to stringent specifications. The part has a density of more than 7.6 g/cm^3, an ultimate tensile strength of 75,000psi (517MPa), yield strength of 25,000psi (172MPa) and a 50% elongation.

The hollow nozzle consists of top and bottom halves that are moulded separately and then joined together into one piece during debinding and sintering. The nozzle's air flow capacity is tightly controlled to ensure optimum use of compressed air as well as to comply with US and EU machine device noise regulations. It can withstand high ambient temperatures and corrosive environments, and meets hygienic requirements of the food processing industry.

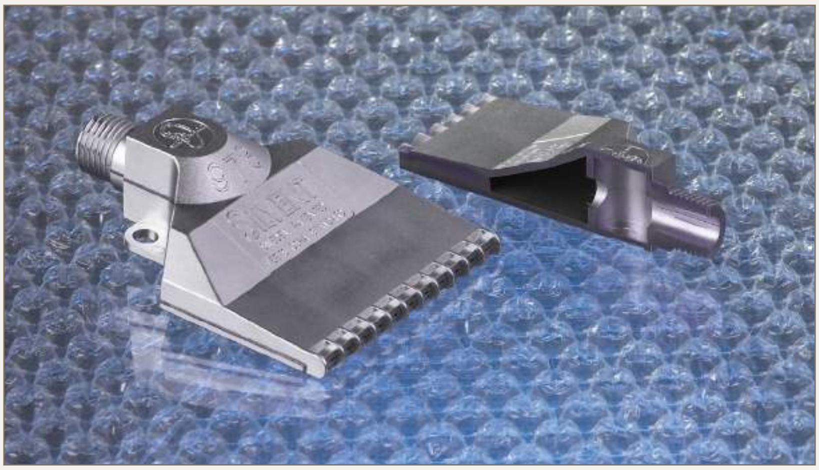


Photo courtesy Metal Powder Industries Federation

Firstly, high dimensional accuracy can be achieved over long production runs, with part density repeatability to within ±0.02 g/cm^3. Secondly, the system allows for the extremely effective control of carbon content.

The company currently operates nine debinding ovens and ten sintering furnaces.

Materials processed

Whilst iron nickel low alloy materials are the most common MIM materials for the majority of industrial applications, FloMet has leveraged its process advantages by focussing on more advanced alloys, especially those demanded by the medical sector. "Stainless steel and low-carbon custom alloys are our speciality," stated Tasseff, "providing superior properties of strength and versatility. Parts are only exposed to hydrogen and argon in our sintering furnaces, which ensures a very low-carbon content (>0.002%). As a result, we can supply parts that offer superior corrosion resistance."

As well as corrosion resistant and nickel free stainless steels, FloMet also offers carbon steel alloys, soft magnetic alloys, high permeability alloys, controlled expansion alloys and low alloy steels, as well as custom materials.

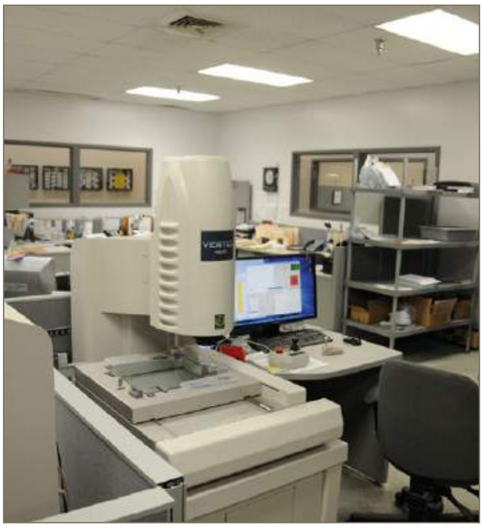
FloMet additionally processes the biomedical implantable chromium-cobalt-molybdenum alloy ASTM F75, an alloy that can rival the performance of medical grade titanium alloys but is cheaper and suitable for high-volume production by MIM.

Although stainless steels, such as 316L and 17-4PH are now driving the majority of new MIM products, speciality and soft magnetic alloys are expanding the range of products for which MIM can be used.

FloMet does not currently process titanium parts, primarily because the company does not see a suitably mature market. "There's plenty of interest from potential customers, but with lower volumes. If high volume opportunities present themselves then we would consider them", stated Tasseff.

Commenting on the ever longer lead times being quoted by metal powder suppliers, Tasseff stated, "Powder supply management is a hands on

Fig. 6 Finishing and quality inspections at FloMet



Figs. 7,8 FloMet's in-house laboratory is used for quality management and product development

business. Variations in powder prices and the ever growing lead times really puts pressure on our sales team to generate accurate long term forecasts".

Finishing operations

FloMet has over the years steadily expanded its non-MIM services to meet the needs of customers. The company today performs a wide range of operations. It can also manage a client's supply chain by outsourcing additional operations such as overmoulding, laser welding, laser marking, pad printing and mechanical assembly for them. "These services cut costs and free clients from outsourcing to several different suppliers," stated Tasseff.

Other processes available in house include automated high speed precision CNC machining, CNC electrical discharge machining (EDM), heat treating and coining/sizing.

Surface finishing procedures undertaken in-house including passivation, ultrasonic cleaning and electropolishing to improve a part's appearance or performance.

Quality and production management

FloMet is an ISO 9001-2000 registered facility and is compliant with FDA ISO 13485 and aerospace AS9100 standards. The company has a large and well equipped quality management and testing lab that screens incoming raw materials and the company's own feedstock batches, as well as testing the chemical, physical and dimensional properties of components.

The laboratory includes full microstructural and spectrum analysis equipment, carbon content analysers, and density and hardness testing facilities. Dimensional inspection capabilities include video inspection, touch probe coordinate measuring systems and optical comparator systems.

Behind FloMet's manufacturing process is an advanced Enterprise Resource Planning (ERP) system. "Our entire system is automated down to shop floor management, operating in real time and audited for accuracy," stated Tasseff. "Comprehensive process documentation assures consistent quality on repeat orders, maximises efficient performance and reduces production costs." Over the years FloMet has introduced multiple continuous improvement programs, including Six Sigma, 5S, Kaizan, and Lean Manufacturing.

Markets

The markets that FloMet serves reflect in part the major recognised markets for MIM in the US, namely medical device and orthodontic components. The company has however also developed additional markets including aerospace, hearing aid technology (Case Study 1), telecommunications, general engineering (Case Study 2) defence (Case Study 3) and electrical applications.

Commenting on the impact of the recession, Tasseff stated, "The orthodontic market was certainly hit, when times got hard getting your kid's teeth fixed dropped down the priority list for many people. The medical device market remained robust, however, and continues to be an important growing market for us. We are also seeing the defence and general industrial markets becoming increasingly important for MIM."

'FloMet is an ISO 9001-2000 registered facility and is compliant with FDA ISO 13485 and aerospace AS9100 standards.'

FloMet continues to leverage the advantages of its process to pursue new components that can benefit from its ability to achieve high levels of dimensional accuracy whilst also achieving exceptional thin wall capability, stated as being 0.254 mm on some parts (See Case Study 1).

Ashley Nichols, Vice President of Technology at FloMet, commented, "Improvement in dimensional accuracy through better process controls has made the MIM process capable of making a wider variety of parts. In terms of part size, whilst there is a general trend towards ever smaller parts, we have made several components measuring more than 12 cm in

Photo courtesy Metal Powder Industries Federation

CASE STUDY 3

Safe and Arm Rotor

This military component brought FloMet another MPIF award in 2010. The part is used in an explosive device for a US Department of Defense application.

Produced by MIM, the 316L stainless steel part is formed to a density of 7.6 g/cm^3. Its significant properties include an ultimate tensile strength of 75,000 psi, yield strength of 25,000 psi, 50% elongation and 67 HRB hardness.

The complex shape features numerous outside radii and angular surfaces. At least 12 functional features and surfaces are geometrically controlled by concentricity, profile, and true position tolerances. The part is assembled into a housing to provide the two-stage safety for the explosive device.

It replaced a zinc die casting whose mechanical properties were ultimately not consistent enough to pass validation testing.

length and requests are coming in for parts exceeding that size."

FloMet currently produces components as small as 0.05 g and measuring measuring less than 1.5 x 1.00 x 0.25 mm. One of the largest parts that the company produces weighs 118 g. Typically 15-20 new parts are introduced each year, state FloMet, with production volumes tending to start at 10-20,000 parts per year. Around 25% of FloMet's production is for export.

'FloMet has for many years built environmental considerations into various stages of its operation'

In summer 2010 FloMet acquired California based MIM producer Injectamax Corporation. The acquisition, stated Tasseff, provided the opportunity for FloMet to serve new markets and develop business relationships with a diverse range of new customers. The firearms industry, a major user of MIM parts in the US, was cited as an example of an important market that, to-date, FloMet has had limited exposure to.

MIM as a green process

There has been growing realisation that the Powder Metallurgy industry, including the MIM sector, needs to do more to make end-users aware of its green credentials. By producing parts to net shape, PM and MIM offer significant materials and energy savings versus competing processes.

FloMet has for many years built environmental considerations into various stages of its operation. In addition to lean manufacturing methods that reduce waste, the company states that all products and materials, from design development through final inspection, are recycled in various manners.

The company's proprietary furnaces are fitted with an innovative ecological scrubber system that internally processes all chemistry, removing any potential for the release of gases into the external environment.

The by-products from the debinding facilities are also recycled, with the various waxes and oils being recycled into a component used in paving roads.

"Our equipment, such as our batch furnaces, is energy efficient. Our binder ingredients are non-hazardous, so our feedstock and resulting products are also non-hazardous. Environmental responsibility is a company-wide attitude" stated Tasseff.

Conclusions

As well as being one of the earliest developers of MIM technology in North America, FloMet has also been a consistently active member of North America's MIM community. Over the year's many of the company's senior figures, including well know personalities such as Arlan Clayton and Ted Tomlin, have actively performed high profile roles within the MPIF and the federation's Metal Injection Molding Association (MIMA).

As a result of the industry's combined efforts, FloMet states that awareness of MIM technology is today significantly improved.

The company states that it is well positioned to expand with the industry. It believes that US manufacturing is able to compete effectively with lower cost competition from emerging economies through a focus on delivering higher quality, high specification products that are at the cutting edge of MIM's capabilities.

In the case of FloMet, this means pushing the limits of dimensional accuracy, material chemistry and component design through innovative and challenging features such as extremely thin wall sections.

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MIM2011 Conference: Industry remains confident as markets and regions continue to evolve

The MIM2011 International Conference on Injection Molding of Metals, Ceramics and Carbides took place in Orlando, Florida, from March 14-16. Organised by the Metal Injection Molding Association (MIMA), a trade association of North America's Metal Powder Industries Federation (MPIF), the event succeeded in attracting more than 130 international participants from industry and academia. *PIM International's* Nick Williams reports on some event highlights.

Florida, drenched in warm spring sunshine, proved once again to be a very welcome choice of venue for the MPIF's annual MIM conference. An international mix of delegates attended MIM2011, travelling from throughout North America, Europe and Asia.

Participants represented all areas of the PIM community, from part producers through to industry suppliers and researchers. The event, co-chaired by Animesh Bose, Materials Processing, Inc. and Bruce Dionne, Megamet Solid Metals, Inc., continues to be an essential forum for networking and the exchange of PIM industry knowledge.

State of the North American MIM Industry

Sessions commenced with reviews of the status of industry in various world regions. Matt Bulger, Netshape Techologies, Inc., and President of the MIMA, gave an upbeat picture of MIM in North America, commenting that, "the North American MIM industry is alive and doing very well."

Presenting data from a MIMA Annual Business Survey, he stated that sales of MIM products in the US had grown steadily over the last few years and optimism was high that further growth can be sustained. It was estimated that there are now approximately 40 MIM producers in North America, excluding CIM and pilot operations, serving a market that is worth around $200 million per year in component sales.

It was also estimated that captive MIM producers accounted for around 30% of total output, with these operations being dominated by orthodontic, firearms and medical device companies.

Bulger stated that more than 70% of MIMA members surveyed said that they expected to increase capital spending in 2011, a clear indication that excess industry capacity was being reduced. This positive sentiment was supported by data indicating that more than 80% of respondents would be looking to increase their workforce during 2011.

In terms of markets for North American MIM parts, Bulger commented that these had shown little significant change year on year, with medical, firearms and electronics

Fig. 1 MIM2011 delegates enjoy a poolside networking lunch (Courtesy MPIF)

Fig. 2 Weight % of MIM parts shipped by market, based on a survey of MIMA part producing members (Courtesy MIMA/MPIF)

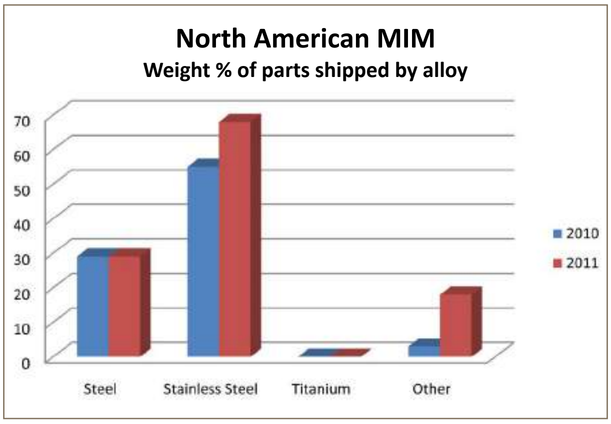

Fig. 3 Weight % of MIM parts shipped by alloy, based on a survey of MIMA part producing members (Courtesy MIMA/MPIF)

remaining dominant (Fig. 2). There was also little change in the materials mix, with stainless steels continuing to grow, whilst steels remained level (Fig. 3). Commenting on titanium, Bulger stated that there was no significant production and that the technology was, "still waiting for adoption in production".

Bulger also commented that although North America's MIM industry is primarily focussed on the domestic market, 60% of survey respondents stated that they exported more than 10% of production.

The materials supply challenge

The MIMA survey highlighted a number of areas that posed challenges for the industry, however at the top of the list were raw material costs and the raw material supply chain. Bulger indicated that powder suppliers are seeing strong demand from MIM producers, with lead times getting pushed out to up to four months for some materials.

It was also commented that the erratic supply of carbonyl nickel had shaken confidence, and that alternative supplies of MIM grade powders needed to be promoted.

Concluding, Bulger stated that despite some industry consolidation, the landscape of MIM in North America had not changed significantly in recent years, "the industry is relatively stable, with solid growth, however growth is more evolutionary that revolutionary."

Developments in Asia highlighted

MIM2011 took place just days after the Japanese earthquake and tsunami of March 11th, and inevitably there was concern about the fate of Japanese colleagues, business partners and friends. The tragedy prevented all the registered delegates from Epson Atmix, Japan's largest MIM producer and important MIM powder supplier, from attending.

Prior to presenting a review of MIM in Asia, Yoshiyuki Kato, formerly of Epson Atmix and now a PM consultant, expressed thanks to participants for the words of support and best wishes that were offered at the event. He was also able to directly advise participants that although the Epson Atmix plant in Hachinohoe had suffered water damage as a result of the tsunami, no employees' lives had been lost.

Kato's presentation covered developments in Japan, Korea, Singapore, Taiwan and Malaysia. He stated that, in contrast to Europe and North America, the MIM market in Asia is typified by lower volume production runs, but with a far greater diversity of parts. "MIM in Asia has grown around electronics," he stated, "although Asian MIM companies are now working hard to penetrate more stable and long term industries that already benefit from MIM in Europe and America, such as the automotive, medical and firearm industries."

Japan

Commenting on Japan, he stated that the Japanese MIM industry is failing to achieve the hoped for levels of growth, and suggested that the global financial crisis has resulted in a pessimistic outlook.

He added that Japanese producers were nervous about the rapid growth of the Chinese MIM industry and that the industry's future lay in exploiting the technology gap that existed between the two countries in order to supply more advanced components for the next generation of automotive and medical applications.

Korea

Kato stated that the Korean MIM industry had recorded remarkable levels of growth in recent years, growing from $4 million of sales in 2007 to an estimated $22 million in 2010. This level of growth was driven by the demand for MIM automotive parts,

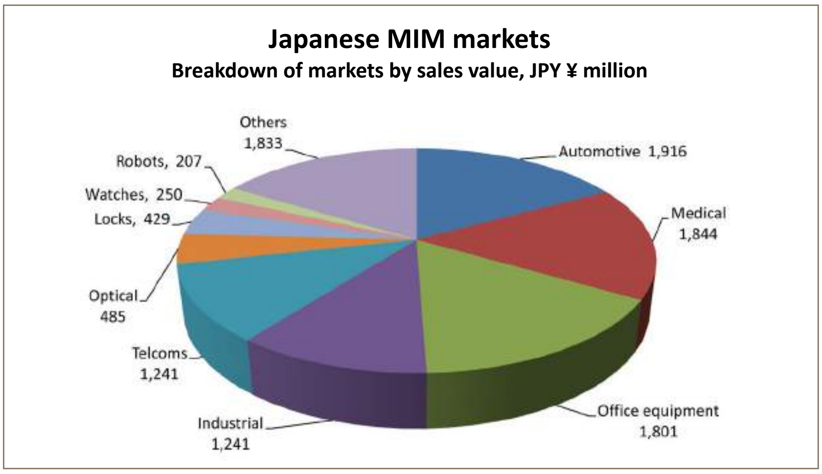

Fig. 4 Breakdown of MIM markets in Japan by sales value (Courtesy JPMA)

MIM shows promise in fuel cell applications

A paper at MIM2011 co-authored by Dr Joseph Newkirk, Associate Professor of Materials Science & Engineering at Missouri University of Science and Technology, USA, and Bruce G. Dionne, Megamet Solid Metals, Inc., Earth City, Missouri, USA, presented the results of initial research into the use of MIM for Proton Exchange Membrane (PEM) fuel cells.

Dionne, presenting, stated that while fuel cells offer many potential advantages for portable power applications, the manufacturing of fuel cells is very problematic. Currently most fuel cells are low volume items and little automation is used. In particular, the bipolar plates and end plates used as electrodes in a PEM fuel cell are relatively small, thin, and have complicated features.

In addition to electrical conductivity, the plates also serve to distribute the reacting gases and carry away the by-products of the reaction. The plates have flow field channels embossed on one or both sides, which can have a total channel length several feet in length, making machining a difficult process to apply for this purpose.

Standard bipolar plates are manufactured from graphite, with the advantages that they are inert, stable and can perform over a long period. The disadvantages are, however, that they lack robustness, have much lower conductivity than metal, and they need to be machined. Metal plates, in contrast, offer high strength, thin design possibilities, superior conductivity and improved manufacturability.

Metal Injection Moulding, stated Dionne, offers many advantages for making parts of this nature and could become a major player in driving this new market.

The paper reported on prototype 316L stainless steel and pure copper bipolar plates, both of which were moulded and sintered at Megamet's facilities to final dimensions and properties.

'MIM offers many advantages for making parts of this nature and could become a major player in this new market'

Testing the validity of MIM bipolar plates

In the initial MIM plate designs, complex flow channels were added that exceeded the limits of most manufacturing processes, with over 1.5 m of channel being moulded on each side. The plates were designed to be used in a fuel cell stack, in which five cells are connected in series. The portable stack is designed to run for about five hours of continuous operation giving 5W power output, 5V and 1 A of current.

Fig. 1 A MIM bipolar plate for PEM fuel cells made from pure copper

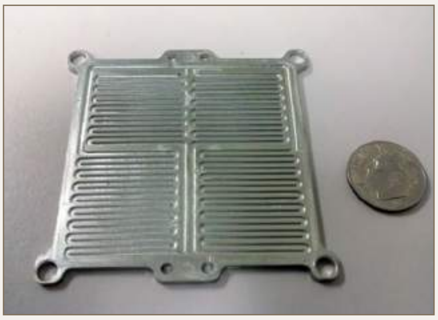

Fig. 2 A 316L stainless steel MIM bipolar plate for PEM fuel cells

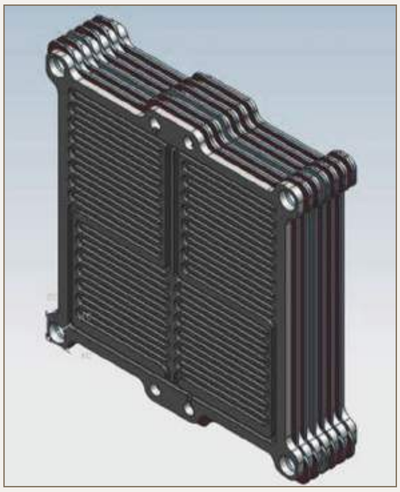

Fig. 3 An illustration of an assembly of MIM bipolar plates

Dionne stated, "With the complex geometries presented, manufacturing with MIM is up to the challenge. The flatness of the plates is critical and very thin cross sections over a fairly large area make moulding challenging, but MIM is by far the most suitable manufacturing method."

"The tolerance capability of the MIM process," commented Dionne, "has to be good enough to support the accurate alignment of the intricate flow channels and clamp holes".

A fuel cell was manufactured with the MIM bipolar plates and testing was performed to confirm:

- The performance of metal electrodes compared to graphite electrodes
- The corrosion resistance of the MIM plates to Membrane Electrode Assembly (MEA)
- The conductivity of the MIM plates.

Flow field testing was also performed to confirm:

- Fill times
- Response times
- The uniform laminar flow of gases
- The adequate extraction of electrons
- The adequate drainage of H_2O.

In addition, corrosion tests will be performed on the MIM bipolar plates. An initial static test will be undertaken for between 15-100 hours at a temperature of 80°C in 0.5M sulphuric acid. A second dynamic test will also include bubbling Ar gas and a cell voltage of 0.9 V.

Dionne reported that the MIM plates performed well in all tests performed to-date, however a preference was expressed for the 316L plate because of its strength advantages over pure copper.

Design modifications to improve cell function

Following the initial tests, a redesign of the bipolar plates was undertaken using knowledge gained from the first round of performance testing. Improvements included a refining of flow channel design, the addition of cooling features and improvements of structural design

Fuel cell modeling and simulation was also undertaken to further optimise designs by analysing cross-sections and dimensions, to predict flow effects (pressure and velocity) during failure, and to predict pressure, velocity, and mass fractions of hydrogen and air in the fuel cell.

Dionne confirmed that, in total, over 40 designs had been created and modeled in various shapes including square, rectangular, circular, elliptical, hexagonal and octagonal. Flow field designs included pin type, straight, serpentine, multiple serpentine and hybrid.

Ongoing development

The authors stated that the development of MIM bipolar plates for PEM fuel cells is an ongoing area of research. Future developments will be reported when available in *PIM International*.

Dionne added that this application serves to reinforce MIM's credentials as a green technology, not only through the efficient use of energy and materials to achieve net shape components, but also through the application of MIM technology in manufacturing the next generation of renewable energy sources.

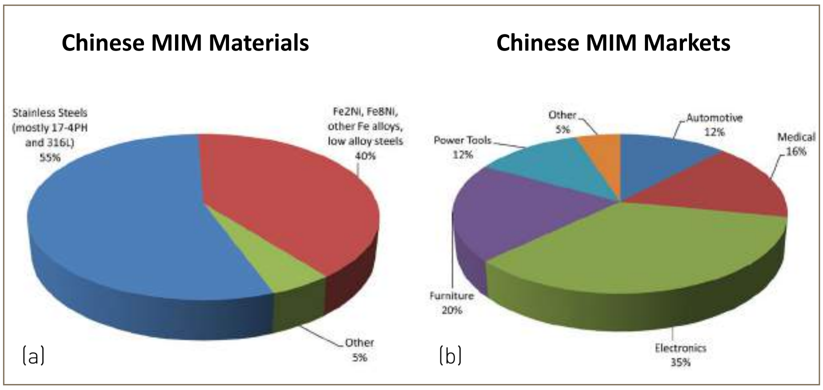

Fig. 5 a) Typical Chinese MIM materials (Courtesy MATE Research); b) Main markets for MIM in China (Courtesy Prof. Hwang)

which in 2010 accounted for 86.6% of Korean MIM sales, compared to 14% in 2007. The production of heat resistant alloys for automotive turbocharger components was cited as a major factor in this growth. Korean MIM sales are now forecast to be in the region of $35-45 million per year.

Kato commented that the Korean MIM industry remained focussed on developing the market for automotive products, reflecting the importance of the automotive industry to the Korean economy.

Development of MIM in Southeast Asia

Kato stated that the MIM industry will inevitably develop in Southeast Asia, primarily in response to the demand for MIM parts in the region. He indicated that although fundamental metallurgy is generally not as advanced in many of the countries in southeast Asia as it is in China and Japan, the prospect of international partnerships would accelerate the adoption of the technology and expand the market.

Whilst Singapore has enjoyed many years of experience in MIM production, Kato stated that new production was underway in Thailand and Australia. Inevitably, he suggested, commercial production would follow in other countries including Malaysia, Indonesia and New Zealand, where R&D work is already underway.

The development of MIM in China

Michael Godin, Mate Consulting GmbH, presented an analysis of the current status of the MIM industry in China. He stated that growth in China was reaching up to 50% per year, with multiple newcomers entering the market. Whilst much of the growth was to satisfy an ever increasing domestic demand, he indicated that at least 50% of production was for export, with the main customers being well known corporations worldwide.

Godin stated that there were currently 69 MIM manufacturers in China, and conservatively estimated sales to be $46 million. He added that low production costs and continuous quality improvements meant that Chinese MIM was now able to start to compete with US and European MIM on equal terms.

Commenting on the general trends, he indicated that foreign powder and feedstock is being replaced with domestic alternatives, adding that most MIM producers rely on feedstock manufactured in-house. Typical Chinese MIM materials were given as 316L, 17-4PH and Fe-Ni alloys (Fig. 5a).

Godin stated that there is also an increasing demand for more advanced production equipment, reflecting a general move towards more complex parts. He suggested, however, that Chinese companies were able to purchase domestic equipment at 15-30% of the price of foreign alternatives.

It was also indicated that there is a clear move away from very low automation to semi-automated production as labour and material costs escalate.

Concluding, Godin stated that the future for the Chinese MIM industry looked very bright. Major new MIM plants were being planned for 2012 with up to 60,000m^2 of floor space. The increasing capacity, he suggested, was set to be serviced by highly qualified staff, with an large number of young professionals graduating with bachelor (around 230) or master (around 220) degrees in PM/MIM from China's leading PM oriented universities in 2010.

Stryker Corporation: The path to vertical integration

A highlight of the MIM2011 conference was a lunchtime keynote presentation by Aaron Price, a Project Manager at Stryker Instruments, who discussed in detail the motivation behind the company's establishment of an in-house MIM facility and their perceptions of MIM.

Stryker Instruments, a division of Stryker Corporation, specialises in surgical power tools and other operating room equipment. A Fortune 500 company, Stryker today has more than 20,000 employees and generates $7.3 billion in annual sales around the world.

Whilst the company's earliest products from the 1930's and 1940's were limited to innovative hospital beds and cast cutting tools, the company has diversified and now offers a portfolio of more than 55,000 products that serve its mission of helping healthcare professionals perform their jobs more efficiently while enhancing patient care.

The company has 29 manufacturing and R&D locations worldwide and last year completed the establishment of a MIM facility in Kalamazoo, Michigan, USA. The first MIM part manufactured in this new facility was launched in November 2010.

The story of MIM at Stryker

Stryker Instruments' relationship with MIM dates back to 2004, when the company's first MIM part was introduced. Price, who joined the company in 2002, is a self-confessed fan of MIM technology, and led the team charged with developing the company's use of MIM, and more recently driving forward the plan to establish in-house production.

Stryker had already extended its outsourcing of MIM component production to four suppliers, manufacturing a total of 19 different components. However as the in-house MIM facility comes on stream, outsourcing of MIM production has been reduced and it currently stands at one supplier producing seven components.

The vertical integration of MIM at Stryker was initiated in 2006 and facility modifications began in June 2009. The facility was commissioned in December 2009 and by the summer of 2010 the manufacturing equipment had been qualified.

'Our first in-house MIM part was launched in November 2010 and we are expecting approximately 20 parts to be launched in 2011'

"Our first in-house MIM part was launched in November 2010 and we are expecting approximately 20 parts to be launched in 2011," stated Price.

Fig. 1 Surgical tool featuring Stryker MIM parts

The upsides and the downsides of MIM

Price cited a number of reasons for the appeal of MIM to a medical device manufacturer such as Stryker. "From a customer's perspective, the cost savings compared to machining are of course very attractive. The mechanical properties, compared to other net shape processes, are also attractive, as is the ability to make parts to more complex geometries with excellent surface finish where needed."

On the downside, Price cited the long lead time for tooling and process development as primary drawbacks, along with the significant capital investment in tooling and a frequent unwillingness on the part of MIM producers to quote for low volume parts. "There are also some uncertainties in the process of

Fig. 2 A Stryker MIM part

Fig. 3 A selection of MIM components under development at Stryker

developing a part, and this combined with a customer's vulnerability when committing to a specific shrink rate can inevitably lead to a level of hesitation," he stated.

Price also indicated that within the industry there was often a lack of sophistication with regards to process validation, as well as a limited capability among MIM producers to offer secondary operations.

The drive towards vertical integration

The foremost reason for integrating MIM into the company's manufacturing operations, stated Price, was the ability to maintain control over component quality and to ensure compliance in process validation. The establishment of the MIM operation also brought the added benefits of stabilising the company's supply chain, having a new core competency, and enabling existing competencies such as machining to be leveraged.

The new facility is also expected to have the effect of stimulating the wider use of MIM in Stryker, rather than being limited to the Instruments division.

Opportunities for the future outsourcing of MIM production

Despite the success of Stryker's in house facility, Price reassured the MIM2011 audience that there would continue to be future outsourcing opportunities. "We will still look to custom MIM producers for partnerships in developing new components. Winning and retaining our business hinges on the ability to deliver quality above all else. Our partners in the industry must understand and be able to deliver on equipment qualification and process validation. They should also expect supplier audits and be able to deliver exceptional product availability."

Price added that the ability to provide additional assembly and finishing operations, or "one stop shopping", was also becoming ever more valuable.

Speaking to MIM part producers attending the MIM2011 conference, Price advised that as a potential customer the "wow" factor of MIM was no longer enough to capture new clients and warned against the temptation to "oversell your capabilities."

"MIM is a great technology with many opportunities," stated Price, "but producers should work to offer customers greater flexibility. Be tolerant of lower volumes, provide support for component redesign and above all focus on a long term partnership."

'Winning and retaining our business hinges on the ability to deliver quality above all else'

Fig. 4 A view of the sintering area at Stryker

Fig. 5 A view of the injection moulding area at Stryker

LÖMI, a leading manufacturer of solvent debinding furnaces, celebrates its 20th anniversary and doubles production capacity

Located in Aschaffenburg, close to Frankfurt in the centre of Germany, LÖMI is an innovative manufacturer of solvent debinding furnaces. In 2011 the company celebrates twenty years of experience in explosion-proof systems for handling flammable solvents. As *PIM International* discovers, the company has become, over a period of just over a decade, a market leader in solvent debinding furnaces for the PIM industry.

LÖMI GmbH was founded in 1991 by José M. Dias Fonseca, an engineer whose vision was to produce reasonably priced, high-quality and reliable solvent recovery systems. The explosion-proof systems that the company developed employ vacuum distillation and meet European directives with regard to occupational health and safety and environmental protection.

The technology proved itself right from the start and only six months after the formation of the company, LÖMI won Ciba-Geigy as a customer. During a two-year period of cooperation, LÖMI developed a completely new solvent recovery system which then was sold worldwide to customers such as Motorola Singapore and Ericcson Australia.

A focus on R&D

Another innovation followed just a few years later. This time for Volkswagen, LÖMI developed a new process to recover lubricating oils, precious metals and high-alloyed steel from abrasive slurry in a research project with Technische Universität Braunschweig, Germany.

In addition to the development and production of process plants, various research projects with renowned project partners became a regular aspect of the company's activities. With Fraunhofer-Gesellschaft, LÖMI developed systems for de-waxing by means of solvent extraction and small peripheral systems for biodiesel production from rapeseed oil and other organic oils.

In addition to innovation, LÖMI's philosophy is that of quality and service. LÖMI's Dias Fonseca told *PIM International*, "Our company sets value on manufacturing the highest quality systems in the market and sees itself as the industry's partner. As a result, we have earned an excellent reputation and our customers come from numerous end-user sectors."

The sectors that LÖMI currently supplies include automotive, aerospace, chemical, optical, electronics, printing, medical and pharmaceutical.

Fig. 1 LÖMI's management team, Christian Ferreira Marques (left) and José M. Dias Fonseca (right)

LÖMI and the PIM industry

The company's involvement with the PIM industry dates back to 2001. Dias Fonseca explained, "We were approached by a feedstock producer

Fig. 2 LÖMI debinding plants EBA-2500 for the high volume debinding of powder injection moulded parts

Fig. 3 Rack with green parts loaded on trays, ready to be inserted into LÖMI debinding plant EBA-2500

who was looking for a debinding furnace for solvent soluble binder systems, where moulded parts were to be immersed in a solvent bath. LÖMI adapted a solvent recovery system to meet the customer's requirements and thus developed its first solvent debinding furnace."

This was a crucial step in the development of the company's relationship with the PIM industry. Over the following years, LÖMI has closely cooperated with its partners, both feedstock producers as well as metal and ceramic injection moulded part producers. "Through these experiences we gained a comprehensive understanding of the PIM debinding process, which has led to continuous enhancements of our debinding furnaces, helping to make them ever more reliable and efficient," stated Dias Fonseca.

Five years ago, Christian Ferreira Marques joined LÖMI as an additional Managing Partner, coming from a large German company. Subsequently, LÖMI restructured its business divisions to meet the increasing demand from the international PIM industry.

Advantages of solvent debinding furnaces

Ferreira Marques told *PIM International*, "Solvent debinding furnaces are very versatile. Injection moulded part producers are free in their choice of feedstock manufacturers, as numerous kinds of feedstock can be processed."

"At the same time, various organic solvents can be employed, including acetone, ethanol, hexane, heptane, trichloroethylene (TCE), just to name a few. Our process allows for very small debinding furnaces, if needed, through to very large plants. Another plus is the very long lifetime of the furnaces as the solvent debinding process causes very little wear and tear," added Ferreira Marques.

Characteristics of LÖMI debinding furnaces

The company's debinding furnaces offer users the ability to process either water or solvent soluble binder systems. LÖMI's compact furnaces with solvent extraction capabilities start with a volume of 50 litres. For small numbers of injection moulded parts, the EDA series of furnaces combine debinding, vacuum drying and solvent recovery in one single unit.

For medium and large numbers of injection moulded parts, the company's systems consist of two units, a debinding furnace of up to 2,500 litres and a parallelly operated solvent recovery system. All systems can be extended on a modular basis.

LÖMI's Marketing Director Ralf Wegemann explained, "Our solvent debinding furnaces are cost-saving through their compact design, low investment and short lead time. Generally, they pay for themselves within a very short period of time after commissioning."

The company states that their furnaces employ well proven technology and are fully customisable by means of programmable logic controllers. In addition, state LÖMI, their systems are environment-friendly as the solvent is operated in a closed system where it is completely recycled.

Complex processes can be handled with the company's debinding furnaces

Fig. 4 Three debinding furnaces EBA-900 with a parallelly operated solvent recovery system VDA-3000, shortly before commissioning at a major Indian customer

Fig. 5 A LÖMI debinding furnace type EBA-150 with a parallelly operated solvent recovery system LRA-150

Fig. 6 The LÖMI production area in Aschaffenburg for EDA-/EBA-50 models, for solvent soluble and water soluble binder systems

and tailor-made units can be specifically developed to meet customer requirements. To facilitate the operation of a system, remote diagnostics and maintenance are also available.

LÖMI today

In its 20th anniversary year LÖMI sees itself as an engineer-operated company with comprehensive knowledge of the entire process chain: research and development, design engineering, production, commissioning and after-sales-service.

The company believes that it has set many new standards in the PIM industry and it regards its technology as "state-of-the-art". Its systems meet European safety regulations and are free to be installed and operated in hazardous areas.

The company states that it is an accredited company according to the EU Water Framework Directive and offers an in-house accredited safety engineer. The company is also a member of various bodies and professional associations, including the European Powder Metallurgy Association (EPMA) and German MIM-Expert-Group, under the direction of Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM).

New opportunities

LÖMI sees a huge potential in the PIM industry. "Currently, there is a lot of activity in the debinding market and many injection moulded part producers are changing to different debinding technologies," stated Dias Fonseca. "Ten years ago, the market for solvent debinding furnaces was a secondary business for LÖMI next to the traditional solvent recovery sector. But over the last four years alone, the orders for solvent debinding furnaces have increased to such an extent that this field of business by now has reached the same volume."

'there is a lot of activity in the debinding market and many PIM part producers are changing to different debinding technologies'

"We believe that we are the market leaders in explosion-proof solvent debinding furnaces and are privileged to be able to count some of the leading MIM manufacturers world-wide as our customers. We are very confident that we will be able to expand the market even further," continued Dias Fonseca.

Tightened environmental regulations, he suggests, are also increasing the demand for clean solvent debinding processes. In addition, occupational health and safety considerations are becoming increasingly important in many countries. With regards to process development, the company believes that the use of water soluble binder systems is also becoming more and more attractive for part producers.

Looking to the future

LÖMI states that it is committed to further expanding its PIM debinding operations. "Together with our partners, we will continue to refine our debinding furnaces. Over the next months, we are doubling production capacity and expanding the area for our own pilot plant stations, where prospective customers are welcome to test their debinding processes. The number of rental systems will also be increased so that customers can perform in-house testing at their own companies," stated Dias Fonseca.

Contacts

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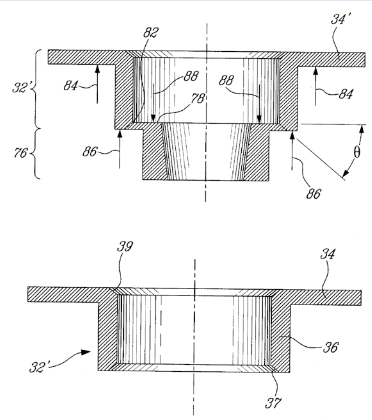
Global PIM Patents

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

WO 2009012556
METHOD FOR MANUFACTURING OF FUEL NOZZLE FLOATING COLLAR

Publication date: 2009-01-29
Inventor(s): Patel Bhawan B et al, Pratt & Whitney, Canada

This patent describes a method of manufacturing a floating collar engaged on a fuel nozzle for providing a sealing interface between the fuel nozzle and a combustor wall. The method comprises metal injection moulding a radially extending flange portion, an axially extending cylindrical portion and a sacrificial or feed inlet portion. The flange and cylindrical portions form the floating collar which is free of injection marks and is separated from the sacrificial/feed inlet portion after injection moulding.



CN 201311177
MULTI-STAGE CONTINUOUS SINTERING FURNACE

Publication date: 2009-09-16
Inventor(s): Shukun Cao, Univ Jinan, China

The patent relates to the technical field of metal powder injection moulding, in particular to a sintering furnace. It comprises of a furnace body, wherein the furnace body includes a debinding stage, a sintering stage and a cooling stage which are distributed linearly from an inlet to an outlet.

A furnace door is arranged at the inlet of the debinding stage, a door is arranged between the debinding stage and the sintering stage and also between the sintering stage and the cooling stage. A furnace door is arranged at the outlet of the cooling stage.

The debinding stage and the sintering stage are both provided with heating devices, the cooling stage is provided with a cooling device, and the debinding stage, the sintering stage and the cooling stage are all provided with actuators.

The sintering furnace adopts a linear structure which combines single debinding, sintering, and cooling processes in traditional MIM procedure, thereby increasing product quality and reducing rejection rate during the sintering process.

WO2008095080
METHOD OF PRODUCING COMPOSITE MATERIALS THROUGH METAL INJECTION MOULDING

Publication date: 2008-08-07
Inventor(s): D. Urevich, Arcmelt Company LC, USA

The patent discloses a method for impregnating a metal injected material to produce a composite article. The method includes the steps of forming a green part from a feedstock, removing a binder from the green part to form a brown part, and impregnating the brown part with select particles to form a finished composite article.

WO2008112555
SCREW DESIGN AND METHOD FOR METAL INJECTION MOULDING

Publication date: 2008-09-18
Inventor(s): K. A. McCullough, Cool Options Inc, USA

A screw and method for processing metal, metallic alloys, and metal matrix composites in a plastic injection moulding machine is disclosed in this patent. The screw includes shank with a screw shaft extending therefrom.

The screw shaft includes a rear portion proximate to the shank, a middle portion proximate the rear portion, and a front portion proximate to the middle portion. Flights extend from the rear portion of the screw shaft for advancing the material through the plastic injection moulding machine into the middle portion of the screw shaft. Flights may optionally be included in the front portion of the screw.

WO 2009029992
METAL INJECTION MOULDING METHOD

Publication date: 2009-03-12
Inventor(s): Liu Zhenyun et al, Univ Queensland, Australia

This method of forming a part by metal injection moulding includes the steps of forming a mixture of a metal powder, comprising aluminium or an aluminium alloy, with a binder and optionally a sintering agent. The mixture is then injection moulded, the binder removed and part sintered. The step of injection moulding includes placing a solid component into a cavity of a mould and injecting the mixture into the cavity, whereby the solid component forms part of the article. The solid component may be a reinforcing component or it may be a magnetic or magnetisable component.

US 2009224442
METHOD OF MANUFACTURING TRANSLUCENT CERAMIC AND ORTHODONTIC MEMBER

Publication date: 2009-09-10
Inventor(s): Sakata Masaaki, et al, Seiko Epson Corp, Japan

A method of manufacturing a translucent ceramic is provided. The method comprises: mixing a raw powder and an organic binder and kneading them to obtain a compound, the raw powder containing an aluminium oxide powder and a magnesium oxide powder, and the organic binder containing a first organic component and a second organic component; moulding the compound in a predetermined shape by an injection moulding method to obtain a green body; debinding the organic binder contained in the green body to obtain a brown body; and sintering the brown body to obtain a sintered body of the translucent ceramic.

When the softening point of the first organic component is defined as "T1" (DEG C.) and the softening point of the second organic component is defined as "T2" (DEG C.), the kneading step is carried out at a temperature in the range of T2 or higher but lower than T1 after the raw powder and the organic binder are preheated at a temperature in the range of T1 to T1+100(DEG C.). An orthodontic member is also provided.

US 2009321971
METHODS OF MANUFACTURING DENTAL RESTORATIONS USING NANOCRYSTALLINE MATERIALS

Publication Date:2009-12-31
Inventor(s): Brodkin Dmitri, et al, Pentron Ceramics Inc, USA

Dental articles are produced using relatively low sintering temperatures to achieve high density dental articles exhibiting strengths equal to and greater than about 700 MPa. Ceramic powders comprised of nanoparticulate crystallites are used to manufacture dental articles.

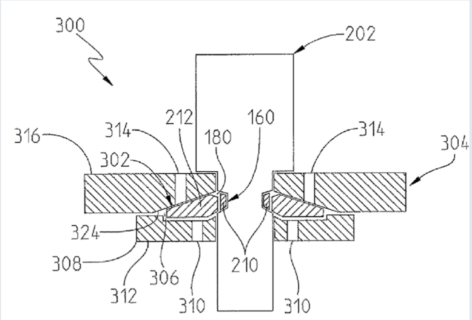
The ceramic powders may include sintering agents, binders and other similar additives to aid in the processing of the ceramic powder into a dental article. The ceramic powders may be processed into dental articles using various methods including, but not limited to, injection moulding, gel-casting, slip casting, or electroforming, hand, cad/camming and other various rapid prototyping methods.

The ceramic powder may be formed into a suspension, pellet, feedstock material or a pre-sintered blank prior to forming into the dental article.

US 2009196761
METAL INJECTION JOINING

Publication date: 2009-08-06
Inventor(s): James Allister W, Siemens Power Generation Inc, USA

A method of joining a first part together with a second part is presented in this patent. The method may comprise providing a first part having a first joining portion including a first channel and a second part having a second joining portion including a second channel. The method may further comprise positioning the first part adjacent to the second part such that the first channel and second channel align with one another to define a cavity. The method may still further comprise preparing a mixture comprising at least one of a metal powder and a polymer binder, placing the mixture into the cavity so as to form a preform and solidifying the preform forming a metal element in the cavity. The metal element joins the first part together with the second part



CN 101538154 (A)
SPONTANEOUS HYDRO-THERMAL METHOD FOR PREPARING SPECIAL COMPOSITE NANO CERAMIC POWDER FOR CERAMIC TOOTH

Publication date: 2009-09-23
Inventor(s): Jingchao Tao, Shanghai Jingwen Material Tech, China

The invention relates to ceramic powder and a preparation method thereof in the technical field of ceramic materials, in particular to a spontaneous hydro-thermal method for preparing special composite nano ceramic powder for a ceramic tooth. The components are as follows according to molar percentage: 5 to 8% of yttrium oxide, 1 to 3% of aluminium oxide and 89 to 94% of zirconium oxide; and the particle diameter of composite nano ceramic powder particles is from 20 to 30 nanometers.

The method has the characteristics of good toughness, nearly no crystal imperfection and favourable sintering activity; after being further processed by surface modification, the ceramic powder can form a spherical or subspherical structure; and the inner components are tightly combined with one another, are endued with favourable flowability and transport property, and can be directly used for the injection moulding of a ceramic tooth piece.

The preparation method has the advantages of simplicity, low cost and easy realisation of industrial production.

CN 101508020
METAL POWDER MATERIAL FOR METAL POWDER INJECTION MOULDING AND MOULDING TECHNIQUE

Publication date: 2009-08-19
Inventor(s): Yiping Zhang, et al, Suzhou Vocational University China

The invention discloses a metal powder material, which comprises the following components in percentage by weight: 7.0 to 9.0% of nickel powder, 0.5 to 2.5% of molybdenum powder, 2.0 to 4.0 % of vanadium powder, 0.6 to 1.0% of carbon powder, and 83.5 to 89.9% of iron powder.

A metal part made of the metal powder material has good hardening capacity during subsequent thermal treatment; after proper thermal treatment, a product has good properties on strength, hardness, abrasion resistance, and the like; and the metal powder material has realistic significance.

Mixing titanium MIM feedstock: Homogeneity, debinding and handling strength

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Although metal injection moulding (MIM) is increasingly being used to produce metal parts with complex geometries, less than1% of the market utilises titanium powders [1]. As a low energy method for producing parts of complex geometry, MIM is a suitable process for reducing the cost of producing titanium and titanium alloys. It is accepted that the final quality of MIM parts is a function of the moulding, debinding and sintering processes. If the green part has defects they will exacerbate during subsequent debinding and sintering due to in-homogeneity of binder components and non-uniformity in particle distribution. Although this is understood there is little available data quantifiably supporting this. In our study, a co-rotating twin-screw extruder is used for batch mixing titanium fine powder with a polyethylene based binder to form a feedstock enabling investigation of limits to homogeneity and to determine how this affects particle adhesion and the strength of green parts.

Introduction

Titanium is found in at least 35 mineral forms, is the ninth most abundant element in the earth's crust and fourth most abundant metallic element [2]. As an advanced material it has good strength (typically over 650 MPa) and ductility (typical elongation to fracture > 20 %) with a moderate density (4.5 g/cm^3) providing good specific properties over other materials and it is corrosion resistant (chemical industry) and highly bio-compatible (medical and dental application). When alloyed (i.e. Ti 6Al 4V) even more desirable properties are found: high strength (>1000 MPa), and high resistance to creep at temperatures up to 650 ºC and high corrosion resistance. The negative aspects that keep titanium from materials selection are generally associated with costs and, for many titanium alloys, poor machinability [3]. Metal injection moulding (MIM) offers a low energy process, compared with casting, press forming, forging and machining. It offers low waste through low production numbers of high complexity at near net shape with little machining requirements and best suited for small to micro-scale parts.

Although MIM is increasingly being used to produce metal parts with and in many cases the only process able to produce complex geometries, titanium powder usage is less than 1% of the MIM market [1]. Researchers and industrialists are working together to increase the awareness of the benefits of using Ti MIM [4]. This is evidenced by the number of presentations at the recent MIM2011 conference [5-7] and the twelve full sessions offered at PowderMet2011 conference where MIM and Ti development and applications is extremely active [8].

One of the reported problems with the use of titanium, referred to as a metallic solvent [9], is its reactive nature whereby during processing at elevated temperatures it has an affinity to contaminants in the process condition window. As the MIM process ensures titanium powders are in close proximity with potential contaminants in the form of the binder system there is the need for investigation into the mechanism of particle adhesion and bond strength as related to contamination uptake. It is well understood that quality of MIM parts is a function of the moulding, debinding and sintering processes. An inherent problem with the generic MIM process relates to green part defects that exacerbate during the debinding stage and further at sintering. Green part quality is affected by the homogeneity of the feedstock which is dependent on powder characteristics such as particle topology and morphology, as well as particle size distribution and binder properties such as component miscibility, homogeneity and distribution.

While mixing efficacy, wetability and powder loading affect quality, it has also been shown that failure to control melt flow uniformity may result in anisotropic shrinkage and strength gradients during injection and cooling stages, causing cracks from debinding process and distortion from sintering process [10]. This shows the need to study the feedstock, moulding, debinding and sintering process steps:

1. Feedstock
Binder composition, to enhance mouldability of metal powder
Binder to metal ratio, to optimise debind process
Homegeneity, provides uniformity of material properties

2. Moulding
Part geometry, physical requirements and mould design
Process parameters, to optimise injection process
Greenpart strength, removal and handling

3. Debinding
Binder solubility/degradability, component selection and process design
Binder residual, handling strength and potential contamination
Brownpart strength, handling and feature retention

4. Sintering
Particulate properties, morphology and surface interaction
Process parameters, required density and geometry retention

This work investigates stages 1-3 with the use of a co-rotating twin-screw extruder and a series of trials to assess effects of mixing on the homogeneity of a polyethylene based titanium feedstock, and analyses particle adhesion and powder compact strength.

Experimental Procedure

Feedstock was produced using a 0.6 volume fraction of commercially pure HDH titanium powder -325 mesh (S.M.P. Co., Inc. Red Lion, PA). The binder was formulated based on a combination of polyethylene and wax. The feedstock was weighed and bag mixed at ambient temperature prior to the first compounding. Using the thermo twin screw extruder (Fig. 1), the batched feedstock was processed at 170 ºC. The batch was extruded one time and the extrudite was granulated.

The process was repeated with the granulated extrudite, for subsequent extrusions, reducing the total volume and samples were taken after 1, 2, 3, 4, 5, 7 and 10 passes. Analysis of each pass of granulated extrudite was done to determine properties for each to allow a comparative investigation. A sample of extrudite is taken of each for visual inspection (PSEM), melt indexing with extrusion plastometer, energy dispersive spectrum analysis (EDS), thermo gravimetric analysis (TGA), differential scanning calorimetric analysis (DSC) and x-ray diffraction (XRD).

Sample plates of 40 mm x 40 mm x 1.6 mm were made to enable investigation of the green part. In order to retain the mixed integrity of each green part with relation to the amount of extrusion, the moulding of the feedstock sample plates was not done in the injection moulder, but was done in a heated press with an aluminium plate mould using injection moulding equivalent temperature, pressure and duration. The sample plates were cut into bars of 8 mm x 30 mm x 1.6 mm for dynamic mechanical analysis (DMA) to assess strength and tokens of 8 mm x 8 mm x 1.6 mm for thermal mechanical analysis (TMA) to assess thermal expansion. The sample specimens cut from the green plates are solvent debound (SD) at 50 ºC for 24 hours to remove part one binder, followed by drying at 50 ºC in vacuum oven for 24 hours. A set of specimens were visually inspected and analysed by using DSC, TMA and DMA respectively. The remaining specimens were thermally debound (TD) for 4 hours at 250 ºC in air to remove part two binder followed by visual inspection analysis by using DSC, TMA and DMA. Measurement by simple dimension/mass calculation is done by all process steps, AM, SD and TD.

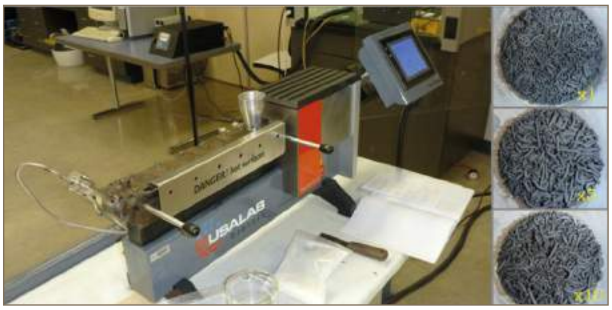

Fig. 1 Pre-mixed powder and binder was repeatedly extruded in the twin screw extruder and feedstock samples taken at 1, 2, 3, 4, 5, 7 and 10 passes

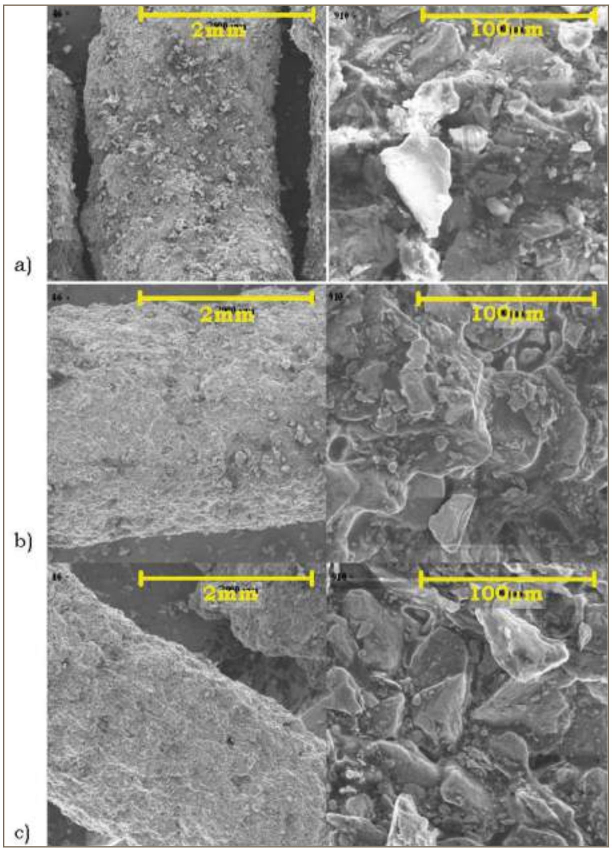

Fig. 2 SEM micrographs showing feedstock for a) one, b) five and c) ten extrusion passes

Results and Discussion

The initial extrusion pass of the batched binder components and titanium powder (0.6 V_f) was problematic and time consuming with some ten hours taken to process 1000 gm of feedstock EM1. Subsequent passes were completed in 30-90 minutes as the bulk of the feedstock diminished through sample collection and process losses. Losses were due to purging between passes and extrudite remaining in the extruder barrel on completion. Visual examination of the feedstock granules indicated how using the correct method of assessment can produce differing results. As shown by the SEM images of the feedstock produced using different numbers of mixing passes in Fig. 2, insufficient mixing produces loose titanium particles, at the surface, with low binder encapsulation (Fig. 2a). This is consistent with the extrusion of filled polymers where preferential distribution of particles is seen whereby the high viscosity polymer will migrate to the centre of the strand, although it is noted that MIM feedstock is a metallic blend and not a filled polymer and hence characteristics will be different. The amount of loose particles diminish as the number of passes increased as shown in Fig. 2b and Fig. 2c. The sample produced with a single pass (Fig. 2a) showed an amount of loose surface particles and inhomogeneous structure. As shown in Fig. 2b, the sample produced with five passes showed reduction of surface fines and a more homogeneous structure. The sample produced with ten passes (Fig. 2c) showed no loose particles and a similar structure as that seen for the sample produced with five passes.

Supporting the concept of loose particles and poor encapsulation due to mixing the flow data, Fig. 3 shows a low flow rate (~17 g/10 min) at EM1 increasing as the number of passes increases and the mixing improves. The flow rate is seen to peak (43 g/10 min) at three passes and remains static through to seven passes (39 g/10 min) then it drops to (28 g/10 min) ten pass. Flow rate drop following the increased mixing passes is contributable to extrusion barrel residence time and process loss of the lower molecular weight binder components, these components may not contribute to retention of part geometries.

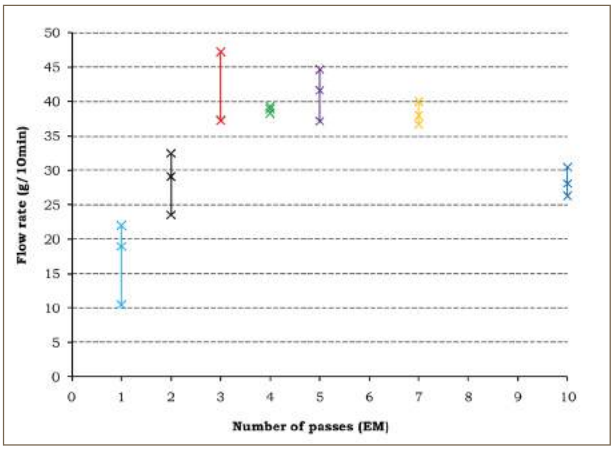

Fig. 3 Flow rates of extruded feedstock determined using the extrusion plastometer

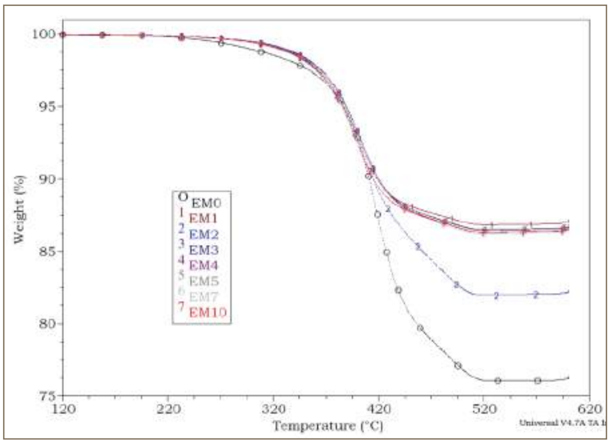

Fig. 4 TGA plots for extruded feedstock 0, 1, 2, 3, 4, 5, 7 and 10 passes

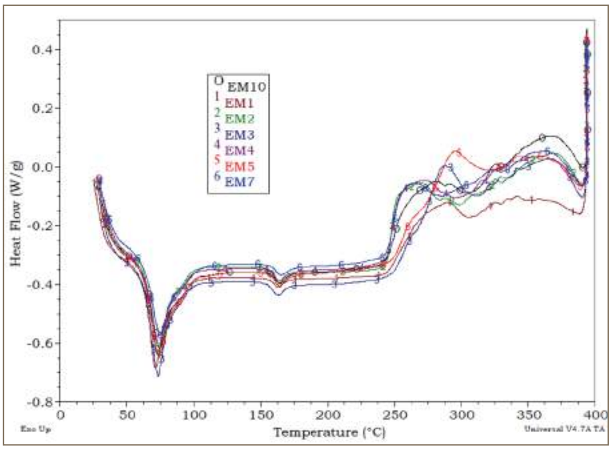

Fig. 5 DSC thermal plots for feedstock mixes 1, 2, 3, 4, 5, 7, and 10 passes

The TGA plots in Fig. 4 provide evidence that the uniformity of the feedstock is not so good for a lower number passes, although the binder may be homogeneous the titanium powders may not be uniformly distributed within the mix. The EM0 binder content for this sample is ~24 % and EM2 is ~17 %, while the remaining samples show at ~13-14 %, which is in line with the 13.2 % value of the powder/binder batched values as originally calculated, for a powder fraction of 0.6. The line trends for each plot do present the same knee at 370 ºC and 445 ºC and all leveling off at 520 ºC.

The DSC data plot for each sample is show in Fig. 5, the samples were heated past their degradation temperature for the binder components. The endothermic troughs appear to be considerably higher than the expected bands relative to the data from the safety data sheets for the binder components, an indication of some changes in thermal properties due to components and possibly some thermal effect of the titanium powder. The lower molecular weight components, those to be removed from solvent debinding have melt temperature values of 65 °C, the components removed during thermal debinding 65 °C - 85 °C, and the backbone/ residual polymers 85 °C - 105 °C. The DSC results for these components indicate that the values reported in the safety data sheets as melt temperature are more likely to be softening points as the endothermic points are given at 72 °C - 82 °C, 69 °C - 90 °C and 118 °C - 175 °C respectively.

Taking account of the component DSC values it can be seen that the plots in Fig. 5 for the feedstock does match the temperature bands for the binder and indicates that miscibility of the components is good, hence the point at 75 °C accounting for the SD and TD components and the trough at 160 °C indicative of the backbone components. The exothermic reactions seen from heat recovery above 250 °C do not show consistency but follow the same trend of two distinct peaks at ~275 °C and 370 °C. Although these temperatures are above degradation/ flash temperatures of the lower molecular components the indicators of miscibility and the titanium effect may account for such a shift.

Moulded sample plates are shown in Fig. 6a along with the analysis specimens post solvent debinding in Fig. 6b and post thermal debinding in Fig. 6c. Characterisation of the binder and feedstock allows possible insight into the mechanical behavior of the AM plates. The plates shown in Fig. 6a were cut prior to debinding to obtain uniform specimens of dimensions suitable for mechanical testing. By cutting the specimens before debinding this eliminated ambiguity caused by specimen location at the edge or middle of the moulded plate where the debinding process may distinguish between central areas of the plate and exposed edges. It will not however account for preferential distribution of the titanium powders should it occur due to non-uniformity or binder separation during moulding.

The binder as a multiphase system has been formulated to allow removal of the components through a gradual process to reduce the likelihood of slumping, distortion or cracking. The first phase is the solvent debinding; this is done in a controlled debinding system over a period of 24 hours with a circulating flow of the liquid solvent at a temperature of 50 °C. Fig. 7a shows binder agglomeration for the single pass specimen, these points would produce voids as the titanium particles are not in close proximity, necessary for coalescence during sintering. The four pass specimen in Fig. 7b shows a uniform distribution, an indication of good mixing with some small areas of binder agglomeration. The ten pass specimen (Fig. 7c) has distinct separation or binder poor areas on the surface; this would contribute to lower flow rate. The SD specimens of Fig. 8 all show signs of binder agglomeration although this appears to be decreasing as the number of passes increase. The particle packing is good with no immediate signs of voids being formed.

The SEM images of TD specimens shown in Fig. 9 present clearer views of the particle packing within the moulded specimens. All images show the presence of voids due to the packing of the particles. It is likely that these voids formed at the sites of agglomeration previously noted. It is not seen here if these void formations would remain so following sintering but it is known that defects such as this will not repair as the sintering forces will not overcome the bonds developed during the moulding stage.

Density values are given in Table 1 based on an average for all specimens, these values are based on theoretical values calculated for the original batched binder components and titanium powder.

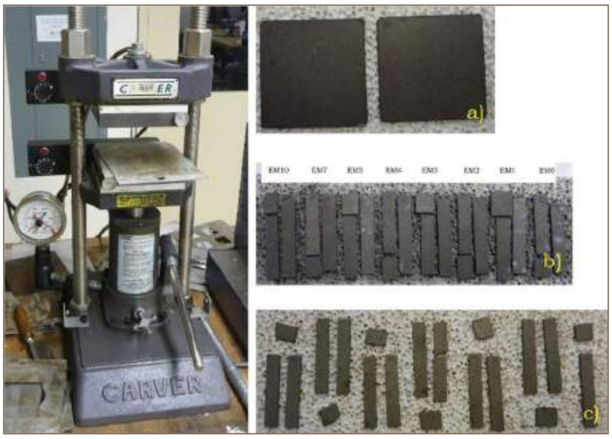

Fig. 6 a) Green part plates moulded using equivalent injection moulding temperature, pressure and duration. Plates cut into bar and token specimens for analysis and debinding, b) solvent debound (SD) and c) thermal debound (TD)

The as-mixed plates have a low average relative density of 78 % for the EM0 process with that trend remaining through the SD and TD specimens, reducing to a average of density of 73 %. The plates and test specimens for EM1 to EM10 all show similar average density values of 90 - 94 %, and as the number of passes increased there was no noticeable change in density. From as-moulded (AM) density value there is an average ~0.6 % increase to SD and then an average ~2.4 % decrease for the TD specimens, there is also an increase in the average standard deviation through the debinding stages from AM to SD and TD. The density vs. number of passes plots, Fig. 10, show the spread of values for the two sets of experiments. It can be seen that the TD2 set shows a similar trend to the other sample sets as the number of passes increases but has values ~5 % less than the equivalent TD1 set, there is no consistent difference for the SD set values. The density of the batched feedstock specimen EM0 had a considerably lower average density at ~78 % that reduced to ~73 % post TD. The SEM image of this specimen in Fig. 11, shows gross agglomeration and non-uniform binder distribution accounting for the lower density.

The proximity of the titanium particles affects the sintered properties of the end part, so dimensional change during processing is investigated using the TMA. As the specimens were heated from ambient temperature to 50 °C, chosen as it reflects the SD temperature, the thermal expansion is measured. As the expansion rates of individual binder components and the titanium powder is different, there would be changes seen to indicate excesses of one or other components. As the expected degree of homogeneity of binder and uniformity of particle distribution increases through mixing this should be noticeable in the expansion rates. The plots of dimensional change as a function of time in Fig. 12 show similar line trends for all AM specimens in the initial heat up phase, 0-25 min, where the specimen is ramped to 50 ºC. Similar line trend is seen for the relaxation dwell period 25-55 min with the exception of EM0 and EM1 specimens, in which a higher degree of relaxation indicates greater hysteresis, indicative of higher polymer content or possible polymer rich areas as seen in Fig. 7.

The handling strength of AM and SD part was investigated to determine the effect of the mixing duration. The tensile properties are generally used for these measures. In this study the flexural modulus is analysed as it is considered that use of the flexural properties allows a measure of both tensile and compressive

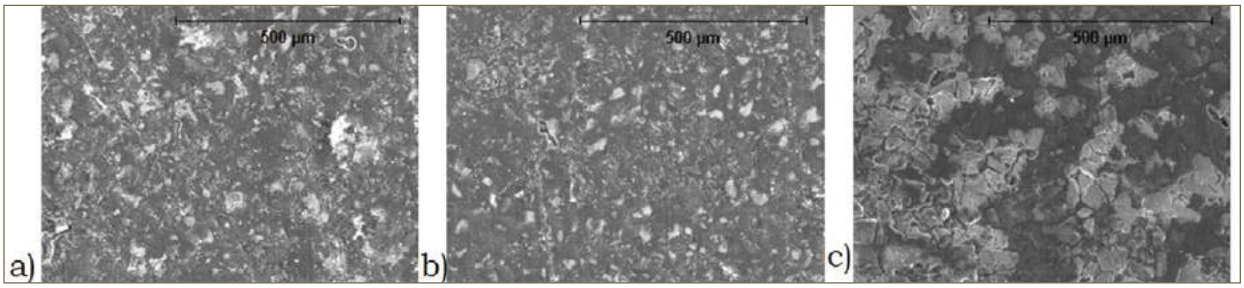

Fig. 7 Surface of as moulded specimen a) single pass with signs of binder agglomeration, b) four pass uniform appearance and c) binder separation area of ten pass specimen

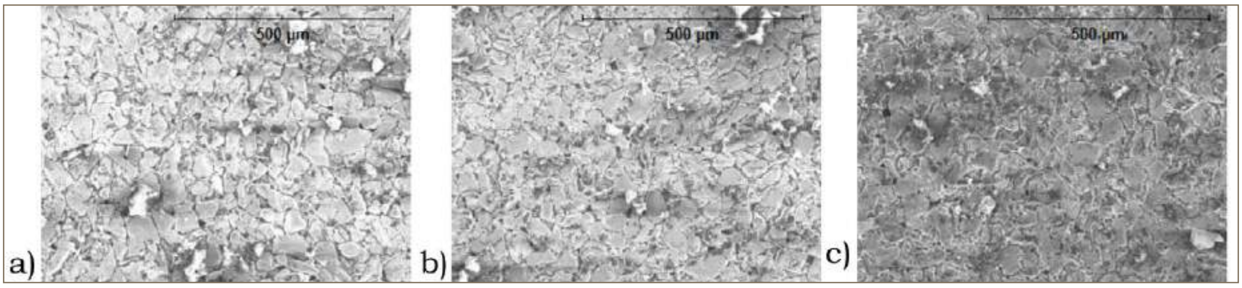

Fig. 8 Surface of solvent debound specimens a) single pass, b) four pass and c) ten pass

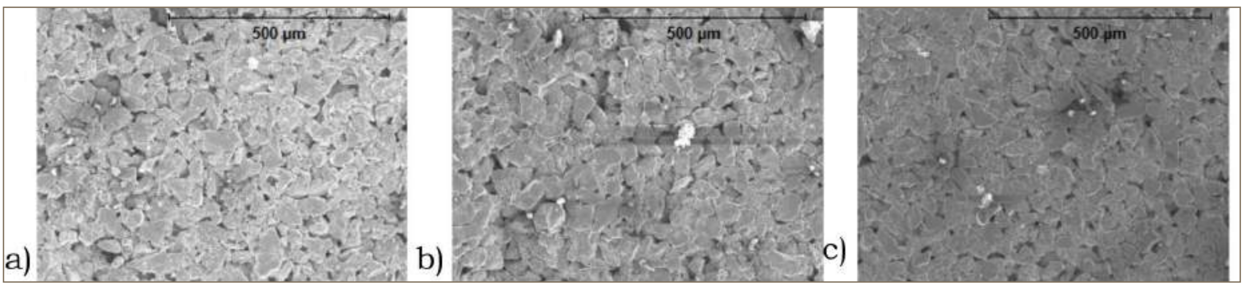

Fig. 9 Surface of thermal debound specimens a) single pass, b) four pass and c) ten pass

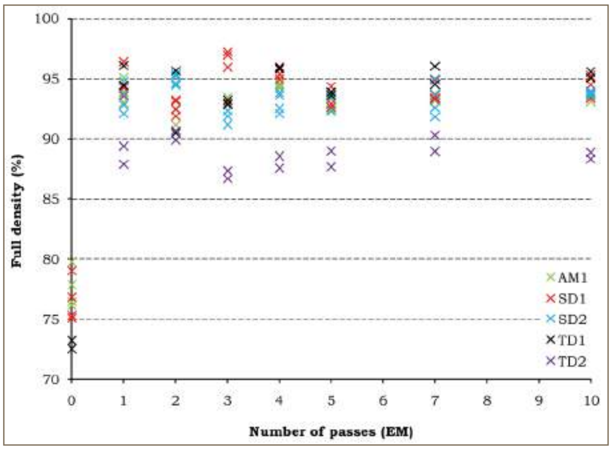

Fig. 10 Plot of percentage full density for both sets of AM, SD and TD specimens

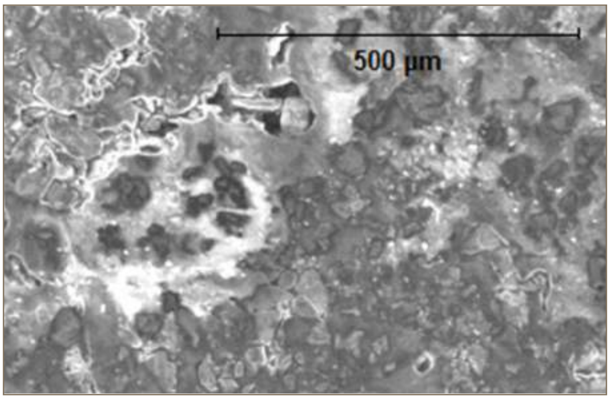

Fig. 11 Batched sample EM0 showing unmixed binder location

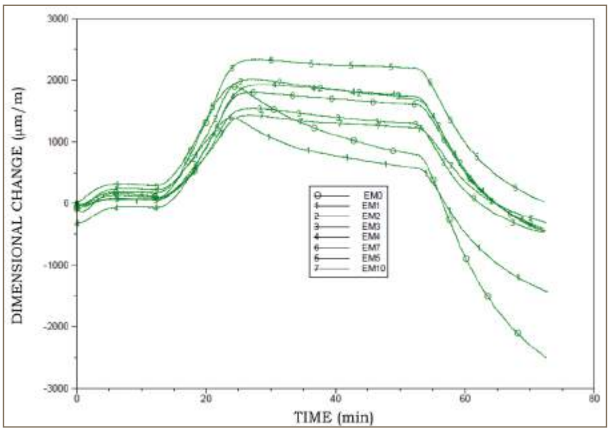

Fig. 12 Thermal expansion of extruded AM specimens from TMA analysis

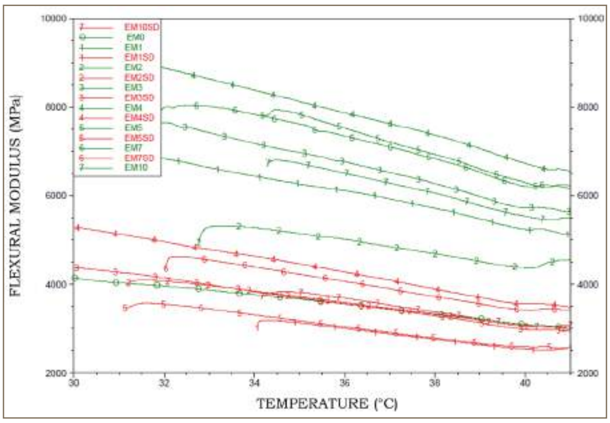

Fig. 13 Comparative DMA analysis of AM and SD specimens

reactions. The DMA results in Fig. 13 show clear difference for the AM and SD specimens. The AM specimens having higher values for all but EM0 and EM2, the SD batch show less deviation between specimens. Both AM and SD do share the same differential across the temperature range. One noticable trend observed from the density measurements shown in Fig. 10, was that the density increased from EM0 to EM4 specimen and then decreased to EM10 specimen. This trend is repeated here, as shown in Fig. 13, where the peak values are obtained for the EM4 specimens and the lower values seen for the EM0 and EM1 specimens, and the EM10 values are also inline with the EM3 values.

Table 2 highlights the difference in flexural modulus values between the AM and SD specimens at 40°C and also shows no distinction as the number of passes increased. Higher modulus values occur for the AM, specimens which have a greater binder content than the SD, although it is seen that EM0 which has the low density value also has the low modulus. This would indicate that EM0 has greater voids within the structure, although this is not obvious from the SEM images, but may account for the relaxation seen in the TMA plot.

EM#	AM		SD		TD	
	Avep	STDev	Avep	STDev	Avep	STDev
	%					
0	78	1.7	77	1.8	73	0.5
1	94	0.9	94	1.3	92	3.9
2	92	0.7	94	1.3	92	2.7
3	93	0.5	94	2.4	90	3.5
4	94	0.2	94	1.4	92	4.5
5	93	0.6	93	0.7	91	3.2
7	93	0.2	94	1.1	92	3.4
10	94	0.3	94	0.6	92	3.9

Table 1 Density values of as-moulded (AM), solvent debound (SD) and thermal debound (TD) samples respectively

It is unsure to this point in study whether the agglomeration of binder components seen in the AM and SD specimens is due to insufficient mixing, limitations of chemical solubility or a combination of both. The effects of this on the specimens and titanium particles are seen in Fig. 7c and Fig. 8c as a reduction in binder at the surface, possibly a result of losses during the extended mixing. This in turn will contribute to the reduction of residual binder that forms on the titanium particles in the brown state. The SEM micrographs in Fig. 14 show the titanium particles as they would appear based on a thermal burnout of the binder. Fig. 14a shows the irregular shape of the HDH titanium particles and fines as received. Fig. 14b, c and d, show residue remaining on the particle surfaces and wear on particle edges. It can also be seen that the amount of wear on the particles increases as the number of passes increases. The SEM micrograph of the EM1 specimen (Fig. 14b) shows greater residue as a distinct contaminant phase, which will be a precursor to defects such as voids and open pores. The surface residue appears greater on the EM10 particles (Fig. 14c), the reduced binder components and extended mixing appears to have improved the surface interaction of the residue.

In summary, the use of the twin screw extruder to investigate the mixing of a titanium feedstock for MIM has presented the following results:

Initial mixing of the batched feedstock components is problematic; as the titanium particles become encapsulated the

EM#	E (40 °C) MPa	
	AM	SD
0	3100	
1	5150	600
2	4700	3000
3	5700	2950
4	6500	3500
5	6300	2600
7	6250	3450
10	5500	3100

Table 2 Flexural modulus values taken from DMA plot at 40 °C, distinct difference between AM and SD specimens

mixing times are much reduced. SEM micrographs in Fig. 2 highlight some differences; the low magnification shows many loose particles adhering to the granule surface of the single pass feedstock, decreasing as the number of passes increased. The higher magnification show the loose particles in Fig. 2a, likely a binder component that has not mixed in with the bulk feedstock at this point, Fig. 2b and c present the five and ten pass feedstock which have similar appearance showing reducing amounts of the agglomerated fractions.

Fig. 3 shows that the melt-flow rate of the feedstock improves with the number of extrusions to peak from three to five passes after which the flow rate is seen to decline. The capillary extrusion rheometer is the most relevant instrument to characterise MIM feedstock, in this study it was considered that the entry and exit effects would alter the as mixed homogeneity of the feedstock and not produce suitable flow data. A fundamental understanding is required to quantify the effects of mixing and the use of the SEM to visually characterise the feedstock through the process showed that the drop in flow rate after ten extrusion passes is due to loss of the binder components. This is not supported in the density measurement although does effect the flexural modulus.

The most prominent issue for titanium MIM is the contamination level prior to sintering. Much MIM research is treating feedstock as if it were a composite material; the powders are wetted to ensure total adhesion with the binder by the use of compatibilisers and wet agents. It is agreed that the binder should be thoroughly mixed and homogeneous but the powders, while dispersed throughout the feedstock, should not bind with the binder unless the adhesion can be completely reversed in subsequent debinding. Fig. 14 shows the clear lines of the as received powders become lost from the mechanical action of an extended extrusion and moulding process and the residual binders change from a distinct contaminant phase amongst the titanium particles to a residue on the surface of the particle. However the greater the bond between the binder and the metal powder the more difficult it will be to eliminate contamination during sintering.

Conclusion

Initial mixing of binder components and titanium powder is problematic and the flow rate of the subsequent feedstock is very low. The flow rate increases as the mixing time of the feedstock is extended which indicates viscosity is also increasing but after five extrusion passes the flow rates and hence viscosity drops. The initial increase in viscosity is due to a reduction in loose powders as particle encapsulation becomes total. The drop in viscosity is a result of binder separation and loss of low molecular weight binder component from processing. Binder component miscibility is the same for all feedstock mixing conditions. Mass loss from debinding green parts and subsequent density reduction is not affected by the amount of mixing after the first extrusion pass. Prior to that, gross agglomeration and non-uniform binder distribution account for the low density. Dimensional change is effected by the amount of mixing. Handling strength reduces as the binder is removed and

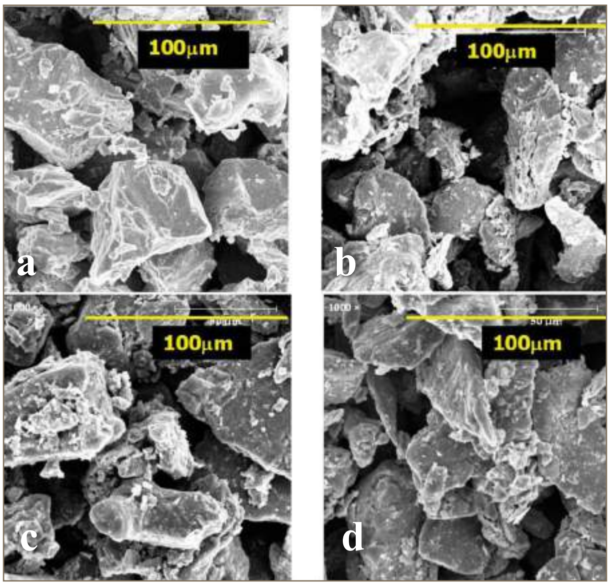

Fig. 14 The effect of mixing on powder particles post binder burnout, a) as received powder, b) single pass, c) seven passes and d) ten passes

becomes more uniform. The titanium particles are subject to wear as the mixing process is extended and the particle encapsulation increases.

The use of elemental analysis such as EDS and XRD is needed to establish the composition of residuals in the green part and the brown part to identify means of elimination.

Acknowledgments

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3D visualisation of flow patterns in injection moulded ceramic green parts

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Mould filling behaviour affects the green structure of an injection moulded part, since defects can be caused by flow patterns. These defects might be pores, or weak spots such as weld lines. These risks can be minimised by optimising the tool design aiming for a desired flow pattern. Hence, understanding the formation process of specific flow patterns is very important and necessary to characterise. In this paper, a method for visualising flow lines within injection moulded green parts is presented. By introducing an X-ray detectable tracer material, a three dimensional image is produced revealing the flow patterns. Four case studies demonstrate the potential of this method.

Introduction

Defects in finished sintered ceramic injection moulded (CIM) components often have their origins in the green part. Cracks can be initiated at weak points such as pores, but also at weld lines or knit lines which result from jetting. Residual stresses in the green part may lead to distortion or warpage during thermal treatment. Since the green microstructure is created during the mould filling phase it depends on feedstock properties and, most importantly, on the tool design, including sprue and gate number, shape and position.

In order to investigate the flow behaviour experimentally several approaches have been developed to visualise the flow pattern. They follow approaches like direct melt observation, evaluating surface marks, introducing tracer particles into the melt and interrupting the injection process.

For direct observation the melt flow is recorded inside the mould by high speed cameras. Flow around obstacles [1], in-mould shrinkage [2], duration of partial cavity filling [3], changes in melt front shape [4] or jetting [5] can be analysed and time resolved. Special tools need to be applied in which one cavity wall is substituted by a transparent window to allow connecting of the camera. Therefore it is limited to flat specially designed testing geometries.

A method, which can be used for any existing tool, evaluates patterns visible on the parts surface. These are, for example, weld lines examined under the microscope [6] or flow lines and ripples on the surface. By decreasing melt and tool temperature those lines can be intentionally evoked [7, 8]. It has to be taken into account that the test parameters diverge from the common production parameters and might affect the flow lines.

By adding a marker material into the melt the flow paths can be derived. This is especially suited for transparent matrices like many plastics. The markers can be particles like pigments, the orientation of fibres or stream lines when two coloured polymers are mixed [9].

The most common way and widely applied in industry is to analyse the melt progression by producing a short shot study [10, 11, 12]. By interrupting the injection phase at different volumes a sequence of filling stages is created. The obvious advantage is its universal applicability to all tools using normal production conditions. Furthermore it requires only modest time and cost. However, the produced samples show only the state at one moment and do not reflect the flow pattern in the final part.

The visualisation method which is introduced in this paper uses a tracer material which can be detected by X-ray computed tomography. The CT images allow a three-dimensional visualisation of the flow pattern. It is not limited to special part geometries.

Experimental

CT-method

Computed tomography is a non-destructive inspection method which provides three-dimensional images of the sample, including its inner structure. During the measurement the sample is placed

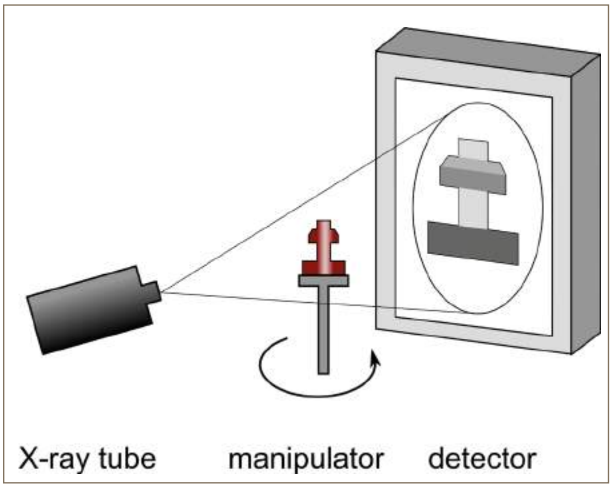

Fig. 1 Principle of computed tomography

between the X-ray source and the detector (Fig.1). The intensity of the transmitted radiation is attenuated according to the Lambert-Beer law and depends on material properties and thickness:

$$I = I_0 e^{-\mu x} \quad (1)$$

Where I_0 is the intensity of the initial X-ray beam, I is the intensity after transmission, x is the thickness and μ is the linear attenuation coefficient. The transmitted intensity is measured by a detector spatially resolved giving a grey-scale image. During the CT scan the sample rotates and projections from several hundred angles are taken to reconstruct the volume.

In this study a CT-Compact (Procon X-ray, Germany) was used which is equipped with a 150 kV microfocus X-ray tube having a minimum focal spot size of 7 µm. The flat panel detector has 1024 x 1024 px. The samples were scanned for 360° in angular increments of 0.45°.

Development of visualisation method

For developing the visualisation method three aspects have to be considered. The marker material shall produce a detectable grey scale contrast (1), its size has to be detectable by the equipment used (2) and it shall not significantly distort the flow behaviour of the feedstock (3).

1. **Material contrast**
   In this study the mould filling behaviour of alumina feedstocks should be investigated. The incorporated marker material should differ in attenuation coefficient from this matrix. The X-ray attenuation coefficient is a function of the atomic number, the density, and the energy of radiation. Alumina has a mean atomic number of 10 and a density of 3.98 g/cm³. Thus, zirconia with a mean atomic number of 18.7 and a density of 6.05 g/cm³ adsorbs radiation to a higher degree and was selected as tracer material.
2. **Tracer size**
   The way of introducing the tracer particles into the feedstock is limited by the spatial resolution of the measuring device, which depends on two factors. At first, the X-rays are not emitted from an ideal point source but rather from an area of several microns. The size of this focal spot determines the distance of two distinguishable points and causes a geometrical unsharpness. The second factor is the position of the object. By moving the sample closer to the X-ray tube it can be magnified to reveal more details. However, the highest possible magnification depends on the dimensions of the sample, since the projection image must be completely captured on the detector during the whole measurement.
   Given the typical size of injection moulded parts, the achievable resolution is 15 to 60 µm. Single tracer particles with diameters in the submicron scale, as they are characteristic for ceramic powders, could not be detected. Therefore, the particles are applied as a homogenous tracer feedstock which is mixed with the investigated base feedstock.
3. **Tracer feedstock**
   The flow behaviour of the tracer feedstock has to be adapted to the base feedstock. This was achieved using feedstocks with the same binder system and a similar solids loading. In Table 1, data of such a pair of feedstock based on a polyethylene-wax binder system are presented. The resulting viscosities are quite similar as shown in Fig. 2. Mixing of both feedstocks is carried out directly during the injection moulding experiments. The feedstocks are fed alternately into the hopper in quantities of 20 ml resulting in alternating layers. During dosage they are mixed inside the cylinder by screw rotation. Advantage is taken of the fact that homogenising is not perfectly accomplished. During mould filling both feedstocks flow into the mould adjacently, so that layers of differing materials become visible in CT measurements. The stream lines can be pictured in two modes. A 2D image, a so-called radiograph, is taken from one direction showing the projection. Performing a CT-scan gives the volume resolved 3D information and is provided as a stack of equidistant images.

Case studies

We will demonstrate the capabilities of the developed visualisation method based on four case studies.

Case study A was performed to analyse how flow pattern develop during mould filling. The sample was bar shaped with a rectangular cross-section of 3.5 x 7.0 mm². The gate was located at the smaller side 17.5 mm distance from the end (Fig. 3). To characterise the different filling stages a short shot study was carried out in volume steps of 0.5 cm³ with the polyethylene-wax based alumina/zirconia feedstock couple. Tool temperature was 65°C and feedstock temperature was 160°C. Since the part had a constant thickness, the images were taken as radiographs.

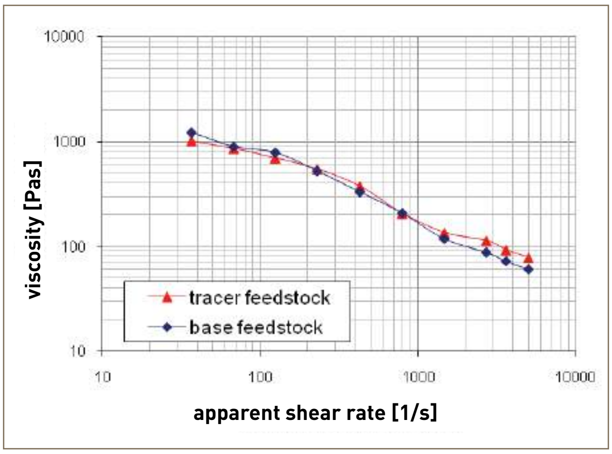

Fig. 2 Viscosity of alumina base feedstock and its associated zirconia tracer feedstock

	Base feedstock	Tracer feedstock
Binder system	PE-wax based	PE-wax based
Powder	alumina	zirconia
Solids loading [vol.%]	55.5	56
Particle size d_{50} [µm]	0.5	1.0

Table 1 Composition of an alumina base feedstock and its associated zirconia tracer feedstock

Feedstock temperature [°C]	Tool temperature [°C]	Injection speed [cm³/s]
165	80	5
175	135	15
		30

Table 2 Variation of injection moulding parameters for the feedstock Catamold®

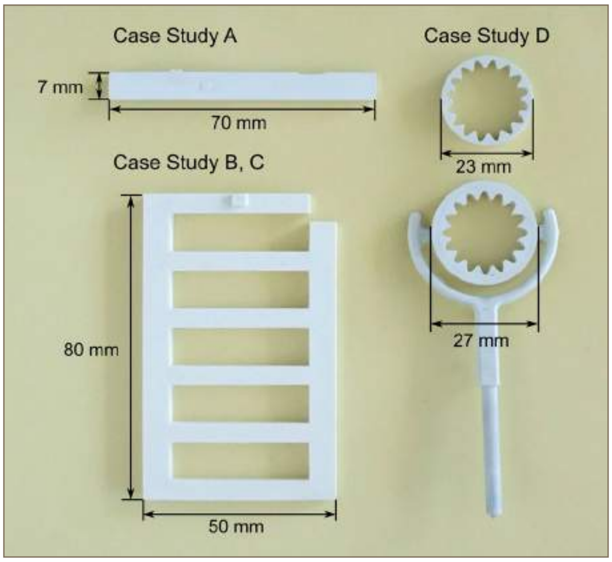

Fig.3 Test parts used for the case studies: A: bar; B, C: modified ladder; D: two-component gear wheel

In case study B experimentally derived flow patterns are compared to mould filling simulations results. The testing geometry was a modified ladder (Fig. 3). It consists of six rungs which are attached at two connectors. Since one side is closed at the melt entrance the cavity is filled asymmetrically. Samples were produced with the commercially available alumina feedstock Catamold® AO-F (BASF AG, Germany). The base feedstock was mixed with an adapted zirconia tracer feedstock. Injection moulding was carried out on an Arburg 320S injection moulding machine at a feedstock temperature of 175°C. The tool temperature was 135°C and the injection speed was 15 cm³/s. Simulation of the mould filling behaviour was performed using the software Moldex3D® (SimpaTec GmbH, Germany). As simulation input data feedstock properties like pVT-diagram, viscosity, specific heat, thermal conductivity, Youngs modulus and density were implemented [12]. The results of the simulation were then compared to the flow pattern visualised by CT measurements.

Case study C is based on case study B and uses the same testing part. It focuses on the question to which extent flow lines depend on the moulding conditions. Samples were injected at parameters according to Table 2 using the Catamold® feedstock pair. The green samples were sectioned after each rung and inspected by CT to obtain a three dimensional image. In the cross-section perpendicular to the flow direction the individual feedstock streams become visible. The areas were measured using the image analysis software ImageJ, (National Institutes Health, USA). In comparison to the Catamold® feedstock a second feedstock, based on polyethylene - wax, which was also used for case studies A and D, was analysed in the same way. The injection parameters were chosen according to the optimal production parameters (feedstock temperature: 160°C, tool temperature: 65°C, injection speed: 10 cm³/s).

Case study D deals with the effects of flow pattern on the microstructure of green parts and consequential defects. The study was conducted on an internal gear wheel which is designed as a two-component part (designed by Bosch, Germany). It consists of two concentric rings with the inner ring holding the gear. The sprues are connected to the part by two opposite located gates (Fig. 3). After the inner ring is injected first, it is transferred to the second cavity by the rotary plate technique to inject the outer ring. Alumina was used for the inner ring and zirconia toughened alumina for the outer ring. Both feedstocks are based on a polyethylene-wax binder system. In order to investigate the microstructure of the green part by scanning electron microscopy it was polished using a broad ion beam technique [13]. Computed tomography was used to characterise the internal structure of one gear tooth after debinding to reveal the developed defects. For analysing the flow pattern, gear wheels were produced with the tracer and base feedstock mixture and scanned by CT. The samples were sectioned into single teeth in order to achieve a voxel size of 15 µm.

Results and Discussion

Case Study A

The chronological stages of mould filling are shown in Fig. 4 in which the injected volume is increased stepwise. The radiographs provide information reflecting the attenuation behaviour summed over the complete radiation path. Therefore material contrast and wall thickness are superimposed and marks of two ejector pins and a pressure transducer overlay the flow line pattern.

After entering the mould the feedstock impinges onto the opposite wall, piles up and splits into two streams. One stream fills the upper, smaller cavity part and the other one the lower, bigger cavity part. The flowing feedstock compresses the already deposited material at the opposite wall and slides upon it. The boundaries

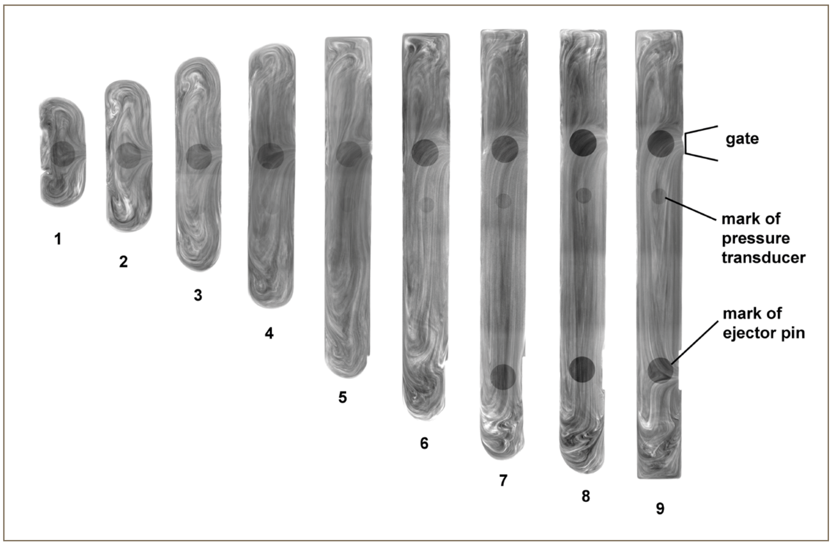

Fig. 4 Radiographs of a short shot study visualising the filling process of a bar shaped sample

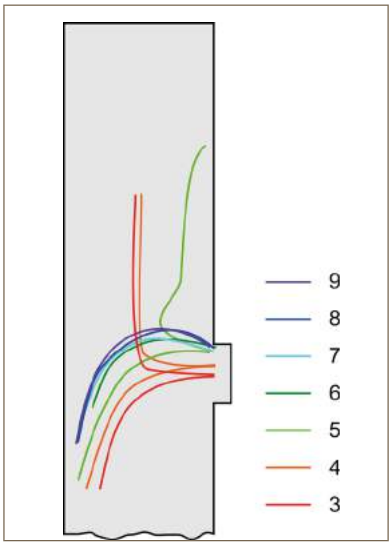

Fig. 5 Stream lines at different filling stages marking the boundary to the dead water zone

can be identified in the radiographs. For a better overview they are marked in Fig. 5 for the bars 3 to 9. At the beginning the separation line between both streams is positioned in the middle of the gate leading to symmetric filling. With increasing filling level of the upper cavity part the ratio changes in favour of the downwards stream. The upwards stream narrows continuously until the cavity is filled and stops after bar 5. The flow pattern which has been formed remains unchanged until the end of filling and is called a dead-water zone. Only at the contact area, between the deposited and flowing feedstock, material is eroded and the boundary moves into the dead-water zone. This includes especially the area opposite the gate. Such inner interfaces, where two feedstock volumes move relative to each other, can be the source for defects as will be shown in case study D.

A second detail in the flow pattern can be observed. After the feedstock has hit the wall the melt front shows internal turbulences in the downwards stream. This pattern stays stable and is pushed forward by the propagating feedstock until it reaches the end of the cavity. Between the disturbed layers and the gate laminar flow develops.

Case Study B

One important aspect for tool concepts are the locations of weld lines since they are potential origins of defects. They can be affected by number, position and design of sprues and gates. The locations where two feedstock fronts meet are preferably placed in non-critical areas of the part. Usually several tool design options are evaluated prior to tool construction by applying simulation software. In case study B the feasibility of interpreting such simulation results is checked on the testing geometry "modified ladder". Mould filling simulation predicts four weld lines (Fig. 6b). One is situated inside the connector between the rungs 2 and 3 and the other ones are inside the rungs 4, 5 and 6. For validating the results a short shot study is presented in Fig. 6a. Each time the filling procedure was interrupted shortly before the melt fronts met. Comparison between predicted and experimental weld line positions confirms the simulation. It also shows that conventional short shot studies are very well suited for this purpose.

However, mould filling continues after this point and changes the final green structure. The final stream lines are displayed as a radiographic image in Fig. 7a. Progressing melt which continues to flow through the rungs pushes the feedstock forward. Then, inside the connector, the streams meet and unite. They move parallel, as can be seen in Fig. 7b. The CT image which is a tomographic cut in the XZ-plane shows that the original streams do not mix. The cross-section in the YZ-plane (Fig. 7c) emphasises that the four streams have defined interfaces. Since the contact angle between the neighbouring streams has changed, the frontal weld lines are transformed into parallel meld lines. This improves the bonding and will eventually lead to increased strength.

The experimental flow pattern points out that the real weld or meld lines might be less critical than the predicted picture implies. In order to improve the interpretation of simulation other outputs should be considered as well. Velocity vectors depict the flow situation near the end of filling (Fig. 8). These vectors are in good accordance with the flow pattern. Thus, the combination of both images allows a realistic assessment of the expected green microstructure.

Case Study C

The shape of the component results in asymmetric filling that creates a characteristic flow pattern. In this case study the injection parameters were modified to analyse the sensitivity of this pattern for Catamold®. Criteria are the volume fractions of the joined

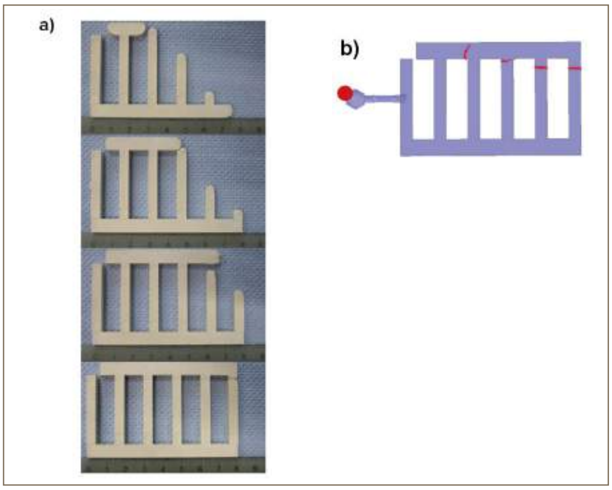

Fig. 6 Positions of weld lines in the testing part modified ladder determined by a) short shot study, b) simulation

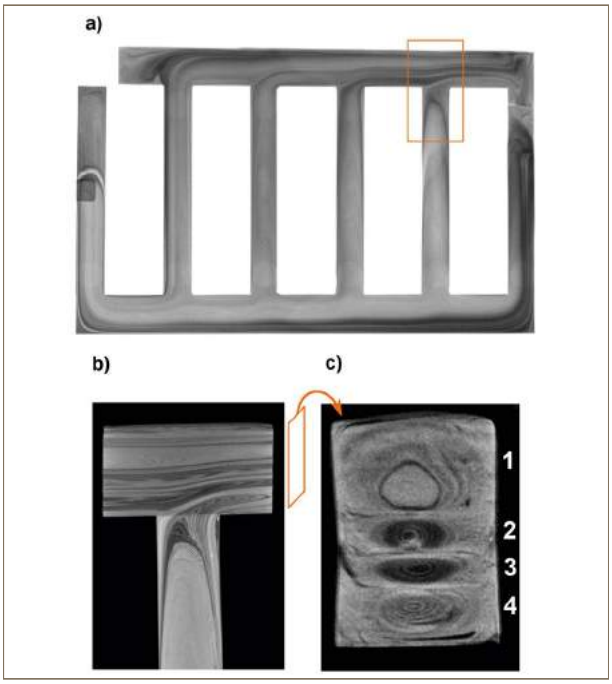

Fig. 7 Flow pattern of the modified ladder; a) radiographic image; b) detail in XZ-plane; c) detail in YZ-plane showing the four joined parallel streams in cross-section

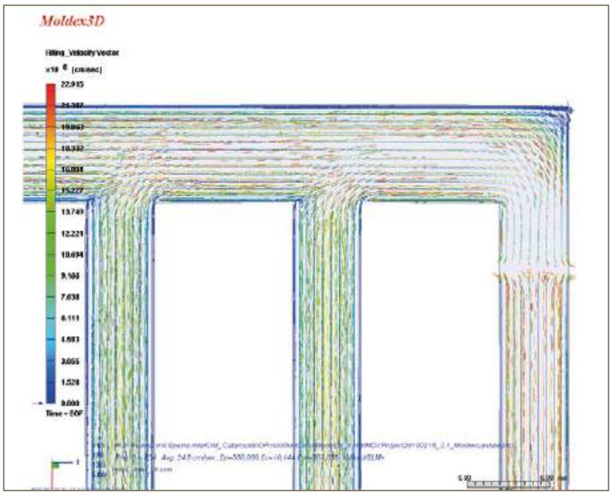

Fig. 8 Simulated velocity vectors at the end of filling

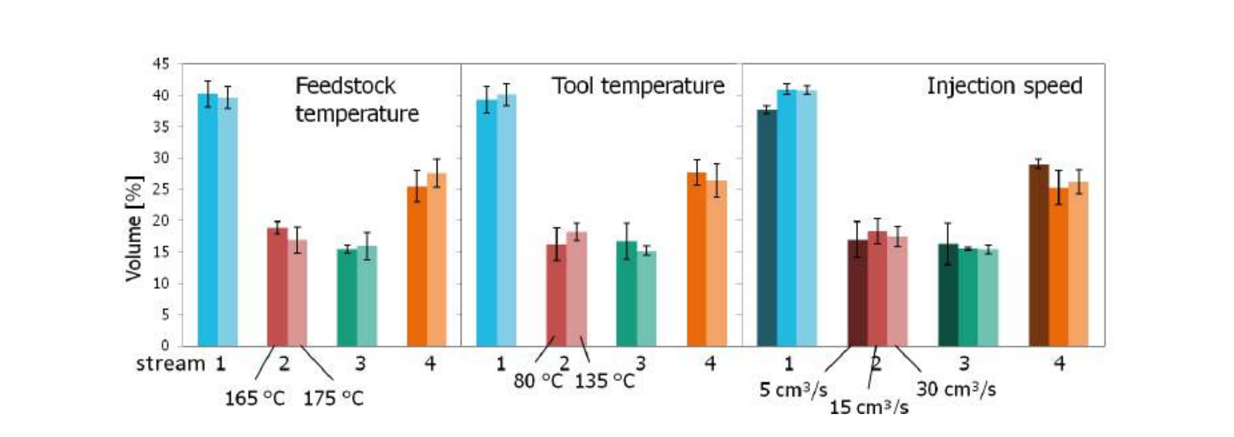

Fig. 9 Volume ratios of feedstock streams measured at cross-sections for different injection moulding parameters

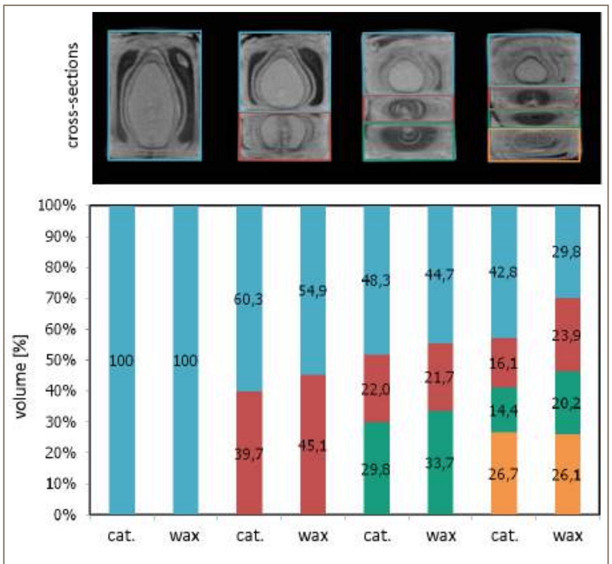

Fig. 10 Volume ratios of feedstock streams after each rung for the Catamold® and the wax-based feedstock

feedstock streams after rung 5. The areas of the streams were measured by image analysis. The area fractions correspond to the ratio of the volume streams. An example of the cross-section is shown in Fig 7c. The first stream having its source in the second rung is denoted with "1" and the upmost layer. Since the other ones join from below they follow subsequently.

The diagrams in Fig. 9 represent the volume ratio of each stream to the complete cross-section. It becomes clear that the contribution of the first stream is approximately 40%, significantly higher than for the others. The second largest fraction (25-30%) is assigned to rung 5 while the streams of rung 3 and 4 are the smallest and nearly even. Unexpectedly, the injection parameters do not have a noticeable effect on the volume fractions. For feedstock and tool temperature the differences are within the standard deviation. Only for low injection speeds the fraction of the stream 1 is smaller compared to the ones injected at 15 and 30 cm³/s, respectively.

Since the flow patterns seem to be stable for all tested injection parameters the question arises, whether they would depend exclusively on the mould design or not. Therefore, the second marker feedstock system (from case study A and D) based on a PE-wax binder system was tested as well. The volume ratios of the feedstock streams were measured after each rung when a new stream had joined. In the two neighboured columns in Fig. 10 the cross-sections are compared for the Catamold® and the wax-based feedstock.

The volume composition differs between both feedstocks. As discussed above stream 1 demands the largest volume for Catamold®. Although the first stream in the wax-based feedstock remains the largest, the four streams are far more evenly distributed. It shows that both feedstocks have deviating properties that affect the flow pattern to a larger extent than changing the injection parameters. Such properties might be the shear or extensional viscosity, the tendency to jetting or the temperature dependence of the flow parameters. Further research will be necessary to identify the sensitive factors.

Case Study D

Both components, the inner and outer ring, of the gear wheel are filled through two opposite sprues. The feedstock moves along the circumference to fill the cavity and forms two weld lines which are located perpendicular to the gates. In the outer ring laminar flow develops in a constant cross-section of 8.1 mm². The cross-section of the inner ring changes due to the gears. It has its lowest value at the foot with 4.3 mm² and increases to 14.9 mm² at the tip. That means that the feedstock is subjected to periodical expansion and compression. The flow lines in Fig. 11 show a wavy line which penetrates the tooth but does not reach the tip. Thereby a dead water area is formed by deposited feedstock which stays still while progressing feedstock flows along. Such layers, where feedstock streams move relative to each other, are internal interfaces. They can lead to structural defects if, for example, binder separates from the matrix. SEM images of the ion-beam polished green part shows binder exclusions which are aligned along the flow lines (Fig. 12). After binder removal gaps are left behind which can be the origin for cracks. Fig. 13 shows a CT image of a debinded gear tooth in which the cracks reflect the flow pattern . Powder binder separation is particularly strong for feedstocks with excess binder. The effect is diminished if the feedstock composition is optimised according to solids loading and binder composition [14].

This example demonstrates the importance of a flawless microstructure with a homogenously dense particle packing. Furthermore, tool designers should be aware of critical sites like dead water areas.

Conclusion

A new method allowing an insight into the flow pattern of injection moulded ceramic green parts has been developed. By using X-ray sensitive tracers the flow paths can be revealed three dimensionally by applying CT measurements.

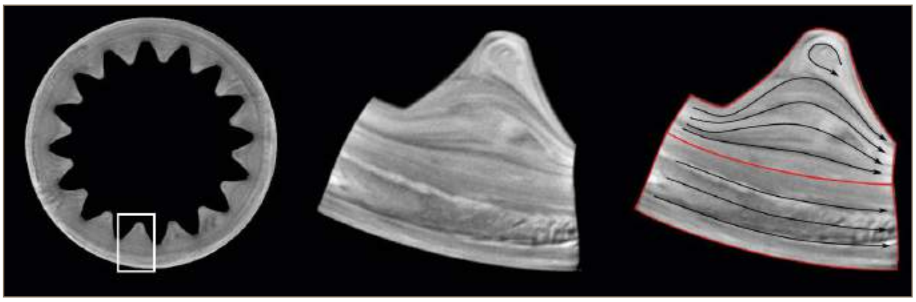

Fig. 11 Visualized flow lines in the gear wheel

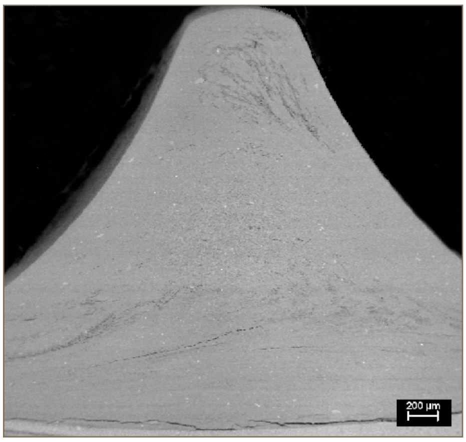

Fig. 12 SEM image of gear tooth showing binder exclusions which have separated along flow lines

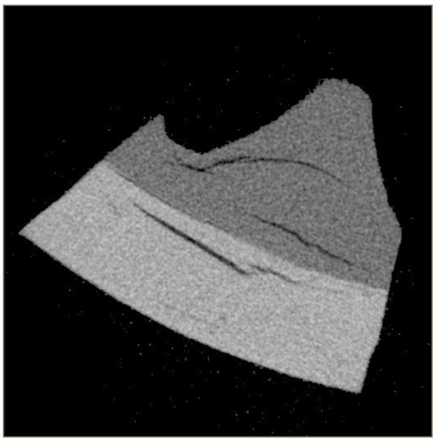

Fig. 13 CT image of a gear tooth after debinding with internal cracks

By analysing short shots of a bar we could follow the development of flow pattern. It showed how dead water areas are formed and that deposited material is eroded by a propagating stream. Internal interfaces created in this way can be the source for defects because they are a critical site for powder- binder-separation. As shown for a gear wheel these binder exclusions can lead to cracks.

Short shot studies are often applied to characterise the filling process. With their help the position of weld lines was confirmed, which had been predicted by simulation. But the short shots only reflect the instant situation of the interrupted filling stage. The visualised experimental flow lines showed that the flow pattern changed afterwards. Velocity vectors of the simulation were able to reproduce this behaviour and should be considered for interpreting simulation results. The feedstock streams which joined after each rung of a modified ladder did not mix but continued to flow laminarly. Feedstock properties played a more important role in affecting the flow patterns than changing the injection moulding parameters.

The introduced flow line visualisation method is a helpful tool for understanding the appearance of certain structures and complements the information obtained by short shot studies. By learning more about correlations of mould design and created flow pattern the tool design process can be improved.

Acknowledgments

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Contribution to the development of 18 carat gold alloy shaped by MIM

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Metal Injection moulding (MIM) is an appropriate manufacturing process for small complex-shaped components with good surface finish. In comparison to parts manufactured by traditional processes, such as investment casting or forging, parts with better tolerances can be achieved. Hence MIM is a viable manufacturing method for the jewellery industry, which additionally desires strong aesthetic criteria (brightness, colour, surface finish, smooth appearance etc.). Nevertheless due to the specific properties of precious alloys, such as low temperature sintering, the MIM process for conventionally used materials (low alloys steels, stainless steels etc.) is not easily transposed to precious metals. This paper will focus on parts made of 18-carat gold alloy. The study, supported by an industrial partner, highlights the technical difficulties encountered at the sintering step and their consequences. In addition, post treatment effects (HIP) are investigated.

Keywords: MIM, gold, sintering, HIP, grain growth, porosity

Introduction

Today, MIM is a well-known mass production process derived from plastic injection moulding. MIM combines plastic injection moulding and powder metallurgy to obtain dense components. With only ten publications before 1970, and more than one thousand by 1999, MIM still stimulates the interest of researchers and manufacturers [1].

Among the diverse range of powders used (standard and low alloy steels, stainless steels, high speed steels, carbonyl iron and nickel, copper based alloys, nickel and cobalt based superalloys, titanium, magnetic alloys, refractory metals and hardmetals), precious metal alloy powder could also be successfully processed, not only for luxury industry but also for additional applications.

As J.T. Strauss stated, "The jewellery manufacturing industry is in a unique position to adopt MIM technology as many of its general advantages are greatly amplified in jewellery manufacturing due to the high cost of precious metal alloys" [2]. In reality, the development of the MIM process based on different gold alloys could enable new means of more efficient and less expensive production for the luxury products industry, especially jewellery. Usual tolerances reported for MIM are between +/- 0.1% (+/- 0.001 in/in) and +/- 0.3% (+/- 0.003 in/in). Density reaches 93% to 100% [2-3]. Not only could new designs with much more complexity or with different coloured alloys be produced, but also a perfect guaranteed microstructure [4].

Moreover, the material losses are minimised. With MIM, only a polishing step is necessary, and in contrast to other processes widely used today, like casting, investment casting or forming, no machining operation needed. For instance, it can be noticed that machining has a global yield of 10% with gold alloys. Without re-melting, it can be possible with MIM to reduce the recycling loop using, for instance, re-ground feedstock [2].

Primary tests with the MIM process were conducted with an 18-carat yellow gold alloy; they showed that it is possible to obtain samples with very good properties. For example the microstructure presented in Fig. 1c shows that the grain size of a MIM part is the same or smaller compared to the other processes (cast Fig. 1a and stamped (Fig. 1b) without addition of a grain refiner.

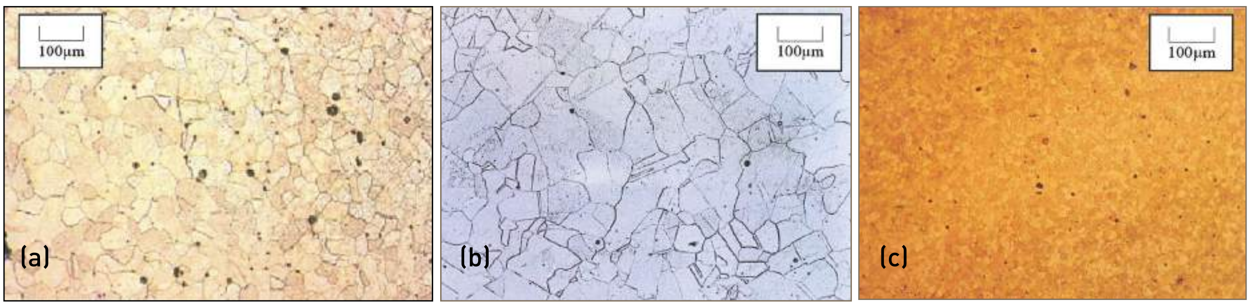

Fig. 1 (a) Gold 18 carat (75Au-15Ag-9Cu-1Zn) with 0.01% Ir added as a grain refiner cast [5]; (b) Gold 18 carat stamped (CETEHOR); (c) Gold 18 carat MIM

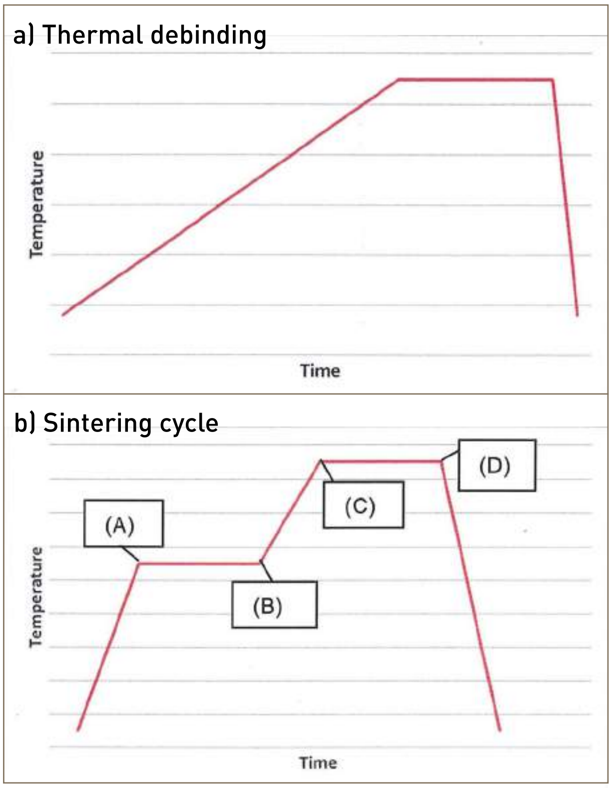

Fig. 2 Schematic view of the reference cycle

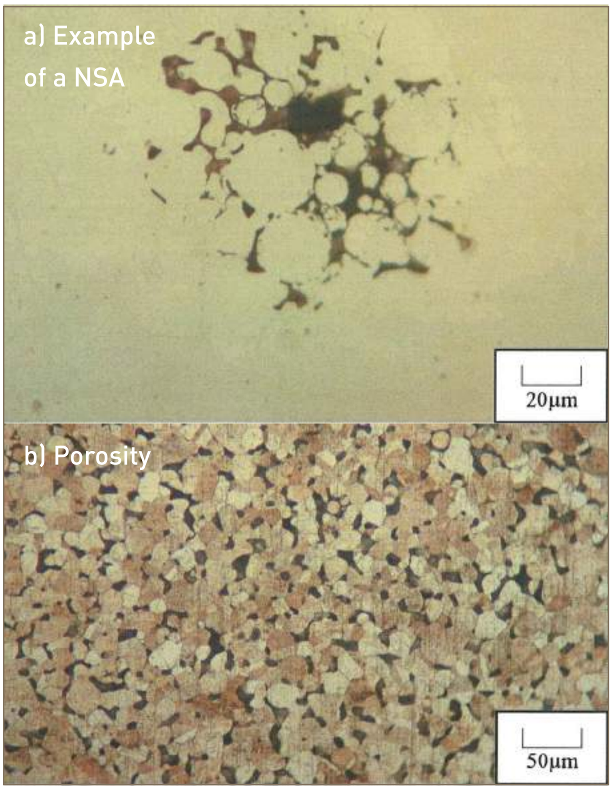

Fig. 3 Defects encountered on injected parts after sintering

As shown in Fig. 1, primary results were satisfactory (especially for the microstructure). Nevertheless some non-sintered areas could be detected. It should be noted that the primary results were obtained for some samples with a relatively high thickness. Some problems relating to green part mechanical behaviour were revealed after the injection step and the thickness of the part was reduced in order to give different and more complex geometry.

A new feedstock, which strengthens the green part, was therefore tested in this work.

Materials and Experimental section

This article focuses on the different experiments which lead to a perfect microstructure. The sintering cycle used to manufacture cold pressed discs and injected parts will be presented in the next section. Discs were made without binder or lubricant. Fracture and SEM analysis were performed as explained in the second point of this section.

Materials section

a) Materials

Two types of parts were manufactured for this study. The first set of yellow gold discs were made by cold isostatic pressing (CIP).

Injected moulded parts were manufactured using a commercial feedstock (Parmaco) and processed on a hydraulic press (Demag Ergotech 35/280-80 concept). The injection temperature was 160°C and the injection pressure 150 bars.

In both cases, the gold powder used was a yellow gold 3N 18 Carat (Au 75 Ag 12.5 Cu 12.5).

b) Presentation of the manufacturing cycle

When processing the commercial feedstock from Parmaco, the following cycle was followed.

Firstly, chemical debinding, where the samples are immersed in a solvent to remove one of the binder components. In this step 50% of the binder is removed. This first step is followed by thermal debinding under air at atmospheric pressure (Fig. 2a). During this step the binder is almost totally removed. Finally a sintering step at approximately 0.8-0.9 of the melting temperature (T_m) under reductive atmosphere is performed (Fig. 2b). The required time to complete the entire process was about 65 hours. A Hot Isostatic Pressing (HIP) treatment can be added after sintering in order to close the residual porosity. During HIP process, parts were heated to 0.8 T_m under inert gas at high pressure (up to 1000bars) .

Part Characterisation

The parts were cut with a linear saw BUEHLER (ISOMET 4000), and prepared with a polishing machine PRESI (mecapol 2B). Polishing was done with diamond particles from 50μm to 1μm. The etching was done with aqua regia (HCl 3 – 1 HNO3) for 20s.

Parts were observed using an optical microscope Olympus BX 60 and by Scanning Electron Microscopy (SEM). SEM studies were carried out with a Philips XL30i microscope model. Cryofracture testing of some injected parts was also undertaken to avoid any contamination due to preparation method. In this case, parts were broken after being immersed into liquid nitrogen and then observed by SEM. Microanalysis X (EDS) was also performed.

Results and Discussion

The aim of the first experiments was to reach the same characteristics obtained with the previous feedstock. After manufacturing parts with the reference cycle, two primary problems were identified: non-sintered areas and heterogeneous grain growth. These problems will be addressed in a later section of this paper. Three different sintering cycles, with two different atmospheres and heating rates were investigated.

In all cases, two different kinds of non-sintered areas (NSA) were observed: some areas where the initial gold powder was observed (Fig. 3a) and where porosity was observed (Fig. 3b).

Fig. 4 Gold powder cold pressed without binder or lubricant and sintered with an atmosphere (80% Ar + 20% H_2)

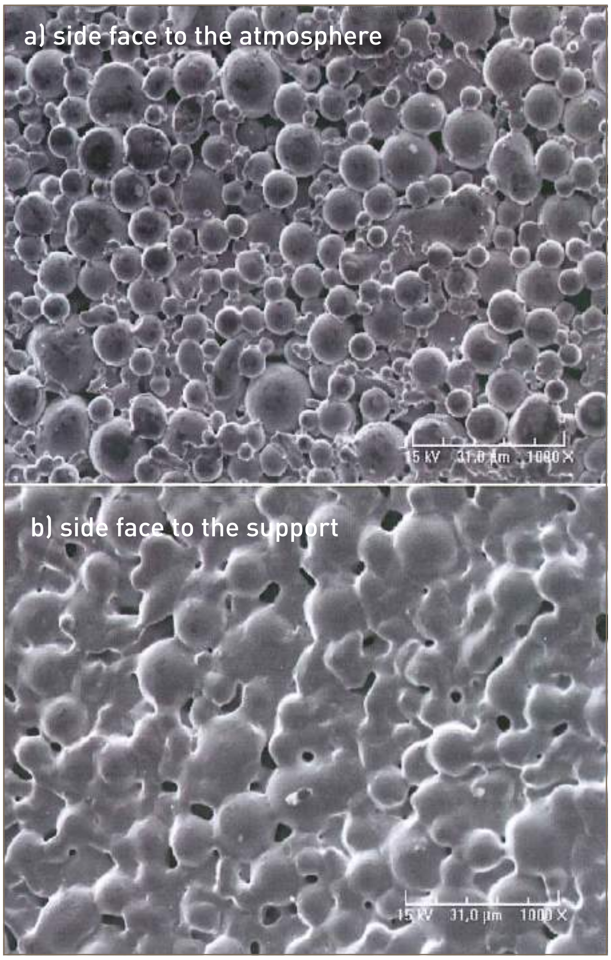

Fig. 5: Injected part at the beginning of sintering cycle (step C)

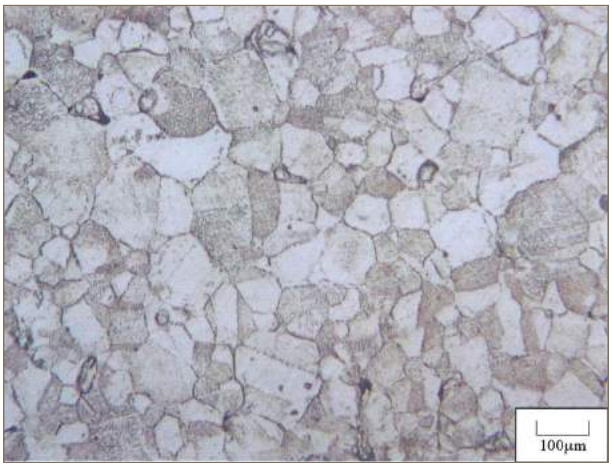

Fig. 6: Gold powder with additional Al_20_3 particles. Pastille cold pressed and sintered with reference cycle

Thus, tests were planned with cold pressed discs in order that the phenomenons described can be better understood. In fact, the experiment was free from the process conditions, specifically the binder. Manufacture conditions and details will be given in a following section, “Non-sintered areas”.

After etching (Fig. 4), two areas of grain size were observed: one around 50-100µm and another one above 800µm reaching up to 1.6mm. The smallest grains were observed close to the surface, which was swept by the gas flow during the sintering cycle (the top left corner in Fig. 4). By contrast, the biggest grains were located at the bottom of the part which is in contact with the parts holder.

Due to this heterogeneity, it was impossible to get a proper microstructure leading to a fine finish after polishing. The sample is not totally shiny and looks more like an orange skin. This is due to the large size of the grain, which introduces different orientation of crystallographic plan and the light is reflected in a different way.

These two areas of grain are similar to the grain obtained by casting with use of grain refiner for the smallest one, and similar to the cast alloy without grain refiner for the largest one [4].

In order to indentify the reasons which cause these defects, it was decided to interrupt the process cycle at different steps and check the sample, especially with SEM.

A first observation was already made after chemical and thermal debinding. At each step of the sintering cycle one part was observed at the beginning (A) and at the end (B) of the pre-sintering level, at the beginning of the sintering level (C) and finally at the end of the cycle (D) (Fig. 2b).

Heterogeneous grain growth

Following SEM analysis, no significant problems were noticed in the part at stages (A) and (B). However, as shown in Fig. 5, the sintering phenomenon occurs with different rates from side to side of the part observed at stage (C). At stage (D), the part is totally sintered and no difference can be observed between each side before a metallography and etching. As already stated, “smaller grains” were observed close to the surface which encounters the gas flow during the sintering cycle (Fig. 4).

If the sintering phenomenon occurs early on one side of the part, we can also assume that grain growth will develop faster on this side. As shown in Fig. 5a, the gold powder particles can be clearly identified and sintering necks are starting to grow; in Fig. 5b, sintering necks are already created and the powder particles are almost unidentifiable. The densification step is just reached on the side face to the support (Fig. 5b) when the sintering level begins. Consequently, the sintering phenomenon does not seem homogeneous on both sides of the part.

The final heterogeneous microstructure is therefore a consequence of this poor control related to the sintering stage. The grains are already created at the beginning of the sintering level for the side face to the support, leading to “bigger grains” at the end of the sintering level.

In order to limit the gap in grain size, a small quantity of aluminium oxide was added to the gold powder. In the literature, cobalt is well-known as a grain refiner for gold [6-8]. Some precious metals such as Iridium can also be used [6-9], but the price of these tests remains prohibitive. Carbides and even oxides are most commonly used in the industry as grain refiners such as boron oxide in the production of aluminium alloy [10-13].

As a reductive gas flow in the pre sintering step is used, one of the most stable oxides and one of the cheapest has been chosen. Aluminum oxide was therefore added to the gold powder to control grain growth.

As shown in Fig. 6, the addition of aluminium oxide particles (approximately 1%) is a very good way to control the grain growth. In fact, grain growth is linked to the grain boundaries' mobility. Small oxide particles act as a barrier and with the mobility of the grain boundary limited, grain growth is sharply reduced. This, however, does not solve the problem of the non-sintered area which is discussed in the following section.

Non-sintered areas (NSA)

In all experiments, two kinds of non sintered areas can be noticed (Fig. 3, from an injected part). On the one hand, some porosity that appears typically during the sintering step, and on the other hand, NSA defined as areas where the initial powder grain can be recognised.

For the first kind of porosity, it is possible to use Hot Isostatic Pressing (HIP). This treatment combines temperature and plastic deformation to reduce micro porosity and to reduce internal voids (Fig. 7)

Even, however, at high pressure (up to 1000 bars) and approximately 90% of the melting temperature, only the residual porosity (shown in Fig. 7a) was resolved. The NSA presented in Fig. 7b remain.

Wiesner qualifies NSA as pores which result from an unequal binder distribution [14]. Some tests were therefore undertaken in order to check this assumption.

In order to avoid these heterogeneous behaviours, experiments were carried out with samples based on compacted gold powder. Cold pressed discs were made under 53 MPa with the same gold powder used for manufactured injected parts, but without any lubricant or binder.

Discs were separated into three groups in order to check if NSA is inherent to the sintering of gold powder or to the process itself, and also to identify the process involved. Preparation is explained in Table 1.

After micrographic analysis, NSA were found in each discs (around two NSA per square millimeter). Feedstock heterogeneity seems to be not a crucial parameter regarding the presence of NSA. Moreover NSA are not linked to the binder as the latter experiments were performed without any binder. So Wiesner's assumption seems to be incorrect.

In fact, the density after sintering depends directly on the densification rate after cold processing. The higher the densification rate, the greater the densification after sintering [15-17]. We decided to highlight the influence of powder compaction on NSA. Considering this, cold pressed discs were made at four different pressures (15, 38, 53 and 75 MPa).

After sintering, metallography studies were done on each disc. As shown in Fig. 8, the number of NSA depends on the pressure used to make the disc. For the low compaction pressure (15 MPa) there are around five NSA per square millimeter in the disc. As the compaction pressure increases, the number of NSA drops to two NSA per square millimeter. The number of NSA has more than halved when compaction pressure reaches 50 MPa.

As expected, compaction pressure is an influencing parameter regarding NSA, but unfortunately, it is not sufficient to avoid all

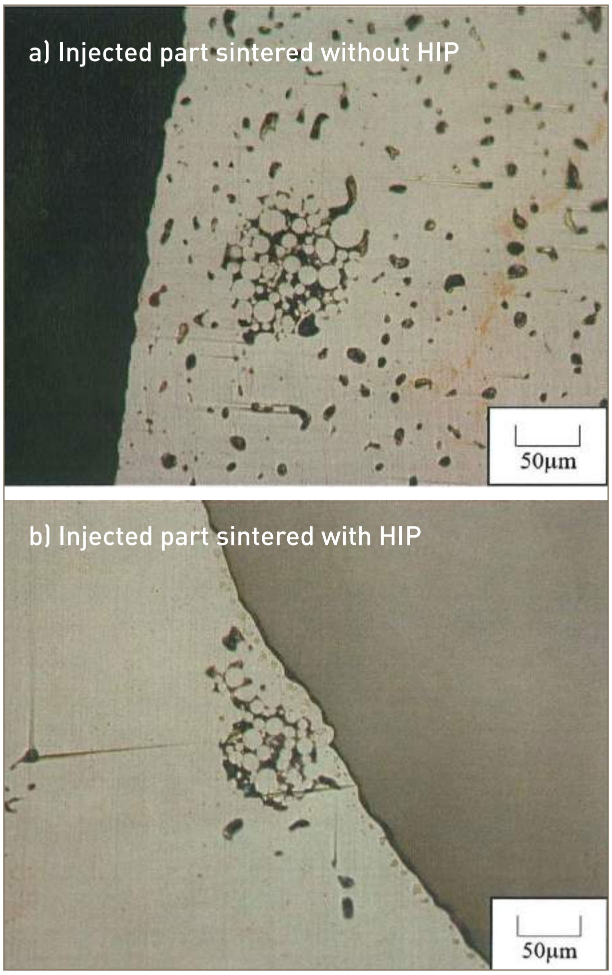

Fig. 7 Effect of Hot Isostatic Pressing (HIP) on injected parts

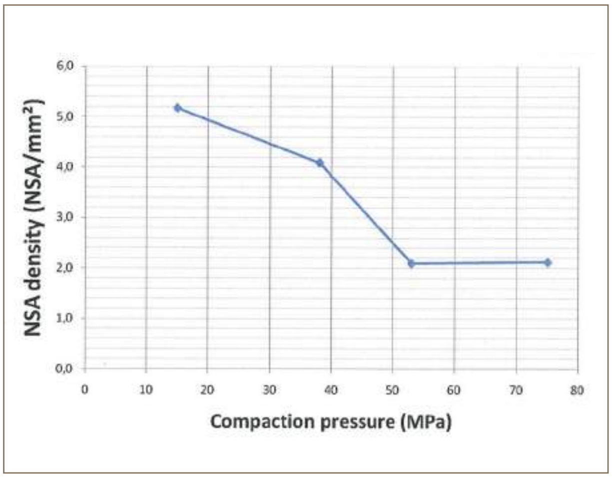

Fig. 8 NSA evolution with compaction pressure

	Compaction	Solvent Debinding	Thermal Debinding	Sintering
Group 1	x			x
Group 2	x		x	x
Group 3	x	x	x	x

Table 1 Differences in disc preparation

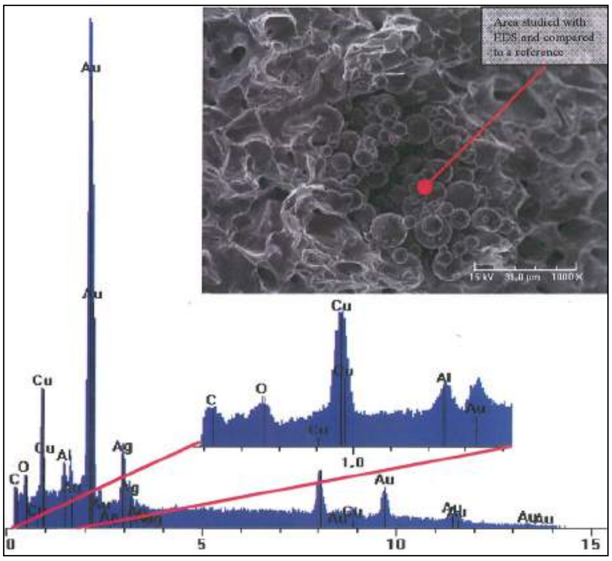

Fig. 9 SEM and EDS analysis of a NSA

NSA. It seems to be pointless to further increase the compaction pressure because the number of NSA reaches a level (around 2 NSA per square millimeter). NSA remain even with a high pressure.

So, a compaction pressure too low increases this phenomenon but NSA seem to be inherent to gold powder sintering. In fact, there is no disc (without binder or lubricant) without NSA.

SEM investigations were led in order to observe the "NSA shape" and analyse the individual particle contained inside them. Fractures were conducted as described in the experimental section.

First, a reference area with no NSAs was investigated. The three main components of the 18-carat gold alloy (gold, copper and silver) are easily detected by EDS. No foreign component was identified.

This reference spectrum was compared to the different spectrum made on NSAs. For example, Fig. 9 gives the "typical" spectrum observed on a NSA. It reveals the main components of the alloy (gold, copper and silver) and other impurities such as aluminium oxygen.

These impurities may have different origin, such as the powder itself, but also the process and the environment where the samples are manufactured. Experiments are still in progress in order to determine the origin of these impurities.

Conclusion

Different experiments were conducted in order to produce thinner parts with a new feedstock. It seems to be possible to obtain a very good microstructure, either by optimisation of the sintering cycle, or through the addition of a grain refiner.

The gas composition and also the flow rate may also influence the grain size. In fact, if the heat conductivity of the gas flow is too high, the sample surface swept by the gas flow could be cooled down during the process, causing a heterogeneous sintering. Experiments with a flow rate five times lower is planned in order to see if there is an effect on the grain size.

In the case of substantial closed porosity, a Hot Isostatic Pressing post-treatment shows some very good results to reduce it but is ineffective towards the NSA, which reveal initial gold particles.

It has been demonstrated that these areas do not come from the binder or the process itself. SEM investigation reveals that an aluminium impurities seem to be located in these NSA. These impurities may have different origins, such as the powder itself but also the process and the environment where the samples were manufactured.

Other alloys will also be investigated in order to adapt the widest range of gold alloys for MIM technology, and give the opportunity to Alliance MIM to meet new requirements from its customers.

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